Education Department Bulletin

Published fortnightly by the University of the State of New York

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

No. 485 ALBANY, N. Y. DECEMBER 15, 1910

New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 145

GEOLOGY OF THE THOUSAND ISLANDS REGION

ALEXANDRIA BAY, CAPE VINCENT, CLAYTON, GRINDSTONE AND THERESA QUADRANGLES

BY

H. P. CUSHING, H. L. FAIRCHILD, R. RUEDEMANN AND C. H. SMYTH JR

ALBANY

UNIVERSITY OF THE STATE OF NEW YORK

1910

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New York State Education Department
Science Division, October 4, 1909

Hon. Andrew S. Draper LL.D.
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SIR: I have the honor to communicate herewith for publication as a bulletin of the State Museum a manuscript entitled *Geology of the Thousand Islands Region,* covering the areas known as the Alexandria Bay, Cape Vincent, Clayton, Grindstone and Theresa quadrangles. This is a report upon several seasons of field work in the region referred to, by Prof. H. P. Cushing, Prof. Herman L. Fairchild, Dr Rudolf Ruedemann and Prof. C. H. Smyth jr of this staff.

Very respectfully,
JOHN M. CLARKE
Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 5th day of October 1909

A. S. Draper
Commissioner of Education

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GEOLOGY OF THE THOUSAND ISLANDS REGION

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BY

H. P. CUSHING, H. L. FAIRCHILD, R. RUEDEMANN &
C. H. SMYTH JR

INTRODUCTION[1]

The field work on which the accompanying report is based was done during the field seasons of 1906, 1907 and 1908. The district was chosen for work chiefly on the recommendation of Professor Smyth, and work was begun by the writer with the understanding that we were to collaborate in doing it. Unfortunately this plan failed of realization, owing to Mr Smyth's inability to take the field, so that his actual participation in the work was limited to a portion of the season of 1908, during which he mapped the major portion of Wellesley island.

Dr Ruedemann assisted in the mapping of the southern part of the Theresa quadrangle during two weeks of the season of 1907 and in 1908, mapped Cape Vincent and the southern half of Clayton. The remainder of the areal mapping is the writer's contribution, comprising the Theresa, Alexandria and Grindstone sheets (with the exception of Wellesley island) and the north half of Clayton.

NOTE. The photographs credited to Ami and Ulrich are published by permission of the Directors of the Geological Surveys of Canada and of the United States.

[1] By H. P. Cushing.

Professor Fairchild spent the season of 1908 and portions of two previous seasons in the study of the Pleistocene geology of the area, and his reports will be found included in their appropriate places.

During both the seasons of 1907 and 1908 Dr E. O. Ulrich of the United States Geological Survey was in the field for a time with Dr Ruedemann and myself. In 1908 Dr H. M. Ami of the Geological Survey of Canada was also present and we spent 10 days together, chiefly in study of the Pamelia, Lowville and Black River limestones, with a short excursion to the district around Kingston, under Dr Ami's guidance. Combined work of this sort is of the utmost value, and as a result of it the indirect contribution of both these gentlemen to this report is most important and is gratefully acknowledged.

In a previous year Professor Smyth had reported upon the larger part of the district comprised in the Alexandria and Grindstone sheets, as well as their eastward extension, doing the work as accurately as the imperfect base map at his disposal warranted. It is a pleasure to testify to the importance and accuracy of this report, especially in view of the date at which, and the circumstances under which the work was done.[1] The different rock groups and their relations to one another were thoroughly worked out, and the independent mapping here reported upon has done little more than to repeat his work and emphasize its correctness. This of itself would justify his appearance as a collaborator in this report, independently of his direct contribution.

For five weeks of the season of 1908 Dr H. N. Eaton of Chapel Hill, N. C., served as voluntary assistant. This generously given help is gladly acknowledged, and the report also bears witness to the service of his camera.

LOCATION AND CHARACTER[2]

These five quadrangles constitute the extreme northwestern portion of northern New York, bordering the lower end of Lake Ontario and the St Lawrence river in the Thousand Islands region. The area mapped extends from the meridian of 75° 45′ w. longitude to Lake Ontario and from latitude 44° to the national boundary. It comprises some 560 square miles.

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[1] Geology of the Crystalline Rocks near the St Lawrence River. N. Y. State Geol. 19th An. Rep't 1899. p.185–104.

[2] By H. P. Cushing.

The area is one of low altitude and comparatively little relief, forming the west end of the plain which borders the entire north front of the Adirondack highland, and merges hereabouts into the north end of the Black river lowland. To the southward the altitude considerably increases and a bit of the high Trenton escarpment which forms the west wall of the larger part of the valley of the Black river, appears in the extreme southwest corner of the Theresa sheet, reaching an altitude of over 800 feet, the highest elevation in the mapped district. Altitudes considerably in excess of this appear not far to the southward on the Watertown sheet. But with this one trifling exception the highest elevations in the mapped area but little exceed 600 feet (this in the southeast corner of the Theresa sheet) and thence drop gently to the north and west to the level of the lake and river (246 feet).

Though the district is thus moderately flat, the local relief is considerable, in minor fashion. Ridges and valleys characterize the districts underlaid by Precambric rocks. The flat-lying Paleozoic rocks form plains which are fronted by steep cliff escarpments. In both cases abrupt changes of level of from 50 to 100 feet are quite common. These features also are most pronounced in the eastern part of the area and fade out westward, so that but little relief is manifested on the Cape Vincent and the larger part of the Clayton sheet.

With the exception of the St Lawrence, the Black and Indian rivers are the only streams of respectable size within the mapped area. Most of the streams flow in narrow, steep walled valleys, and no deep, broadly opened valleys have been detected. There are many features of interest in the minor drainage to which attention will be directed later on. The group of lakes of an unusual type forms a very prominent feature. Several of these lakes may be noted near the eastern edge of the Alexandria sheet and there are a few more beyond the map limits. They are not a usual feature of this part of the State. Their presence and their very localized distribution require explanation.

Glacial deposits are in small bulk in the district and much bare rock appears, with wide areas where the soil is very thin. In the limestone districts the streams show a tendency to go underground and bared limestone surfaces show considerable amount of rock removal through solution along the joint planes.

The district is largely one of small farms. Little or no forest remains on it, though there is much waste land. The largest single area of the sort appears in the southeast part of the Theresa sheet, on which is found the western portion of the "sand plains," the great Pleistocene delta of the Black river.

Interesting historically from having been the scene of exploitation and settlement by French immigrants of high class, during the early part of the nineteenth century, the district preserves many traces of this immigration, especially in the matter of geographic nomenclature.

SUMMARY OF GEOLOGIC HISTORY[1]

The rocks of the region are readily separable into two great groups, the one of older crystalline rocks, and the other ot younger sandstones, limestones and shales which rest upon the older group. The rocks of the older group are of Precambric age, are among the most ancient rocks of which we anywhere have knowledge, and are in most respects identical with the crystalline rocks which compose the great central region of northern New York, the Adirondack region, and with those of the much more extensive area which lies to the northward in Canada. These rocks, in the district here reported upon, form a narrow connecting link, or isthmus, between the exposures of these two areas, which otherwise are completely separated from one another by a belt of country of considerable width in which the surface rocks belong to the younger group. It is only in the immediate region therefore that direct connection can be traced between the old rocks of Canada and of New York, and this fact gives added interest to the study of these rocks here.

These Precambric rocks furnish us with our most ancient direct records of the history of the earth, but like most ancient records they are fragmentary and difficult to decipher. Nevertheless they plainly indicate that Precambric time was of enormous duration, involving many millions of years.

Here, as elsewhere in northern New York, these rocks consist of but a single series of water-deposited rocks, so far as our knowledge goes. This is known as the Grenville series, and comprises rocks which, originally deposited as shales, limestones, and sandstones, are now greatly changed in character and have become white, coarsely crystalline limestones, glassy quartzites, and schists and gneisses of many varieties. Curiously we have not as yet, in

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[1] By H. P. Cushing. This is a simple statement of the outlines of the history of the region as disclosed by the study of the district. The detailed evidence upon which these statements are based, will follow later.

New York, been able to discover anywhere any trace of the older rocks which formed the floor upon which these water-laid sediments were deposited, though plainly, with such an origin, they must originally have been laid down on some such floor of older rocks. It follows therefore that we do not know the base of this Grenville series. Neither do we know its summit, since that has apparently been everywhere removed by erosion. Hence we can not know its thickness, though we do know that it is a very thick rock series, several thousands of feet at least.

Since the deposition of this formation it has undergone many changes. The rocks have been greatly compressed and intricately folded and plicated. They have been invaded from beneath by huge masses of igneous rocks, which have broken up the once continuous Grenville formation into separate and disconnected belts and patches, have probably engulfed and digested large amounts of it, and are likely responsible for the utter disappearance of the old floor on which the formation originally rested. As a result of this mishandling the rocks have been profoundly changed in character. They have been entirely recrystallized, with complete destruction of the textures which, as sediments, they originally possessed, and with the production of a foliation cleavage, or schistosity, due to a banded arrangement of the minerals formed by the recrystallization. In addition a quantity of contact rocks has been produced in the vicinity of, and by the action of, the igneous rocks, which interact with the others to produce rocks quite different from either, and with opportunities for manifold variation, with variation in the character of either or both sets of the original rocks. In this manner many rock types have arisen, often of puzzling nature.

The changes which have been produced in these Grenville rocks are of such nature as to lead to the confident belief that they took place at some considerable depth below the surface, or in other words that a considerable thickness of other rocks then overlay them, a rock thickness which subsequently disappeared because of surface wear continued through long ages.

Igneous intrusions

As has been implied the Grenville sediments are the most ancient rocks of which we have definite knowledge in northern New York. Subsequent to their formation they were repeatedly invaded from beneath by igneous rocks in molten condition. In the immediate district the bulk of this igneous rock consisted of granite, and the more basic rocks which appear in large quantity further east are but sparingly present. But granitic intrusion took place on a large scale at least twice, probably three times, and possibly several times. This it was which was so effective in breaking up, altering and destroying wholesale the Grenville sediments and their floor.

Laurentian granite gneiss. The oldest of these igneous rocks is a granite which has, since its intrusion, been sufficiently subjected to compression to have become pretty thoroughly crushed, or granulated, with the development of a rude foliated, or gneissoid, structure. It is a reddish to gray granite gneiss which contains nearly everywhere inclusions of the Grenville rocks in varying abundance, but always most abundant near the contacts with the Grenville, into which it always sends a multitude of dikes. The inclusions are usually of amphibolite and all stages of their assimilation by the granite are found, giving rise to a group of intermediate rocks which seem unquestionably to have been derived from the digestion of the one rock by the other. It is possible that some of these amphibolite inclusions may actually represent fragments of the old Grenville floor, and furnish the sole remaining traces of that floor, but as yet this is mere conjecture. This granite gneiss occurs in both large and small masses, so called bathyliths and stocks, which invaded the Grenville rocks from beneath at an exceedingly early period.[1] In addition to forming a large portion of the present surface occupied by the Precambric rocks it likely also underlies the Grenville rocks over the entire district, except where they have been cut away by succeeding igneous rocks. Since the rock solidified it has been subjected to compression, together with the Grenville rocks, giving to each a foliation parallel to that of the other, and elongating the bathyliths in a northeast-southwest direction with corresponding shortening at right angles to this, the shortening being of course in the direction of the pressure and the elongation at right angles to it.

Alexandria syenite. On the Alexandria quadrangle, some 3 miles a little west of north of Redwood, is a mass of rather coarse grained igneous rock which shows little sign of crushing and is unquestionably younger than the Laurentian granite gneiss. In association with it is a much greater amount of a coarse, but crushed, porphyritic igneous rock, now converted into an "augen" gneiss.

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[1] Bathylith is a term applied to large masses of igneous rock, which masses are believed to continue to great depths with generally increasing size downward. A stock is a smaller mass of the sort.

What relation the two bear to one another could not be definitely ascertained. Either the augen gneiss is a crushed border phase of the other, that representing an uncrushed core, or else it is a separate and older rock. It is a fairly basic rock, varying much in this respect, seems at times to owe its character to partial assimilation of amphibolite, and so far as seen, its exposed contacts are all with Grenville rocks, which it cuts. If the two intrusives belong together the mass reaches considerable size and is to be classed as a small bathylith. If the augen gneiss is distinct from the other the latter is only a stock.

In case the augen gneiss is distinct the question naturally arises whether it may not be merely a porphyritic phase of the Laurentian granite gneiss. A decisive answer to this question can not be given owing to lack of contacts between the two classes of rock. But such evidence as there is seems decidedly against such a correlation. The rock is a more basic one than the general run of the granite gneiss, and is not so severely crushed, or granulated. The weight of the evidence is decidedly in favor of the view that it is a gneissoid, border phase of the syenite.

Syenite southwest of Theresa. Up the creek valley above Theresa are exposures aggregating about a square mile in extent of a gray to gray green rock which is a syenite. It may have considerably greater extent underneath the sandstone which adjoins it on each side. It is by no means so mashed as the granite gneiss and seems clearly a younger rock, but since it is not found in association with any of the other younger igneous rocks its age relations to them are not ascertainable.

There is a single outcrop of a coarse, unmashed eruptive which is to be classed as a gabbro, close to the upper bridge at Theresa on the west bank of the river. It may have considerable extent under the adjacent sandstone but with the most generous possible allowance for such extension the mass would still have to be rated as a stock of no great size.

Picton granite.[1] The most extensive and important of these younger Precambric intrusives is the coarse red granite which outcrops widely on Grindstone, Wellesley and some of the smaller

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[1] The most considerable outcrops of this rock within the State are on Grindstone island, but the name of Grindstone granite would perhaps be misleading, and Grindstone Island granite is too long a name. The smaller Picton island is however the seat of the chief quarries at the present time and the name would be wholly appropriate except for the fact that the island appears on the maps as Robbins island. It is universally called Picton island by residents, many of whom have no knowledge of any such name as Robbins island.

islands, and to a small extent on the mainland, and which is named from Picton (Robbins) island, where the most extensive quarries occur. This rock shows little or no signs of the crushing which has affected the other Precambric intrusives in greater or less degree, though it becomes fine grained in certain situations, chiefly marginal, and notably so in many of the dikes which it sends out into the adjoining rocks.

The rock holds a multitude of inclusions, of Grenville quartzites and schists, of Laurentian granite gneiss, and of the augen gneiss associated with the Alexandria syenite. Over much of Wellesley island the abundant inclusions are but little disturbed. in other words their dips and strikes are concordant and in accord with those of the neighboring Grenville rocks, and with these unchanged dips and strikes the inclusions occur in linear belts, now of quartzite, now of schists and again of granite gneiss, so that the original distribution of these rocks can be mapped as confidently as though the granite invasion had never been. This indicates that here we are near the very roof of the granite bathylith, where cooling had rendered it so stiff and pasty as to be no longer able to pluck away and engulf blocks from its roof, the present inclusions being such as had been last broken away but were unable to founder and retained their original orientation.

The utter lack of signs of crushing in the rock leads to the rather confident belief that it is the youngest of all these early Precambric intrusives, though there is some question as to whether it is actually younger than the syenite and the gabbro about Theresa, and with no possibility of definitely settling the matter.

The bathylith is also of large size, extending out of New York into Canada among the islands and on the mainland. The granite which outcrops about Kingston seems surely identical, and is distant 17 miles from the nearest outcrops of the rock on the west end of Grindstone island.

The molten mass of the granite was also richly charged with mineralizing fluids and hence exhibits prominent contact effects on the adjacent rocks, much more prominent than those shown by any of the other intrusives of the immediate region.

When compared with the Precambric rocks of the general Adirondack region (the rocks hereabouts comprising the extreme western edge of the Precambric of northern New York) the most obvious difference to be noted is the comparative scarcity of igneous rocks belonging to the syenites and gabbros in this western area.

It seems also to be the case that metamorphism is not so extreme here as farther east, in fact there seems to be a slow but progressive increase in severity of metamorphism in passing east. The differences in this respect are not so prominent in the Grenville and Laurentian rocks as in the later igneous rocks, but characterize all. Even here, however, the character of the metamorphism indicates a considerable depth for the rocks concerned during the time when it took place. But it also suggests a less depth of overlying material than is possessed by the region farther east.

This overlying material has since been removed by slow surface erosion. Greater thickness has been removed on the east than on the west apparently, the differences in metamorphism being thus most readily explained. Further, this removal by erosion took place wholly in Precambric time indicating that the region was a land area for a long period. Precambric time however was very long, the Grenville sediments were deposited early in it, the district subsequently rose above sea level and remained as land during the long ages of the middle and late Precambric. The large amount of rock thickness removed not only argues for a long erosion interval but likely indicates renewal of uplift on one or more occasions, since it is not probable that the region ever attained an altitude as great as that represented by the thickness of rock removed.

Late in Precambric time, and toward the close of this long, erosion period, came renewed igneous activity, an upward movement of heavy, black, basic lava taking place. Not improbably some of this material reached the land surface of the time and spread out as lava flows. If so subsequent wear has removed every trace of their presence, cutting away the surface sufficiently so that the only sign of this igneous activity which remains on the surface of today is the trap dikes, the lava-filled channels of ascent of the molten rock. The trap is absolutely unmetamorphosed and gives every indication of having solidified at quite shallow depth. Hence the conclusion is forced that the eruption occurred toward the close of the long Precambric erosion period previously described, and since only a comparatively slight amount of wear followed, that these dikes are of very late Precambric age; in fact it is by no means impossible that they may be as young as the early Cambric.

If we could follow these dikes down into the earth beneath the surface of today, no doubt we should find that they lead upward from underground masses of trap of considerable size, quite analogous to the bathyliths of the earlier granites.

Close of the long period of erosion

Eventually this long period of surface wear on a land area drew to a close, and for a time the history of the region became of very different nature, in other words instead of loss of surface material it began to gain it in the shape of deposits on the old, worn land surface. These deposits blanketed and preserved the old erosion surface, and since the wear of today has come down to that precise horizon over parts of the district, and the overlying deposits are being peeled away from it, it is returning to daylight with precisely the characters it possessed when it was buried and preserved ages ago. Seldom does a district reveal so abundant and clear evidence of the nature of an old fossil land surface. It is clear from its study that long wear had reduced it to a surface of comparatively slight relief, showing that no considerable elevation of the region occurred during the latter portion of the long erosion interval. Nevertheless it is very far from being a plane surface, but is of considerable minor relief, of low ridges and shallow valleys, or of low knobs and basins, the depressions eaten out on the weaker rocks, chiefly the Grenville limestones and some of the schists, while the more elevated ridges and knobs are due to the resisting qualities of the Grenville quartzites and of many of the igneous rocks. The knob structure is practically confined to the igneous rock areas, chiefly in the Laurentian gneiss.

While the region therefore is quite rugged in a mild fashion, the extreme differences in altitude are but slight. One hundred feet is about the measure of difference. Seldom does the difference in level between valley bottom and ridge crest reach that figure, and rarely does it exceed it. This is a small difference, considering the wide variation in resisting power to wear which the various rocks present and is indicative of a long period of wear under comparatively stable conditions of level.

Paleozoic sediments

Potsdam sandstone. A change in conditions followed and deposition of sand commenced upon this old land surface. It naturally began on the valley bottoms and encroached on the ridges only as the valleys filled. The old limestone surfaces were pitted by small depressions, and were somewhat intersected with widened joint cracks also, and in these the first materials collected, sometimes full of coarse fragments of resistant thin quartzite bands or granite dikes such as are found nearly everywhere in the Grenville limestones, sometimes containing only sand. There is comparatively little basal conglomerate in the district back from the river, but there, both on the mainland of the Alexandria quadrangle and on Wellesley and Grindstone islands is an exceedingly coarse conglomerate, from 10 to 20 feet thick, full of coarse cobbles derived from the ponderous and resistant Grenville quartzite of the vicinity.

Except for these conglomerates the formation is everywhere a sandstone and mostly pretty thoroughly cemented, the cement being chiefly of silica. Its colors are red, brown, yellow, white, and rarely black. Its thickness over the immediate district will scarcely exceed 100 feet, and it thins out toward the west and south. The deposits of sand began forming first in the Champlain region and gradually worked their way westward, being deposited in a shallow trough or basin whose axis roughly coincided with the modern St Lawrence axis, so that hereabouts we find simply the thinned western edge of the formation. As its thickness here is substantially equal to the difference in altitude between the ridge crests and valley bottoms of the old erosion surface upon which it was deposited, it follows that it varies rapidly in thickness from place to place and was but scantily deposited upon the elevations, some of which it utterly failed to overtop.

It is not known whether or not the formation in its entirety is a marine formation. The sparse fossils indicate such origin for the upper beds with comparative certainty, but many things about the remainder of the formation suggest a land surface and an arid climate as the conditions under which the accumulation took place.

Theresa dolomite. A change in conditions ensued and deposit of dolomite began. Some sand was still supplied from the neighboring land however, as the dolomite is everywhere sandy, and at first the supply was from time to time in excess, so that layers of coarse weak sandstone alternate with those of dolomite. Hence there is a gradation from one rock to the other instead of a sharp boundary between the two. The greatest thickness of the formation within the area mapped does not exceed 35 feet, though its original thickness may have been somewhat greater. The thickness increases eastward and diminishes to the west and south as was the case with the underlying sandstone. The waters were more fitted for the existence of life and the fossils are more abundant than in the sandstone, but unfortunately conditions for their preservation have not been favorable.

The Theresa formation followed close after the Potsdam and they were laid down in a trough or bay along the present St Lawrence line which was landlocked on the north, south and west. The depression of this trough originated to the eastward, where the deposits are thickest, and deposits did not commence in the immediate region until late in Potsdam time. The extreme western extremity of the bay can not have lain many miles west of the immediate region at the time of its greatest expansion. Then it commenced to contract and slowly work back eastward.[1]

Uplift following the Theresa. This tendency to contraction of the trough, caused by slow uplift of the land, seems to have continued until the bottoms of both the St Lawrence and the Champlain troughs had been raised above sea level, so that all the northern portion of the State was above that level. After a time renewed depression followed, apparently commencing simultaneously on the west, south and east sides of the Adirondacks, and the Tribes Hill phase of the Beekmantown formation was laid down. This was followed by uplift which began at the west and worked eastward, bringing the west and south sides of the district above sea level, while subsidence still continued in the Champlain valley, in which a large thickness of later Beekmantown rocks was deposited. This Tribes Hill subsidence came in on our district here from the south and its deposits constitute the upper portion of what is mapped as the Theresa formation. Until the Beekmantown formation along the St Lawrence valley has received further study we can not say whether the Tribes Hill limestone extends east of the Frontenac axis or not. Our present view is that it did not, and that the Beekmantown of the St Lawrence valley represents the higher portion of the formation, deposited in a trough which extended westward up the valley from the Champlain basin. This depression did not carry the immediate region below sea level. The district tilted to the southwest and received a thin edge of Tribes Hill deposition, then rose and was tilted back to the eastward, though not sufficiently to allow the later Beekmantown sea of the district to the east to quite reach it.

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[1] Since the field work was completed and this report written, work elsewhere in New York has shown that probably the Theresa formation, as here mapped and described, is in reality composed of two probably unconformable formations, of quite different ages, and that the name should be restricted to the lowermost of these, the upper being of lower Beekmantown age, and equivalent to what we are calling the Tribes Hill formation in the Mohawk valley. The matter is discussed in more detail on a later page.

In the Champlain valley the Beekmantown rocks are overlaid by the Chazy limestones. There is evidence there of a break between the two formations and the Chazy has a basal sandstone. The Champlain Chazy trough also had a westerly bay but it never extended as far west as the district under discussion. During the long time interval therefore during which Beekmantown and early Chazy sedimentation was transpiring in the subsiding Champlain trough, the district here was above sea level and experiencing wear rather than receiving deposit. Considering the length of the interval the amount of erosion which it suffered was but slight, arguing for low altitude and gentle slopes for the land. Broad, shallow valleys were cut in the surface of the Theresa limestone but the depth of cutting seems never to reach the base of the formation.

Pamelia (Stones River) limestone. The Chazy basin of the Champlain, St Lawrence and Ottawa valleys was landlocked to the south and west during lower and middle Chazy time. During this time interval, however, other and larger basins of subsidence and deposit existed to the south and west but completely separated from the Chazy basin. Both the rocks and the contained fossils therefore differ from the Chazy and the formation is known as the Stones River. Notwithstanding difference of name the two formations represent substantially the same time interval.

As Chazy time passed on, the large Stones river basin to the southward encroached northwardly and toward the latter part of the interval had become sufficiently extended to submerge the immediate district. The slow warping of the land which brought about this subsidence gave the district a wholly different direction of slope. In Potsdam and Theresa times it had sloped to the northeast and formed part of the extreme westerly end of the subsiding trough. It now came to slope to the southwest, was invaded by the sea from that direction, and to the northeast lay a land area which separated it from the Chazy basin beyond. Though the district was covered by the waters of both marine invasions it was near the shore line in each case and received only comparatively thin, marginal deposits, representing only a small fraction of the entire thickness of the formations concerned. Hence in a broad way it is true that what had been the western shore of the earlier sea became now the eastern shore of this later western sea, or that the general district formed an axis or pivot from which the land tipped now in one direction and now in the other, remaining throughout an area of small subsidence.

The deposits laid down in this depression are of upper Stones River age and the name of Pamelia limestone is proposed for this New York phase of the formation. Locally it is known as the "blue limestone" though the local name commonly includes the overlying Lowville limestone as well. A thin, basal sandstone appears, after which follow alternating black, blue and gray limestone beds, then the black limestone disappears and white, earthy limestone alternates with the others. During the deposit of this upper portion the waters seem to have become shut off from the open sea, by the development of some shoal or reef as a barrier, and in the lagoon thus formed water lime was deposited, the waters often evaporating sufficiently to expose wide mud flats which dried and cracked under the sun's influence. The marine fauna found these conditions uncongenial and disappeared, though returning from time to time for a brief space with fresh influx of water from the sea outside. Deposition became intermittent and eventually ceased and some slight wear occurred locally.

Lowville, Watertown and Trenton limestones. Subsidence then recommenced, and upon this slightly worn Pamelia surface the dove-colored limestones of the Lowville formation were laid down. The Lowville submergence was somewhat more extensive than the Pamelia, since the former appears in the Mohawk valley while the latter does not. And though both formations occur along the Black river valley it seems probable that the Lowville sea encroached more widely upon the borders of the land which lay to the eastward.

The Lowville is a quite pure limestone for the most part, and carries a much more abundant and varied marine fauna than do any of the older rocks. Above it lies a more massive, cherty limestone, separated from the main mass of the Lowville by an unconformity, which we are calling the Leray limestone, and classing as an upper member of the Lowville. Above this, also with an unconformity between, comes a similar massive limestone, without chert, which we are proposing to call the Watertown limestone. The Watertown and Leray limestones taken together are known in the region as the Black River limestone, the Leray being locally more like the Watertown than like the Lowville in character. Because of this, and because of their small thickness (about 10 feet each), we have felt constrained to map them together. They carry an abundant marine fauna, the large cephalopods being especially conspicuous.

The Watertown limestone is unconformably overlain by the thin bedded limestones of the Trenton. The time interval between the Lowville and the Trenton was a considerable one, but the surface exposures of these rocks in New York are so near the old shore lines of the time, that the deposits exposed represent the interval very imperfectly. The shore line was one of many and frequent local oscillations, and the rocks which have, of late years, been classified as Black River limestone, represent very different parts of this general interval.

The Trenton limestone is abundantly fossiliferous and has a thickness of 400 feet or more in the immediate region, exceeding the combined thickness of the Potsdam, Theresa, Pamelia, Lowville and Black River together. Found on all sides of the Adirondacks, and with large thickness everywhere, the Mohawk valley excepted, large subsidence is shown, with probable great encroachment of the waters upon the Adirondack island, much diminishing its size.

As Trenton time drew to a close fine muds commenced to appear in the waters, brought in by currents from the northeast, and in slowly increasing amount. Hence the limestones become impure and grade upward into black shales, at first strongly calcareous, later on lacking lime. This change came on the region from the eastward, hence shales were forming there while limestone was still being deposited on the west. But the change to mud deposit spread slowly over the whole region and the Trenton is found everywhere to be overlaid by the black Utica shales. This Utica submergence seems to have been the most extensive in the State's geologic past, and it is quite possible that the entire Adirondack island was submerged. If so it seems to have been the last time that such was the case, as it was the first.

Above the Utica lie the lighter colored shales and shaly sandstones of the Lorraine formation, the combined thickness of the two shale series being several hundred feet. While neither formation is found within the limits of the area mapped, in which the lower Trenton is the youngest rock found, yet they outcrop in great thickness on the Watertown quadrangle and reach to within 6 miles of the south margin of the Theresa sheet, and it seems quite certain that they were originally deposited over part, and likely all, of the district mapped, and are now absent from it because of subsequent erosion. It is even probable that the Oswego and Medina sandstones, thick sand formations which overlie the Lorraine shales, and whose present northern margin of outcrop is distant but 15 miles from the map limits, may also have been somewhat deposited within it. Certainly the sandstone extended orginally farther north than now, but just how far no one can say.

The deposit of these sands indicates a shallowing of the waters over the region, following which it was uplifted above sea level. Thenceforth in the main, throughout the millions of years which have since elapsed, the district has remained a land area. It is quite possible that the succeeding Siluric and Devonic seas, whose waters covered central and western New York, may have washed over this district, and laid down thin deposits. But if so, every trace of such deposits hereabouts has disappeared through erosion, so that no certainty can be arrived at in the matter.

As a result of the various oscillations of level which the region has undergone the rocks described have been changed from their original nearly horizontal position, into a series of low folds. This folding seems to have commenced early and to have been continued on various occasions, since there is some evidence that the Potsdam and Theresa formations were somewhat folded before Pamelia deposition began. Subsequently more folding took place, involving the entire series, and though the folding is gentle its topographic expression is plain.

The principal folds have axes which trend northeast-southwest, but there is also present another set with northwest-southwest trend, or at right angles to the first set, whose arches and troughs are thus folded up and down, producing gently elevated domes and depressed basins, the former where the arches of the two sets cross, and the latter at trough intersections. Many of the outliers shown on the accompanying geologic maps owe their existence and preservation to this folding.

Subsequent history of the region

But little that is definite can be said of the history of the district during its long existence as a land area following the deposition of the rocks previously described. It seems quite certain that the amount of rock worn away from the surface during this time is slight, considering the length of the time interval, and that therefore the land has seldom had any considerable altitude. Where the entire thickness of overlying rocks has been worn away and the Precambric exposed at the surface, as is the case on parts of the Theresa and Alexandria sheets, it seems quite certain that not over 3000 feet of rock thickness has been removed, and likely considerably less. Since the overlying rock has been worn away down to the Precambric over only a small portion of the whole district, it follows that in the remainder the erosion has been less than the above amount by the remaining thickness of such overlying rock. The character of the district to the south of the map limits however indicates an uplift of the land of *comparative* recency to the amount of several hundreds of feet, and the present-day stream valleys of the region have been worn down below this old level in this comparatively recent period. This relatively considerable recent elevation and erosion makes still more emphatic the necessity for assuming slight elevation of the region during the much longer interval which preceded it. As compared with much of the district surrounding it this area has been one of but slight changes of level during its past history. While in their early history these surrounding districts were submerged and subsiding, allowing thick accumulations of deposits, this area subsided less and received but scanty deposit. Only during middle and late Lower Siluric time, during Lowville, Trenton, Utica and Lorraine deposition, was it a district of considerable subsidence and deposit. In its subsequent history as a land area it seems to have been one of but small uplift as compared with much of the adjacent region.

As has been stated, in the comparatively recent past the district experienced uplift to the amount of several hundred feet. Prior to this it had been worn down to a surface of comparatively slight relief. The uplift gave the streams power to deepen their valleys by an equivalent amount, and the processes of wear which have given the present relief to the region were set in motion. Then, as now, the Black river was the chief stream of the neighborhood, and perhaps turned west into the Ontario lowland as it now does; but the lake was not in existence then, nor was the drainage of the lowland to the eastward, but the Black river flowed through it in a westerly direction, receiving many tributaries from the north and the south. There were also easterly flowing waters in the district, however, the beginnings of streams which drained down the St Lawrence valley. But the St Lawrence of the time had its sources in the immediate region, and contained no waters coming from farther west, the divide between the easterly and westerly flowing waters being here, crossing the present St Lawrence in the Thousand Island region on the hard rock barrier which the Precambric rocks furnish. On the New York side the divide can be traced across the Clayton, Alexandria and Theresa quadrangles in a southeasterly direction, with sharply cut ravines heading against it on both sides, marking the extreme heads of the small streams which flowed on the one hand northeast to the St Lawrence, and on the other hand southwest to the Ontario drainage. On the Clayton quadrangle the French creek valley belongs to the former, and the Chaumont river valley to the latter category; on the Alexandria most of the country was on the St Lawrence side of the divide, the valleys of Crooked creek, Cranberry creek, Butterfield lake-Black creek, and the valleys now occupied by the other lakes belonging there, while Mullet creek valley drained the other way; on the Theresa the valley into which the Indian river breaks at Theresa village seems to belong to the easterly drainage, while the remainder of the valleys on the quadrangle carried water to the westward drainage.

The valleys excepted, the prominent topographic feature of the region is the rock cliffs, usually low, which mark the edges of outcrop of the various formations, and which owe most of their present relief to the wear which followed the considerable uplift. In general, each rock formation of the region is somewhat less resistant to wear than the formation beneath and somewhat more so than the formation above. Hence the overlying formation tends to be slowly stripped away from that beneath, which yields more slowly and, because of the nearly horizontal attitude of the rocks, remains as a comparatively flat terrace, above whose level stands the receding front of the overlying formation, while in the opposite direction the lower formation has its terrace terminated by a similar front which drops down to the level of the formation next underlying. Each formation then shows a receding front of the sort, the Theresa above the Potsdam, the Pamelia above the Theresa and so on. Because of the greater thickness of the formations the Trenton and Pamelia fronts are the highest and the most conspicuous as topographic features. The Trenton front only gets within the map limits in the extreme southeast corner of the Theresa sheet, but the Pamelia front can be followed as a cliff of more or less prominence across the Theresa and Clayton quadrangles, until the formation is lost beneath the river. This is the kind of topography invariably produced when a district of nearly horizontal rock formations of varying resistance is being worn down, but the general type is magnificently illustrated in the region here.

The Pleistocene[1]

During the geologic periods of the Devonic, Carbonic and Permic, and the Mesozoic and Cenozoic eras, each millions of years in length, our area was doubtless always above the sea and subjected to the wasting processes of atmospheric erosion.

Closing the immensely long time of erosion and bringing the history down to the present time, three geologic episodes are conspicuously recorded in the existing surface features. The first of these episodes was the burial of the entire area for some scores of thousands of years under the Labradorian ice sheet with its grinding flow. The second was the burial for further thousands of years under glacial and marine waters that immediately succeeded the latest of the ice bodies. The third episode is the present time, a restoration of the subatmospheric conditions of erosion, which has endured, probably, some 10,000 or 20,000 years.

It is now comparatively certain that during the long geologic history great changes of climate have occurred. The idea, once prevalent, that there had been during all geologic time a steady lowering of temperature and refrigeration of climate from a primitive condition of excessive heat and moisture is wholly an error. The oldest rocks of sedimentary origin contain records of glaciation. In the Permic, ice work was great and wide-spread, and glaciation was probably frequent during past time in elevated regions now eroded. The warm climate of the middle Tertiary was followed by glacial cold in northern lands, and all of New England, New York State and the basin of the Great Lakes was deeply buried under successive sheets of ice which had their origin or centers of accumulation in Canada and Labrador. The peculiar effects of the glacial invasions will be described in a later chapter.

Following at least the latest of the ice sheets the entire area under description was buried for some thousands of years beneath waters held up to high levels by the glacier acting as a barrier across the St Lawrence valley. The shore features and deposits characteristic of lake action are found over the region.

During the time of the ice retreat this portion of the continent was lower, or nearer ocean level, than at present, and when the ice barrier melted away in the St Lawrence valley, the glacial waters (Lake Iroquois) were drained down to sea level, and the north and west sections of our area were long swept by oceanic waters, a branch of the Champlain (Hochelagan) sea called

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[1] By H. L. Fairchild.

Gilbert gulf.[1] The shores of the glacial and sea level waters are conspicuously preserved in many places, and specially in Jefferson county immediately south of the area; while their sediments occupy the valleys [*see* pl. 29].

The slow tilting uplift of this part of the continent finally raised the Thousand Islands district above the ocean level and then Lake Ontario was initiated. The uplifting has continued until the outlet and lake are now 246 feet above tide.

As the lake and marine waters were slowly drained away from the gently sloping surface of the area the storms and streams resumed their briefly interrupted work, and for a few thousand years they have again been gnawing at the rocks and land surface with important effects.

THE ROCKS[2]

Precambric rocks

The Precambric rocks of northern New York, as at present known, may be most conveniently classed in four groups, (*a*) a series of old sediments or rocks laid down under water, the Grenville series; (*b*) a series of granitic gneisses of igneous origin, which cut the Grenville sediments intrusively and hold abundant inclusions of them and which, in so far at least as the immediate region is concerned, are correlated quite confidently with the Laurentian granite-gneisses of Canada; (*c*) a series of somewhat younger igneous rocks which cut and hold inclusions of both the preceding groups, which have a great development in the eastern Adirondacks but occur in less force in the immediate region, and which consist of anorthosites, syenites, granites and gabbros, the last three of which occur here in masses of usually small size; and (*d*) of much younger igneous rocks, of late instead of early Precambric age, which appear as dikes of diabase or trap, and which have some development in the region, though less abundant than in the eastern Adirondacks.

The Grenville sediments are the oldest known rocks of the region, and the fact that they are water-deposited rocks necessitates belief in the existence of a floor of older rocks on which they were laid down. No certain trace of this old floor has ever been discovered in New York, and though it is possible that fragments of it may be contained as inclusions in the granite gneiss, we are as yet unable to distinguish such, if present, from

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[1] Gilbert Gulf (Marine waters in Ontario basin). Geol. Soc. Am. Bul. 17:712-18.

[2] By H. P. Cushing.

the similarly situated inclusions of the Grenville rocks themselves. The same conditions prevail in general over the much more extensive Precambric areas of eastern Canada. Recently, however, Miller and Knight have announced the discovery, in central Ontario, of a basement to the Grenville formation, Grenville limestone being found resting on an ancient lava flow, whose surface is thought to show signs of slight previous wear.[1] Miller and Knight correlate this old lava, or greenstone, with the oldest known formation of the upper lake region, the Keewatin, which consists mainly of greenstones, old lava flows and beds of fragmental volcanic materials. There are present, however, some associated sediments, and Miller and Knight regard the Grenville as of Keewatin age. These are most important results and if future work fully establishes these correlations, it will follow that the Keewatin has steadily increasing sedimentary content and less and less volcanic material as it is followed eastward. By the time New York is reached the greenstones have entirely disappeared, so far as is known. At least no rocks similar to them have ever been discovered in the New York Precambric. It should also be stated that Adams is not disposed to accept the reference of the Grenville to the Keewatin on the basis of the evidence yet in hand, believing a reference to the next overlying group, the Huronian, to be more probable.[2]

However this may be, the difficulty of accounting for the disappearance of the old floor of deposit is not helped, but merely pushed a stage further back. Miller and Knight speak of only slight erosion of the old lava flow prior to the deposit of the Grenville limestone upon it. It is of course possible that this may be merely an interbedded flow of Grenville age and itself rest upon other Grenville sediments. But in any case these Keewatin lava flows and fragmental deposits are surface deposits and require the presence of a floor on which they were laid down just as much as do the Grenville sediments; but no such floor to the Keewatin is known. It is always found resting on Laurentian granite gneisses of igneous origin, or upon yet younger igneous rocks which invaded it from beneath in molten condition, cut it to pieces, and apparently engulfed and assimilated its basal portion along with the floor upon which it rested. Precisely these same conditions prevail in general in respect to the Grenville and its former floor.

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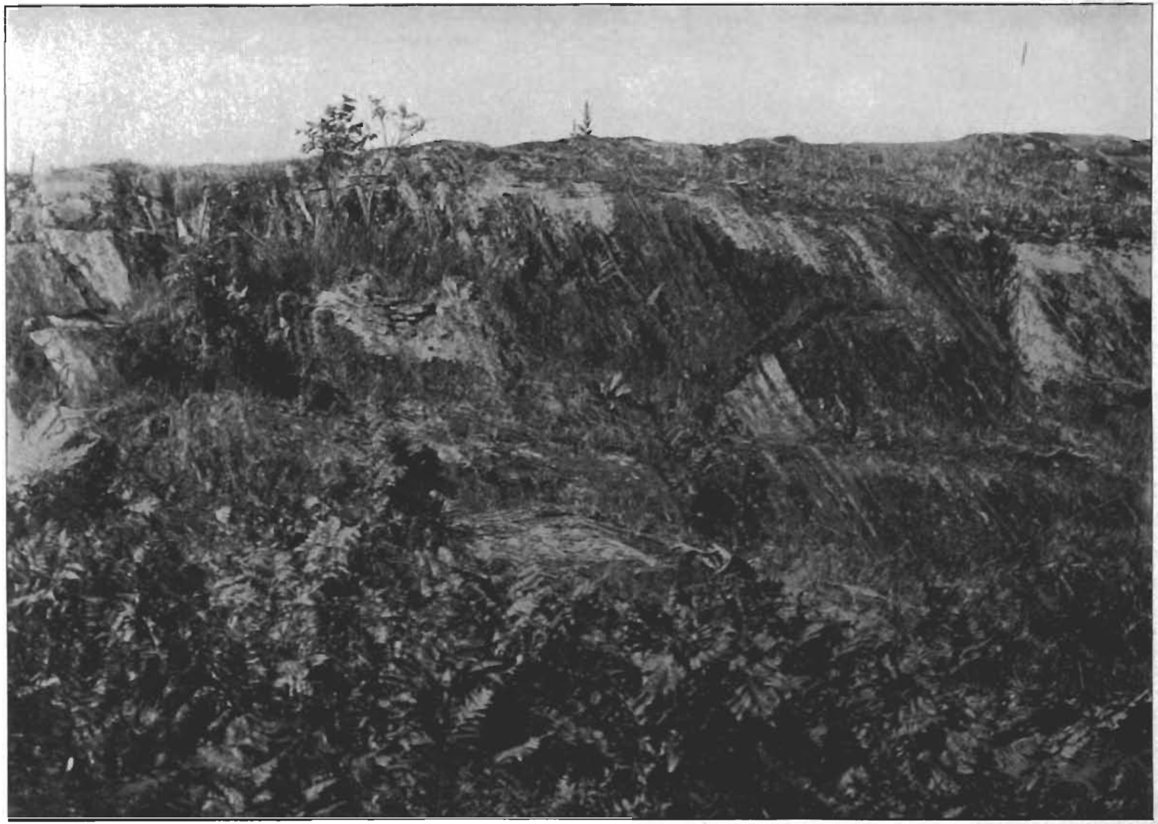
[1] Bureau of Mines, Ontario. 16th An. Rep't, pt 1, p. 22–23.
[2] Adams, F. D. Jour. Geol. 16:634–35.

In New York then the Keewatin volcanics are wholly absent, except for the possibility that some of the amphibolite inclusions of the granite gneiss may be greenstone fragments considerably metamorphosed. Otherwise the Grenville sediments are the oldest recognized rocks, and they occur in patches or in belts of varying size and extent, resting on, surrounded by, and all cut to pieces by the granite gneiss and the yet later intrusions.

Grenville rocks. These rocks as originally deposited consisted of limestones, shales and sandstones, both pure and in their various transitional phases. In all probability too there was some intermingled volcanic material, though the presence of such material has never been definitely proved for the New York Grenville. The rocks have been profoundly changed in character since their formation, in part owing to great compressive stresses which operated throughout the district, and in part owing to the heat and pressure furnished by the great igneous intrusions, and also to the mineralizing agents to which these gave rise. These changes moreover were brought about early in Precambric time and under deep-seated conditions. As found today the rocks are wholly crystalline, having completely recrystallized under the severe conditions to which they were subjected, with loss of all traces of their original clastic textures. In their stead there has been developed a cleavage, or foliation, due to parallel arrangement of the mineral particles on recrystallization. The old bedding planes of the rocks can still be made out, however, in places where the composition of the original rocks changed, as where limestone was succeeded by shale or by sandstone, and from these old bedding planes it can be seen that the development of the foliation is parallel in direction to them. The original limestones have become coarse, white crystalline limestone or marble, the sandstones are now hard, glassy quartzites, while the shales and impure limestones and sandstones have become schists and gneisses of many types, while yet other varieties are contact rocks whose nature is due to action of the intrusives upon adjacent sediments. The variety of rocks is so great that it would be a hopeless task to attempt to map them all upon any such scale as that of the maps which accompany this report. One or more beds of very thick limestone occur, such as that along the Indian river northward from Theresa, or that along Butterfield lake; thick quartzites also occur, especially on Grindstone and Wellesley islands; a large thickness of green schists of a peculiar type is found to the south

Plate 1



Grenville green schists near the St Lawrence at Forsters landing. Alexandria Bay quadrangle, 2½ miles south of Chippewa Bay. Strike of schists n. 25° e. and dip 55° e. View looks north. H. P. Cushing, photo, 1908

and southwest of Alexandria Bay. But the bulk of the Grenville of the district occurs as a great schist series, with rather rapid alterations of varying types in bands of no great thickness, and interbanded with these are thin limestones and quartzites. After trial of various methods it was found that, on a map of this scale, and with rocks of this rapidly varying character, no further subdivision of the Grenville was possible than a separate mapping of the thicker limestone and quartzite beds, the entire remainder being mapped singly as a schist formation. It is feared that even this amount of subdivision has resulted in a map too complicated for easy use.

It was hoped that the careful, detailed mapping attempted might solve the problem of the order of superposition of the rocks and give some definite idea of the thickness of the whole. The outcome was disappointing and neither hope distinctly fulfilled, though some results were obtained. The mapping therefore is purely lithological and not on a structural basis, as it was endeavored to make it.[1]

The average trend, or strike, of the Grenville rocks is to the northeast. The direction to be sure varies considerably, swinging around to the north on the one hand, and to the east or even somewhat to the south of east on the other, yet these variations are not sufficiently frequent to offset the general statement. The dips are usually high, seldom less than 45° and frequently very steep or even vertical [pl. 1, 2]. Over the greater part of the area north dips prevail, but are replaced by south dips throughout a belt of country from 2 to 3 miles broad across the Alexandria quadrangle. This is certainly indicative of folding of large magnitude, and is corroborated by the fact that in many localities minor folds are clearly to be made out, and intricate minor puckering and corrugation. Of the two broad limestone belts within the map limits, the one along the Indian river north of Theresa, and the one about Butterfield lake, the former has a north, and the latter a south dip, and in each case the breadth of outcrop across the strike is about a mile. With the steep dips a thickness of about 4000 feet is indicated for this limestone in each case, and it is therefore conjectured to be the same thick stratum, with the structure synclinal. If this be the true interpretation then the complex of quartzite and

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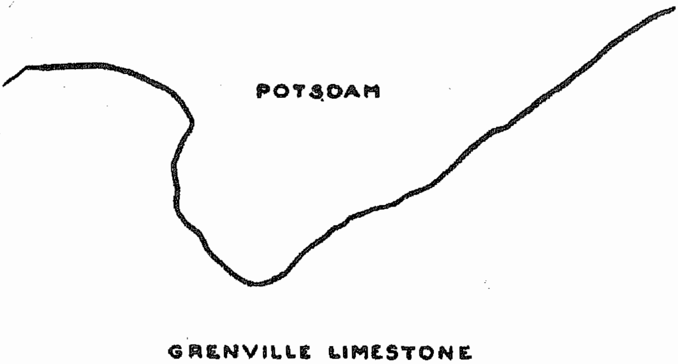
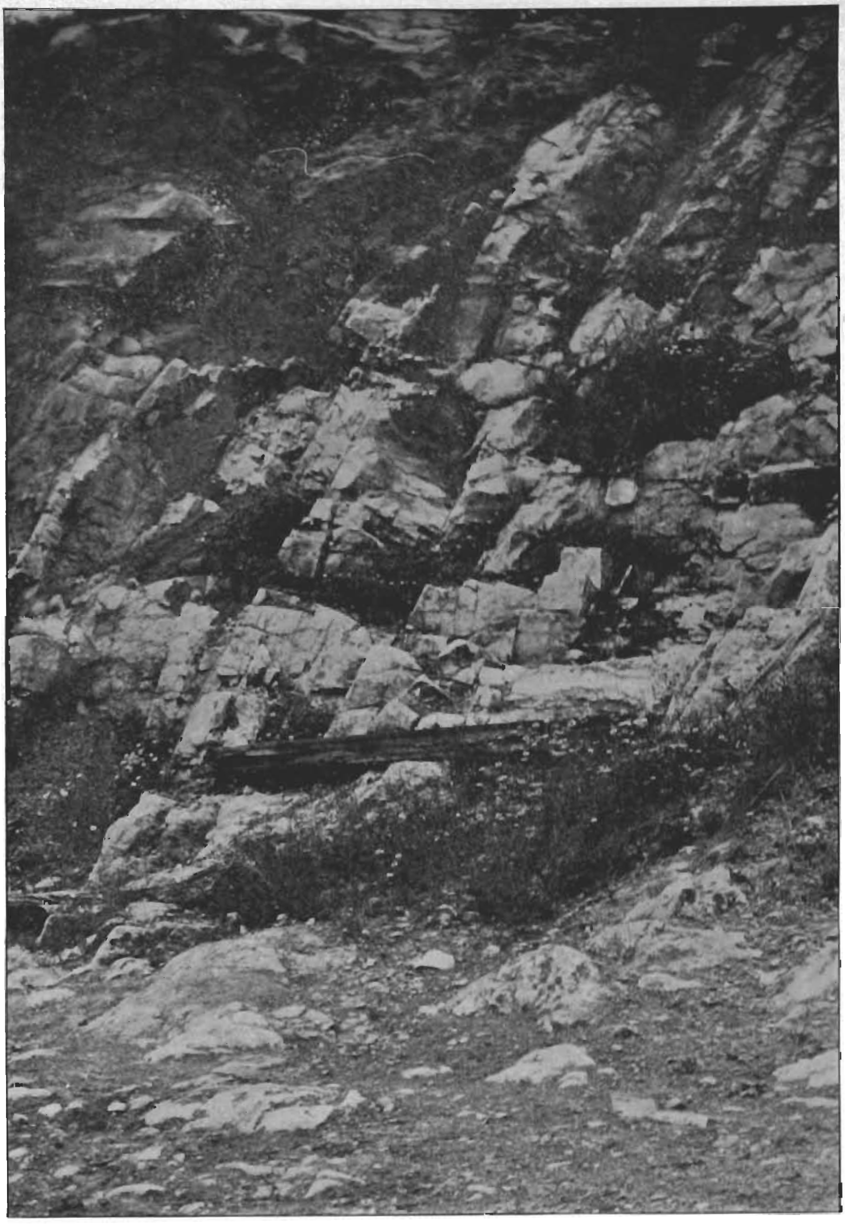
[1] Though the work was of vastly more detailed character than the earlier work of Smyth on the same rocks, it will be seen by any one who will take the trouble to compare the two maps that the basis for the subdivision of the Grenville is substantially the same in each case. No more convincing testimony could be given as to the high class character of Smyth's work.

schist, which lies between the two in the southeast corner of the Alexandria sheet, and which consists of alternating bands of quartzite and various schists of no enormous individual thickness, but which, taken together, must have a thickness of several thousand feet, rests upon the thick limestone and is the youngest portion of the Grenville exposed within the map limits. To the north, and beneath the limestone would come the great complex of green schists and impure greenish limestones which there occurs, which have steep dips and must have large thickness, at least as great as the two previous groups, and likely greater. Doubt is thrown, however, upon this interpretation by the fact that the rocks which follow the thick limestone to the south, on the Theresa sheet, differ considerably from the green schist series which follows it to the north on the Alexandria sheet, and yet according to this interpretation the two should be identical, representing the series directly beneath the thick limestone. Each does consist of schist, calcareous schist, and thin limestone bands, with an occasional thin quartzite, but the Theresa rocks are not of this distinct green schist type. A possible answer to this objection may be found in the fact that, notwithstanding a rather intimate acquaintance with the Grenville series all over northern New York and in parts of Canada, the writer has nowhere else seen the counterpart of this green schist series. It is in rather close association with the Picton granite, which was richly supplied with mineralizing agents, and is everywhere cut with numerous dikes from this granite, so that its peculiar characters are thought to be largely, or wholly attributable to this contact action, and thus explained as due to these local conditions. If this be not the explanation there seems no alternative but to regard the two thick limestones as separate beds, thus largely increasing the thickness of the section, already great. If the structure is thus correctly interpreted, a thickness of at least 20,000 feet is indicated for the Grenville of the district, and this is a conservative estimate. If the structure is not synclinal this thickness must be nearly doubled.

This matter will be discussed somewhat more in detail on a later page. The purpose here is simply to give an outline of the supposed Grenville succession and some idea of the great thickness of the series.

Limestones. The general Grenville limestone of the district is a coarsely crystalline and quite pure white marble, only sparingly charged with other minerals. The great bulk of the rock of the thick belt, or belts, just referred to, consists of 95% or upward of


POTSDAM
GRENVILLE LIMESTONE



Road metal quarry in Grenville limestone at Theresa near the falls. The limestone bed is a thin one in the general schist series and the quarry face is down the dip, here 75°. At the upper part of the cliff is Potsdam sandstone with irregular contact with the limestone, and showing one of the depressed pockets characteristic of these contacts, filled with weakly cemented calcareous sandstone. H. P. Cushing, photo, 1907

calcite. Toward the edges, however, the rock becomes much less pure, and at times the same thing happens in the near vicinity of the igneous intrusions, large and small, which repeatedly cut through it. This is by no means the invariable rule however. In the case of the thin limestone bands which occur in the general schist series [pl. 2] there is much less pure limestone, since these bands show the same impure borders as does the thick belt, leaving only a small central thickness of the purer rock. In this pure rock occasional graphite scales, flakes of brown mica (phlogopite) and occasional small crystals of white pyroxene (diopside) are the usual accessory minerals and in very small amount. Others occur, but very sparingly. These rocks must originally have been extremely pure limestones, slightly contaminated with organic matter, which now appears in the form of graphite.

The impure limestone of the area is owing to two distinct causes. Certain thin bands of impure limestone in the schist series, and the impure borders of the otherwise pure bands seem unquestionably owing to original deposit as shaly or sandy limestones, forming gradations between the pure rock and the overlying and underlying shales and sandstones. Hence on recrystallization a much smaller percentage of calcite and a much larger one of other minerals has resulted. The other cause is the interaction of the limestone with igneous rocks, producing what are known as contact rocks, in which certain added ingredients are supplied to the limestones from the igneous rocks and react with the limestone to form minerals which thus have a mixed origin. Such contact rocks are thus limited to the near vicinity of the igneous rocks.

The two most common kinds of impure limestone of the first type in the region are the quartzose limestones, and the pyroxenic limestones. Much of the marginal limestone seems to have been sandy, and even to have contained thin layers of fairly pure sandstone. This has recrystallized as quartz, partly in fine grain, forming a mosaic with the calcite, and partly coarser and in films and patches in the limestone. Each mineral at times contains inclusions of the other, they evidently recrystallized together, and the quartz evidently had the stronger crystallizing force. There is a considerable amount of limestone in the area which is a calcite-quartz rock, with little or no admixture with other minerals.

Even more common is the pyroxenic limestone, where the calcite is accompanied by a greater or less amount of a white or a light green pyroxene. This is prone to alter to serpentine, a dull green, greasy to earthy looking mineral, producing a mottled green and white rock which is of common occurrence in the Grenville wherever known. In the writer's experience this is far from being true of the quartzose limestone which occurs in much greater force here than is customary.

Of the various Grenville rocks the limestones are much more yielding under compressive stresses than are the schists and quartzites, behave more like plastic and less like brittle bodies, and hence change shape more readily. As a result rocks which much resemble coarse conglomerates are a frequent feature in the Grenville limestone. Frequent dikes of granite traverse it, many of which are of slender width. Under compression these are brittle under conditions which are sufficient to cause flowage in the limestone, hence the dikes fracture, the separate fragments are somewhat shifted in position and limestone is squeezed in between them. The same thing takes place where thin bands of quartzite or of schist are present in the limestone, as is frequently the case. These fragments of granite, quartzite or schist weather less rapidly than the surrounding limestone, and hence project somewhat on weathered surfaces, with considerable increase in conspicuousness, and the separate fragments surrounded by calcite give an admirable mimicry of a conglomerate in appearance.

In addition to the normal white limestone frequent patches or streaks of gray or blue limestone also occur in association with it, which outwardly look much more like ordinary limestone. This is in line with the further fact that all the Grenville rocks seem somewhat less severely metamorphosed than is the case with the equivalent rocks to the eastward. Even the white marble has at times a grayish or bluish cast, and does not average as coarsely crystalline as the eastern Grenville limestone. On the other hand limestone of these characters is commonly not so pure as is much of the white limestone, and these gray or blue portions often occur in such situation as to suggest that they are contact effects of igneous rocks on the white limestone. In some instances certainly the white limestone changes to gray adjacent to an igneous rock mass of good size, and in others gray patches in white limestone occur in direct contact with granite dikes, an unlikely situation if they are really less metamorphosed portions of the white limestone. It is also true, however, that some of the gray limestone is very pure, that in some places it has no discoverable nearness to any igneous rock, and that in general the contact action of the igneous rocks of the district upon the limestone has been but slight, though with local exceptions to this statement. With such arguments in mind it has seemed to the writer as though the weight of the evidence were in favor of the view that at least some of the gray and blue limestone was representative of the white in less metamorphosed condition, and if some, then likely all.

Nowhere else in northern New York has the writer met with Grenville limestone of this fine grained, darker colored type. A comparison is at once suggested with the district in Ontario recently described by Adams who has shown that a similar, though better marked change comes over the Canadian Grenville limestone when followed westward, a local development of bluish limestone in thin bands within the coarser white limestones.[1] The evidence seems to indicate that we have here in New York the first glimpses of a similar tendency.

The consideration of the contact effects which the various igneous rocks have had upon the limestones is deferred until the igneous rocks themselves have been described.

Quartzites. There are two belts of ponderous quartzites in the region, one on Wellesley and Grindstone islands, and the other in the district east of Redwood (Alexandria sheet). In both cases the quartzite is interbanded with various schists and amphibolites, in highly folded condition, so that the number of quartzite beds is uncertain, and whether there is more than one massive, thick quartzite can not be positively stated. There is certainly a considerable number of thinner bands. Unless our interpretation of the structure is wholly at fault, these two belts represent lines of outcrop of the same geologic horizon, and form the youngest rocks of the series exposed in the district. In addition to this main horizon there are also frequent quartzite bands found in the general schist series, and thin bands even occur at times with the limestones. The more prominent of such bands are indicated upon the maps.

The ponderous quartzites are the most resistant rocks of Precambric age in the region, and since they are interbedded with schists which are far weaker, the districts where they outcrop are quite rugged topographically, as Smyth pointed out 10 years ago. The quartzite ridges tower abruptly above the narrow valleys eaten out along the schists.

Since the rock is an altered sandstone, recrystallized under heat and pressure, and since sandstones often range in composition from a high degree of purity to those which are quite impure, either shaly, or calcareous, it is but natural to find much variation in the rock from place to place. The thick bands are chiefly constituted

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[1] Adams, F. D. Jour. Geol. 16:623-24.

of massive, coarsely crystalline quartz, running up to as high as 90% of the rock, though feldspars and accessory minerals are always present. The thinner quartzite beds are generally more impure, though containing layers of coarse, massive, quite pure quartzite. The impurer beds are often well foliated, consisting of alternate films of pure quartz and of other minerals, the former very resistant to the weather, the latter less so, so that on the weathered surfaces the contortions and puckerings of the complexly folded schist series are much more perfectly displayed than in any other rock type of the region. They are often very close jointed, especially near granite, weathering out into small blocks [pl. 3].

Much of the quartzite of the district is more or less permeated with brown, iron-stained spots, due to the weathering out of some mineral with iron in its composition. These spots vary greatly in abundance in different occurrences and different layers, and may have a fairly uniform distribution, or, in the foliated varieties, be confined to the films containing other minerals than quartz, giving a brown and white, banded rock. In some cases, notably those of the first type, the mineral removed seems to have been pyrite, a mineral of consistent occurrence in the quartzite; in other cases it seems to have been pyroxene, though even here probably oxidized pyrite was responsible for most of the yellow, iron stain.

In texture the rock shows great variation, ranging from the very coarsely crystalline, glassy rocks, down to varieties which have a finely granular make-up.

Next to quartz, feldspars form the most prominent mineral constituent, orthoclase, microperthite and oligoclase all occurring. Much variation in relative amounts of the two mineral groups is shown, but in the great bulk of the rock, quartz is in excess and usually greatly in excess. In some varieties white to light green pyroxene appears in quantity, when the feldspar retreats. There is considerable of such quartz-pyroxene gneiss in the region, the quartz usually constituting 75% of the rock. Light brown mica (phlogopite) is sparingly present in much of the quartzite, and some varieties become quite micaceous. Pyrite is a frequent mineral, as has been stated. Zircon and titanite are nearly always present, and at times fine needles of rutile are abundantly included.

Here and there in the region rocks are found which present a puzzling half way stage between quartzite and granite, so that they are likely to be classed, now with one rock, and again with the other, according as the observer comes upon them from quartzite, or from granite. In all cases where the relations could be worked

Plate 3

Grenville quartzite of the much jointed type showing its characteristic weathering. The Potsdam lies just above but shows poorly in the view. Locality near the south margin of the Alexandria Bay quadrangle, nearly 1 mile south of Crystal lake, by the roadside. H. P. Cushing, photo, 1907

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out such rocks either occur along granite-quartzite contacts, or else are included in granite. They are apt to show close set, block jointing, like the quartzite. They have been found only in association with the granite gneiss. The field evidence seems to us strongly indicative of the fact that these are really intermediate rocks, in the sense that they represent quartzites in various stages of granitization; that the quartzite is being permeated, soaked and even digested by the granite. The character of the intermediate rock, the shading of the two into one another, and the field occurrence of the intermediate stages, all point to this conclusion, and seem incapable of explanation on any other hypothesis.

Amphibolites. The name amphibolite is a convenient, comprehensive term for a group of rocks of gneissoid habit and dark color, composed essentially of hornblende and feldspars, with often considerable amounts of biotite or pyroxenes, and with accessory minerals of which magnetite is easily chief, and quartz and garnet of frequent occurrence. In respect to origin, the rock has long been a puzzling one since apparently identically appearing amphibolite might be produced by metamorphism from either igneous or from sedimentary rocks of the proper character. In a multitude of localities in the Adirondacks it has been shown that gabbro intrusions (whose character and origin is rendered certain by a core of practically unchanged rock) are largely changed over into amphibolites, every step in the process being open to inspection. Similar relations have been shown in many localities in all continents. Also in the Adirondacks, wherever the Grenville series is exposed, bands of amphibolite of varying thickness are found so definitely interstratified with other Grenville rocks of unquestioned sedimentary nature, that there seemed no escape from the conclusion that the rock must have resulted from the metamorphism of a sediment; and amphibolite of such origin is equally of world-wide distribution. In addition it has recently been shown by Adams that amphibolite can also be produced on a large scale by the contact action of granite on limestone. Here are therefore three different modes of origin, and the rock may be either igneous, sedimentary, or a contact rock. Each occurrence of the rock must therefore be studied by itself, in so far as its origin is concerned. Amphibolite of all three types is present in our district.

Within the mapped area amphibolite has not the bulk and importance that it has in much of the Precambric district adjacent. There is much of it present as inclusions in the granite gneiss bathyliths and stocks, inclusions of much variation in size and in abundance. Frequent bands of it occur within the Grenville series, but these are usually of no great thickness. There is but little of the rock present to which an igneous origin may be definitely assigned. There are small areas of such rock in the district north and northeast of Theresa, where a somewhat more heavily bedded amphibolite occurs, which holds much pyroxene in addition to the hornblende, and which seems to definitely cut the limestone with which it is associated. There are, however, amphibolite bands interstratified with the same limestone, and the mass has been severely deformed, with the production of flow in the limestone and the fracturing of the amphibolite into blocks, making one appear to cut and be included in the other, but this does not seem to be a case of the sort. In our experience amphibolites which result from the metamorphism of gabbro, usually contain pyroxene in quantity, while those originating from calcareous shales are more apt to be micaceous and lack the pyroxene, but this is far from being an invariable rule, and is only suggestive of origin, not demonstrative.

The amphibolites interstratified within the Grenville series, and regarded as metamorphosed sediments, calcareous shales or something of that sort, are mostly quite finely and evenly granular rocks, which have wholly recrystallized, and vary from very solid looking, dense rocks in which mica is but sparingly present, to very schistose, highly micaceous rocks, which rapidly break down under the weather. In most of these orthoclase feldspar is apt to predominate over plagioclase, and much of the rock contains some quartz, the micaceous varieties often considerable. The manner in which the variations appear is itself highly suggestive of metamorphosed sediments which differed somewhat in character from bed to bed. Some of the rock contains garnets, in some cases reaching large size, but they are exceptional rather than the rule.

The amphibolite of contact origin will be discussed under the general topic of contact rocks.

Schists. Under this heading are included a large number of rock types, so many that it seems hopeless to attempt to describe all, or many of them. No doubt they have diverse origins. Some of them quite certainly owe their present character to contact action, and no doubt contact action of varying kind, and in varying degree, is in large measure responsible for the great diversity of the group. Some of the rocks grouped here are no doubt igneous, and in their character distinctly suggest such an origin, though the proof is difficult to obtain.

A very common variety of Grenville schist, the so called "rusty gneiss" with its characteristic yellowish tinge on weathered surfaces, is but sparingly present in our area here. In the district east of Redwood it occurs somewhat, as it does also to the northward of Theresa. It is a quartzose gneiss, usually containing the mineral "sillimanite" and holding pyrite in quantity, the easy decomposition of which is chiefly accountable for the weakness and the color stain of the rock.

There are reddish, acid gneisses which, so far as composition goes might be either original granites, or shaly sandstones. There are black and white gneisses, which are feldspar-pyroxene-quartz gneisses. There are very granular, dark reddish, weak, microperthitic feldspar-hornblende gneisses; gray, feld-spar-hornblende gneisses, holding much pyrite and titanite; there are leaf-quartz gneisses, the quartz in coarse spindles or lenses, and with little other than feldspar in addition; evenly granular, white, spotted gneisses which are microperthite-quartz-hornblende rocks; garnetiferous, quartz-biotite gneisses, with but little feldspar and a lot of pyrite; quartz-feldspar-phlogopite gneisses with graphite; gneisses which somewhat suggest metamorphosed volcanic tuffs, though in no case has it been possible to demonstrate such an origin for them. Many of the rocks contain calcite, which at times has resulted from alteration and at times suggests itself as an original constituent. Graphite is a frequent mineral in many of the schists.

Nowhere in the district has a rock been found which at all suggests the greenstones of the Keewatin formation.

Belts of badly altered rock, considerably impregnated with iron, so as to constitute lean iron ore, occur within the Grenville schist belts, striking with the belt and apparently behaving like an integral part of the series. Fragments of one such belt are found in the granite of the Alexandria bathylith near Cranberry creek, and a prominent belt occurs east of Redwood, especially along the north side of Millsite lake. The rock is exceedingly weak, earthy looking, either red, or yellow brown in color, and has a considerable local use for road metal. It is so thoroughly altered that it is almost impossible to get any clear notion of its original character being simply a mass of clayey, alteration products, with considerable calcite, and the whole impregnated with hydrated iron oxid, chiefly the red oxid. There are fresher streaks and bunches here and there which appear to be granite gneiss. None of the so called "serpentine" rock, which is generally associated with the similar, but richer, belt of iron ore which runs through Antwerp and Rossie, just east of our map, has been noted here, but with that exception there is a strong resemblance in the material.

Igneous rocks. *Gneissic granites* (*Laurentian*). There are two extensive (bathylithic) masses of granite gneiss in the district, both of which are only in part within the mapped area. The western end of what we have called the "Antwerp bathylith" is exposed on the Theresa quadrangle, disappearing westward under a Paleozoic cover. The Alexandria bathylith, on the mainland and islands of the Alexandria quadrangle, seems of smaller size but also disappears under a Paleozoic cover, both eastward and westward, and passes across into Canada as well. There are in addition numerous smaller masses. It is highly probable that all are connected underground, and represent the upper portions of a great, underground mass of granite, underlying all of the Grenville of the district, except where cut away by the later intrusions.

That this granite came to its present resting place after the Grenville was deposited was pointed out by Smyth 10 years ago, and is shown clearly in a host of exposures. Dikes without number run out from the granite masses into the Grenville rocks, the granite is everywhere full of included fragments of the Grenville, and along the contacts between the two sets of rocks, the Grenville rocks have plainly been modified by the contact action of the intrusive.

The general rock is a quite acid, red granite, composed chiefly of feldspars (microperthite, microcline and oligoclase) and quartz, with small amounts of mica (both biotite and muscovite) and magnetite, and with zircon, titanite and apatite as accessories. Such rock does not appear especially gneissoid, though usually of rather fine and even grain, but in thin section it invariably shows much crushing, and a considerable amount of recrystallization. The rock is everywhere cut by its own aplite, pegmatite and quartz dikes, some of which are much coarser grained, as usual. Many of the granite dikes which penetrate the Grenville, especially the limestones, are coarser grained, and less mashed than the general rock.

In a minor way the rock of the bathyliths is quite variable, and that in two main ways, one apparently representing original variations in the rock, and one owing to relative abundance of inclusions and the effect of the granite on them. The rock varies from one which is almost wholly constituted of feldspars and quartz, to one which contains several per cent of mica, which thus becomes a conspicuous constituent. The rock changes from deep red through lighter shades to nearly white. It varies also much in texture, from throughly solid looking, crystalline appearance to varieties which weather to a sugary, granular aspect.

As usual in the Laurentian, inclusions abound, and as usual the bulk of these are of amphibolite. Quartzite inclusions also occur, but infrequently, limestone inclusions never. The amphibolite inclusions are found everywhere but always most abundantly near the margins, where they abound. In fact a sharp boundary line between the granite gneiss and the adjacent Grenville rocks can not be drawn. In passing from granite to sediments the inclusions show steady increase in number until they come to constitute 50% of the rock, beyond which we find sediments cut by granite dikes rather than granite holding inclusions of sediments. This reduces boundary mapping to a matter of estimating equality or inequality in amount of the two rocks, or in drawing a boundary where no real one exists. An attempt, however, has been made to indicate, by convention, on the maps, the actual state of things found in the field.

The granite dikes usually represent the extreme acid state of the rock. The main mass averages less acid, chiefly because of the inclusions and of the attack of the granite upon them. In its preliminary stages this usually takes the form of an injection of the granite in thin sheets along the foliation planes of the amphibolite, the so called "lit-par-lit," or leaf type of injection, producing a banded rock of alternations of igneous and sedimentary material. Then, here and there, the granite breaks out from the foliation planes and spreads through the rock adjacent, forcing its grains apart by the injection of a thin film of granite between. This process becomes more and more pronounced, until much of the rock is broken up into a granular mosaic of particles cemented together by granite films, producing what may be called the mosaic type of injection, as distinguished from the leaf type. A fine example of injection of this type is shown in plates 4 and 5. The injected rock is not amphibolite, but is green schist, a closely related rock, and the type of injection is identical. As a further stage, in both types of injection, the sharp boundaries become blurred, and this shading of the two rocks into one another becomes more and more prominent until finally rocks result which seem unquestionably to be due to the complete digestion of the amphibolite by the granite, gray gneisses of distinctly intermediate composition. As would be expected these more advanced stages are usually found in the case of inclusions away from the near vicinity of the border.

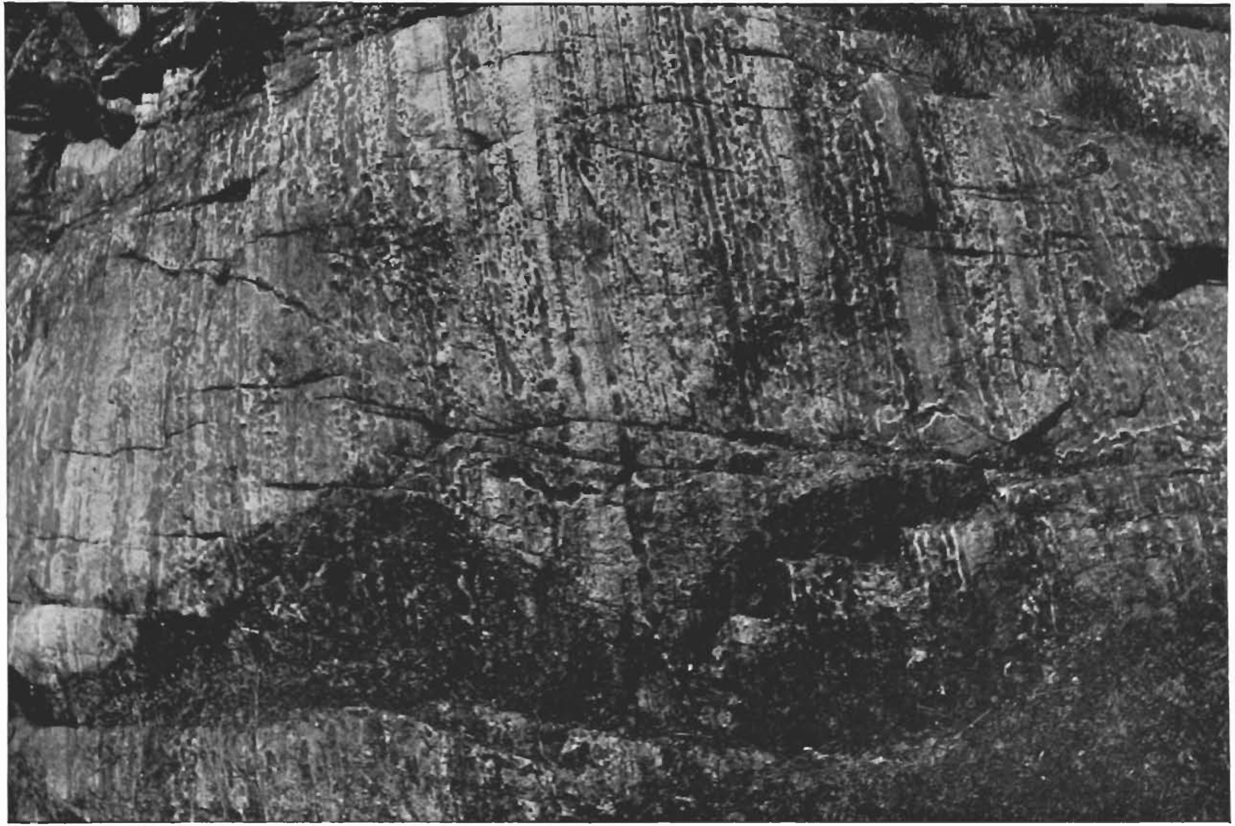
We have not, up to the present time, definitely classed any of the granites of northern New York as of Laurentian age. Just across the border in Canada however, where the rocks are identical, this term is definitely applied to the granite gneiss of the bathyliths which invaded the Grenville series from beneath, broke it up into disconnected belts and patches and destroyed all trace of its floor. The absolute identity of the rocks and their relations, leads us to apply the name here to the granite gneiss bodies with much confidence in the wisdom and propriety of the correlation. Whether these Laurentian granites are recognizable, however, over any considerable part of the Adirondack region, in distinction from granites of later date, is a much less certain matter, though we believe it to be the case. It is thought for example that what we have called the Saranac gneiss in Clinton county, and the Long Lake gneiss of that quadrangle, are in all probability of Laurentian age.

Theresa syenite. This comparatively small intrusive mass lies to the southward of Theresa, in a valley floored by Precambric rocks, but walled in by Potsdam on all sides It is somewhat less than 2 miles in length and with a breadth of less than half a mile, so far as the exposures go; at the south it may have greater breadth underneath the Potsdam.

The general rock is of medium coarseness and granitic texture, though always with evidence of mashing and granulation, and of gray to greenish color. Most of it is chiefly made up of feldspars. It resembles in high degree the common greenish, augite syenite of the Adirondack region, is unhesitatingly classed with that, and is the only representative of that rock type within the mapped area. Like it, this rock is quite variable, becoming red and granitic looking on the one hand, and more basic with increase of black minerals on the other. Near the border some varieties become feebly porphyritic.

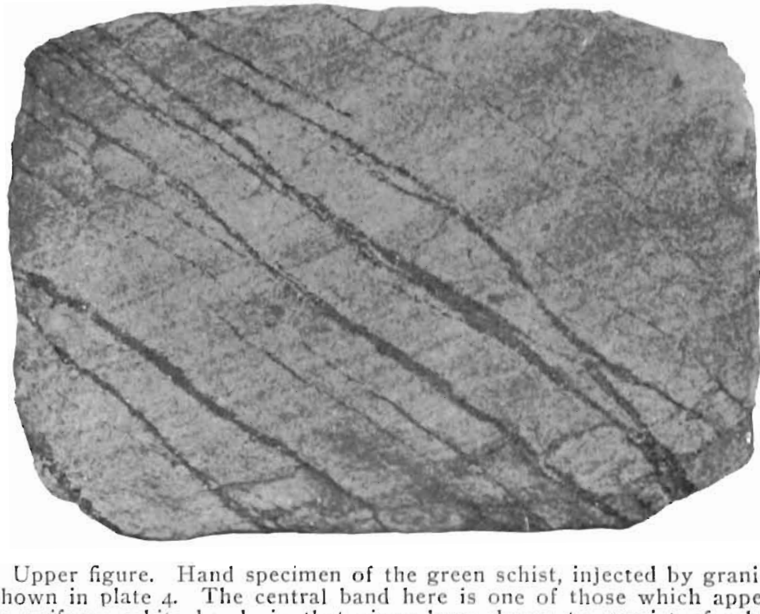
Microperthitic feldspar is always the chief constituent of the rock. Some oligoclase is always present. Quartz varies from some 15% in the more granitic, red varieties, down to complete absence. Augite is the most prominent black mineral in the ordinary rock, with biotite usually and hornblende sometimes sparingly present; magnetite, apatite, titanite and zircon are the chief accessories, the apatite usually quite prominent, another feature which the rock has in common with the general Adiron-

Plate 4



Grenville green schists intimately cut by granite. Forsters landing, by roadside not far from spot shown in plate 1; looking east. Hight shown is about 10 feet. The schist shows dark and the granite white. The granite is injected along the foliation planes of the schist and then ramifies out into the intervening space, separating the schist into mosaic blocks or grains. Only the coarser of these show well in the view but the broader white bands are the same mixture on a small scale. This is regarded as the initial step in the process of the digestion of the schist by the granite. H. P. Cushing, photo, 1908

Plate 5



Upper figure. Hand specimen of the green schist, injected by granite, shown in plate 4. The central band here is one of those which appear as uniform, white bands in that view; here shown to consist of schist thoroughly and minutely broken up by, and inclosed in the granite.

Lower figure. Hand specimen of sheared, banded, acid gneiss from near the shore of Wellesley island, due west of Alexandria Bay. Shearing has produced numerous, slight faults, the shear planes are solidly welded up by secondary minerals, and dikes of the Picton granite cut across these, these of course not showing in the specimen. H. P. Cushing, photo

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dack syenite. In the most basic variety seen, these dark minerals constitute no more than 15% of the rock, the remainder being feldspar with a little quartz.

Granting the equivalence of the rock with the general augite syenite, its age is rather definitely fixed as one of the great intrusives of the region, younger than the Grenville and the Laurentian granite, and also younger than the anorthosite intrusion. Since this latter rock is not represented in the district, and the only direct evidence of age seen in connection with the Theresa syenite is that it cuts the Grenville, this additional evidence is welcome.

Alexandria syenite. The intrusive mass of syenite called for convenience by the above name, since nearly the entire mass is in Alexandria township, lies west and north of Redwood, with a major axis of nearly 6 miles, and with a greatest breadth of nearly 2 miles; this on the supposition that but a single intrusion is here represented, as is believed to be the case. It is possible that two intrusions are here in which case the southern one fourth must be separated from the rest.

Much of the rock is considerably crushed, granulated and recrystallized, converting it into an augen gneiss. The size of the augen, many of which are a half inch long, bespeaks either a very coarse grained rock originally, or a porphyry, the latter being regarded as most probable. These coarse augen gneisses are chiefly peripheral, and mostly at the south end of the mass. Centrally, considerable cores of much less mashed rock remain which, while of medium coarseness of grain, do not approach the coarseness of the augen. The bulk of the rock is an augen gneiss with small augen, and it may be that the coarse augen gneiss at the south should be separated from the remainder; the two seem, however, to grade into one another, and no evidence that one cut the other was found, except that in a few localities the coarse augen gneiss is cut by dikes of fine grained red granite. These seem rather acid for dikes from the syenite. It is possible that they are stray dikes of Picton granite.

The least mashed cores show a rock of granitic texture and medium grain, composed chiefly of a reddish feldspar and black hornblende, the latter in sufficient quantity to give some of the rock a strong resemblance to a diorite. These least gneissoid portions always show much mashing, when seen in thin section, the feldspars being granulated at their margins, and the hornblendes fraying out into biotite scales. This change increases until finally we get a rock in which but few unmashed feldspar centers remain, the hornblende has entirely disappeared, and the rock is a finely granular aggregate of feldspars, mica scales, and some quartz.

Of accessory minerals, apatite and titanite are prominent, the former being abundant for this mineral, and of good size, the latter usually rimming the magnetite, as well as occurring away from it. The feldspars comprise microcline, microperthite and plagioclase (oligoclase-andesine), with the latter somewhat in excess when the plagioclase in the microperthite is included with it. The quantity of the two, however, is not far from equal in most cases. There is little or no quartz in the least mashed rock, and the quantity steadily increases in the gneissoid varieties. Some of this increase is certainly due to reactions during recrystallization since quartz commences to appear with the appearance of biotite. On the other hand the rock varies somewhat in acidity and some of the quartz is unquestionably primary.

The coarse augen gneiss at the south has much the same mineralogy as the remainder, though more quartzose and acid, approaching a granite in composition. Smyth holds the view that it is a separate intrusion from the main mass of the syenite, and older, having noted an exposure in which the syenite appeared to cut the augen gneiss. We did not have the good fortune to observe any such exposure, hence his positive evidence must outweigh our lack of such. Chemically also the augen gneiss is much more acid than the syenite, being remarkably like the Picton granite in composition. If the two are separate, the augen gneiss is the older, and both are younger than the Laurentian, while the Picton holds inclusions of the augen gneiss.

This syenite differs considerably from the usual type of syenite of the Adirondack region, represented here by the Theresa syenite, both in general appearance and in mineralogy. Analyses and more detailed description will be given in a later section of this report. It is more gneissoid, giving the appearance of greater deformation than the Theresa syenite, and hence it is tentatively inferred that it is somewhat older than that. The appearance may however be entirely deceptive, since the one rock gives rise to abundant mica when deformed, and the other furnishes little or none, nor any other mineral which promotes foliation. Hence the same amount of deformation would produce a better foliated rock in the former case than in the latter, a rock which would appear more greatly deformed.

Picton granite. This is the latest, most extensive, most interesting, and most important of the intrusives of the region. It is named from Picton island (called Robbins island on the map) where it is most extensively quarried. It is, however, best and most extensively exposed on Grindstone island and would have been named after it except for the fact that the whole name was too long, and the term "Grindstone granite" possibly misleading. It is extensively exposed also on the west end of Wellesley island. Abundant dikes of it appear on the mainland of the Alexandria sheet, cutting the Alexandria granite gneiss and the Grenville schists, but the main mass falls short of reaching the shore. It does reach the mainland on the Clayton sheet, however, judging from the exposures of the Precambric inlier up French creek, and may have wide extent here under the Paleozoic rocks. Across the border in Canada it seems to have large extent, though it has not yet been differentiated from the Laurentian in mapping. If, however, we are correct in correlating the granite at Kingston with this rock, a bathylith of considerable extent is implied.

The general rock is a rather bright red granite of quite coarse grain. It varies much in this respect however, and much of the border rock is of much finer grain, as is also true of the general run of the dikes which radiate out from the mass. To a certain extent this diminution in apparent size of grain is due to mashing, but certainly the major part of it is a primary difference.

Red feldspars (microperthite, microcline and oligoclase) constitute 75% or more of the rock. Considerable quartz is usually present and is frequently characterized by a slightly bluish cast, which makes a helpful diagnostic feature of the rock. Hornblende and biotite are sufficiently abundant to show prominent black spots in the otherwise red rock. In the finer grained border varieties and dikes, these black minerals retreat, quartz becomes somewhat more prominent, and the rock appears more acid. The general rock, however, does not impress one as a particularly acid rock for a granite, and this impression is borne out on analysis (given in a later section).

The rock of the inlier to the south of Clayton, and that at Kingston are correlated with this granite with some reserve. The Kingston rock is a red granite of almost identical appearance with this, agrees closely in composition, and the only hesitancy felt in the matter is owing to the distance separating the two areas. In all likelihood the rock can be carried across on the Canadian islands to the mainland and thence west to Kingston, but until this has been done some reserve must be felt in making the correlation. The rock near Clayton differs in containing no quartz, and in being somewhat more mashed than the generality of the rock. It is in fact an acid syenite rather than a granite. Otherwise the two are exceedingly alike, and since the granite itself is low in silica for a granite, approaching a syenite in that respect, but slight variation is needed to cause the disappearance of the quartz.

It must be borne in mind, in inspecting the maps, that the boundaries drawn between the Picton granite and the Laurentian are in the highest degree conventional. They are of the same vague sort as those between the Laurentian and Grenville, but even more vague than those because of the similarity of the two rocks. The fine grained dikes of the Picton are exceedingly like the acid dikes sent out from the Laurentian, and it is almost an impossible matter to tell which rock is in excess. On the other hand the maps do show the chief areas of the two rocks, bring out the fact that the one is younger than the other, and show their relative distribution and extent as accurately as possible in rocks of this kind.

That the rock is the youngest of the intrusives of the region is indicated in several ways. It shows less sign of mashing than do any of the others, that is its unmashed central core is relatively much larger. Besides its abundant inclusions of various Grenville rocks it contains also frequent masses of granite gneiss of Laurentian type, and sends abundant dikes into similar rock where bordered by it, as it is locally on both Wellesley and Grindstone islands; and also it contains inclusions of an augen gneiss which is absolutely identical in character with the rock of the Alexandria syenite. Such age for the rock then seems to us in the highest degree probable, though it falls somewhat short of actual demonstration.

Dikes of the granite are thought to range widely in the rocks east and south, though no attempt to indicate this upon the areal maps has been made. They are believed to be numerously present in the green schist belts of the western part of the Alexandria quadrangle, and also in the granite gneiss of that quadrangle. Even as far east as Alexandria Bay broad dikes of acid, usually fine grained, granite occur abundantly, cutting the granite gneiss all to pieces, and often inclosing sharp inclusions of it. We have never seen inclusions of this type held abundantly in the aplite dikes of the granite gneiss itself, and regard the granite of the dikes as likely Picton.

The contact relations of this rock with those adjacent are of much interest. It was apparently richer in mineralizing fluids than any of the other intrusives, and gives rise to interesting contact rocks, to be described in the succeeding section. But the field relations are also most important and interesting.

While mapping Wellesley and Grindstone islands it quickly caught our attention that the abundant inclusions with which the Picton granite is everywhere charged were arranged in belts, that is, along a given line the inclusions were all quartzite, along an adjoining line they were all amphibolite, along another nothing but granite gneiss inclusions appeared. It was also seen that these belts had northeast-southwest trend, concordant with the general rock strike of the region, and that further the individual inclusions to large extent retained their original orientation and dip, notwithstanding the intrusion. Our strikes and dips, read on the rocks in the field, gave absolutely concordant results as we passed from one inclusion to another, results also concordant with the readings obtained on the same rocks beyond the reach of the intrusion. We were able to map the original belts of Grenville quartzite and schist, and the intrusions of Laurentian granite gneiss, as accurately as though the Picton granite was not present, so little had they been disturbed by the intrusion. An attempt has been made to bring out these facts upon the geologic maps. We could only account for the phenomena on the assumption that we have exposed here the very roof of this portion of the bathylith, the abundant inclusions representing masses but just loosened from their original place, not greatly sunken, and preserving unimpaired their original orientation. If this be the correct interpretation, the locality furnishes a fine illustration of the general phenomenon.

Other intrusions. While the above furnish the only examples of intrusions of considerable size in the region, there are many others of small size, mostly too small to map, and which it seems hardly worth while to describe in detail. These are chiefly of granite gneiss, and are regarded for the most part as of Laurentian age, and as representing comparatively small upward protrusions from the general roof of the great mass of Laurentian granite gneiss which is believed to underlie the entire district, except where broken through by the later intrusions. A good illustration is that of the granite gneiss in the extreme southeast corner of the Alexandria sheet, which forms a wonderful cliff along the Indian river.

In quite a number of localities syenitic rocks were found, always of trifling extent, and with field relations wholly indeterminate.

At the west end of the upper bridge at Theresa, is a small intrusion of gabbro, which is but little mashed, and has some features of interest in that it recalls the anorthosites and gabbros of the general Adirondack region, and is the only representative of these rocks seen here. It is a dark colored rock, showing numerous, glittering, lath-shaped feldspars up to an inch in length, on broken surfaces. It is made up of feldspar (labradorite), augite, hypersthene and hornblende, with considerable magnetite, and a little pyrite and apatite as accessories. The feldspar constitutes from 60 to 70% of the rock. In composition therefore it is distinctly a gabbro, though with more abundant feldspar than the usual Adirondack gabbro. Yet, in spite of the coarsely lath-shaped feldspars the structure is more nearly that of a gabbro than a hyperite, recalling in this respect the anorthosite-gabbros farther east.

Diabase. Cutting all the other Precambric rocks of the region, occasional dikes of trap rock are found. The fact that they cut all the other rocks shows that they are younger, but it can also be shown that they are much younger than the other igneous rocks, though nevertheless older than the Potsdam sandstone. They are found only in the form of dikes, which are lava-filled fissures that in general represent plugged channels of ascent of the molten rock, leading downward to some source of supply of the material, and tending upward toward the surface. The dikes have chilled borders, showing that the inclosing rocks were comparatively cool and hence at no great depth beneath the surface at the time of solidification. Furthermore they show no sign of having undergone the kind of deformation which all the other igneous rocks have experienced in greater or less degree, a kind which takes place only at considerable depths. Since the diabases cooled much nearer the surface than the granites and syenites, a long time interval of surface erosion during which a considerable rock thickness was worn away from the surface, must separate the two.

In the district mapped these dikes have a somewhat unequal distribution. They are most abundant on Grindstone island, seven having been noted there, mostly of large size, none of them less than 20 feet wide, and ranging from that up to 100 feet in the case of the dike numbered 1 on the map. Two have been found on Wellesley island, the wider of which measures 30 feet. Seven have been found on the mainland of the Alexandria sheet, in rather widely scattered distribution, and in general much narrower. None have been observed on the Theresa sheet. Smyth has described them as abundant on the Canadian mainland and islands in the vicinity of Gananoque, hence in the near vicinity of Grindstone island, which would seem to have been the chief center of activity. For petrographic details the reader is referred to his account which, though based on Canadian material, also describes these accurately.[1]

The dikes trend in various directions, from northwest around through north to northeast. Smyth states that those seen around Gananoque trend chiefly to the north, and were all cutting granite. It is to be noted that all those trending northeast, in our district here, are cutting Grenville rocks with general northeast strike, while all the dikes cutting the igneous rocks trend north or northwest. This is also true of two of the dikes cutting the Grenville, but in both cases the Grenville is in comparatively small bulk, and entirely inclosed by igneous rocks. The dike directions are therefore apparently determined by preexisting structures in the rocks, by the strike in the Grenville, and by a joint set in the igneous rocks. Small masses of Grenville rocks did not suffice to change the direction of dikes passing across them, the igneous rocks here being the determining factor.

Though they give no evidence of having been severely deformed, yet the rock of the larger dikes does show evidences of considerable pressure. Many of the feldspar crystals are distinctly bent, and both the feldspar and augite of the rock shows evidence of strain by their undulatory extinction. In this respect they contrast with the diabases of the eastern Adirondacks, which show no such strain effects. The eastern dikes also have chiefly east-west trends, differ somewhat in mineralogy, and are more numerous and widespread; and are also separated from this area by a wide region in which such dikes are absent. We seem here therefore to be dealing with a wholly different center of igneous activity, and a much less extensive one than that farther east.

Owing to their size and comparative freshness these dikes have a potential value in the region as a comparatively accessible source of good road metal.

Contact rocks. The contact effects of the igneous rocks upon the Grenville sediments, and vice versa, may be grouped under three

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[1] N. Y. Acad. Sci. Trans. 13:209-14.

categories, effects produced upon the igneous rocks themselves, effects of the igneous rocks upon the sediments whereby rocks of intermediate composition are produced, and effects produced upon the sediments by the injection into them of fluids from the igneous rocks, fluids rich in mineralizing agents, and of quite different composition from the general mass of the igneous rock.

Bleaching of granite by limestone. In the early stages of the work it was noted that, while granite dikes and knobs of all sizes were of frequent occurrence, cutting the Grenville limestone wherever exposed, in all cases the granite was white, nearly as white as the limestone in fact. The granite of the bathyliths is, however, uniformly of red color, as are also the dikes in rock other than limestone. This led to search for limestone contacts along the margin of the Antwerp bathylith and of the smaller granite intrusions of the Theresa sheet, when it was found that in every case the margin of the granite, adjacent to the limestone, was turned white. It also proved to be the case in subsequent work that whenever, in passing over granite country, a whitening of the rock was observable, directly beyond crystalline limestone was sure to be found. It also was found that the general granite of the Antwerp bathylith had had singularly little contact effect upon the limestone, pure, unchanged limestone lying directly in contact with the granite in most cases, and that the dikes also had had no contact effects, so that the rather unusual condition was presented of granite-limestone contacts in which the granite was the rock showing contact effects, not the limestone.

Study of the white granite, both chemically and in thin section, affords no explanation of the change. The white granite is in general somewhat more acid than the red, but that is believed to be nothing more than an expression of the general fact that the dikes which radiate out from the bathyliths are more acid than the main mass, whether they be red or white (they are usually red in all rocks except the limestone), and that the granite also is apt to become more acid near the margins. A little tourmalin is sometimes developed in the granite where white, but it also developed elsewhere. The change seems to consist merely in a decoloration of the feldspar, changing it from red to white; that of course on the assumption that the red color of the feldspar is original and not a later coloring due to slight alteration. In that case, however, it is difficult to understand why both feldspars, of the white granite as well as of the red, should not have undergone the alteration; this seems in fact so highly improbable, that we seem justified in regard-ing the color as beyond question original. The red color which so many feldspars possess is usually ascribed to ferric oxid, though in general without any definite proof in the matter. In such case the loss of color might be ascribed to simple reduction of the iron, but what reducing agent the limestone might furnish is a difficult problem and greenish, rather than white, feldspar would likely result. Analyses of both white and red granites are given on a later page, where the matter will be somewhat further discussed. The chemical differences between the two rocks are but slight, and we are in doubt whether in any recognizable respect they are due to influence of the limestone. The field relations are, however, perfectly clear, and susceptible of no other explanation.

Mixed rocks. Rocks which seem definitely of intermediate composition between the intrusive and a sediment, to be due to the intimate penetration and final digestion of the latter by the former, and which show all stages in the process, occur as the result of action of granite upon amphibolite and upon quartzite. In the former the action is chiefly seen in the case of the amphibolite inclusions which so abound in the granite gneiss, and which are found in all stages of being first penetrated by films of the granite and later slowly absorbed by it. The process has already been described; so has the gradation of granite into quartzite which is found in some localities and which seems only explainable on the assumption of production of a border zone of true mixed rock between the two.

Contact rocks. These, as here understood, result from the injection into the sediment of fluids from the igneous rock which contain only certain of its constituents instead of all, and which may, and often do, differ very materially in composition from the rock itself. The injection is apt to be more or less local, here much, there little, or none at all; the injected fluid may differ in composition at different points along the border of the igneous mass; the bordering rocks themselves differ from place to place, and finally the various igneous masses are quite sure to differ among themselves in the character of their mineralizing fluids. Since we have here three separate granite bathyliths, to say nothing of the syenites and smaller granite masses, and Grenville rocks of great variety of composition, the opportunity for contact action of diverse sorts is exceedingly good.

Green schists in Alexandria. Reference to the geologic map of the Alexandria quadrangle will show, to the south and southwest of Alexandria Bay, three northeast-southwest ridges of Grenville schists. These are cut out on the north by the granite of the

Alexandria bathylith, though there is a zone between the two in which exposures are poor and infrequent. They are separated from one another in part by tongues of Potsdam sandstone, and in part by low, marshy valleys in which no rock outcrops appear. The exposures, however, cover an area of several square miles, and extend to a distance of at least 3 miles from the edge of the bathylith. The schists are everywhere cut by dikes of granite, most numerously as the granite is approached. While chiefly of the Alexandria granite gneiss, it seems to us that dikes of the Picton granite are also present numerously, though it is difficult to arrive at certainty in the matter. Certainly they are present in the granite gneiss itself. Nowhere else in northern New York have we seen just this type of schists, except as occasional occurrences of small extent and bulk. We are disposed to regard them as contact rocks, produced by the action of the granite upon what were, prior to the intrusion, somewhat impure limestones. We are disposed also to regard the Picton granite dikes as especially influential in the action. It must be frankly stated, however, that there are certain difficulties in the way of this view, and they will be later summed up.

The schists are well banded and foliated and range from light to dark green, or greenish black, in color. They are usually of finely granular texture though these alternate with somewhat coarser grained bands. These latter show poorer foliation and are mottled green and pink in color. Narrow, dark red bands sometimes appear, due to subsequent infiltration of ferric oxid. At times the green minerals become scant, and the rock then has a light red to pink shade. Narrow bands of black amphibolite and of finely micaceous schist also appear, and an occasional thin quartzite band. But the bulk of the series is of green schist. Granite dikes and dikelets abound everywhere, cutting across or parallel with the bedding, in the latter case often forming a good injection gneiss. The dikes are of fine, granite gneiss, of coarse granite, of yet coarser granite pegmatite, or of quartz, the first most abundant.

In composition these green schists are essentially feldspar-pyroxene rocks, the latter of green color and responsible for the general hue of the rock. Actinolite is commonly present, and very abundant in some of the bands; it is the only amphibole noted in the schists, except in the occasional amphibolite bands. Epidote is often present, though far less common than the actinolite. Some layers hold frequent, small, light colored garnets. Small, scattered, black tourmalins occur throughout the rock in all exposures.

Small titanites *abound* in the rock, magnetite and hematite appear in varying quantity, with pyrite, apatite and zircon as other accessories.

Quartz is present in many of the bands but seldom in any great quantity and often wholly absent. The feldspar is in part microcline and in part plagioclase (andesine-labradorite); some microperthite is usually found also, and often much feldspar not characteristically marked.

In addition to the above minerals the rock nearly always contains calcite, and this in steadily increasing quantity as the distance from the granite bathylith increases. The rocks from the schist inlier in the Potsdam due east from Omar, average 20 to 25% of calcite; in the long ridge just to the north of this it occurs in large, though somewhat less amount; while in the ridge northwest of this, and nearest the granite, much of the rock shows but little calcite, only the coarser, mottled beds having it in quantity. The calcite is coarsely crystalline, in sharply bounded individuals, and clearly formed at the same time as the other constituents of the rock.

The mineralogy of the schists strongly suggests contact effects, the tourmalin, actinolite and epidote being especially suggestive in this respect, none of them being normal Grenville minerals, away from the immediate vicinity of igneous rocks. The green pyroxene also is an abundantly formed contact mineral in the Grenville, though not so distinctive of contact metamorphism as the others. These, with the constant presence of calcite, give an impression that we are here dealing with a limestone belt much changed by contact action, with the granite and pegmatite dikes which abundantly penetrate the series as the source of the mineralizing fluids. The fact that these green schists, though here present in great bulk, are not a usual member of the Grenville succession in the general region, also suggests a local cause for their presence. It would seem that a series so thick could not but occur repeatedly elsewhere were it an ordinary member of the general series. Similar rocks do occur in small bulk in the general schist series north of Millsite lake, but their small amount here but emphasizes the bulk of the other occurrence.

As opposed to this suggestion of contact origin, the breadth of the belt and the distance it extends from the granite margin, its general uniformity of character, whether in contact with a dike or at a considerable distance from one, whether near the granite margin or remote from it, (the only observed difference being in the amount of calcite, and that a very slow and gradual change), seem more suggestive of regional than of contact metamorphism. On this view the belt would consist of original impure limestones and calcareous shales, metamorphosed to the pyroxene-feldspar-calcite combination, and with the tourmalin, actinolite and epidote alone due to the later contact action. While unable to definitely decide between the two, the first seems to us the more probable. It is possible that the granite is close in place underneath the whole belt. In our view, then, the belt is due to the contact action of an especial granite, its localization being thus explained, acting upon a limestone series of considerable thickness, and certainly somewhat impure at least, as shown by the bands of quartzite, amphibolite and mica gneiss within it. Part of the regular Grenville succession of the area consists of alternating thin beds of limestone, various schists and an occasional quartzite, and it would seem as if such a combination might well be turned over into a group like that of the green schists by contact metamorphism. This would be all the more likely if acted upon by two successive, granite injections as is supposed to be the case here, since dikes of Picton granite are believed to be present.

The coarse pegmatite dikes of the north schist ridge, which furnish well crystallized specimens of orthoclase and specular hematite, to be found in many mineral collections, have already been described by Smyth.[1]

Tourmalin contact zones in Alexandria. The Picton granite is found cutting Grenville quartzite and amphibolite, but no other members of the series, and the same is true of its *known* dikes; that dikes suspected to belong to it cut other members has just been seen. This granite seems to have been much more potent in tourmalin-forming capacity than any other granite of the region and its contacts with the Grenville on Grindstone and Wellesley islands are characterized by narrow tourmalinized zones which Smyth has clearly described, as follows:

> Along their margins these dikes frequently show much black tourmalin and this is usually most abundant in the very narrow ones, in which the imperfect crystals of tourmalin interlock across the entire width. At the same time the schists along the contact become impregnated with fine, granular tourmalin, producing strips and irregular areas of a lustrous black rock. The remarkable feature about these contact zones in the schist is their extreme irregularity in form and extent, and their entire independence of the magnitude of the accompanying dike. A dike of granite a foot wide

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[1] *op cit.* p. 194.

may have no contact zone, while a mere thread of granite a few feet distant, may be bounded on each side by a band of the tourmalin rock 2 or 3 inches wide. Again, the tourmalin, instead of forming a continuous band, appears in lumps and bunches of every conceivable shape, irregularly scattered along a dike, and sometimes extending several inches away, at right angles to the course of the dike.[1]

Tourmalin is also at times developed in the quartzite as well as the schists, but not in the same definite manner. It is not at all certain that dikes from the Alexandria bathylith are excluded from the category of rocks producing this contact effect. In many cases the dikes from the two bathyliths can by no possibility be distinguished from one another. In addition to these bands and bunches of abundant tourmalin, developed in this localized fashion, more scattered crystals of tourmalin, of the same evident origin, range much more widely through the rocks.

Smyth dissents from the view that the Picton granite was especially influential in the formation of these tourmalin zones, and in other contact phenomena. He points out that, in his belief, the tourmalin zones are most abundant at the extreme east end of Wellesley island, quite remote from the Picton granite, though with the Alexandria bathylith near at hand; also that the Alexandria bathylith is much nearer the Alexandria green schists than the Picton. He therefore regards the Alexandria bathylith as the most important granite of the region in producing contact effects. We are not sufficiently certain of the truth of the opposite view to urge it, and simply chronicle the matter as one on which we mildly disagree. It is not a matter of great importance in the interpretation of the geology of the region, on the general features of which we are in absolute agreement.

Contact amphibolites. Adams has recently shown conclusively that, in central Ontario, amphibolite occurs as a result of intense contact alteration of Grenville limestone by granite, limestones passing into rocks in which pyroxene, hornblende, feldspars and scapolite appear in increasing quantity up to final disappearance of calcite, and with final entire replacement of pyroxene by hornblende and scapolite by feldspar.[2] We have had the privilege of going over his territory with him, and fully agree in his conclusions. Perhaps the chief interest attaching to his work is the explanation thereby afforded of the abundance of inclusions of amphibolite in the Laurentian granite gneisses, where cutting the Grenville rocks,

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[1] *op cit.* p. 190.

[2] Adams, F. D. Jour. Geol. 17:7–18.

the scarcity of inclusions of other types, and the invariable utter absence of limestone inclusions, notwithstanding the abundance of limestone in the formation. Beyond doubt many of these inclusions represent limestone fragments altered in this fashion. Intense alteration, however, seems necessary, and that perhaps furnishes a reason why the comparatively small fragments caught up in the granite mass are so uniformly changed over, while at the contacts the change is much less obvious, or common. In our district here we have amphibolite inclusions everywhere in the granite gneisses, but no instances of the conversion of pure limestone into amphibolite along the contacts, similar to those in Ontario. There are, however, one or two instances of similar alteration on a small scale, in connection with narrow bands of limestone and small granite intrusions. The most clearly shown of these is right in the village of Theresa, at the road metal quarry near the lower bridge. The rock quarried here is a contact phase of the limestone cut through and through by granite dikes. The chief rock is green in color and consists of pyroxene, titanite, feldspars and calcite, the latter running as high as 50% of the whole in the portions of the rock most remote from the dikes. In contact with these, however, the rock is black, consists chiefly of hornblende and feldspars, though with a little remaining pyroxene and calcite, and has nearly completed its transformation into amphibolite. Very near at hand is the pure limestone band shown in plate 2, and there can be little question but that the green rock of the quarry is an altered phase of that, and no question at all but that the green rock is changed into amphibolite by the granite. On a small scale then it is a change identical with that described by Adams.

Contact rocks of the Antwerp bathylith. In so far at least as the portion of the Antwerp bathylith included within the mapped district is concerned, the contact action of this granite is but slight, and it would seem to have been quite deficient in mineralizing agents, though as effective in the production of mixed rocks as the other granites. The dikes and stocks of white granite run everywhere through the limestones without affecting them any, except in trifling amount in a few localities, nor does near approach to the margins of the bathylith produce any observable change in the Grenville rocks. In the case of dikes of granite pegmatite however, some contact action is the rule, coarsely micaceous rocks being the usual ones produced. Locally the mica becomes very coarse and in well formed crystals, so much so that at one locality north of Theresa an attempt was made to mine it commercially. The mica is of light brown color, in the coarser varieties very light brown, resembling muscovite, though it seems undoubted phlogopite.[1] Scapolite is also an abundant mineral in these zones, a phlogopite-scapolite-calcite rock being the usual combination. This is not one of the customary types of Grenville contact rocks in the general region, though the common one here.

There are two other types of contact rocks which occur in small quantity within the area here, though common enough elsewhere, which call for brief attention. They occur in the district east of Redwood where Grenville rocks of all types are cut by small granite masses. One is a heavy, basic, black rock, weathering rapidly, and composed chiefly of green pyroxene and black hornblende, with a little graphite, considerable pyrite, and some 15% of calcite remaining. Heavy, pyroxenic rocks of this type occur throughout the Adirondack region at limestone contacts, though usually not so hornblendic as this rock.

The other rock consists of large, gray green pyroxenes set in a felt of tremolite needles, with rather abundant pyrite as the only accessory mineral. Such tremolite rocks occur not infrequently in the Grenville, the tremolite quite commonly altering to talc. The especial interest attaching to this particular exposure is that the tremolite rock is developed at the contact of granite against Grenville rusty gneiss, and seems quite certainly a result of the contact action of the one upon the other. So far as we recall, just that type of contact action has not heretofore been noted in the region.

Great Precambric erosion

The Grenville rocks are the only Precambric sediments in the region, and are of very early Precambric age. The remaining rocks of this age in the district are all igneous, and there is no evidence that any later Precambric sediments were ever deposited hereabouts, though it is possible that some such were deposited and subsequently worn away. The Precambric rocks of the present surface, both sedimentary and igneous, present characters which, so far as we know, are only given to rocks under conditions of high pressure, and at least moderately high temperature, conditions which in general prevail only at considerable depths below the surface. All the igneous rocks except the diabases give evidence that they solidified well beneath the surface, and the deformation of both these and the sediments is of deep-seated type. It is, however, not

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[1] It is of the second order and with very small axial angle.

quite so prominently of this type as in the case of the corresponding rocks of the central and eastern Adirondacks. We are forced to argue that, when these rocks were deformed, a considerable thickness of other rock overlay them, which thickness was subsequently worn away. This surface wear goes on very slowly at best, and must have been continued through long ages, yet was completed before Potsdam deposition began. The time involved is many millions of years, in all probability a rock thickness of at least a mile or two was removed, and yet at the close the region was pared down to a surface of comparative smoothness. Much Grenville has thus disappeared, the tops of the igneous bathyliths are gone, together with whatever of younger rocks may have been present above them. The diabases were intruded toward the close of this long period, since plainly they solidified not far beneath the surface.

PALEOZOIC ROCKS[1]

The Paleozoic rocks of the district, for mapping purposes on maps of this scale, are separable into six quite distinct lithologic units, which in large part coincide with the subdivisions of these rocks made long ago by the early geologists of the State. These are, in order of age from below upwards, the Potsdam sandstone, Theresa dolomite, Pamelia limestone, and Lowville, Black River and Trenton limestones. Above the last named the Utiça and Lorraine shales come in, but these nowhere reach the map limits, their northerly boundaries being found on the Watertown and Sacketts Harbor sheets, next south.

The basal member of this sedimentary series, the Potsdam sandstone, was deposited upon the worn surface of the Precambric rocks, and in order to properly describe the sandstone it is necessary to present in some detail the character of this surface.

Precambric surface underneath the Potsdam

That the surface on which the Potsdam sandstone was laid down was far from being an even one was clearly stated by Smyth, in his report on the district.[2]

That a similar irregular floor is present in many parts of Canada, of the upper lake region and of northern New York, has been shown by many observers. There is therefore nothing novel in the features to be described, but they are worthy of somewhat extended descrip-

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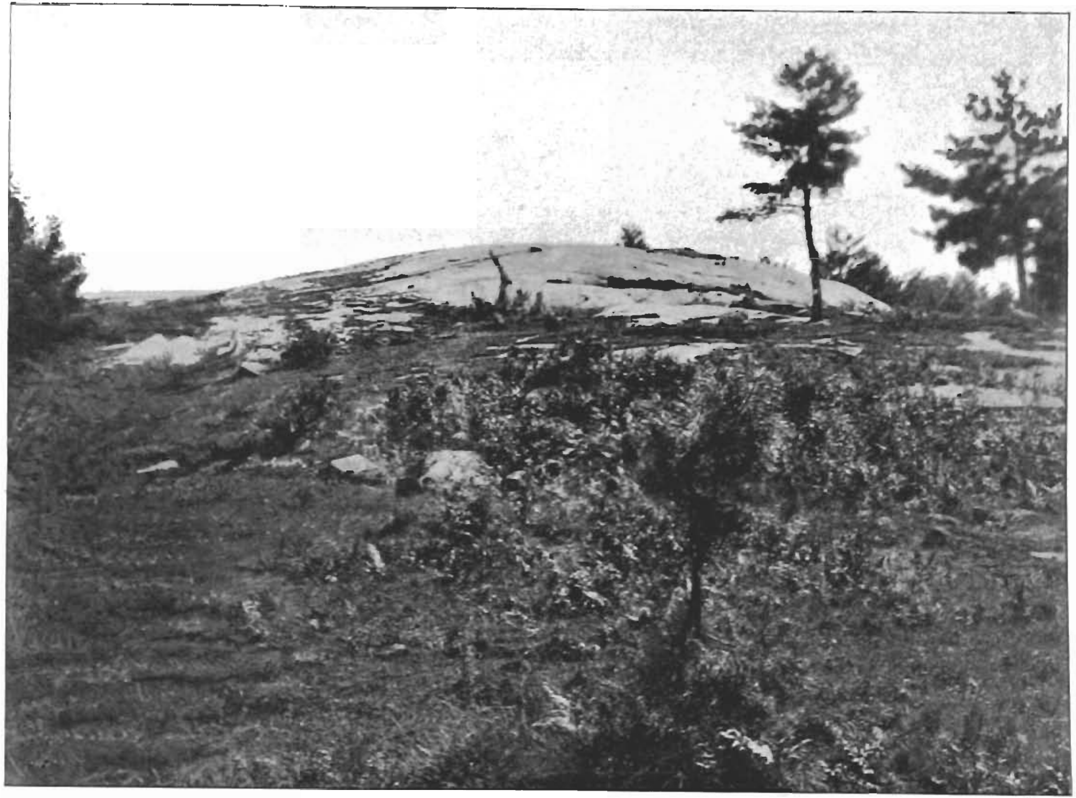
[1] By H. P. Cushing.
[2] N. Y. State Geol. 19th An. Rep't, p. 1100–1.

Plate 6

The "granite knob" country. View taken from nearly 3 miles southeast of Theresa, looking southeast, showing one large and several small knobs of the Antwerp granite bathylith. H. P. Cushing, photo, 1907

Plate 7



A granite boss, Forsters landing, 3 miles east of south of Chippewa Bay, Alexandria quadrangle. H. P. Cushing, photo, 1908

Before page [illegible]

tion since it is very exceptional to have the evidence as abundant and as clearly shown as it is here.

The evidence of surface irregularity is of threefold nature, (*a*) that given by exposures of direct contacts, (*b*) that given by the tracing of the lines of contact of the Potsdam and Precambric, even without exposures of the actual contact, and (*c*) that given by the topography of the present Precambric surfaces, since it can be shown that these surfaces are substantially those upon which the Potsdam was originally deposited; in other words that the Potsdam is just being pared away from the Precambric over part of the district, its numerous outliers testifying to its former presence over the whole and to the recency of its removal where now absent.

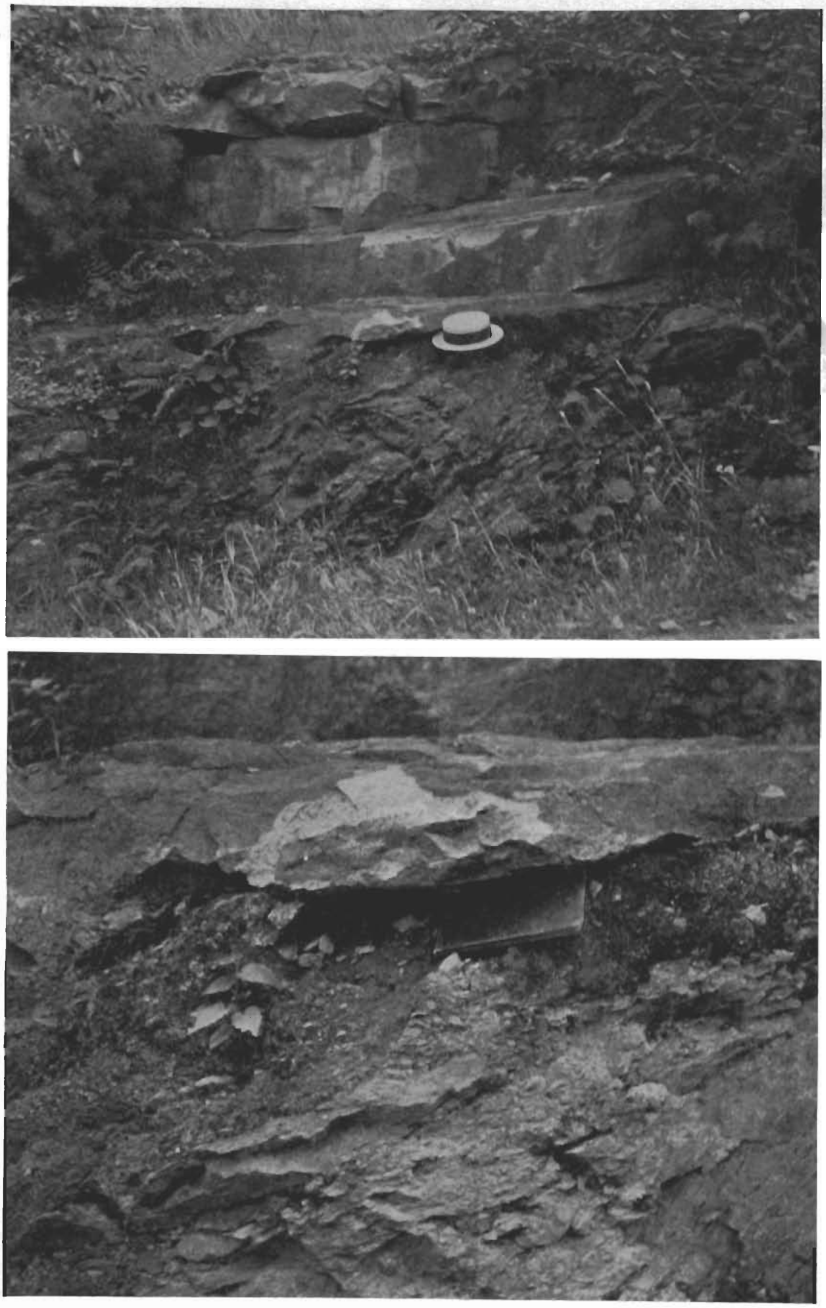
Where the Potsdam has been removed the Precambric surface disclosed is one of low ridges and valleys, with general northeast-southwest trend. The ridges are low and with hummocky surface, and the valleys are broad and shallow, and developed on the weak rocks (such as the limestones and weak schists) or on lines of structural weakness (as along lines of sheared and shattered granite). The extreme of relief does not much exceed 100 feet, and is generally less. The quartzites, resistant gneisses and some long and wide granite dikes constitute the ridges. In the relatively elevated country occupied by the igneous bathyliths the surface is of the knob and basin type [pl. 6 and 7]. The numerous granite dikes and small bosses which cut the limestone and are resistant to weathering, diversify the valley bottoms. Hence a large part of the area consists of slopes, and extensive flats do not appear.

The surface underneath the Potsdam is precisely of this sort. The smaller Potsdam outliers are usually mere remnants remaining in places where the floor was lowest and the sandstone thickest. The larger outliers cover both high and low ground. The Potsdam resists wear, and hence usually presents cliff fronts at its margins, showing thicknesses of from 20 to more than 60 feet of sandstone, yet even with these thicknesses the summits of the outliers are often overtopped by neighboring granite knobs. The evidence of the occasional inliers of Precambric rocks in the Potsdam is even more obvious. The two small inliers east of Goose bay (Alexandria quadrangle) along the road from Alexandria Bay to Chippewa Bay, have their tops at the same level as that of the sandstone plain in which they lie, yet a 20 foot thickness of sandstone shows at the Potsdam margin, just to the northward. This line of evidence might be pursued at great length but since it is less conclusive than are the other lines the above will suffice.

The second line of evidence is that obtained in following and mapping the long Potsdam boundaries. A single example, that of the Potsdam margin along the west bank of Indian river in the southeast corner of the Alexandria sheet and for 1 mile southward on the Theresa sheet, will serve as well as a multitude of illustrations to indicate what the evidence is. The section is convenient since it has a horizontal base, the edge of the Indian river marsh. The Potsdam faces the river in a prominent bluff which, when it comes down to the marsh level, as it frequently does, forces the pedestrian to take to the swamp, so that the walk is not recommended as a pastime. But the unbroken cliff margin renders accurate mapping of the Potsdam base possible, and underneath it Precambric exposures are numerous. At the south end of this section, on the Theresa sheet, inspection of the map will show the Potsdam coming down to the river level in a point. Going northward it soon runs up the bank until the base is 40 feet above the river, with Grenville limestone outcrops showing beneath, then it returns to the river level and again rises, repeating the performance three times within a mile of distance. Soon after passing on to the Alexandria sheet the sandstone retreats prominently up the bank and back from the river, showing a 60 foot thickness of limestone underneath, then returns to marsh level, withdraws 30 feet up the bank, comes back again forming a point, retreats quickly for 60 feet up the bank and again returns to the river, all the while with limestone underneath, cut by occasional granite dikes, so that all these oscillations merely represent irregularities of the limestone surface. Northward from this last point of reaching the river, however, the limestone is cut out by granite gneiss, and this turns the Potsdam straight up the bank and out to the road, with a rise of more than 100 feet in the level of the Precambric surface. Equally striking are the oscillations in level of the same margin when followed southward on the Theresa sheet, and this margin is easy to follow, using the railroad as a base. There are many other excellent examples, since this sort of thing is the rule throughout the district. The mapping of the Potsdam base is thereby rendered laborious but nothing can be imagined more beautifully demonstrative of the character of the surface on which the Potsdam rests and its identity with that of the surface from which the Potsdam has been removed.

Lastly there is the evidence given by the actual contacts. There are quite a number of these, more than the writer has seen in the entire remaining border of the Adirondack region. Besides the actual contacts there are a host of others where but a few feet of

Plate 8



Contact of the Potsdam sandstone on Grenville quartzite by roadside 1 mile southeast of Redwood, looking west. The quartzite is somewhat contorted but its dips are not steep, from 20–30°. The upper view is from 15 feet distance, the lower with the camera only 4 feet away and showing only the lower layer of the Potsdam clearly. H. N. Eaton, photo, 1908

FOLLOWS PAGE 50

Plate 9

Contact of Potsdam sandstone on Grenville limestone in Theresa village near the upper bridge. The Potsdam was deposited on a steepey sloping limestone hillside, and the limestone has now been somewhat eaten away leaving a portion of the actual under surface of the sandstone exposed. This is sparingly charged with pebbles. H. P. Cushing, photo, 1907

FOLLOWS PAGE 45

#2

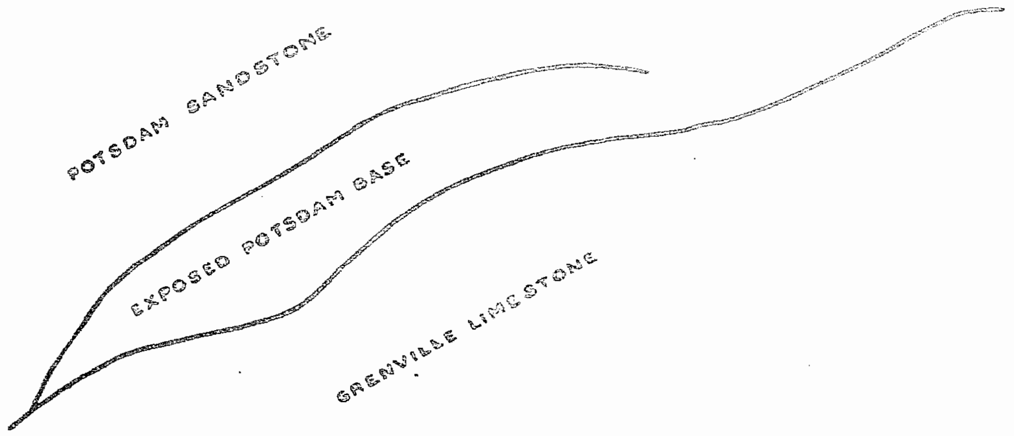
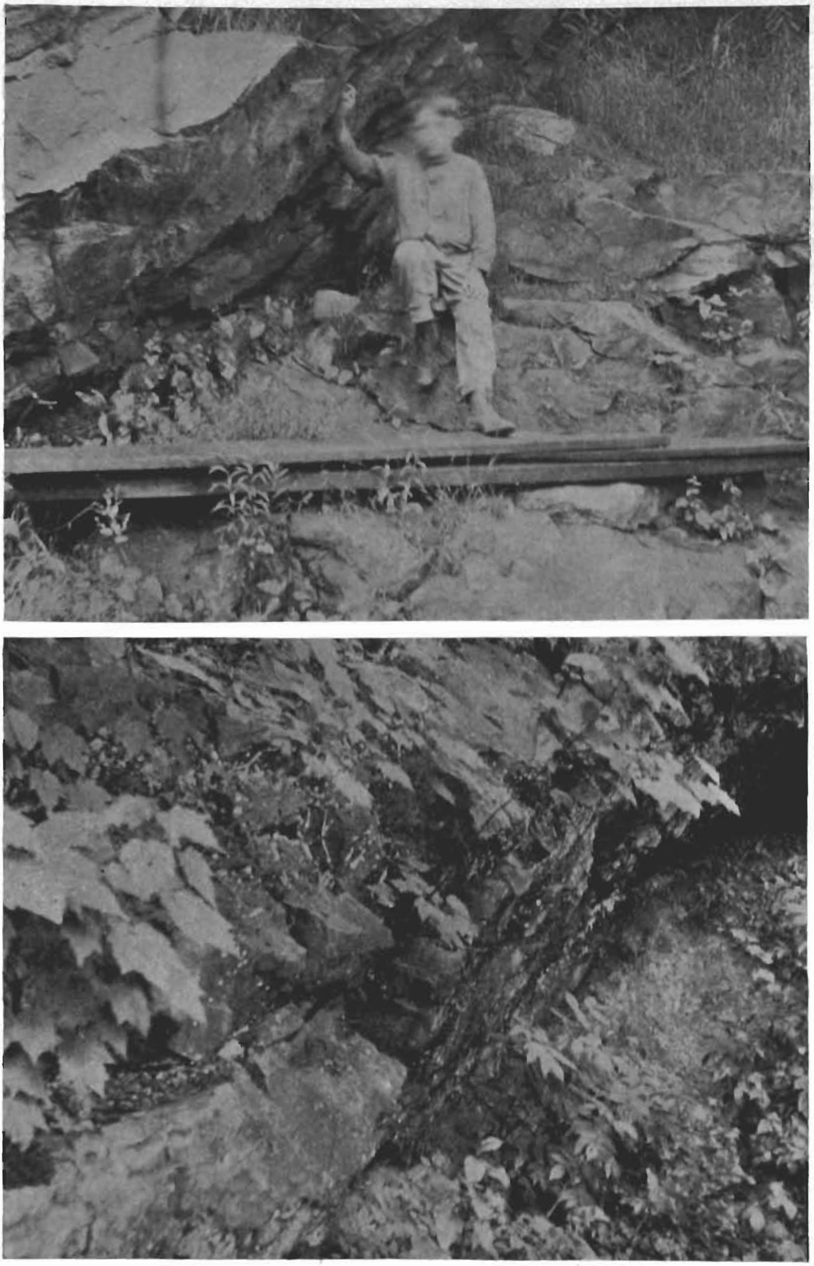

POTSDAM SANDSTONE
EXPOSED POTSDAM BASE
GRENVILLE LIMESTONE

Plate 10



Upper view. Contact of Potsdam sandstone on Grenville limestone just north of lower bridge at Theresa, near the point at which plate 11 was taken. The Potsdam base rests against the side of a limestone hill, and the boy is seated on the limestone, with his hand resting on a portion of the Potsdam base from which the limestone has been removed.

Lower view. Nearer view of a portion of plate 9 showing the rotted limestone and the portion of the Potsdam base which projects out beyond it owing to removal of the limestone. H. N. Eaton, photo, 1908

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space intervenes. This is due in part to the many miles of Postdam boundary in the region and in part to the scanty glacial deposit and hence abundant rock exposures. Many of the exposed contacts are on slopes, and on limestone, and it is these that are most unusual and interesting.

Plate 8 shows Mr Eaton's photographs of a contact on quartz schists, 1 mile southeast of Redwood on the Rossie road, a contact already described and figured by Smyth. The contact here is on the summit of a ridge of quartzite, hence is fairly horizontal where photographed, though the level drops away on each side at no great distance.

Two fine examples of contacts on slopes occur within the limits of the village of Theresa, along with others almost as good. One of these is by the roadside a short distance west of the upper bridge. A high Potsdam cliff borders the roadway for a few rods, with the base of the formation well below the road level. At the west end the base comes up to the road level, the cliff sets back some 20 feet, and the base rises sharply to from 12 to 15 feet above the roadway, exposing impure Grenville limestone underneath. The recess faces north, and is beset with shade of trees so that satisfactory photography is difficult, the view shown in plates 9, 10 being unsatisfactory. The surface of deposit has an angle of slope of 45° or more, and the soluble limestone has been somewhat eaten away from beneath the sandstone, so that several square yards of the actual basal surface are exposed. This is set with occasional quartz pebbles, but these are sparse, and except for them the rock is quite like that above. The sandstone is very massive and irregularly bedded, with a semblance of parallelism to the floor of deposit as is usual with the basal Potsdam hereabout.

The other contact mentioned is exposed on the north side of the river just above the lower bridge. The map shows a small Potsdam outlier there, whose narrow, southwest edge appears as a low cliff by the roadside [pl. 11]. The ground level falls toward the river and at the south end of the cliff the base of the sandstone is exposed, resting on Grenville limestone underneath. Plate 10 is a photograph of this contact. At the south the cliff bears sharply away from the road and by turning into the yard of the first house to the south a fine exposure of the south margin of the outlier is obtained, showing the Grenville limestone rapidly rising in altitude and carrying up the Potsdam base with it. The limestone surface falls not only to the west but also to the north. As in the previous case a part of the sandstone base is exposed, owing to solution of the limestone beneath. A sketch of the relations here is given in figure 1, the arrow showing the camera position for plate 11. It is at this locality that the best examples of sand extending down into widened joint cracks in the Grenville limestone were seen. At the east end of the outlier the limestone is cut out by granite gneiss, whose summit is 20 feet above the top of the sandstone, hence terminating the outlier in that direction. Of course the full original thickness of the sandstone is not present in the outlier, but only the mere basal portion, and formerly the sandstone extended over the granite as well.

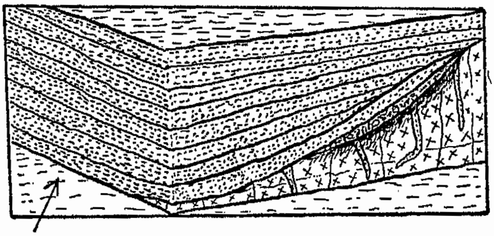

Fig. 1 Potsdam contact on Grenville limestone, just north of lower bridge at Theresa, showing the sloping Grenville hillside on which deposition took place, and the sand-filled cracks in the limestone.

Another interesting contact occurs along the Potsdam front, 2½ miles northeast of Theresa. From a previous northeasterly trend the front here turns and for a mile and more runs northwest across the strike, crossing a prominent granite ridge and then dropping 70 feet in level into a limestone valley. Near the turn the contact sketched in figure 2 is shown. A low knob of ferruginous, quartz schist projects upward into the Potsdam to the amount of 20 feet. The Potsdam here is more evenly bedded than in the cases described at Theresa, the bedding abutting squarely against the sides of the knob. Its small size as compared with the long ridge slopes of the other contacts is thought to be the chief reason for this difference.

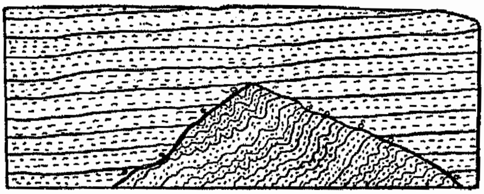

Fig. 2 Potsdam contact on Grenville quartz schist, 2½ miles northeast of Theresa. The much contorted and steeply dipping schists constitute a ridge over 20 feet high around which the Potsdam was deposited.

There is an occasional quartzite pebble along the contact, otherwise the sandstone is normal, and gives no sign of basal conditions.

Around to the left the slope of the knob steepens. There are occasional bands of coarsely crystalline, purer quartzite in the schists which are far more resistant to weathering. On this steep front one such layer projects as a cornice with the sand-filling beneath, as shown in figure 3. Photographic attempts here proved wholly unsatisfactory.

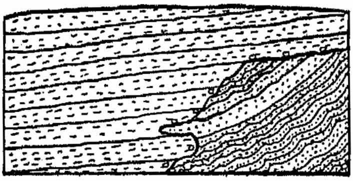

Fig. 3 A nearer view of a portion of the contact showing a local steep slope of the hill and projecting cornice of an extra resistant quartzite layer.

Besides the contacts on larger slopes, of which the preceding are instances, there are a number of minor examples of the sort, chiefly as filled hollows of the limestone surfaces. A sand-filled hollow of the sort appears at the top of the limestone quarry near the Theresa boat landing, and is shown in plate 2. In the section there shown the hollow is about 6 feet deep and with twice that width at the top. Another example may be seen at the quarry just south of the Theresa depot, though the overlying sandstone is gone except for the small residual patch resting in the hollow so that its original size can only be guessed at. A considerable number of other examples have been seen, some merely sand-filled, others containing rock fragments as well. In all cases the cement is calcareous and the rock weak and easily removed.

The above evidence of the character of the surface on which the Potsdam was deposited, is of precisely the sort so convincingly set forth by Wilson in his discussion of similar features in Ontario.[1] In New York these features are developed in a belt of considerable breadth across the strike, showing a great number of ridges and valleys, with patches of overlying Potsdam, and with the relief in every case owing to differential erosion on rocks of varying resistance, and in no case to subsequent folding. In this State exposed patches of residual materials resting on the old surface are more numerous than in Ontario, and these are in the depressions in all cases, showing that the depressions were in existence and served as receiving pockets for this material at the commencement of sandstone deposition. The evidence is abundant, clear and convincing that the Precambric surface underneath the sandstone is precisely like that where the sandstone is absent, and that the present topography of the Precambric areas is that resulting from recent stripping

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[1] Wilson, A. W. G., Can. Inst. Trans. 7:146–55.

away of the sandstone; in other words that it is the reappearance at the surface of a topography of tremendous antiquity.

It further shows that this surface was little affected by the ice sheets of Pleistocene times, otherwise this identity of character could not have been so well retained.

Except for the local accumulation of a very scanty amount of residual material in small pockets in the depressions (and this almost exclusively quartzose) the Precambric surface, as it passes under the Paleozoics, is remarkably free from signs of surface decay, even the weak rocks being astonishingly fresh. In this respect also the conditions are like those noted in many places in Canada and the United States, as described by numerous observers.

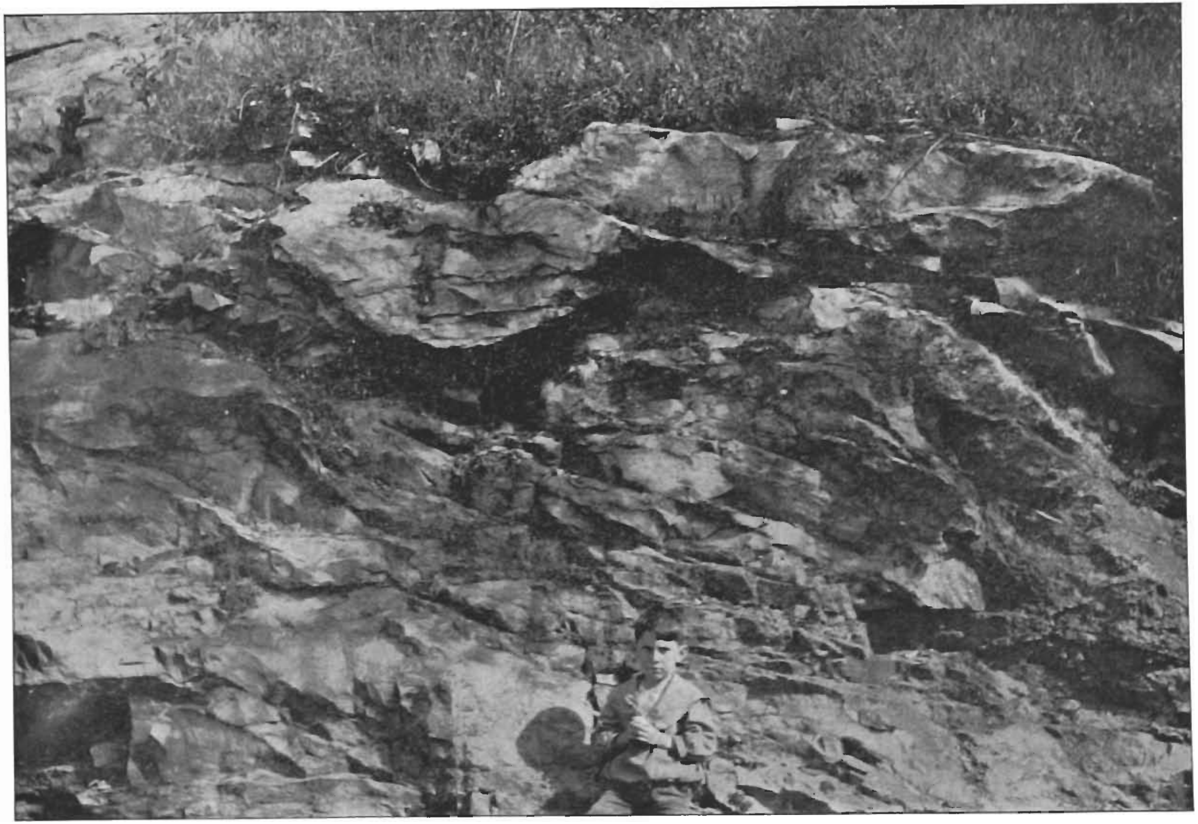
The relief of the Precambric surface under the Potsdam is much the same in character here as elsewhere along the northern and eastern borders of the Adirondacks, but is apparently less in amount than it is further east, where there are differences in level of three or four hundred feet at least. The evidence there, however, is complicated by the presence of numerous large faults and is by no means so well shown as it is here. On the south border, in the Mohawk valley region, the surface was much smoother than here, exceedingly smooth in fact.

Potsdam sandstone

The first deposits laid down upon the worn Precambric surface consisted of medium grained, quite pure quartz sand, now firmly cemented to sandstone. On the Alexandria quadrangle the formation attains a maximum thickness of about 125 feet. This thickness diminishes both southward and westward, but shows a steady increase to the eastward of the area mapped. Within that the thickness of the sandstone is not greatly in excess of, or else does not quite equal, the variation of level shown by its floor, so that it is subject to continual variation from place to place, and thins to 20 feet or less over the old ridge summits. On the Theresa quadrangle, and on Wellesley island, it locally failed to overtop the highest of these, and the Theresa dolomite is found resting directly on the Precambric.

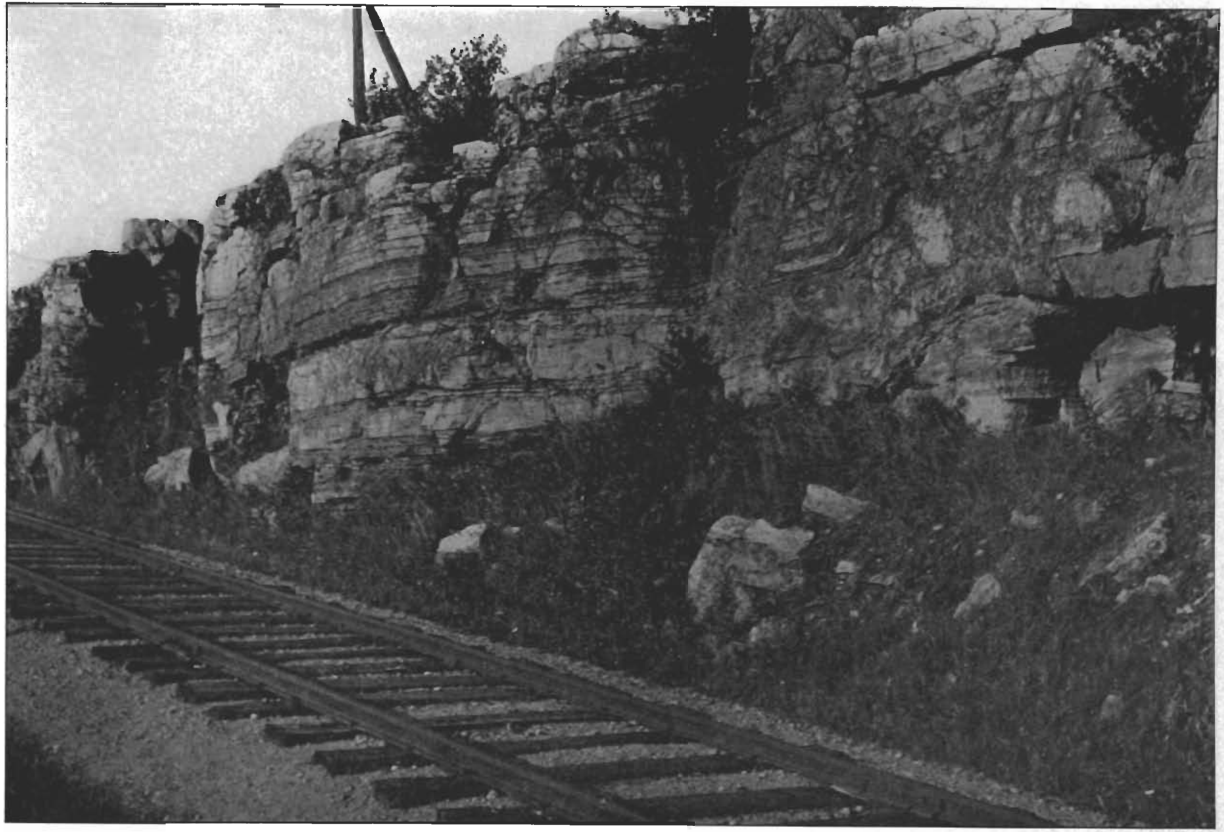
The bulk of the formation consists of a very pure quartz sand, quite thoroughly cemented with a silicious cement. The general color is light gray to buff, weathering white, but in the northern portion of the mapped area there is much red, or banded red and white rock in the lower half of the formation. The bulk of the formation is evenly bedded, and the greater part is thick bedded,

Plate 11



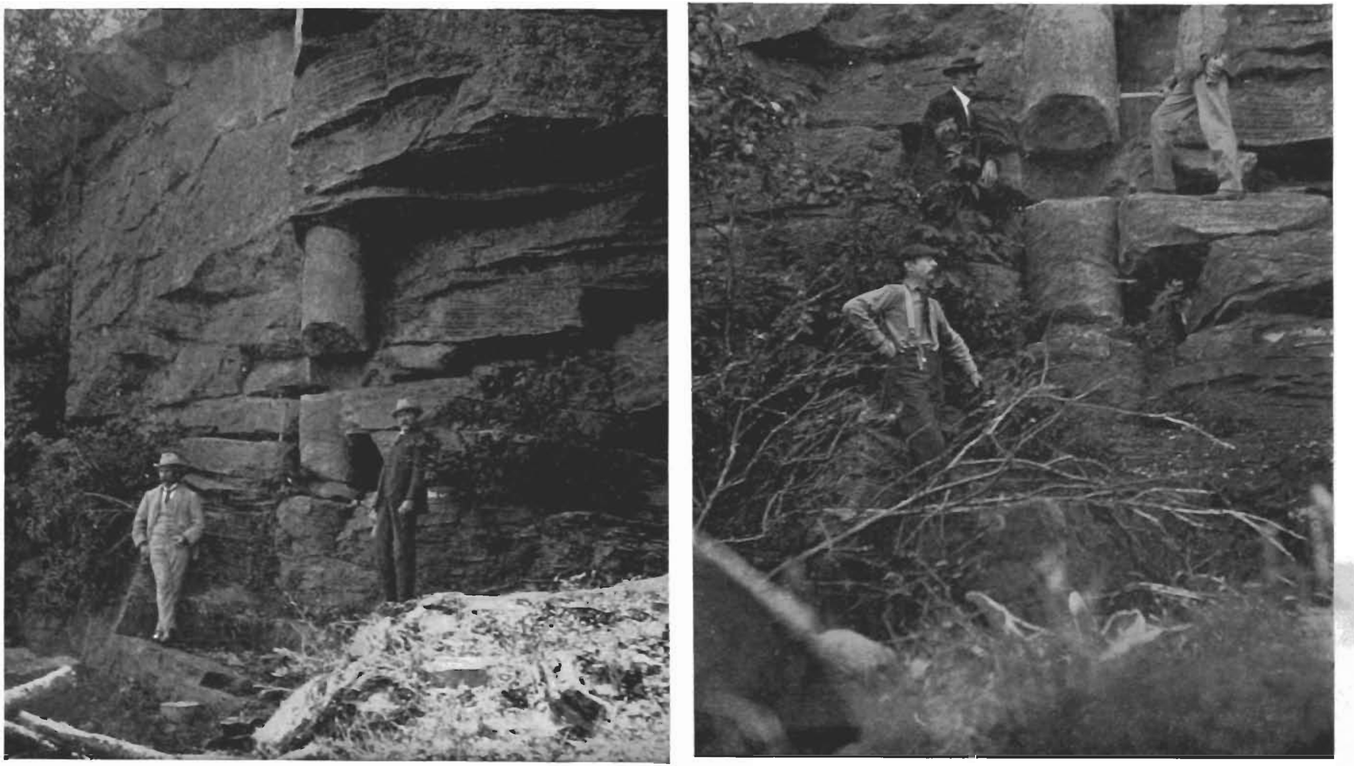
Potsdam sandstone in Theresa village just north of the lower bridge. Just to the right of the view its contact with the underlying Grenville limestone is exposed, the contact being on an irregular and sloping surface. The view illustrates the very irregularly bedded character of the Potsdam in such situations, which is certainly in part due to the irregularity of the floor on which it was laid down. H. P. Cushing, photo, 1906

Plate 12



Railroad cut in Potsdam sandstone 2 miles north of Theresa, looking east. Note its evenly bedded character as compared with plate 10; also the slight dislocation toward the right. H. P. Cushing, photo, 1907

Plate 13



Potsdam sandstone, Gildersleeve quarry, near Rideau, Ontario; red sandstone, somewhat banded with white. An excellent example of the "tree concretions" shows midway in each view. Right-hand photo by H. M. Ami; left-hand photo by Geological Survey of Canada.

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with thinner bedded upper portions; where deposited on sloping surfaces the lower portion is often very massive, and quite irregularly bedded with a rude tendency to conform to the surface of deposit [pl. 11, 12]. Cross-bedding is present somewhat but in by no means prominent development. Ripple marks, however, abound. Much of the silicious cement has been deposited as secondary enlargement of the original quartz grains, the slides furnishing some beautiful examples of this.

Occasional long, cylindrical concretions (?) of a telegraph pole type appear in the sandstone, and are called "tree trunks" by the populace. As seen in cross section on rock surfaces they appear as circular portions of the rock, from 1 to 3 feet in diameter. On cliff sides they are long, vertical cylinders of sandstone. There is no perceptible difference in composition between them and the adjacent rock, but in every case the two are sharply separated by what may be for convenience styled a circular joint. No tendency to taper at the ends was noted, but the actual terminations were in no case seen. They certainly reach a length of 20 feet and may be considerably longer. Unless they represent a type of concretionary structure, we are wholly at a loss to account for them. If so they certainly are an unusual type both because of size and shape, and because of having the same composition as the inclosing rock. In plate 13 is shown an excellent example of one of them, in the Potsdam sandstone at Rideau, Ont., seen by us in 1908 under Dr Ami's guidance. This has been already described by the Canadian geologists, and is here introduced because, while corresponding precisely to the New York examples, it furnishes a much better illustration than any there seen.[1]

Only at the base and the summit does the sandstone vary from these general characters. Basal conglomerates are present in but scant amount, with small thickness and patchy distribution. The majority of contacts show only a few, scattered quartz or quartzite pebbles in the basal layer of the sandstone. There are, however, frequent patches of coarse, basal conglomerates, especially on the Theresa quadrangle. They seem in all cases to occupy local hollows in the limestone valley floors, and to occur only where the limestone contained thin quartzite bands, or granite dikes. The pebbles are all sizes up to that of the fist, and show little or no rounding in most cases, being usually very angular. They consist chiefly of quartzite and of white granite, though in some cases pebbles of red, quartzose sandstone also occur. The cement is

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[1] Ells, R. W. Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 103.

calcareous in all cases. The angular form of the pebbles is due to the close jointing of the quartzite bands and granite dikes in the limestone, and the trifling amount of wear exhibited points to residual accumulation in the hollows, whereby they were protected from abrasion. The very small supply of such material, taken in conjunction with the small amount of decay shown by the underlying rocks, is a factor of much significance.

On the Alexandria quadrangle, both on the mainland and on Wellesley and Grindstone islands, a more extensive and bulky conglomerate occurs, which has already been described by Smyth [*see* pl. 14].[1] The most impressive display of this conglomerate known to us is that in the cliff along the St Lawrence in the extreme northeast corner of the Alexandria sheet where, rising sharply from the river level it reaches a hight of 20 feet above it. Here, as usual, the deposit has a calcareous cement which dissolves away, loosening the cobbles, and giving an exterior resemblance to a cobbly moraine, while the adjacent river bottom is solidly paved with the material which has already weathered out. The deposit is everywhere very coarse, a cobble deposit rather than a gravel. In the exposure here the cobbles run up to a foot in diameter, and average probably 3 inches. They are round to subangular and consist exclusively of Grenville quartzite. Smyth notes the presence of a few small pebbles from the tourmalin contact zones, but agrees in asserting the entire absence of granite and schist material, though several of the conglomerate outcrops rest on these rocks.

In addition many of the exposures show that the conglomerate is not strictly basal, but has pebbleless sandstone beneath, up to a thickness of at least 10 feet; and in all cases the abrupt transition from sand to coarse cobble at both upper and lower contacts is one of the most interesting features of the deposit. Its coarseness, its abruptness, its horizon, and the lack of variety in material of the cobbles render it an exceedingly difficult deposit to explain.

There occur, in a few localities on the Theresa quadrangle, small patches of a dark red, very thoroughly indurated and vitreous sandstone which thus differs from the general run of the sandstone of the district, though similar rock occurs in the formation elsewhere, as in the Clarkson quarry at Potsdam. As it occurs here it seems to be distinctly older than the general formation. All seen of it was absolutely basal, nowhere was the thickness as great as 1 foot and it is only visible at actual exposures of the Potsdam contact on the Precambric. But all the sand-filled cracks seen in

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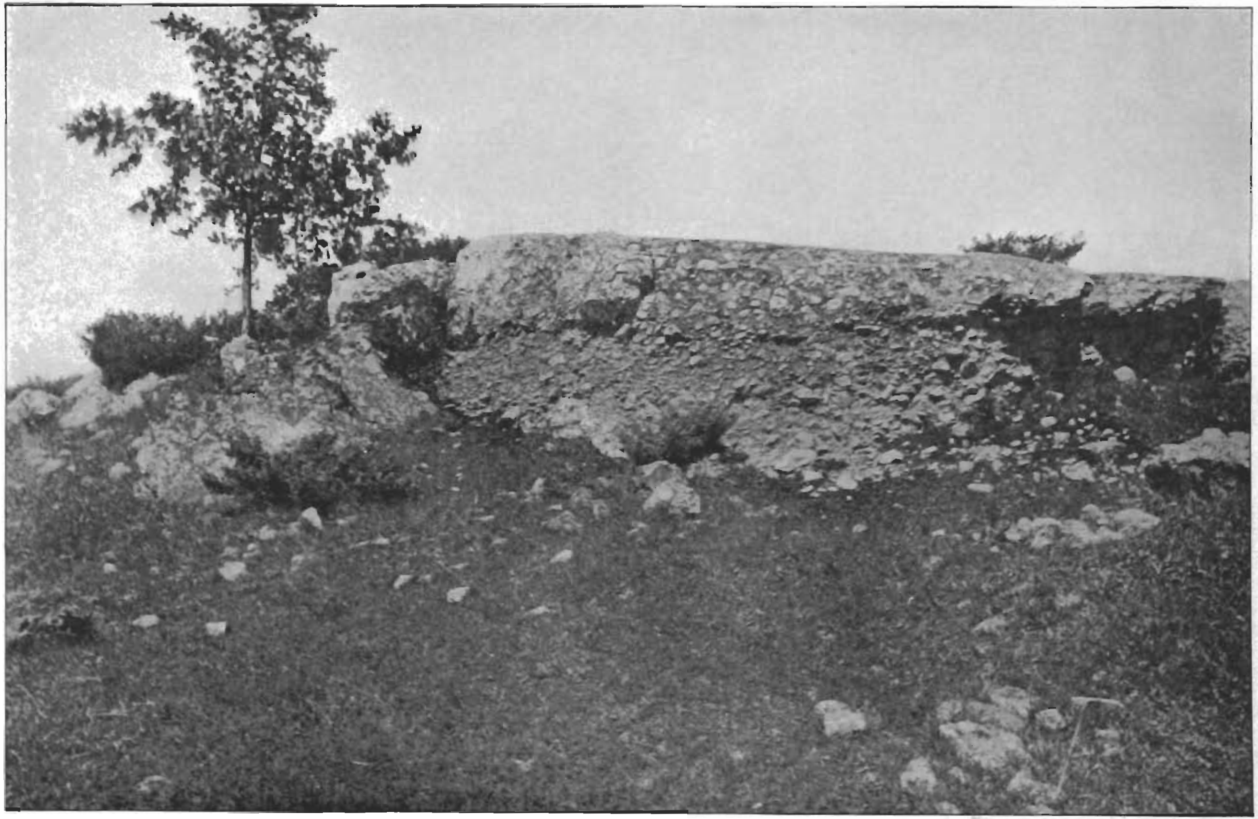
[1] *op. cit.* p. 199.

Plate 14



Potsdam conglomerate, Wellesley island, nearly opposite Point Vivian, and south of schoolhouse 21. H. L. Fairchild, photo, 1908

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the Grenville limestone were filled with this type of sandstone, and it occurs frequently as pebbles in the otherwise basal conglomerates, being the only sort of sandstone occurring as pebbles in such situation. The thorough induration seems certainly to have taken place before the pebbles were formed. There seems no way to account for these conditions except to assume that there was an earlier deposit of sand in the district, likely in no great amount, and chiefly in the Grenville hollows, deposition ceased, thorough cementation followed and then erosion; in other words that there was a slight amount of deposition here in earlier Potsdam time, separated by an erosion unconformity from the bulk of the formation.

Occasional beds of black, and of mottled black and white sandstone appear in the upper part of the formation. The coloring matter is entirely in the cement, which is silicious, and is wholly discharged at a low red heat, hence likely organic.

In the uppermost 10 to 15 feet of the formation calcareous cement reappears, foreshadowing the change which gave rise to the overlying dolomite formation. In consequence of this the rock weathers easily to a weakly holding, brownish sand, usually mottled with spots of deeper brown. This portion is mostly thin bedded but terminates above in a very massive layer, 2 feet thick or more, which is comparatively resistant owing to its massiveness; and this heavy, brown mottled layer often full of small, rounded sand concretions, makes a convenient summit for the formation, owing to its relative prominence. The first layer of gray dolomite usually comes in directly above, and if not, no more than a foot or two of sandstone intervenes. The two formations grade into one another, so that any line of subdivision must be an arbitrary one. We have drawn it at the base of the first dolomite layer to appear, and this closely corresponds with the summit of this thick sandstone. There is, however, some reason for the belief that the base of the upper, calcareous sandstones should be made the division line.

With the exception of the long trails of an unknown animal, to which the name of Climactichnites has been given, some of which have been found in the sandstone 1 mile west of Theresa, no fossils have been found in the formation in this district except in these upper, calcareous beds.[1] In these a large linguloid shell (identified by Ulrich as Lingulepis acuminata) is quite common, and passes up into the lower beds of the Theresa formation.

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[1] Woodworth, J. B. N. Y. State Pal. Rep't 1902. p. 959–66.

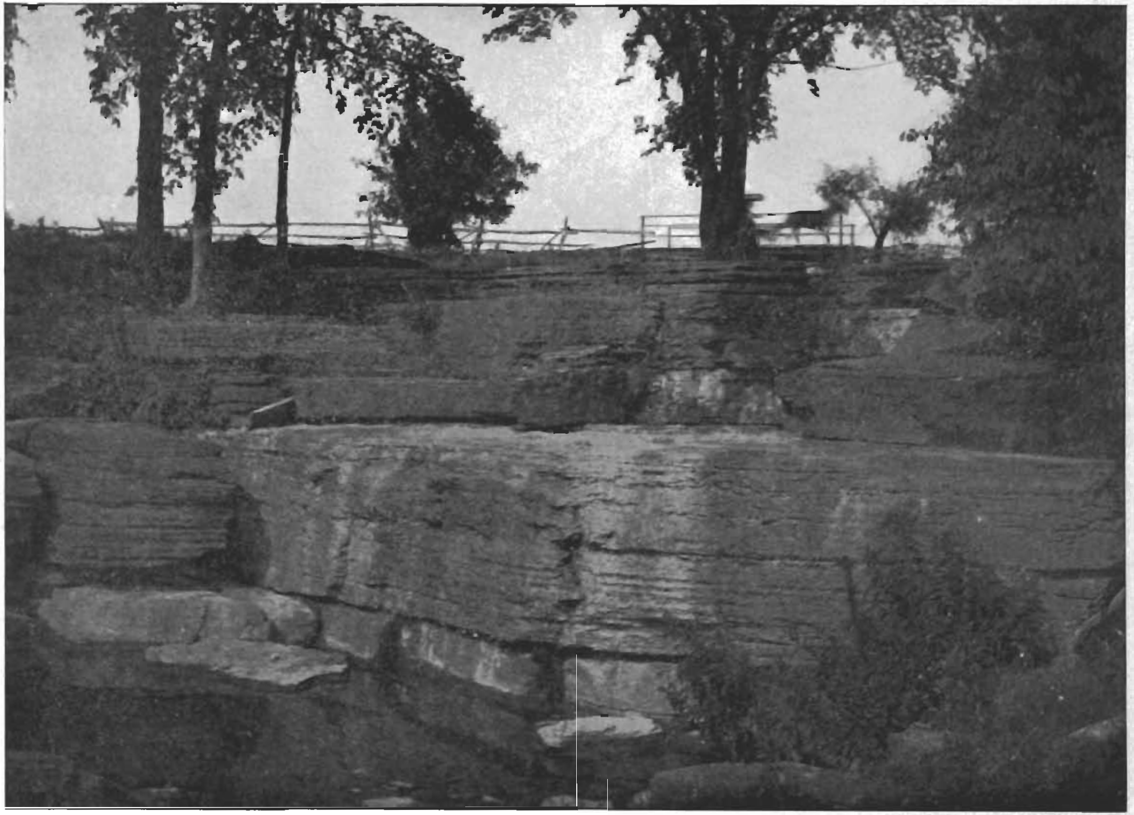
Theresa and Tribes Hill formations

These formations, as mapped, consist chiefly of rather thin bedded layers of blue gray, sandy magnesian limestone which are exceedingly tough and resistant rocks when fresh, but weather rapidly to an ocherous, rotten stone [pl. 15]. The basal portion, through a thickness of 15 feet, carries frequent beds of weak, calcareous sandstone in alternation with the limestone, the sandstone being identical in character and appearance with that forming the summit of the Potsdam. These form apparent " passage beds " between the sandstone and the limestone above. The overlying beds consist chiefly of magnesian limestone though occasional sand streaks continue throughout, and there is a varying and, in general, considerable amount of sand in most of the beds. While this tends to have a streaky distribution, it seldom wholly gives out. The sand is chiefly of quartz, certainly 90% of it consisting of that mineral, but grains of feldspar, mica, magnetite, pyrite, titanite and zircon are also present and all in quite fresh condition.

All the rock effervesces freely with acid, and the thin section shows this to be chiefly due to the presence of calcite cement, most prominent in the more sandy portions of the rock. A prevailing and highly characteristic feature of the rock is the appearance, on freshly broken surfaces, of lustrous calcite cleavages. These are due to the coarsely crystalline character of the calcite cement, the crystals ranging from ¼ inch to 1 inch in length, and inclosing a number of sand grains, so that they are veritable sand crystals. This lithologic peculiarity is a feature of the rock of this horizon across the entire northern border of the Adirondacks.

As mapped the general thickness of the formation over the district is from 60 to 70 feet, but the thickness is variable. The thickness steadily diminishes to the west and to the south in the same fashion as the Potsdam's. But there are also local variations in thickness which are to be ascribed to wear of its summit during an erosion interval which separated its completed deposition from the beginning accumulation of the succeeding formation. For instance it has a thickness of but 20 feet near the north end of Perch lake (Theresa sheet) though recovering its normal thickness of 60 feet both to the east and to the west; and that the diminution in thickness is because of the wearing away of its upper beds with the production of a shallow valley is shown by the fact that the overlying formations thicken here by the same amount that the Theresa thins, and that the thicken-

Plate 15



Tribes Hill limestone in creek wall 1 mile west of Lafargeville, looking west. The fairly massive beds, with their tendency to weather into thinner bedded form are well shown. Hight of section 15 feet. H. P. Cushing, photo, 1908

ing is due to the presence of basal layers which disappear to the east and west as the Theresa thickens.

The field work in the district was completed, and this report written under the impression that this comparatively thin formation was a unit and all of the same age. In its lower portion Lingulepis acuminata is abundant; above, specimens of a rather large, flat-coiled gastropod occur abundantly in places; occasional cystid plates are found, and unrecognizable traces of other forms. The horizon seemed the same as, and the beds identical with beds which directly overlie the Potsdam sandstone all across northern New York, a length of outcrop of 150 miles, and which have heretofore been called "passage beds" between the Potsdam and the Beekmantown, the Beekmantown being the formation which overlies the Potsdam for much of this distance. In the belief that no Beekmantown was present here, and yet that there was here a formation which required mapping separate from the Potsdam, the name Theresa was proposed for this magnesian limestone formation, it being well exposed in the township of that name.[1] Recent work by Ulrich, Ruedemann and myself in the Mohawk valley has, however, tended to throw much doubt upon the entire correctness of this position. We find that the formation in the Mohawk valley known as the Little Falls dolomite, and heretofore regarded as of Beekmantown age, is made up of two unconformable formations, the uppermost of which is of lower Beekmantown age, and is a quite fossiliferous limestone which we are proposing to separate and call the Tribes Hill formation; while the underlying dolomite formation is of Upper Cambric (Ozarkic) age. Now the Tribes Hill formation contains, as one of its fossils, a gastropod (named Pleurotomaria hunterensis by Cleland) which Ulrich regards as identical with the gastropod from the Theresa formation; it also contains numerous cystid plates, and these he also regards as identical with those from the Theresa. The Lingula, however, occurs in the Little Falls dolomite, instead of the Tribes Hill formation, and is in fact a characteristic Ozarkic fossil all around the Adirondack region. Ulrich's present view is therefore that the Theresa formation, as here mapped, is in part of Ozarkic, and in part of Tribes Hill (lower Beekmantown) age. If this be true there must be an undetected unconformity between the two portions. In the field the only lithologic difference noted between the upper and lower portions of the

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[1] Geol. Soc. Am. Bul. 19:155-76.

formation was the absence above of the sandstone beds which are interstratified with the limestones in the lower division. Otherwise the formation constitutes an apparent lithologic unit and appears as such on the maps; and it seems better to leave it as such instead of attempting to subdivide it at this juncture. If, however, it does consist of these two separate formations the necessity for the name largely disappears, and it is rather a pity that it was ever suggested. It is likely, however, to prove useful as a name for the considerable thickness of alternating beds of sandstone and magnesian limestone which everywhere immediately overlie the Potsdam sandstone in northern New York, and which should be mapped separately.

There is then some reason to believe that there is present in this district a thickness of from 20 to 30 feet of limestone of lower Beekmantown age, quite like a similar thickness of rock at the summit of the Little Falls dolomite at Little Falls (where an unquestioned unconformity exists between the two), and holding the same fauna. This is to be separated from the Little Falls dolomite under the name of the Tribes Hill limestone, and the same separation needs to be made in this district. The Theresa formation is to be restricted to the alternations of sandstone and magnesian limestone which constitute the lower half of the formation as mapped.

Age of the Potsdam and Theresa formations. These two formations, with a maximum thickness in this district of from 125 to 150 feet only, represent the attenuated western edge of formations which, in the Champlain valley, have tenfold that thickness. Their distribution shows that they were deposited in a subsiding trough along the present St Lawrence valley line, and that their deposit commenced at the east and worked westward. Everywhere along this line we find a sandstone beneath, grading upward into an overlying dolomite, and everywhere the horizon is characterized by the presence of the fossil Lingulepis acuminata. Everywhere along this line too there seems to be a break between these formations and the next formation above. The two formations seem then to be indissolubly bound together, to rest unconformably on the Precambric, and to be separated by an unconformity from the overlying formation. Since the formations are thin in the immediate district, and are thinning to the west and south, it follows that we are here in the vicinity of the western edge of the subsiding trough. Just how far west its deposits extended can not be told. According to

Ells the Theresa formation outcrops on Howe island, and on the Canadian mainland to a point midway between Gananoque and Kingston.[1] In the district about Kingston, as seen by us in 1908 under Dr Ami's guidance, the Potsdam is certainly present, though no Theresa was seen. The Potsdam is in patchy distribution, in depressions of the old Precambric surface, and is still thinner than it is at Clayton. The Theresa may never have been deposited here, or it may have been thinly laid down and then eroded, prior to Pamelia deposition. But it certainly seems as if, here at Kingston, we are very near the westerly end of this old, St Lawrence, Upper Cambric trough.

On the basis of its fauna and position the Potsdam sandstone of northern New York was classified as of Upper Cambric age by Walcott, and in this he has been followed by practically all geologists. One can start on the formation at Lake Champlain and follow it without a break to Clayton, as a single continuous sandstone formation. Unquestionably its deposition commenced first at the east, and gradually extended westward; unquestionably the basal portion in the western sections is younger than the base in the east. But, so far as known to us, there is not a scrap of evidence to show that the deposition of sand had ceased, and that of dolomite begun on the east, before sand deposit had even commenced on the west. And even were this true, as is quite possible, there is certainly no evidence of such considerable age difference between the eastern and western ends of the formation, as to warrant their classification in two entirely different geologic periods, the one end Cambric, the other Ordovicic, as has been recently done by Professor Grabau, who classes the Potsdam here as of Beekmantown age.[2] That seems to us a stretching of facts to fit theory that is certainly not permissible. It is quite possibly true that the sandstone deposition slowly worked its way westward by progressive overlap, as the trough continued to subside; but the evidence seems to us to indicate clearly that the length of time consumed in the process is far less than Grabau would have us believe. We have now gathered evidence from many points in New York indicating that everywhere the Beekmantown formation is unconformable on what lies beneath. Detailed study of section after section has shown the presence of the unconformity in every case; and though the

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[1] Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 97–108.

[2] Science, n. s. 29:356–58.

work is only begun we are strong in our belief that uplift of the whole region preceded the Beekmantown.

The type locality of the formation, at Potsdam, is precisely midway between Clayton and Lake Champlain. If one of these ends is of Potsdam, and the other of Beekmantown age, it is of interest to conjecture what the age may be at the type locality.

To the writer it has long seemed clear that the sandstone and the overlying dolomite must be classed in the same period, not only here on the west but everywhere in northern New York. By the overlying dolomite is meant not the true Beekmantown formation, but the dolomites which underlie this and which, the evidence indicates, underlie it everywhere unconformably. These dolomites have heretofore been classed with the Beekmantown and constitute Brainard and Seely's " Division A" of that formation in the Champlain valley, with the underlying "passage beds." But while the beds of this division grade downward into the Potsdam they are separated by an unconformity from the beds of " Division B " just above, as recently shown by Ulrich; because of which the writer has recently argued that, since this unconformity is everywhere present in New York, marking the emergence of the entire region, it forms the logical plane of division between the Ordovicic and the group beneath. If this contention be well founded, the Potsdam and Theresa formations, the Little Falls dolomite, and " Division A," fall into the upper Cambric group of present classifications. Ulrich has, however, recently proposed a different classification, involving the insertion of a new group of period rank between the Cambric and Ordovicic, for which he proposes the name " Ozarkic," and into which the Potsdam and Theresa formations would fall. For many reasons the writer is in accord with this suggested innovation.

Pamelia formation

In our district here the Theresa formation is everywhere overlaid by the limestone group here called the Pamelia formation. This is in some respects the most interesting formation in the section since it represents the thinned, shoreward edge of a formation which, while widepread elsewhere, has not heretofore been recognized in New York, and is in existence as a surface formation in the State only in this immediate area. Because of its wide separation from other areas where the formation appears, and because it represents only a local facies of the mere upper part of the whole, the giving of a local name seems justified, and in Pamelia township the entire thickness is exposed. As has been shown there is plain evidence of an erosion interval between this and the Theresa, indicative of uplift to above sea level and of erosion on this land surface. As will be later shown this is an important and widespread break. The comparatively slight amount of erosion is indicative of low altitude for this land surface.

The renewed depression which initiated Pamelia deposition came in from the southwest instead of from the east, involving change in the direction of slope of the surface.

The formation consists essentially of limestone, though much of it is not pure limestone. It is conveniently separable into lower and upper divisions which differ in lithologic character. The lower division has always a sandy base, followed by alternations of black limestone, blue limestone and gray (somewhat magnesian) limestone, often with shaly partings between the beds. The upper division contains much whitish, earthy limestone, with interbedded dove limestone and gray magnesian limestone. The black limestone characterizes the lower, and the earthy and dove limestones the upper division.

In the western portion of the Theresa quadrangle the formation has a thickness of 150 feet or more. Traced eastward across the quadrangle it thins considerably, and on the eastern margin appears to have less than half this thickness though here the drift is so heavy, and exposures so poor, that no good measurements can be obtained. However, 60 feet seems a generous allowance for the thickness here, and it is the beds of the lower division which have disappeared.

Following the formation westward, across the Clayton quadrangle to its disappearance beneath the river, the belt of outcrop swerves somewhat to the north, and the formation thins somewhat in this direction also. If it could be followed due west across the quadrangle it would no doubt hold its thickness or even perhaps increase. It is the northward shift that causes the thinning. A thickness of at least 80 feet is maintained to the river however, and the formation passes across into Canada with this amount not materially reduced. The shore lines of this depositional basin then lay not far distant to the east and north of the district and the invasion of the sea must have come from the opposite direction.

In the immediate district the formation rests everywhere on the sandy dolomites of the Theresa. In the district about Kingston it rests either on the Potsdam or on the Precambric. In the upper Black river valley it lies on the Precambric. All these formations are capable of furnishing sandy material and hence the sandstone base of the formation is but natural. The Theresa, however, is less capable in this respect than are the other formations, thus accounting for the fact that this sandy base is a less prominent feature of our area here than it is in the others.

Hereabout, the best section of this basal material seen is at the foot of the Pamelia inface, 2 miles east of Perch lake, Theresa sheet. The small creek there runs over a massive, bared layer of Theresa dolomite, above which a 14 inch layer of the same shows in the bank. Above this lie weak, greenish sands and sandy shales, with an exposed thickness of some 7½ feet, the basal layer somewhat pebbly and more massive than the remainder. The cement is calcareous and abundant. The rock is therefore weak and seldom exposed, yet in a sufficient number of places, and sufficiently well to show that it everywhere underlies the limestone throughout the district with a thickness of from 10 to 15 feet, much of which is shaly. It is a more calcareous, and vastly weaker rock than even the most calcareous beds of the Potsdam, and quite different from it lithologically; so unlike in fact that the two rocks can be readily distinguished from one another by lithologic character alone throughout the whole region. This becomes of importance in the region around Kingston, where in our opinion both sandstones are present but without the separating Theresa formation. The Pamelia basal sandstone rests, now on the Potsdam and now on the Precambric, is less shaly and attains greater thickness than on the New York side, and shows at times astonishingly coarse basal conglomerate. In its green color, weathering to a red mottling, in its abundant calcareous cement, and in its weakness, it corresponds exactly with the New York rock, while the silicious Potsdam beneath also corresponds with the Potsdam across the river in every minute lithologic detail, even in the "tree" concretions.

In the upper Black river valley both Potsdam and Theresa are absent and the Pamelia rests on the Precambric. At Martinsburg the wonderfully complete section shows a thickness of 19 feet for the basal sandy portion, weak green sandstone, blotched with red, abundant calcareous cement and with thin conglomerate at the base.

Where thickest, the limestones of the lower division show, above the basal sandstones, beds of gray, magnesian limestone with frequent shale partings; these are followed upward by black, fossiliferous limestones, holding a rather abundant marine fauna; then succeed alternations of blue limestone and gray, magnesian limestone, with occasional white, earthy beds, and with thin recurrences of the blackish limestones with traces of the marine fauna; in the other beds the fossils are chiefly, or exclusively, ostracods. As the formation thins to the east and west the lower gray beds disappear, bringing the basal sands up under the black limestone; with further thinning this disappears in its turn, but at the same time the higher black layers seem to show increased thickness and prominence, so that where the lower division has been thinned to a few feet, as it has over much of the region, it is still characterized by black, fossiliferous limestone.

This lower division has a measured thickness of 70 feet in a nearly complete section by Perch lake. It is likely somewhat thicker to the west but probably does not exceed this more than 15 or 20 feet. A well near Stone Mills was drilled 125 feet in the formation without reaching the base, but drilling commenced in the upper division and how large a part of that is involved is not known, though likely 50 feet must be allotted to it.

The upper division consists of alternations of white earthy limestone, and of dove limestone, with occasional beds of gray, and of blue, hard, subgranular or subcrystalline limestone; there is also some yellow, earthy limestone, and a horizon where a reddish tinge is likely to prevail. The summit is chiefly of dove limestone. The earthy limestones hold numerous nodules of coarsely crystalline calcite, which attain quite large size in some of the upper layers, with diameters of from 3 to 5 inches. Celestite nodules also occur, but much less frequently. Much of the upper division is thin bedded, weathering into small, yellow stained slabs an inch or two in thickness; and the stone walls of this thin material which line the roadsides and separate the fields everywhere characterize the upper Pamelia country.

The surfaces of many of the layers are covered with shrinkage cracks, especially in the upper part of the division. Sand grains also appear in some of the white, earthy beds. Abundant Styliolites occur at certain horizons in the upper dove limestones. The evidence of estuarine, or lagoon deposition, with evaporating waters, occasional exposure of broad mud flats, and from time to time replenishment of the water from the sea outside, freshening it and bringing in traces of the outer marine fauna to mingle with the ostracod fauna of the lagoon, is very plain and conclusive; prevalence of somewhat arid climate is also suggested. The rock is very like, and the climatic and depositional conditions very similar to those which prevailed during the formation of the Siluric waterlimes of central New York.

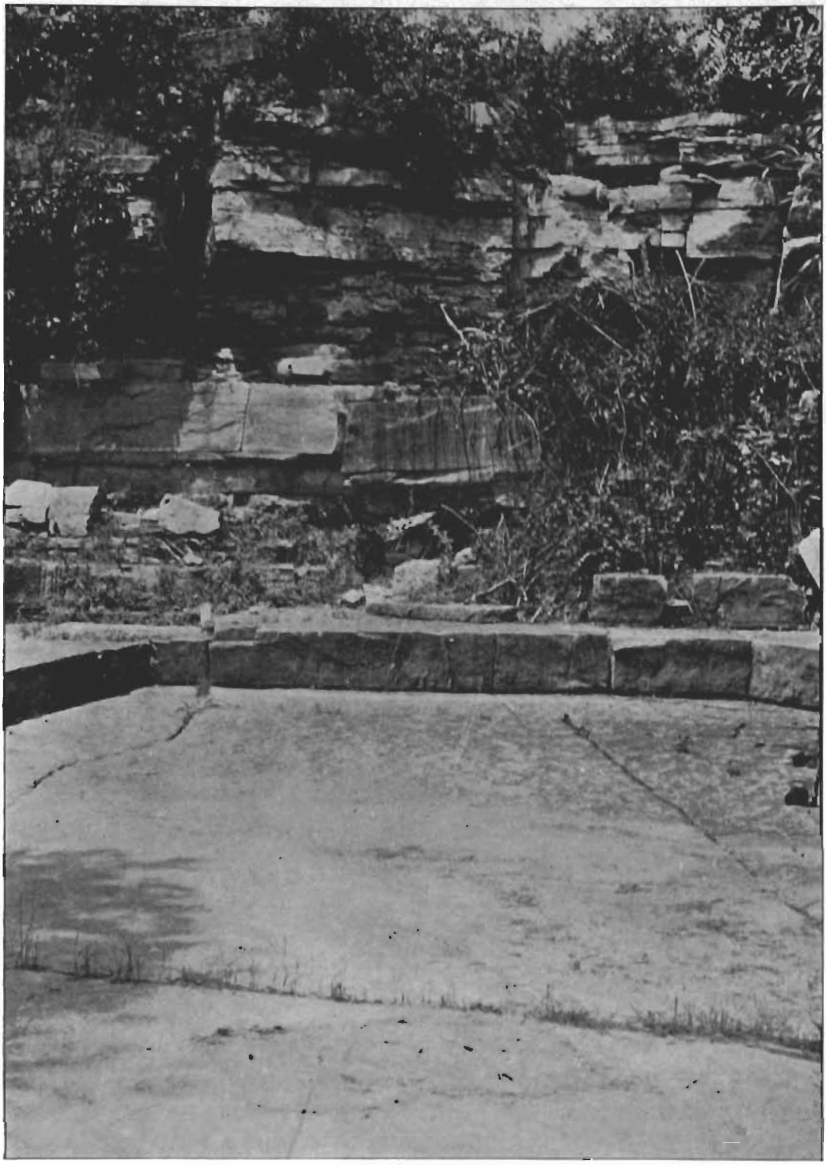
The thickest measured section of the upper division, 1 mile southwest of Depauville, Clayton sheet, gave a thickness of 82 feet. The contact with the overlying Lowville was shown, and the base of the section can not have been greatly above the base of the upper division. Near the river west from Clayton a similar thickness was found, though the upper part of the section was considerably interrupted. In all probability the thickness does not vary greatly from this over the entire map limits, with the exception of the eastern margin of the Theresa quadrangle. The thickness of the two divisions together then indicates a maximum of about 150 feet for the formation hereabout.

The fauna of the formation consists chiefly of ostracods, which are found at all horizons, and Ulrich remarks on the absence in the formation of certain large sized species of Leperditia and Isochilina which occur in the Lowville above. The marine fauna of the lower division includes gastropods, cephalopods, lamellibranchs, trilobites, corals and sponges. The most abundant and characteristic form is the coral Tetradium syringoporoides, which abounds in certain layers of the black limestone. The most common trilobite is a species of Bathyurus which is very like the common Bathyurus extans of the Lowville, but which Ulrich distinguishes as a different and unnamed species, which is a common Stones River form. Among the gastropods he identifies Lophospira perangulata, another Lophospira, and a Helicotoma. The fauna as a whole is quite similar to that of the Lowville, though the differences are characteristic.

Since the formation is a new one to the State the publication of a few detailed sections is advisable. The best continuous section of the lower division is found in the bed of a small creek which tumbles down the steep bluff face east of Perch lake (Theresa sheet), cutting the 400 foot contour where the figure 400 appears on the map.

6′	White, earthy limestone in thin beds, often shaly looking
3′ 6″	Brittle, tough, blue to blue black limestone, thick bedded
1′ ½″	Gray, subgranular, magnesian limestone, weathering white
1′ 5″	Massive bed of blue, subcrystalline limestone
1′ 3″	Massive bed of gray, magnesian limestone
5″	Blue, subcrystalline limestone
1′ 8″	Gray, magnesian limestone, two layers
1′	Concealed
3′	Finely laminated gray to blue gray, magnesian limestone, fine-line weathering on edges
10′	Concealed
10′ 3″	Black to blue black, fossiliferous limestone, upper 3 feet thin bedded, remainder fairly massive

Plate 16



Exposure 1¼ miles east of Perch lake, of limestones of the lower division of the Pamelia formation; about 6 feet of black, fossiliferous limestone above and twice that thickness of gray, magnesian limestones beneath. H. P. Cushing, photo, 1907

8′	Gray magnesian limestone, weathering whitish, fairly massive below, upper 2 to 3 feet thin bedded and earthy
1′ 6″	Curdled looking intergrowth of blue limestone and gray, magnesian limestone, the former weathering most rapidly with production of fantastic weathered surface
19′	Alternating, gray, earthy, impure magnesian limestones, and thin, shaly looking partings, limestone weathering at times to a greenish tinge, at other times whitish
2′	Greenish to olive, calcareous shale
2′	Greenish, calcareous sandstone, coarse, well rounded sand grains set in calcite paste
72′ ½″	

The lower 4 feet of the section belong with the basal, sandy portion of the formation, without any question, so that the actual base is nearly reached. Above is a thickness of 28 feet of impure, magnesian limestone before reaching the base of the fossiliferous black limestone, the most characteristic member of the lower division. Plate 16 is a photograph of beds of this horizon exposed in the creek bed just north of the road 1¼ miles east of Perch lake. In the section here 14 feet only of gray magnesian beds are found underneath the black limestone, as against the 28 feet of the Perch lake section. A mile further east these have disappeared letting the black limestone down on the basal sand beds, or rather bringing them up to it.

Judging from other sections the concealed 10 feet of the section is occupied by weak, earthy, thin bedded, whitish limestone, and the section would be capped by a very massive, blue, subcrystalline limestone which forms a strong shelf everywhere through the district.

The best sections of the upper division are all on the Clayton quadrangle. One measured up the bed of the small creek which tumbles down the bluff into the Chaumont river a mile southwest of Depauville is as follows:

1′ 8″	Brittle, light gray, subcrystalline limestone
16′ 1″	Thin bedded, brittle limestone, mostly dove, but with beds of grayer limestone
1′	Massive layer of dove limestone
10′ 8″	Irregularly bedded, gray to white, earthy limestone, mostly thick bedded; midway is somewhat sandy
5′	Thick bedded, uneven, gray limestone
3′	Thin bedded dove limestone in 3″ to 6″ layers
4′ 2″	Gray white, earthy, irregular limestone, both thick and thin beds
5′ 4″	Dark and light gray, brittle, subcrystalline limestone
1′ 8″	Gray white, impure, earthy limestone
1′ 8″	Brittle, blue gray, subgranular limestone
5′ 10″	Impure, earthy, white limestone, irregularly bedded
1′	Hard, blue gray, subcrystalline limestone
57′ 1″	

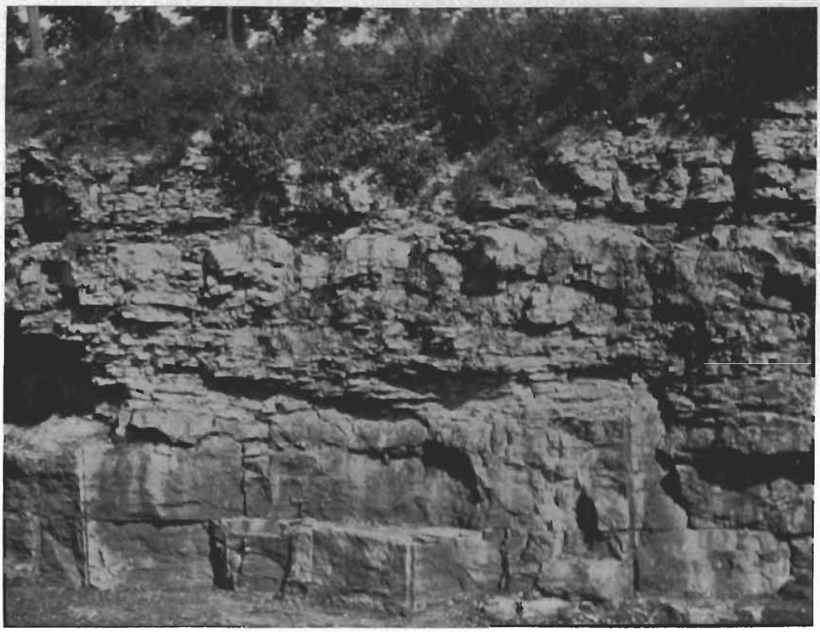
The section terminates downward 20 feet above the river level. Above, after a 10 foot gap, come 15 feet of thick and thin bedded, dove limestone, often mud cracked, and then the Lowville base, giving an 80 foot thickness to the section. It is not certain whether its base overlaps the summit of the previous section of the lower division or not, though it is thought not. But the uppermost 6 feet of that section belong to the upper division and the thickness is nearly the same as that of the impure, earthy limestone at the base of this section. Even granting that amount of overlap, the two sections taken together give a *certain* thickness of 150 feet to the formation and this may need to be increased by from 10 to 20 feet.

Another most excellent section is that given in a quarry up the river bluff 4 miles west of Clayton [pl. 17]. A slightly generalized statement of it will serve the purpose here.

1′ 8″	Thin bedded, dove limestone
5′ 6″	Gray white, impure earthy limestone, mostly thin bedded, some thick and irregular beds
7′ 5″	Rather massive limestone beds averaging 20″ in thickness, gray in color, in part earthy, in part subcrystalline
2′ 9″	Dove limestone, three beds, the lower thick, the two upper thin
3′	Hard, gray, subcrystalline limestone, two thick beds with a thin shaly parting between
1′ 5″	Dove limestone, two beds
1′ 8″	Hard, gray limestone, upper inch is shale
1′ 8″	A hard, dove limestone layer
1′	Gray white, earthy limestone, thin bedded
2′ 9″	Brittle, gray, subcrystalline limestone
1′ 8″	Massive, dove limestone bed
11″	Thin bedded, whitish, earthy limestone
1′	Gray, subcrystalline limestone, slight pinkish tinge
7′ 1″	Gray, earthy limestone in thick beds with shaly partings; a thin dove layer near the top; reddish tinge at times
9′ 6″	Blackish limestone, upper bed very massive
49′	

The black limestone at the base of the section seemed to the writer to smack strongly of the lower division, though the marine fauna was but feebly developed, and Ulrich expressed doubts in the matter. Certainly beds of the type are not usually found in the upper division. A short distance back from the river another quarry shows a thickness of 15 feet of the succeeding beds, the entire thickness being of dove limestone, both thick and thin beds, with sparing fossils. Further back, by the roadside is a shallow quarry exposing 4 feet of still higher beds, two massive dove layers with similar but thinner beds between, the thick beds holding Phytopsis. Such beds elsewhere mark the extreme summit of the Pamelia. Were the upper part of the section complete there would be shown here a thickness of more than 80 feet belonging to the formation.

Quarry in the upper Pamelia formation, by the river 4 miles west of Clayton; alternating beds of dove limestone, and whitish, earthy limestone. The upper view is a somewhat more distant one showing a greater thickness of the upper beds. Photo (upper) by H. M. Ami and (lower) by E. O. Ulrich, 1908



Upper view. Dove colored limestone beds of extreme upper portion of Pamelia formation in railroad cut just south of Sanford Corners. Theresa quadrangle, looking east.

Lower view. Contact of Pamelia and Lowville formations at the south end of the railroad cut. E. O. Ulrich, photo, 1908

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Both these sections are imperfect in their showing of the beds of the extreme summit. The most excellent section shown in the railway cuts just south of Sanford Corners (southeastern part of Theresa quadrangle) supplies this deficiency [pl. 18].

1′ 4″	Two 8″ layers of blue gray, crystalline limestone, abundant lamellibranch casts full of crystalline calcite; dove limestone mud balls
1′	Mud cracked, argillaceous, somewhat granular, bluish limestone, weathering yellowish
1′	Thin bedded, blue, granular limestone, conglomeratic, quite shaly below, very fossiliferous, chiefly bryozoa; base of Lowville
11″	Dove gray, fine, impure limestone, weathering light
3′ 2″	Laminated, mud cracked, gray dove, argillaceous limestone, thin bedded, ripple-marked, worm-burrowed
1′ 9″	A 6″ layer below and an upper 15″ bed; fine dove limestone with calcite spots, gastropods and cephalopods
1′ 10″	Gray, granular limestone, crystalline specks and spots; shaly below, more massive above
5′ 6″	Finely granular, blue dove limestone, shaly below, more solid above; blocky weathering; calcite seams and spots; sparse Phytopsis in upper part
4′ 6″	Mottled, blue dove limestone, thin bedded above and below; much crystalline calcite replacing poorly preserved fossils
8″	Blue black, finely granular, dove limestone; calcite spots
1′ 10″	Blue gray, calcareous, sandy shales, weathering yellowish
7″	Dark blue, finely crystalline limestone; conglomeratic
8″	Blue gray, calcareous shales, weathering yellowish; sand grains
8″	Blue dove limestone; base weathering sandy looking
9″	Sandy, argillaceous, shaly limestone, weathering yellowish
9″	Blue dove, mottled limestone
3′ 1″	Gray blue, dove limestone, somewhat muddy, shaly fracture
7″	Blue dove limestone, small limestone pebbles
1′ 9″	Solid layer of blue dove limestone, rudely laminated with organic streaks
1′ 10″	Laminated, argillaceous, fine grained, mottled, blue dove limestone; two seams
1′ 4″	Fine, flinty, dove limestone; slightly conglomeratic at base
1′ 10″	Fine, flinty, dove limestone, with a shaly streak of 3″; lower portion with Phytopsis
4′	Rather compact, fine dove limestone; a little Phytopsis in the upper 3″
1′ 2″	Blue dove, thin and irregular bedded limestone
2′ 6″	Measures concealed
5″	Blue dove, mottled, laminated limestone, small ostracods
45′ 5″	Of which the lower 41′ 8″ belongs to the Pamelia

The 1 foot layer, third from the top of the section, is divisible into an upper 3 inch portion, full of fossils, making an irregular contact with the remainder, which lacks fossils, and in Ulrich's judgment, with which we coincide, the line between the two formations is properly drawn at that slight break. These upper dove limestone layers, over 40 feet thick in this section, have puzzled us much and have been difficult to classify. They are above the white, earthy beds which are the most characteristic lithologic feature of the upper Pamelia, and while they are precisely like the dove limestones which are intercalated with these, they are also very like the Lowville, with which we at first classified them. Their shift from the one to the other considerably diminishes the supposed thickness of the Lowville of the district and correspondingly increases the Pamelia.

In this cut, the first of three such along the railway south of Sanford Corners, the rock dip is to the south, carrying the Pamelia summit below the track level before reaching the second cut. The dip then reverses, becoming north, and bringing up the Pamelia again in the third cut. At the north end of this cut the basal, bryozoan, conglomerate layer of the Lowville has increased in thickness to 38 inches, as against a 3 inch thickness in the section just given, and immediately beneath it is a layer of exceedingly fine grained dove limestone mud, which is the exact counterpart of the material composing the conglomerate pebbles [pl. 31, lower figure]. This layer was wholly lacking also in the previous section. At the south end of the cut the Lowville shows 6½ feet thickness of basal layers which did not appear in the section in the north cut, and there is also a thickness of full 6 feet of the pebble-furnishing, dove limestone at the Pamelia summit, which is also lacking in that section. The evidence of unconformity between the two formations is clear, and found as Ulrich had predicted that it would be. The fact that both formations thicken together is, however, somewhat unusual, and suggests that some of the warping shown occurred in the uplift following Pamelia deposition, its summit being protected from wear in a shallow trough, in which also the first beginnings of Lowville deposition took place.

The section here in the south cut is given on page 84 under the account of the Lowville formation.

The section just described gives an excellent idea of the depositional conditions which prevailed during the closing stages of Pamelia deposition. The fine limestone muds, much sun cracked, worm-burrowed, even ripple-marked; the injection of sand grains and the occurrence of the occasional limestone conglomerates, together with the abundance of ostracods and the general absence of marine forms; all these point unquestionably to intermittent deposition in a shallow lagoon, with drying mud flats produced from time to time, and with only occasional admission of sea water. Though the uppermost break, here chosen as marking the base of the Lowville, seems much the most considerable of all, the presence of more than one conglomerate horizon, of more than one horizon of sand grains, indicates several minor breaks in the summit of the formation, and much complicates the successful working out of the section.

Extent of the Pamelia formation. In a preliminary paper published some months ago, based on the field work up to the close of 1907, the writer attempted to predict the extent of the Pamelia formation in New York and adjacent Ontario, in so far as the published literature warranted. The result of the field work of 1908 necessitates some modification of the statements there made, all of which prove to have been too moderate.[1]

The study of the formation on the Clayton sheet, and the work about Kingston, show that the formation does not thin as rapidly in those directions as had been supposed. About Kingston the formation has much prominence and considerable thickness, much of the upper division, and the basal sandstones being well represented. The upper dove limestones of the New York section are here capped by thin bedded, earthy, shaly layers, weathering yellow, above which the Lowville comes in, with its basal conglomerate. The division plane between the two formations is therefore much easier of recognition than on the New York side.

Up the Black river valley we measured sections at Lowville and on Roaring creek, near Martinsburg, the latter a wonderfully fine, continuous section from the Precambric up into the Trenton. We were at the time ignorant of the fact that Prof. W. J. Miller was engaged in the areal mapping of the Port Leyden sheet, on which this section occurs. That being the case its detailed exposition is left for him.[2] Suffice it to state that it shows a thickness of 72 feet, 6 inches of Pamelia, overlaid by 54 feet, 7 inches of Lowville; and that, of the Pamelia, the lower 19 feet is of sandy beds, followed by 8 feet of blackish limestone with abundant marine fossils, the remainder showing alternating beds with the characters of the upper division though the upper dove beds are lacking. Miller reports that the formation is traceable to the south line of the Port Leyden sheet, but does not appear beyond. This is, however, well toward the upper end of the Black river valley, and gives the formation in New York a measured length of outcrop of 70 miles, from southeast to northwest. The Kingston occurrence adds 15 miles more to this distance, and it is quite probable that the formation may run west for some miles across the Ontarian peninsula.

Our work was done, and a preliminary paper published, while in ignorance of the existence of a paper by Dr Ells upon the adjacent Canadian district. This paper, as the quotation which follows will

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[1] Geol. Soc. Am. Bul. 19:165-71.

[2] N. Y. State Mus. Bul. 135, p. 22, 23.

show, distinctly recognizes the chief physical oscillation of the region.

It would, therefore, appear that some marked but well defined change of level occurred in the area south of the Kingston-Brockville Archaean axis at the close of the Potsdam, which was also materially reduced in thickness. This is in marked contrast to the conditions which prevailed north of that axis throughout the Ottawa basin; and it may be supposed that, at a certain stage in the deposition of the sandstone formation, the surface was raised above the level of the sea, and so remained till the beginning of Black River time throughout the whole extent of Lake Ontario.[1]

Age of the Pamelia formation. Our section here shows the Pamelia formation to lie between the Theresa and Lowville formations, separated from each by an unconformity, the lower of which is much more important than the upper. In the Champlain valley two great formations, the Beekmantown and the Chazy, with a combined thickness of 2000 feet, occupy this same interval, yet the Pamelia formation is unlike either. On the basis of its position and fauna, Ulrich correlates it with the upper part of the Stones River formation, a formation of Chazy age, but laid down in a separate basin from the Chazy, so that faunally and lithologically the two are quite distinct. The Stones River basin lay to the west and southwest of the Chazy trough, and was much larger. The barrier between the two in New York comprised the Mohawk valley region, much of the Adirondack district, and at least the westerly portion of the St Lawrence trough.[2]

Curiously too, although much sedimentation occurred in the Champlain trough during Beekmantown-Chazy time, and only Pamelia deposit in our district here, yet this is practically un-

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[1] Roy. Soc. Can. Trans. ser. 2, v. 9, § iv, p. 106.

It is to be noted that Black River is here used in a general sense as including the whole body of limestone.

[2] Since the above was written another paper by Professor Grabau has appeared which presents more definitely his interpretation of the rock succession and age in this district [Jour. Geol. 17:211-26]. The fundamental difference between us seems to be that he regards the break between the Theresa and Pamelia formations as representing the somewhat expanded westward continuation of the break in the Champlain valley between the Beekmantown and Chazy, and recognizes no break there between the Cambric and Beekmantown. We regard it as representing most of Beekmantown and all of lower and middle Chazy time and think that, to the east in the St Lawrence valley, it splits into two breaks with a wedge of later Beekmantown inserted between. He thinks there is no Cambric here, and that the Potsdam and Theresa are of Beekmantown age; and he recognizes no break between the Cambric and Ordovicic. We find evidence of a considerable series of oscillations of level in the general region, while he argues, if we correctly understand him, for a slow, progressive subsidence of the region during Potsdam and Beekmantown time.

represented in the Champlain area, Ulrich correlating the dove, reef limestone, only a few feet in thickness, which forms the basal member of the upper Chazy there, with the Pamelia horizon. In the much more complete sections about Chambersburg, Pa., a 200 foot thickness of limestone with an upper Chazy fauna, separates the Pamelia horizon from the Lowville. Subsidence apparently ceased in the Champlain basin during the time of Pamelia depression and deposit in this district, and as this ceased here, upper Chazy depression was renewed there, the unconformity between the Pamelia and Lowville representing this upper Chazy interval. Knowledge of this led Ulrich to predict the unconformity and induced the search for it. Otherwise it might easily have escaped our notice.

Mohawkian series[1]

The Mohawkian series comprises the Black River and Trenton groups. The Black River group is composed of the Lowville beds including the Leray limestone, and the Watertown limestone. In giving to the Black River group this larger scope, we return to the original conception of several of the geologists of the First Geological Survey of New York, i. e. Hall, Vanuxem and Mather, with the exception that the Black River then also included the Chazy limestone. Emmons, however, to whose district the Black River region belonged, did not use the term "Black River." He distinguished the "Birdseye limestone" and the "Isle La Motte marble" employing the latter term for a bed locally the main object of the quarrying industry, and known as the "Seven foot tier." Hall, in the first volume of the *Palaeontology of New York*, restricted the term Black River to this "Seven foot tier" and through his influence and the description of a very striking cephalopod fauna from the bed, the term "Black River" was quite generally accepted for the "Seven foot tier." Since, however, mainly through the investigations of Dr Ulrich, the fact has become apparent that beds which in the Mohawk valley and the Lake Champlain region have been referred to the Black River limestone, are both older and younger than the Black River as restricted by Hall, but fall within the limits of the original conception of Black River, it has become advisable to revive this original usage of the term to avoid confusion. The "Seven foot tier" or Black River limestone of Hall has then to be renamed and the term "Watertown" is here used for this formation [*see* p. 84].

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[1] By R. Ruedemann.

Lowville limestone. The Lowville limestone which is the "Birdseye limestone" of the old Geological Survey reports has its maximum development in New York in the region of the lower Black river, or in the southern portion of the area here mapped. It reaches there about 60 feet in thickness. It consists typically of thick and thin bedded, fine grained dove limestone which shows a characteristic ashen gray weathering and contains either numerous more or less vertical worm tubes denoted as Phytopsis and filled with calcite (producing the "birdseyes" in sections) or shows in profusion the horizontally spreading tabulate coral Tetradium cellulosum and related species. Between these typical Lowville beds there are intercalated others of subcrystalline dark to black limestone, or of oolitic or also of shaly whitish weathering limestone. These intercalations usually contain a larger fauna than the dove limestone and carry lamellibranchs, gastropods and cephalopods, as well as ostracods and trilobites.

The basal bed is conglomeratic and of very variable thickness; it is overlain by several feet of strata that contain quartz grains or grit bands and are more or less shaly, the shaly limestone gradually becoming more massive upward and assuming the characters of the typical rock. These more or less sandy beds comprise about 4 feet.

The uppermost portion of the Lowville beds which has been mentioned by the earlier authors as the "cherty beds" has been found by Professor Cushing and the writer to be quite distinct from the typical Lowville beds and separated from them by an unconformity. It has for that reason been here distinguished as a subdivision under the name Leray limestone and will be described separately [*see* below].

It appears that in this region the Lowville beds beneath the Leray member can be conveniently divided into an upper and lower division of nearly equal thickness, the upper division alone containing the abundant Tetradium cellulosum and larger Phytopsis, as well as the typical massive dove limestone strata, while in the lower division more dark or black subscrystalline limestones containing only smaller forms of Tetradium and Phytopsis and more thin bedded dove limestones abound.

In this lower division also two or more horizons of Stromatocerium can be observed, which give the beds a very irregular concretionary appearance. These horizons are well seen in the railroad cut just south of Sanford Center, also where the road crosses the southern branch of Horse creek on the Clayton quadrangle and best along the Black river just east of the boundary of the map. Such beds are seen in the lower third of the exposure on plate 19; other bunchy surfaced layers also appear, with the depressions filled in with shaly material, which seem clearly due to rill action on tide flats.

While the sand grains which are found in greater or smaller number floating in the basal limestones indicate, if we may follow recent investigations, the conditions of quiet embayments, in which sands washed in from the land, drifted out into the bay and gradually sank to the bottom, becoming imbedded in the limestone mud, the following beds indicate that this sea became gradually deepened. The lower division still exhibits in the shaly beds the sun cracks and ripple-marks and numerous mud balls characteristic of mud flats while the upper beds in their more uniform, massive character contain the criteria of deposition farther off the coast line. It follows thence that the Lowville sea was an advancing sea in the area here mapped. From the development of the Lowville in the Mohawk valley and north of the Adirondacks, it can be inferred that this transgression took place from the southwest. In the Mohawk valley the distribution of the Lowville is very erratic, as fully discussed by Cushing in a former paper [Geology of the Northern Adirondack Region], it being entirely absent in some localities while in others it is connected by so called passage beds with the underlying Beekmantown. This erratic distribution is then clearly due to the irregularity of the surface over which the sea advanced, the Mohawk valley intersecting the deeply indented coast line of the Adirondack peninsula in Lowville time. In the Champlain basin at the base of the Black River group an outcrop of typical Lowville rock occurs in the Crown Point section. The bed referred to consists of 5 feet of dove limestone with Phytopsis tubes but otherwise apparently unfossiliferous. However, 12 feet above this dove limestone the writer found a large colony of Tetradium cellulosum together with Orthoceras recticameratum, another typical Lowville fossil, thereby clearly demonstrating the presence of the Lowville fauna in the Champlain basin.

Four species of fossils have to be considered as highly characteristic of the Lowville formation in the area here mapped, viz:

Tetradium cellulosum (*Hall*)
Orthoceras multicameratum (*Emmons*) *Hall*
O. recticameratum *Hall*
Bathyurus extans (*Hall*)

These species are not known to occur above or below the Lowville limestone, and are common enough to occur in every exposure of the formation.

Tetradium cellulosum forms large colonies, attaining sometimes a diameter of several feet (specimens of this size collected by the writer along Black river) and consisting of frequently dividing branches that radiate horizontally and obliquely upward from a common center. Its most characteristic aspect, however, is seen on sections where the squarish cells with their fission septa produce a neat lattice pattern. Different, hitherto undescribed species with looser arrangement of the polyparies or cells, occur in lower horizons.

Both Orthoceras multicameratum and O. recticameratum are easily recognized by the close arrangement of their septa and the latter form possesses in the angular course of the septa a character not shown by other species.

Bathyurus extans apparently occurs throughout the formation but is most frequent in several bands. It is, as Dr Ulrich informs us, preceded by closely related and very similar prenuncial forms in the Pamelia formation.

On account of the but slight difference in the compactness of the rocks between the Lowville and Pamelia formations, the former is not set off by an escarpment from the other, but both form one continuous plateau. In some districts the lower Lowville contains easily worked layers, furnishing subcubical blocks and the composition of the fences of such blocks is a quite characteristic aspect for this horizon.

Since the formation received its name from Lowville and a section of this type locality has not yet been furnished, we insert here the section, obtained at this place in the quarry at the railroad bridge over Mill creek, where in the creek bank the uppermost part of the Pamelia (about 12 feet) is shown and a continuous section into the Leray limestone can be obtained. On account of the nearness of Lowville to the area here mapped, the Lowville section is to be considered as typical also for this area. For comparison we add the section measured in the Sanford cut which contains about three fourths of the formation. Another fine section was observed in the bank of the Black river above Watertown, opposite the filter plant, just outside the map limits, and a section of about 56 feet from the 7 foot tier downward is exposed in the high river bank opposite the Ontario Paper mill, 2 miles east of Brownville.

Unfortunately no good sections were found in the northwestern portion of the area, permitting a comparison with that of Lowville as to thickness and arrangement of horizons.

Section at railroad bridge at Lowville (type section)

Lowville section

6′	Cherty beds. Dark blue, finely granular limestone, dirty white weathering. Columnaria horizon at base
1′ 6″	Bed full of horizontal worm tubes. Chert horizon at base
5′ 9″	Transitional bed from Leray to typical Lowville. In aspect like cherty beds with a few cherts, but contains also Tetradium cellulosum, besides Leperditia fabulites, Rafinesquina minnesotensis, and other brachiopods and bryozoans
	Base of Leray
3′	Dove limestone, massive. Phytopsis tubulosum common near top; a few Tetradium cells
3′ 1″	Compact dark dove limestone, full of fossils (Tetradium, gastropods, lamellibranchs) and of crystalline calcite
4′ 9″	Thin bedded, dove limestone, full of Tetradiums (form with narrow, round tubes)
5″	Dark, fine grained impure limestone with argillaceous streaks, containing a small Monticulipora
2′ 4″	Lighter, massive bed of dove limestone with few Tetradiums. Lowest 8 inches black, with thin seams of flint
4″-7″	Stratum of granular, light gray limestone full of lamellibranchs and gastropods, their shells filled with calcite
1′ 3″	Black, massive, crystalline limestone, full of Tetradium
3′ 4″	Black to dark gray thin bedded dove limestone, containing a few Phytopsis
4″	Same rock as above, but full of a narrow form of Phytopsis
4″	Black, dove limestone stratum full of crystalline calcite
1′ 7″	Dark gray, granular limestone with many calcite crystals. Bottom of quarry
4′	Dark gray, thin bedded, dove limestone, weathering shaly
4′	Harder, argillaceous limestone
3′ 10″	Shaly dove limestone, varies much, very shaly in middle, full of sand grains, contains a few lamellibranchs
1′	Hard, oolitic blue limestone, full of quartz grains and pebbles
6″-10″	Shaly bed with seams of quartz grains or grit bands
0 - 3′+	Dark bluish gray limestone, full of pebbles, shale below. Very variable in thickness. Unconformity. Base of Lowville
1′ 10″	Gray and pinkish granular limestone, dove in parts
4″	Thin bedded, shaly limestone, sand grains near top
1′ 10″	Dove, dark mottled, fine grained limestone, typical upper Pamelia
1′ 7″	Dove limestone with argillaceous reticulation, light pink in parts, weathering shaly
9″	Bluish black flinty dove limestone
10″	Gray, granular limestone with calcite and quartz grains, in parts conglomeratic, a few fossils. (Rafinesquina incrassata)
1′ 5″	Light dove limestone, somewhat argillaceous, coarsely laminated. Phytopsis on top
2′	Grayish, bluish, blocky, subgranular limestone
1′	Compact bed of harder, light bluish gray limestone
1′+	Dove, light gray limestone with crystalline specks

Sanford cut section

27′ 2″	Lowville
1′ 4″	Blue gray, oolitic limestone, full of lamellibranchs and with Tetradium cellulosum
6′	Massive Tetradium beds, dove limestone full of crystalline calcite
5′	Thin bedded, blocky dove limestone; second zone of Bathyurus extans
4′	Irregular, thin bedded, blocky, dove limestone, more massive above, culminating in a heavy, irregularly surfaced Stromatocerium layer; holds B. extans below
22″-14″	Thin bedded, fossiliferous, dove limestone, with Camarotoechia plena, fitting to uneven surface beneath
16″-24″	Heavy, massive dove limestone, Tetradium and other fossils, masses of Stromatocerium at surface, giving bunchy character
4′ 6″	Speckly dove limestone with shaly seams; bryozoa, Tetradium syringoporoides (Ulrich, ms) and other fossils
3′ 2″	Heavy, massive bed of gray, crystalline limestone, full of fossil fragments at base, bryozoa and gastropods above; conglomeratic, many quartz grains, base of Lowville
1′ 6″	Shaly, dove, mud limestone, three beds; very fine, even grained, cherty looking

Leray and Watertown limestones. Emmons had already pointed out that the Seven foot tier was closely connected by its lithologic character with the underlying formation, and the writer had found, while in preceding years collecting the cephalopods of the formation, that the characteristic cephalopods of the "Black River" limestone for which the Watertown region is renowned among paleontologists, viz, Gonioceras anceps, Hormoceras tenuifilum, Lituites undatus and also the "Black River" coral Columnaria ?halli (=C. alveolata auct.) appear already below the Seven foot tier,[1] while at the same time the characteristic fossils of the Lowville cited above, especially also the omnipresent Tetradium cellulosum, disappeared. Since this faunistic extension downward of the "Black River" is coupled with a greater lithologic similarity of the uppermost 20 feet of the Lowville, as formerly conceived, with the "Black River" than with the typical Lowville, and this upper portion of the Lowville is characterized by seams of chert nodules which make good horizon markers, we decided to draw the Lowville-Black River line where Tetradium cellulosum abruptly disappears and the chert layers begin. In mapping the "Black River" on this basis, it was found that, on the whole, the cherty limestones also exhibit the characteristic blocky weathering of the Watertown bed,

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[1] While these cephalopods first appear in greater number in the cherty beds just below the 7 foot tier, a few stragglers either identical or only prenuncial mutations of them, have already been noticed in much earlier horizons of the Lowville. Thus Hormoceras tenuifilum and a large colony of Columnaria ? halli were noted 11 feet below the cherty beds in a Tetradium bed in the section opposite the filter plant at Watertown.

and are a unity with them also in that, as a rule, they together form a distinct escarpment above the Lowville plateau. In some cases, however, the lowest 2 or 3 feet of the chert beds have remained clinging in very irregular patches to the underlying Lowville, thus forming the serpentine shaped outliers seen in the southern portion of the map.

The authors, under the necessity of drawing a definite boundary line between the "Black River" and Lowville limestones, which would meet the requirements of being lithologically and faunistically so well marked that it could be mapped with sufficient ease and precision, decided on uniting the cherty beds with the Seven foot tier, the two forming a physiographic and economical unit, as demonstrated by their being quarried together at Chaumont and other places. Dr Ulrich's investigations had shown him a more complete section in Kentucky from which it became apparent that the cherty beds are intimately connected there with the rest of the Lowville and that the unconformity observed in the Watertown region between the cherty beds and the other Lowville represents the hiatus which is filled in Kentucky and elsewhere by beds of transitional character, while on the other hand the cherty beds were found to be also separated by an unconformity from the overlying beds. Since, moreover, the "Seven foot tier" or Hall's "Black River limestone" is of but local importance, while the Lowville, including the cherty beds, is a most persistent unit over a very large area, it has been finally deemed preferable by the authors to disregard the local conditions of the Watertown region, and to retain the "cherty beds" limestone as a sub-division of the Lowville limestone, under the term "Leray[1] limestone," on account of the typical exposures in the town of Leray.

The following diagram indicates the relations of the beds as now understood by us:

- Black River group
  - Watertown limestone
  - Lowville formation
    - Leray limestone member
    - Lowville limestone s. str.

Since a very irregular surface is observable beween the uppermost tier of cherty beds, about 6 feet thick, and the underlying beds [*see* section of Klock's quarry, *postea* p. 90], and this bed contains the cephalopods more frequently than the other cherty beds, Dr

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[1] Owing to an error of the printer this word was made to read Leroy on page 72 of Museum Bulletin 138.

Ulrich is inclined to unite it with the Seven foot tier or Watertown limestone. We adopt here this view, leaving the final decision as to the exact boundaries to a future close study of the faunas involved, but consider the difficulty of an easy recognition of this boundary — located within a lithologic unit — in the field as another practical reason for mapping and discussing here the Leray and Watertown limestones together.

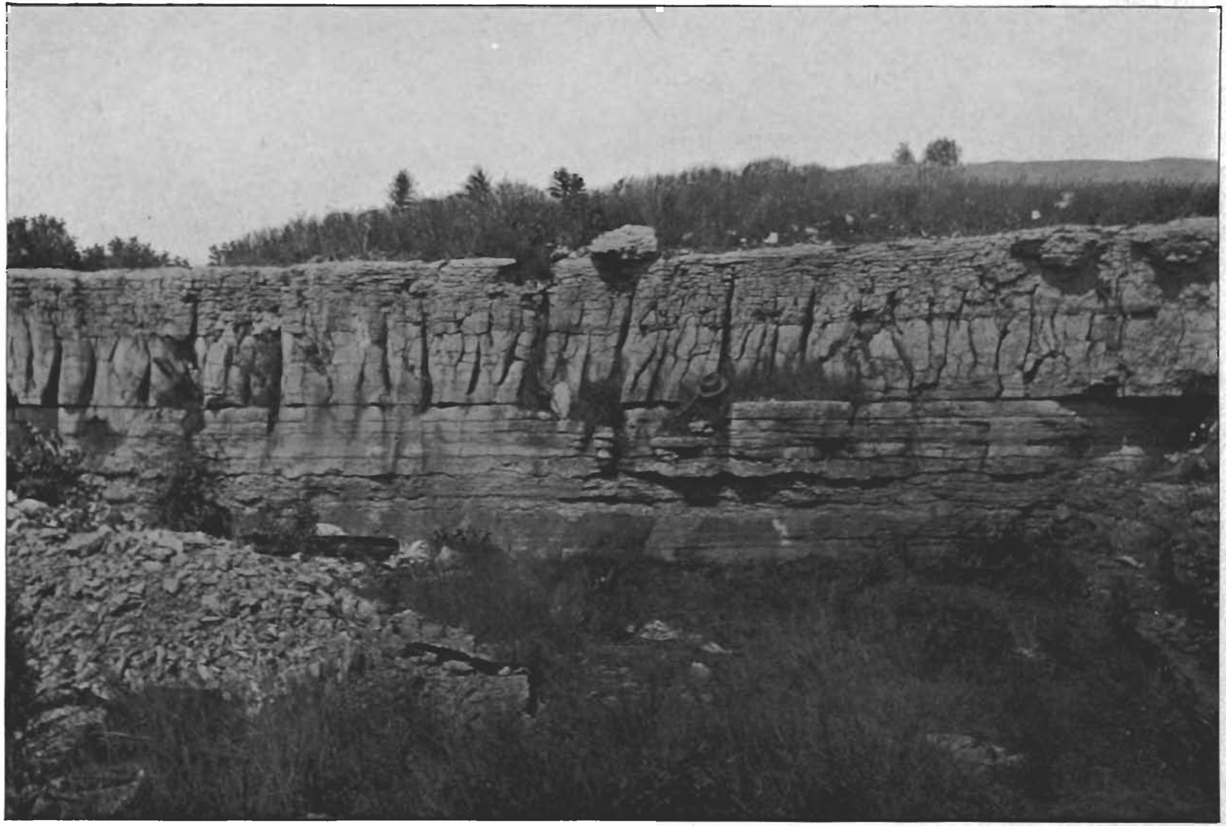
Finally, it was found in studying last summer, in company with Dr Ami, Professor Cushing and Dr Ulrich, the section at Klock's quarry at Watertown [*see* below p. 90], that there is properly referred to the Watertown also a bed 1½–2 feet thick, of black limestone, that still overlies the Seven foot tier.

With these upward and downward extensions of the formation, the limestone will be about 15 feet thick in its type region while the Leray limestone is about 13 feet thick, consisting of dark gray to black, heavily bedded, dove limestone, with layers of black chert nodules. The nodules are more or less scattered through the chert beds, forming here and there strings in the section and a distinct horizon over the whole mapped area near the base of the beds. Since large rock exposures of the surface of the Leray limestone are frequent in the region, one has often opportunity to observe large quantities of these cherts, half weathered out, on the rocks, presenting a flat, cakelike form. Some of the chert beds present, when weathered, a peculiarly fucoidal surface through intricate intermixing of the limestone with earthy films, and others are distinctly cross-striated.

The contrast between the massive chert beds and the thinner bedded underlying Lowville strata is well shown in plate 20. In natural exposures or where the quarry face is weathered, the Watertown and Leray formations are readily distinguished from the lower Lowville beds by their breaking up into small cubic blocks the size of a fist. The beginning of this breaking up, which is apparently due to a reticulate system of mud seams, is seen in plate 20 and farther progressed in plate 21. Here the rock is so weathered that it can be brought down with the pick and is of convenient size for road metal. It is also well shown on plate 19, where the hat lies just above the boundary line. This picture exhibits especially well the contrast between the evenly and thinner bedded typical Lowville limestone and the thick bedded blocky weathering Leray and Watertown beds.

In plate 22 will be found an excellent illustration of the unconformity between the Lowville and Leray limestones. The lower of

Plate 19



Leray limestone resting on upper Lowville in quarry at Threemile Bay station, Clayton sheet, looking north. Note the reef layer of Stromatocerium midway in the Lowville. H. L. Fairchild, photo, 1908

Plate 20

Upper portion of the Lowville limestone with overlying lower Leray limestone, full of chert, showing its thick bedded character as compared with the underlying Lowville. Quarry 2 miles northeast of Watertown and near the south margin of the Theresa sheet. Shows also, on the right, a joint widened by solution, with thick turf-filling above. H. P. Cushing, photo, 1907

the two massive beds of Leray limestone which appear in the upper view is absent in most sections, as in plate 20, where the basal Leray bed is the equivalent of the upper bed of plate 22. In addition most of the Lowville shown in plate 22 is absent in other sections, the top Lowville bed in plate 20 being the equivalent of the basal bed of plate 22.

The Watertown limestone is a solid bank of dark bluish gray to black limestone, with rather indistinct bedding planes, very hard when fresh, showing numerous small calcite crystals (crinoid joints) and a fine reticulation from mud seams and many worm tubes. The mud seams or the earthy intergrowth causes the rock to break up most typically in small blocks.

When fresh the Leray and Watertown limestones, especially the Seven foot tier, furnish very large blocks. They are for this reason still extensively quarried at Chaumont where at present the immense blocks required for harbor improvements at Oswego and other cities along the Great Lakes are obtained.

The fact that the 1½–2 feet of black, knotty, impure limestone which overlie the Seven foot tier are separated by a very irregular contact from the overlying horizontally bedded Trenton, indicates that also this bed should be properly included in the Watertown formation.

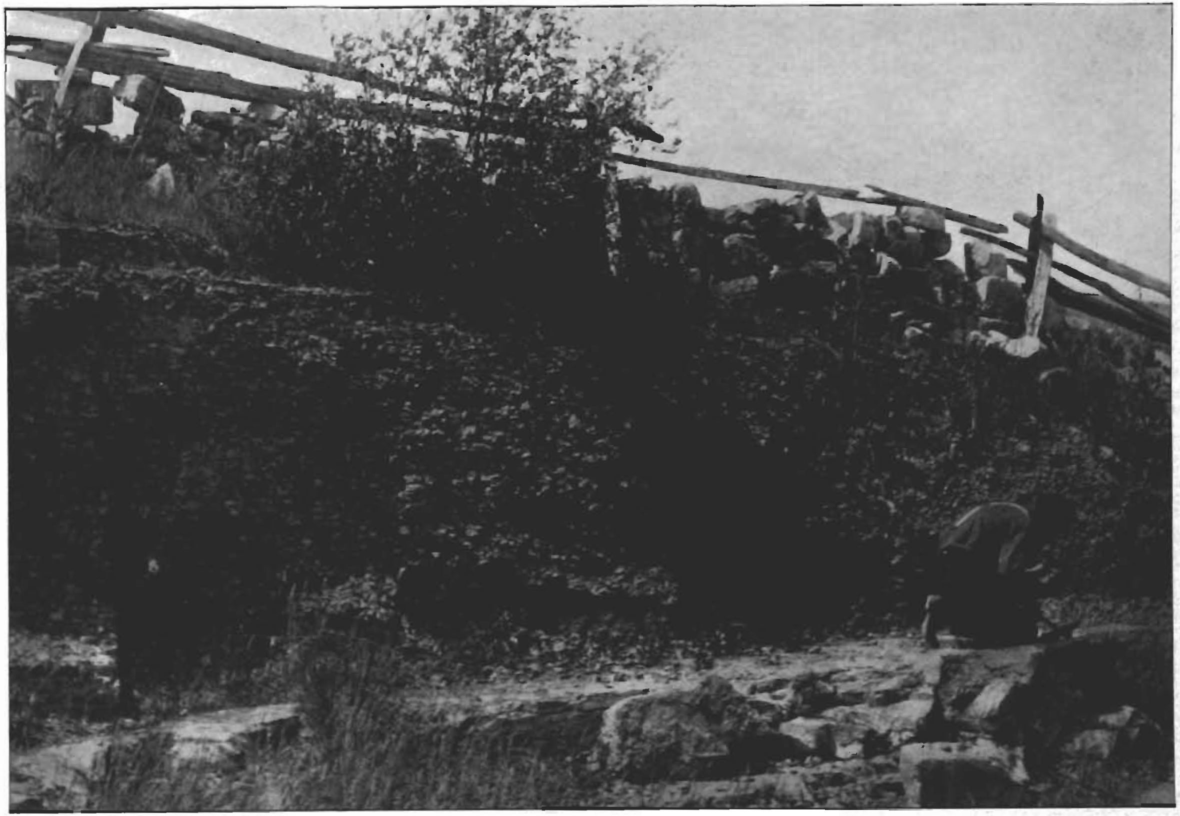
The Seven foot tier and the just mentioned top bed of the Watertown formation owe their deep black color to the great amount of organic matter in the rock. This saturation with organic matter shows itself also in the presence of petroleum in the rock. In the large quarries at Chaumont endoceratites and other cephalopods have been found whose chambers were partly filled with petroleum and the writer was in a cellar in the hotel in Black River village above Watertown that is cut in the Watertown limestone and in which the petroleum is constantly oozing out of the cellar walls in such quantities that the floor is constantly covered with the oil and gallons of it are taken out for cleaning and oiling purposes. The top layer of the formation is especially strongly bituminous, and gives off a strong odor when struck with the hammer.

The upper beds of the Black River group of the neighborhood of Watertown have become world famous among paleontologists by the fine preservation and size of their cephalopods, some of which, notably Gonioceras anceps, have not been found elsewhere. It is essentially a cephalopod facies. The straight conchs of Hormoceras tenuifilum with their large pearly siphuncles, are especially common on the many ice-polished rock surfaces of the region and on the rock shelves bordering the river. They are well known to the populace as "fish bones" which they indeed much resemble when broken through the middle. Also two species of large Endoceras, distinguished by Hall as Endoceras longissimum and E. multitubulatum are frequently seen to attain several feet in length and half a foot in diameter. Gonioceras anceps, readily recognized by its lyre-shaped septa, is rarer and Lituites undatus, another of the characteristic cephalopods of the formation is also less frequently observed. There is also a fairly large fauna of brachiopods and gastropods present, which, however, has been generally lost sight of since the fossils are hard of extraction in the massive rock and inconspicuous in comparison with the large cephalopods. This smaller fauna has not yet been described.

Physiographically the Leray and Watertown limestones form by far the most striking feature of the region. Their massiveness and hardness as compared with both the underlying typical Lowville limestone and the overlying shaly Trenton beds cause them to form a distinct plateau or terrace, rising with a frequently vertical escarpment from the Lowville exposure. This escarpment, however, does not present the straight face of the Helderberg cuesta but is deeply indented or composed of many parallel ridges separated by about equally wide valleys, and stretching in fingerlike groups for miles upon the Lowville plain. These fingers are especially well seen on the map northeast of Limerick, and west of Perch river. They rise abruptly from the Lowville plain while the intervales rise more gradually to the level of the Watertown limestone plateau. The direction and form of these fingerlike erosion ridges and their relation to the prevalent direction of jointing in each special case suggest that they originated from ice plucking between especially deep and wide joints.

The Watertown limestone plateau is in comparison to the small thickness of the formation abnormally wide and the Watertown belt correspondingly broad on the geological map. This is due to the fact that the Trenton rocks are little compact and were easily swept off the massive Seven foot tier by the ice. The latter forms thus the surface rock over a very large area and is in many places swept clear of soil. This fact and the many deep joints make it a very poor underground for agricultural purposes, and the plateau is therefore frequently wooded, especially so the jagged and deeply jointed boundary region along the Lowville belt. Even small brooks have frequently formed deep solution and erosion ravines in this forma-

Plate 21



Leray limestone overlying Lowville, 2½ miles northwest of Sanford Corners. The view illustrates the characteristic weathering of the Leray. Dr Ruedemann is at work on the upper surface of the Lowville. H. P. Cushing, photo, 1907

Plate 22

Upper view. Leray limestone overlying Lowville in quarry 1½ miles south of Sanford Corners, looking south. A thickness of 9 feet of massive limestone of Leray character is shown, of which the upper half is equivalent to the basal cherty bed shown in plate 20, while the lower bed does not appear in that section. The Lowville shown beneath consists of beds which are higher than any in that section.

Lower view. Upper Lowville in quarry very near to that in the upper view, and showing the beds just beneath these there shown. The uppermost beds here shown are also absent in most sections, the Leray resting on some of the lower beds. H. M. Ami, photo, 1908

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tion. One of the best examples of such a gorge is that of the Perch river at Limerick. Many brooks disappear entirely under the Watertown formation, forming long underground courses and caves. Several such courses are know in Watertown, where, however, they have been filled by the damming up of the river. Others are known below Watertown and at Black River village.

Phenomena entirely peculiar to this formation in the region are the inliers at the Natural bridge and Limerick. A glance at the Watertown-Leray belt on the Clayton sheet north and east of Chaumont bay reveals the fact that in several places the typical Lowville beds appear from beneath the Watertown-Leray limestones. These inliers consist of elongate strips of Lowville limestone exposed along brooks and surrounded on all sides by the Watertown-Leray limestones. The conditions which have produced this peculiar and rare form of inlier are the following: The coincidence of the dip of the beds and of the course of the brook and the greater resistance of the underlying Lowville limestone to solution. The brook as a rule reaches the inlier by a fall, and finally leaves it again by very gradually passing again upon the overlying rock.

A very characteristic example of such an inlier is seen along Threemile creek and a very large one at the head of Guffin bay. The most interesting of all is that below the village of Limerick on Perch river. It begins with the fall shown on plate 23 and ends above the Natural bridge. At the latter place the river passes underground through a ridge of Watertown-Leray rocks crossing the valley. Below the bridge the river reappears for a short distance [pl. 38] and disappears again, its course being thence traceable as a depression between the cliffs of Watertown-Leray rocks on both sides. The depression shows in the different tilting of the huge blocks of the Seven foot tier that it is the result of a gradual sinking down of the whole mass; and this indicates that the river, which has its underground course on the top of the typical Lowville beds, is dissolving the Watertown-Leray beds along its course from the base upward. There is little doubt that also the inlier above the Natural bridge, which can not have been produced by normal corrasion, is the result of solution of the Watertown-Leray beds, and that finally also between the Natural bridge and the lake the typical Lowville beds will be exposed and the river flow again overground, as it already does just below the bridge.

One of the best exposures of the Watertown-Leray beds is that at Klock's quarry, at the end of Huntington street at Watertown. This section which is here inserted, begins close to the base of the

Leray limestone and reaches to the base of the Trenton. The contact with the typical Lowville beds is shown on the opposite side of the river and on Diamond island. Plate 24 shows a part of the quarry.

Section at Klock's quarry, Watertown

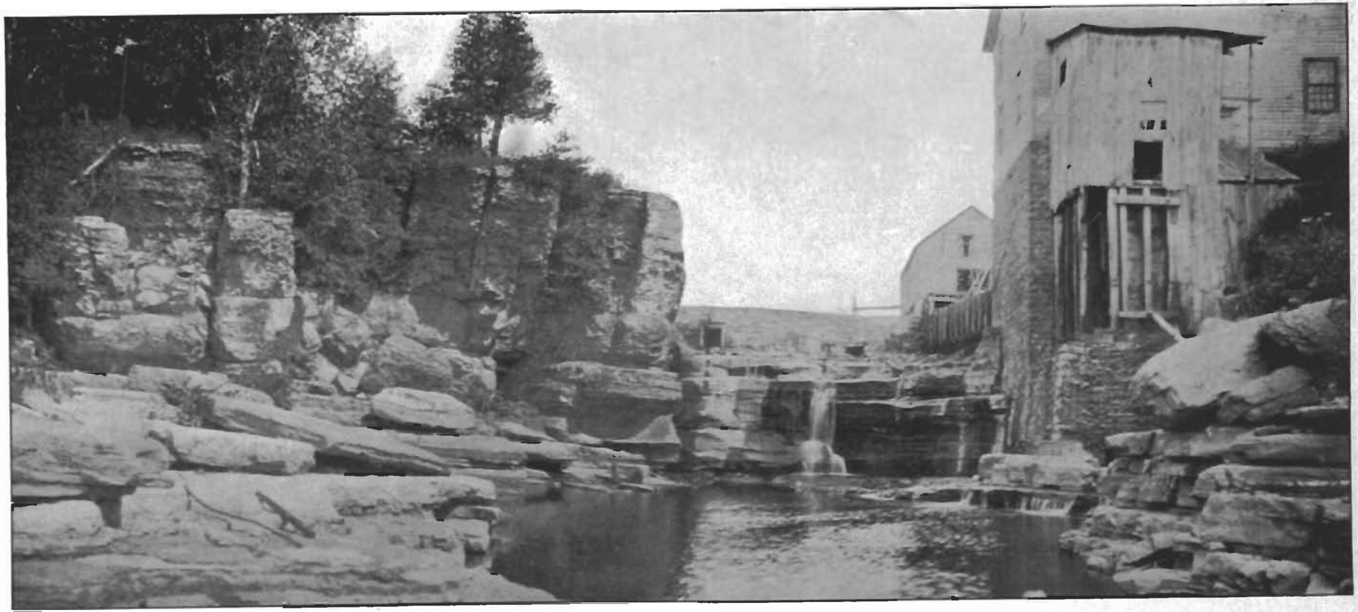
1½'-2'	Black, knotty, impure, dark limestone with Strophomena filitexta, Leperditia fabulites, Orthis pervetus, Isotelus platycephalus, Orthis tricenaria, Illaenus americanus, etc.
7'	7 foot tier. Heavy black limestone, with Gonioceras anceps, Hormoceras tenuifilum
6'	Dark gray to black, heavily bedded, cross-striated limestone with a few cherts, containing also Endoceras, Gonioceras. Resting on an irregular surface; base of Watertown limestone
2'-2½"	Irregularly bedded, dark to black, dove colored, fine grained limestone, characterized by weathered, fucoid, earthy markings
5'+	Fine grained dark gray limestone, with cherty layer on top. Cherty beds. Bottom not shown

These chert beds are in this neighborhood underlain by 4–5 feet of fine grained dark gray beds with Tetradium cellulosum, which also weather blocky like the Watertown limestone. Below this are found the dove colored, thinner bedded, typical Tetradium beds.

A series of good sections of the Watertown-Leray limestone are exposed in the large quarries about Chaumont. Since, however, the Seven foot tier forms here the top of the section and an unknown thickness of the same is always eroded, the thicknesses obtained are always a minimum. In the large quarries at the head of Chaumont bay the combined beds measure 18 feet; in the big quarries along Chaumont river 19 feet of these limestones are found, below which 22 feet of typical Lowville beds are exposed to the river edge.

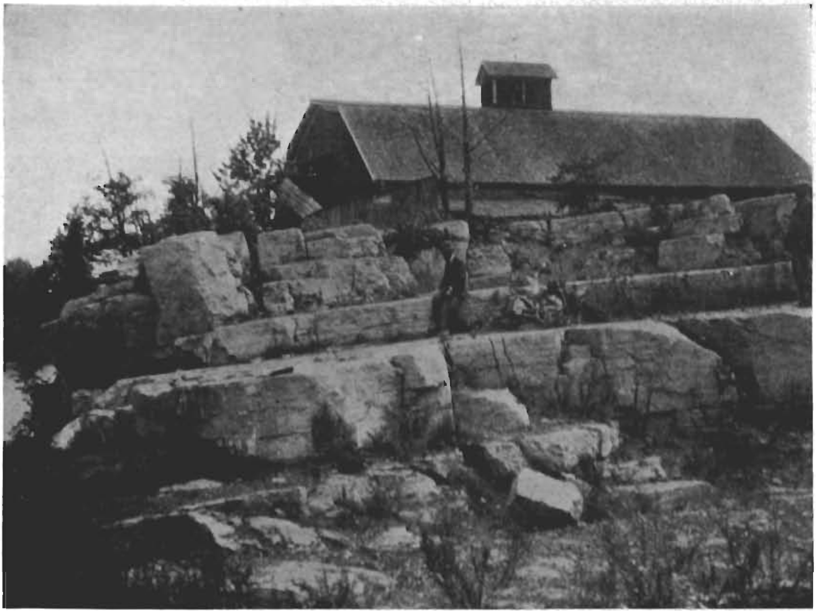
Trenton limestone. The last of the Lower Siluric stages occurring in the area of the map is the Trenton limestone. It appears first in outliers near the mouth of Black river, then occupies the southern portions of the peninsulas jutting out into Lake Ontario and finally on the Cape Vincent sheet forms a continuous belt. In contrast to the underlying formations and notably its direct predecessor, the Watertown limestone, which forms a remarkably level plateau with a distinct escarpment at the northern boundary, the Trenton appears in well rounded hills, its boundaries approach subcircular curves, in contrast to the many fingered and deeply indented Watertown exposures. This is due to the fact that the Trenton is a much thicker and at the same time a much less resistant formation, consisting almost entirely of thin bedded limestones with shaly intercalations. It is therefore also much more covered by drift and as a rule exposed only along the shore line or

Plate 23



Falls of Perch river at Limerick, Clayton quadrangle; cliffs of Leray limestone overlying Lowville. E. O. Ulrich, photo, 1908

Plate 24



Upper view. Watertown limestone near river at Watertown, showing seven foot tier and the upper portion of the cherty bed beneath.

Lower view. Trenton limestone in creek bank near Threemile Bay, Clayton quadrangle. A closer and more detailed view of part of the section shown in plate 25. E. O. Ulrich, photo, 1908

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on the *stoss-seite* of the hills. But since the thin limestone slabs over the Trenton belt have been incorporated in great quantities into the drift, whence they have found their way into the stone fences, these stone fences composed of thin Trenton slabs are almost the most characteristic feature of the Trenton formation in the district and they are remarkably closely bound to the present distribution of the Trenton.

The contact between the Black River and Trenton groups is but rarely seen, but where found, it indicates an unconformity, either by the irregularity of the contact line, as at the Klock quarry at Watertown, or by the presence of a basal conglomerate bed in the Trenton as at Threemile Bay.

The best continuous exposure, or in fact the only good one within the boundaries of the mapped area, is that found along a brook at the western outskirts of the village of Threemile Bay [pl. 24, 25]. This section is given below. Another fairly complete section can be obtained from Klock's quarry to the top of Pinnacle hill at Watertown and a third, which however lacks the base, at the west end of Carleton island in the St Lawrence river.

Section of lower Trenton limestone at Threemile Bay
(generalized)

16'-17'	Fine grained thin bedded limestone with shaly intercalations
3'	Thin bedded limestone layers with shaly intercalations, rich in lamellibranchs, gastropods and cephalopods
10'	Fine grained black limestone with shaly partings, in part barren, in part full of fossils on shaly partitions, mostly large conical or hemispheric bryozoans (Prasopora simulatrix) in horizon about 2 feet from base
3' 6"	Black, fine grained limestone full of worm tubes, no other fossils
5' 6"	Gray, crystalline, thin bedded limestone with many crinoid joints on top (2 feet) and fine grained dark thin bedded limestone below, with shaly intercalations. The limestone beds full of brachiopods (Dalmanella, Rafinesquina) and bryozoans
6'	Dark gray to black compact limestone, in strata 1 foot thick with thin shaly partings. Very fossiliferous. Dalmanella testudinaria, Plectambonites sericeus, Calymmene, bryozoans (Pachydictya acuta) and crinoid joints
5"	Conglomerate bed with crystalline matrix and crinoid joints
	Base of Trenton
....	Black River beds

It follows from this and the other sections that the Trenton begins with a thin conglomeratic bed, on which rest about 6 feet of dark gray to black compact limestone, in beds about 1 foot thick, with thin shaly partings. The latter are very fossiliferous, containing most profusely Dalmanella testudinaria, Plectambonites sericeus, Pachydictya acuta and crinoid joints.

This black basal limestone of the Trenton contrasts strongly with the equally thick underlying Seven foot tier in being a most inconspicuous element in the physiography of the region. In fact its presence is hardly suspected over the greater part of the area, since it is nearly always hidden at the base of the rounded Trenton hills. Only where the formations are planed to one level, as about Rosière, is it observed to outcrop as a recognizable belt.

The remainder of the Trenton, as far as the area of the map is concerned, consists then of about 50-60 feet of thin slabby limestones, with shaly intercalations. The limestones are partly gray and crystalline with many crinoid joints and partly fine grained, dark gray to black. The latter limestone swells sometimes into thicker beds (1 foot thick and more) of black limestone which is either quite barren of fossils save worm tubes, or as on Carleton island, almost entirely composed of the shells of Plectambonites sericeus.

Plate 25 shows the general aspect of the thin bedded limestones in the creek bed at Threemile Bay and plate 24 which gives a closer view of the rocks in the same locality, illustrates the regular alternations of limestones and shales in the formation.

The greater middle and upper part of the Trenton is found in the region south of the map, on the other side of Black River bay.

The fauna of the Trenton has the general aspect of that of the formation in other parts of the State. Its details have not yet been studied.

SUMMARY OF PALEOZOIC OSCILLATIONS OF LEVEL[1]

It has been shown that the Potsdam and Theresa formations were deposited in the west end of a sagging basin or trough which occupied the general line of the present St Lawrence valley; that the deposition began at the east and worked westward, involving our region here only in its later stage; and that the depressed trough was a westward extension from a similar subsiding trough along the Champlain valley line. There the Potsdam is very thick, is followed by beds similar to those here called Theresa, and these are overlaid by nearly 400 feet of dolomites which have been heretofore classed with the Beekmantown formation, as Division A of that formation. No such beds as these last appear in our district here, though the Potsdam and Theresa may be equivalent to them in time. In the Champlain valley also appear four other divisions of the Beekmantown, with an aggregate thickness in the neighborhood of 1400 feet.

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[1] By H. P. Cushing.

Plate 25

Thin bedded limestones of lower Trenton age in creek bed at Threemile Bay, Clayton quadrangle, looking northwesterly, upstream. H. P. Cushing, photo, 1908

Ulrich has recently made the important discovery of an unconformity between these beds and Division A, and we coincide in believing that this division is properly to be classed with the beds below rather than with the Beekmantown. The Beekmantown that is thinly present in the district here reported upon is not of the Champlain type, but of the Mohawk valley type, lithologically and faunally quite like the beds at Little Falls and thence eastward through the Mohawk valley, which have heretofore been called the "fucoidal beds," and which we are proposing to call the Tribes Hill formation. This Beekmantown did not come into this northern district from the east but from the south, and so far as we know did not extend on eastward. But in passing to the eastward, beyond the limits of the region here mapped, Beekmantown beds begin to appear above the Theresa, and in our belief are unconformable, though this has not yet been demonstrated. Also in our belief this Beekmantown is not representative of the lower portion of the formation but of the upper portion, and we must go yet farther east to find the lower beds coming in; while the thin edge of Tribes Hill Beekmantown in our district here is lowest Beekmantown. Following a condition of uplift Beekmantown submergence seems to have commenced fairly simultaneously on the east, west and south sides of the Adirondack region. Submergence on the west was quickly followed by emergence due to a general eastward tilting of the region, so that at Little Falls and about Theresa only a slight thickness of the very lowest Beekmantown was laid down, the Tribes Hill formation. This formation steadily thickens to the eastward, along the Mohawk valley, though apparently representing nothing but the lowermost Beekmantown. The chief area of Beekmantown sedimentation in New York was the Champlain valley trough and its prolongation southward. Along with the steady subsidence in that trough seems to have gone a subsidence of the St Lawrence trough which, like the previous Potsdam subsidence, seems to have commenced at the east and worked westward; so that, in that trough, the lowest Beekmantown is absent, and steadily higher beds are at the base going west. The extreme westward reach of this Beekmantown depression of the St Lawrence trough seems never to have reached the Theresa district, where the only Beekmantown represented is the thin base of the Tribes Hill formation of the Mohawk Beekmantown type. Until the Beekmantown on the north side of the Adirondacks has received more thorough study, this view of Beekmantown conditions in the St Lawrence trough can not be regarded as based on sufficient evidence, though evidence on the other three sides of the Adirondack region in respect to these conditions seems now quite well substantiated. Our immediate district in late Cambric (Ozarkic) time sloped to the east and received the thin deposit of Potsdam and Theresa beds laid down in the western end of the St Lawrence trough. Uplift followed throughout New York, producing unconformity between these beds and those of the Beekmantown which follow. Beekmantown subsidence seems to have commenced simultaneously on the east, west and south sides of the Adirondacks, with a tilting of the surface in our district here, so that its slope was to the southwest, instead of to the east. This was quickly followed by tilting of the whole region to the east, stopping Beekmantown deposit on the west and south sides of the Adirondacks and confining it to the eastern trough. From this trough a bay seems to have developed westward up the St Lawrence trough, during Beekmantown time. The Beekmantown was brought to a close by another uplift of the entire northern New York region. In the Theresa district this time gap was a long one during which 1000 feet or more of Beekmantown rocks were deposited in the Champlain trough, and a much greater thickness in other regions.

Through these early times then our district had a general slope of its surface toward the east, though with an intervening time of short duration during which the slope was to the southwest. There were three depressions, alternating with three elevations of the surface, though apparently the deposits of the third depression just failed to reach the district.

In the Champlain valley the Beekmantown is succeeded by the Chazy limestone formation, the two being separated by a slight unconformity, indicating that the Beekmantown was followed, as it had been preceded, by general uplift of the whole area. Depression was then renewed in that trough for the third time, and for the third time a bay was developed westward from it. This Chazy bay, however, seems not to have reached as far westward as the preceding Beekmantown bay, and certainly fell many miles short of reaching our district here.

The Champlain Chazy is divided into lower, middle and upper subdivisions. The typical Chazy rocks are limited to the Champlain trough and its prolongation north and south. This trough was separated from a much larger depressed area to the westward, by a land barrier, which prevented the passage of organisms from the one basin to the other. At the same time therefore in which the Chazy rocks were being deposited in the Champlain trough, other deposits, characterized by a different fauna, were forming to the west of them, and the rocks of this group are known as the Stones River formation. During Chazy time the depression in which Stones River rocks were forming was encroaching upon northern New York from the south and west, and by the close of the middle Chazy this depression had become sufficiently extensive to involve our district here, and the deposition of the Pamelia formation commenced, the Pamelia being the local New York facies of the Stones River formation, and representing only a portion of its upper division. The tilting of our district necessary to permit of this invasion from the southwest, changed its former easterly inclination to a southwesterly one, over most of the district; but apparently this change of slope died out on the eastern edge of the Alexandria sheet, east of which lay the land area which separated the Pamelia basin from the Chazy basin; and this received no westerly tilt, but chiefly retained its old slope to the east. This in our view is the origin of the Frontenac axis, as the narrow isthmus of Precambric rocks which connects the main Adirondack Precambric mass with the great Canadian area of these rocks, and which passes through our district here, is called. It simply represents an axis of the old Precambric floor which became less depressed than the portions of the floor east and west from it. The Potsdam-Beekmantown-Chazy depressions sagged the district to the east, covering it with steadily increasing thickness of their deposits in that direction; the Pamelia depression sagged the district to the west, and in that direction the overlying deposits steadily increase in thickness. The Frontenac axis is the pivotal district between the two, where sagging was least and deposit thinnest. Subsequent erosion could thus wear away this thin cover and bring the Precambric back to daylight, along this line, as it has done, while yet the thicker cover, east and west, in part remains.

According to Ulrich the Pamelia formation is of age intermediate between the middle and upper Chazy of the Champlain valley, but little sedimentation having taken place there in Pamelia time; in other words while this region was subsiding and accumulating deposit, that ceased to subside. With the cessation of Pamelia deposition on the west, resulting in the unconformity between the Pamelia and Lowville, deposition was renewed on the east and the upper Chazy was laid down. In like manner the Lowville formation is but slightly represented in the Champlain valley, though well developed here, as if, with renewed subsidence here it again ceased there. Toward the close of the Lowville, uplift occurred on the northwest giving rise to the unconformity between the main mass of the Lowville and the Leray limestone. At the same time depression began in the Champlain region, and what has there been called Black River limestone commenced its accumulation. This deposit consists of a small thickness of typical Lowville at the base, the equivalent of the Leray limestone at the summit, and intermediate beds which represent the Lowville-Leray hiatus of the northwest; while the Watertown limestone is lacking. With our suggested nomenclature this may still be properly called Black River, while on any other arrangement it could not be so called. The Mohawk region was close to the shore line throughout Black River time and received only the very thin, near-shore edge of the deposits of the group, never more than a few feet thick, often practically absent and varying much in horizon from place to place.

At the close of the Leray, uplift was widespread and the Watertown limestone is practically absent except in that locality, in strong contrast with the widespread occurrence of the preceding Leray. Then followed subsidence on the east with accumulation of the Amsterdam limestone, which is wholly absent on the west. Then ensued on all sides of the region the Trenton submergence; limestone quickly followed by black shale on the east so that the bulk of the eastern Trenton is of shale; the shale gradually encroaching westward, but the western Trenton, of the type locality and northward, remaining of limestone throughout. The black shale of the Utica followed, with northern New York more largely submerged than at any other period in its geologic history, the Grenville possibly excepted. Possibly the Adirondack island was entirely submerged. With the close of the Utica local elevations began to appear, and by the close of the Ordovicic much of the State was again unsubmerged. Since then most of northern New York has remained a land area. The appended chart will, it is hoped, aid in the understanding of these views.

	Watertown region	Trenton Falls	Mohawk valley	Saratoga vicinity	Champlain valley
	Utica shale	Utica shale	Utica shale	Utica shale	Utica shale
Trenton group	Trenton limestone	Trenton limestone	Dolgeville shale	Trenton shales	Cumberland Head shale
			Trenton limestone		Trenton limestone
Black River group			Amsterdam limestone	Amsterdam limestone	Amsterdam limestone
	Watertown limestone				
	Leray limestone	Leray limestone			Black River limestone
	Lowville limestone	Lowville limestone	Lowville limestone		
Chazy group					Valcour limestone
	Pamelia limestone				
					Crown Point limestone Day Point limestone
Beekmantown group					Division C, D and E of the Beekmantown
	Tribes Hill limestone		Tribes Hill limestone		Tribes Hill limestone(?)
Saratogan	Theresa formation Potsdam sandstone	Little Falls dolomite	Little Falls dolomite	Little Falls dolomite Hoyt limestone	Little Falls dolomite
				Theresa formation Potsdam sandstone	Theresa formation Potsdam sandstone

NOTE.— Parallel lines represent the greater, and dotted lines the lesser unconformities. Unbroken lines represent absence of breaks.

Dip of the Paleozoic rocks

It has just been stated that the Paleozoic rocks dip away from the Frontenac axis in both directions, and it is desirable to scrutinize the matter somewhat more closely.

In the southeastern corner of the Theresa quadrangle the base of the Leray limestone is at 600 feet altitude. The general line of outcrop of the formation runs across the mapped area in a west-northwest direction, and on the Cape Vincent sheet passes beneath the river level 247 feet. This is a drop in altitude of 353 feet in 27 miles, about 13 feet to the mile, in this west-northwest direction. In the direction of due west it is about 16 feet per mile, as nearly as can be calculated. Neither one of these, however, gives the direction of true dip, which lies somewhere between s. 30° w. and s. 45° w. At Adams, which lies some 30 miles somewhat west of south of the village of Theresa, three deep wells were drilled for gas some years ago, and the records of these wells are given by Orton.[1] Fairchild, who is familiar with the region, has also supplied me with data. Starting on ground whose altitude is approximately 600 feet above sea level, these wells reached the Precambric at depths of 915, 950 and 960 feet respectively. The Precambric surface is here approximately 315 feet below sea level, while at Theresa it averages about 400 feet above the sea. In the 30 miles then, this surface drops 715 feet, or nearly 24 feet to the mile. This however is the slope of the Precambric surface, which may or may not coincide with the dip, and in all probability does not. If the different limestones could be distinguished in the well records the data would be at hand for determining the dip, but this is unfortunately not the case. If the Paleozoic rocks thicken in that direction, the dip is somewhat less than the above figure; if they thin it is somewhat greater. At Adams the Potsdam and Theresa formations, 150 feet in thickness about Theresa, have disappeared. The other formations are present however and are unquestionably thicker than at Theresa. Beginning near the summit of the Trenton, the drill at Adams penetrated through 900 feet of limestone before reaching the Precambric. If we knew the thickness of the Trenton in our district here we should again have the necessary data, but all the upper Trenton lies to the south of the map limits, and the thickness of the formation has never been accurately measured so far as we know. It is certainly as much as 500 feet and may be a hundred feet more than that. We have then at least 800 feet of Paleozoic rocks here below the Utica, and perhaps 900. It seems therefore that the thickening of the upper

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[1] N. Y. State Mus. Bul. 30, p. 457-58.

limestones at Adams just about compensates for the disappearance of the Potsdam and Theresa formations there, and that the dip is substantially the same as the fall of the rock floor, or 24 feet per mile. At most there is a deduction of but 100 feet to be made, amounting to 3 feet a mile in 30 miles, and reducing the total to 21 feet per mile. If, as is likely, this is still not the direction of true dip, being too nearly due south, the figure must be somewhat enlarged, and in all likelihood it amounts to from 25 to 30 feet per mile, certainly not exceeding 35 feet.

It is of interest to note that this dip, and this slope of the Precambric floor, are much less than those worked out in the upper Mohawk valley by Miller and myself (Remsen and Little Falls quadrangles) where the dips approach 100 feet per mile to the southwest, and the Precambric floor underneath has a slope exceeding that of the dip by some 30 feet. The matter of the present dips is simply the sum total of tipping given to the rocks since they were deposited, by the various oscillatory movements to which each region has been subjected since; showing that the Mohawk rocks have been somewhat more tipped than those here. The matter of floor slope however shows clearly that the shore line in the Mohawk region had a somewhat greater cant than was the case here, producing more rapid overlap of the rocks there.

In the northeast portion of the Alexandria sheet the dip has flattened out to practical horizontality, Potsdam with overlying Theresa forming the river bluffs. Going east, down the river, the dip soon changes to the northeast, carrying these formations beneath the water and the westerly edge of the Beekmantown becomes the surface rock, beyond which, for many miles, the river flows through Beekmantown rocks, all with slight northerly dip. These are the deposits of the eastern basin, and received no tilt to the west.

ROCK STRUCTURES[1]

Foliation

Foliation is the name applied to the species of cleavage developed in rocks which, under compression, have wholly or largely recrystallized. The cleavage is chiefly due to the arrangement which the compression enforces on many of the recrystallizing minerals, which tend to develop in the shape of

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[1] By H. P. Cushing.

leaves or needles; so that, in so far as the mineral particles have longer diameters, or scalelike shapes, these develop in the planes at right angles to the direction of compression and give the rock a tendency to split along them. Obviously a better cleavage will usually develop in rocks which consist of more than one mineral than in those composed chiefly of a single one, and in the former case a better cleavage will appear where there is large difference in the characters of the different mineral species than where this difference is small. Thus a quartz-mica rock, or a feldspar-hornblende rock, will be apt to have a much better foliation than a quartz-feldspar rock.

A rock in which a good foliation cleavage is developed, so that it tends to split rather evenly and readily is said to be schistose, or called a schist. When the foliation is less even, and less ready, gneissoid is the adjective, and gneiss the substantive employed. As a general rule certain sediments, such as shales and impure (or shaly) limestones and sandstones, recrystallize into schists, while pure sandstones and limestones, which recrystallize into pure quartz or pure calcite rocks, and consist chiefly of the one mineral, show little or no foliation. Igneous rocks are usually already crystalline, and in general do not recrystallize with as prominent a foliation as do many of the sediments, hence are more prone to form gneisses than schists.

Foliation in the Grenville rocks. The pure Grenville quartzites and limestones are now quite massive crystalline rocks with little or no foliation, though there is some development of fracture cleavage in the resistant quartzites, which is lacking in the more plastic limestones. Even the quite impure limestones show usually but little foliation. The impure quartzites have developed either pyroxene or mica on recrystallizing, usually the former, and this rock has poor cleavage while the latter become quartz schists. In the mass of Grenville rocks of varying composition to which the general name of the "schist series" has been applied, foliation cleavage is in general prominent. But even here rocks with considerable development of minerals of the mica type are relatively rare, and since such constitute the most prominently foliated rocks, their rarity militates against the prominence of foliation in the series, the bulk of which would be better classed as gneissoid, rather than as schistose. Some varieties of the amphibolites are quite micaceous and hence possess good foliation cleavage. The green schists and ordinary amphibolites usually show fair foliation only, and a general assemblage of all the types of Grenville rocks of the district does not give the impression of a group of extra well foliated rocks. This is largely due to the comparative scarcity of micas, and of amphiboles of slender habit, in the series and the abundance of pyroxenes and of stout amphiboles. This again is a result of the prominently anamorphic character of the metamorphism.

The foliation of the Grenville rocks is parallel to the bedding. In the schist series rapid alternations of materials of somewhat varying composition is a feature, producing a very well banded structure, sometimes so fine as to somewhat mimic a coarse foliation.

Foliation of the granite gneiss. It has been shown that the Laurentian granite is characterized by frequent inclusions of older rocks, chiefly of amphibolitic types, and that there is also present much intermediate material, resulting from the soaking of the amphibolite with granitic substance, or from its actual digestion by the granite. The rock itself contains normally some mica or hornblende, and hence, through the greater portion of the mass these minerals are present in varying quantity, and the rock is susceptible of foliation development under the proper conditions. That such conditions have obtained is clearly shown, a foliation cleavage of varying prominence appearing nearly everywhere, though it becomes very obscure in those relatively small portions of the mass which consist solely of quartz and feldspar. The general rock is thus foliated but with foliation of the crude type which proclaims the rock a gneiss, rather than a schist.

The foliation structure of the granite gneiss conforms everywhere in dip and strike to that of the adjacent Grenville rocks. While this by no means excludes the possibility that the Grenville rocks may have been compressed and foliated prior to the intrusion of the granite, it does demonstrate that both sets of rocks have undergone compression in common, subsequent to this intrusion. It is quite possible that much of this compression was a result of the actual intrusion, and that the granite gneiss actually solidified with a foliated structure. This is not at all uncommon in great bathylithic intrusions, which, in order to make a place for themselves, must endeavor to shoulder aside the rocks previously occupying the space. This shouldering pressure exerted on the adjacent rocks under bathylithic, or deep seated, conditions, that is with a thick cover of overlying rocks, tends to give the rocks thus compressed a foliation which parallels the margins of the bathylith, and hence boxes the compass in direction. At the same time the rock of the bathylith, while solidifying, may develop a similar and parallel foliation.

While it can not be affirmed that such results were not brought about in the region, it can be positively stated that, if so, they have been so disguised by subsequent compressive stresses that the effects of the two can not now be successfully disentangled. This is shown in several ways: (*a*) the microscopic study of the granite gneiss indicates that, to a considerable extent at least, its foliation is due to recrystallization rather than to original crystallization, in other words the rock has been much crushed and somewhat recrystallized under compressive stress, since it originally congealed; (*b*) these later stresses seem to have been severe enough to materially change the shape of the bathylithic masses, elongating them greatly in the northeast-southwest direction and correspondingly pinching them together in the direction at right angles to this; (*c*) instead of the foliation running around the bathyliths, with parallelism to the margin, it retains its general northeast-southwest strike throughout the region, independendently of these margins, so that either no such marginal foliation was ever developed, or else it has been practically eliminated by the subsequent compression; (*d*) later igneous rocks than the granite gneiss have also had a foliation developed as a result of compression, most prominently in the earlier ones, and with steady decrease in prominence in the later.

It thus appears most probable that the general parallelism of the foliation of all the Precambric rocks, and its substantial uniformity in direction throughout the region, is chiefly owing to compression of later date than that of the Laurentian granite intrusion. This appears increasingly true in going eastward into, and across, the Adirondack region. The rocks show steady increase in amount of metamorphism, in degree of mashing and recrystallization, in uniformity of foliation, and in obliteration of such possible structures as primary foliation. Some of this increase may be ascribable to greater thickness of cover, but the evidence of thoroughgoing compression of much later date than the Laurentian, is very clear.

Foliation of the later igneous rocks. The Alexandria and Theresa syenites seem closest to the Laurentian in age, among the conspicuous igneous rocks of the district. The Alexandria syenite shows cores of fairly massive rock, not foliated though with a considerable amount of crushing. But the porphyritic border phase is considerably metamorphosed and converted into a thorough gneiss, with the augen (the uncrushed remnants of original large feldspar crystals) alined in the direction of the foliation. This also is coincident with the direction of foliation in the Grenville and Laurentian rocks. While it is true that the metamorphism exhibited by the syenite is not as severe in degree as that shown by the other two groups, it is clear that there was severe compression of the region at, or after, the time of syenite intrusion, and compression under quite similar conditions as regards overlying load.

The Theresa syenite does not appear so foliated as does the Alexandria, chiefly because of difference in composition, which shows itself mineralogically in the much slighter development of hornblende and mica, the rock consisting largely of feldspar. It also lacks the coarsely porphyritic phase. Foliation is therefore much less prominent, though the rock shows crushing and recrystallization in degree quite comparable with the other. It has therefore likely experienced compression of substantially equivalent amount and duration, but its composition prohibits good foliation development.

Picton granite. This, the latest of the early intrusives of the district, shows little or no foliation, and to the eye gives little evidence of crushing, as if the intrusion was wholly subsequent to the great squeezing of the region. The thin sections bear out this impression.

This evidence would seem to indicate compressive stresses applied at intervals through a considerable length of time during the region's very early history, with gradual cessation, and that the foliation structure in the Grenville and Laurentian rocks must be due to something more than the pressure and heat furnished by the intrusion of the Laurentian granites.

Joints

The clean-cut divisional planes, usually highly inclined, which occur in most rocks, are termed joints. While generally vertical, or nearly so, they may have any inclination. In a "joint set" the divisional planes show a close approach to parallelism, both in trend and in inclination. In most regions more than one set is present. When there are two, the usual condition is that they are approximately at right angles to one another. Often there are more than two sets as is the case in our region here. When four sets are present it is usually found that they are separable into two pairs, each pair consisting of two joint sets at right angles to one another, and the joints of one pair bisecting the angles between the joints of the other pair. In such districts it is seldom the case that all four joint sets are exhibited in a single rock exposure, two or perhaps three of the four showing, rather than the whole number. In many, if not in most, regions where four or more joint sets occur, it is found that one pair tends to north-south and east-west directions, with another pair showing northeast and northwest trends. The joint planes often curve somewhat, so that the compass direction of a given set may vary through a considerable number of degrees. This tendency much increases the difficulty of discrimination between the different sets in districts where more than four are present, as is quite frequently the case.

In folded rocks the character of the jointing differs considerably from that found in rocks not folded. Since in our region here we have rock masses of each sort, Precambric rocks which have been greatly compressed and folded, and overlying Paleozoic rocks which are comparatively undisturbed, it will be convenient to consider them separately.

In the Precambric rocks. The diagram [fig. 5] presents a summation of the readings taken on the joints of the Precambric rocks of the district included in the maps. They are comparatively few in number, partly because of the comparatively small area which presents these rocks at the surface, and partly because the joints were found to be so irregular that no satisfactory readings could be obtained in many exposures. The rocks are not as abundantly jointed, nor are the joints as clear-cut as usual in the Adirondack region.

In closely folded sediments, such as the Grenville, joints are apt to be present as a result of compression, and to have their directions controlled to a considerable extent by the folds, or in other words by the strike and dip of the folded sediments. These have been shown to have a general northeast strike throughout the district, though locally varying in direction through more than 90°. The more usual direction however is n. 40° e.--n. 60° e. Two sets of joints are present which have the same surface trend, that of the rock strike, the one set controlled by the dip and having approximately the same inclination, the other inclined in the opposite direction, or to the southwest, and closely at right angles to the first set. Figure 4 is an attempt to illustrate these relations. These two joint sets, both having the same strike as the Grenville rocks, are much the most prominent of the joints which these rocks show, and conspicuous at every good exposure of the Grenville schists or quartzites, though much less conspicuous in the limestones. The quarry face in plate 2 is on the dip joints, here steep, and the other set are quite flat and show well in the view, as does also a vertical set of northwest joints. So common are they that they soon came to be recognized as a matter of course, which it was superfluous to chronicle in the notebook. Hence the number of observations on joints striking n. 40° e.–n. 60° e. shown on the diagram [fig. 5] is misleading as to their abundance and importance. The comparatively slight variation in the number of readings for all points between n. 30° e. and east is however a result of, and indication of, the swerving of these joints with swerve in the rock strike.

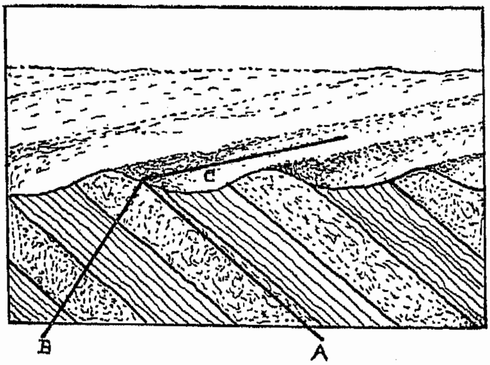

Fig. 4 Sketch and section of alternating quartzite and amphibolite bands of Grenville series, the quartzites forming low ridges on the surface. The line A represents the direction of the joints which follow the dip, the line B that of those at right angles to the first set, and C represents the direction in which both sets cut the surface

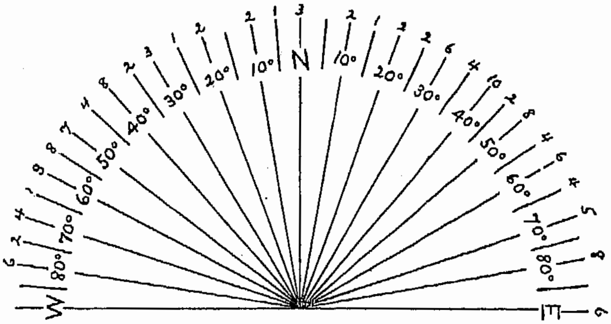

Fig. 5 Diagram to indicate the number of readings on joint directions in the Precambric rocks of the district for each 5° point of the compass, the outer row of figures giving this number, and the inner row the compass degrees, corrected for variation

The foliation of the Laurentian granite gneiss, and of the gneissoid portion of the Alexandria syenite is concordant with that of the Grenville rocks, and in them these same joint sets are developed, though in a much less prominent way. In the more massive igneous rocks they are replaced by a set of vertical, northeast joints.

At right angles to the set, or sets, of northeast joints is a set with northwest trend, with planes nearly or quite vertical, and ranging from n. 40° w. to n. 55° w. in direction, 27 of the readings falling within those limits. A less conspicuous east-west set is also indicated by the 12 readings between n. 70° w. and n. 80° w., together with the 14 between n. 80° e. and e. As seen in the field also this set is more variable and less prominent than the northwest set. The number of northerly readings is not great, and is spread rather uniformly over 50° of compass range, coinciding with the impression given in the field as to the comparative scarcity and great irregularity of that joint set.

Notwithstanding the rather small number of total readings the diagram shows that 30 out of the possible number of 36 different 5° directions are represented. Nowhere in the field were more than four sets of joints noted in a given rock exposure, and all the joints showed considerable tendency to curve and vary in direction, leading to the belief that this spreading of the readings is owing to this variability and in no wise indicative of a great number of joint sets.

Locally the more rigid of the Precambric rocks, the quartzites and granites, are excessively jointed, the joints being very close spaced, chopping up the rock into small, angular blocks [*see* pl. 3]. In such places signs of slipping are usually to be made out. These so called "shear zones" result from readjustment under compression under conditions such that these rigid rocks fractured and slipped along the fractures, while those less rigid, the limestones for example, effected readjustment in other manner.

That the Precambric rocks were jointed prior to the deposition of the Potsdam sandstone is conclusively shown, firstly by the absence in the Paleozoic rocks of compression joints and shear zones, and secondly by the occurrence of joint cracks in the Grenville limestones which became widened by solution and in that condition were filled with sand as the Potsdam sands commenced to be deposited. In the few cases in the district where contacts between Potsdam and Grenville limestone are exposed these features appear [*see* fig. 1, p. 58] and are apparently widespread.

In the Paleozoic rocks. In the Paleozoic Rocks of the district, Potsdam to Trenton, the joints are vertical, or nearly so, and show also considerable variability in direction, though this seems not quite so pronounced as is the case in the Precambric. Figure 6 gives a diagrammatic summary of 280 readings on these joints, and shows again a spreading to all points of the compass, 34 of the 36 possible directions being represented. The great number of readings in the direction n. 70° e.–n. 80° e. constitutes the most prominent feature. The next point at which readings are concentrated is the n. 50° w. direction, but readings with this general trend are spread from n. 40° w. to n. 65° w., in other words these joints are somewhat less true in direction than those of the preceding set, which may however be regarded as extending from n. 60° e. to n. 80° e. A third direction of more abundant readings, from n. 20° e. to n. 40° e. is also shown, while the fourth direction, n. 10° w.–n. 30° w. is the least prominent of all. This last, however, is the one at right angles to the first, and most prominent, set. As thus outlined there are 99 readings for the first set, 81 for the second, 45 for the third and but 25 for the fourth. There remain 40 readings which lie wholly without these groups. It is to be noted that the mean directions of the four groups do not correspond with the cardinal points of the compass, but show a general deviation of 20° from them.

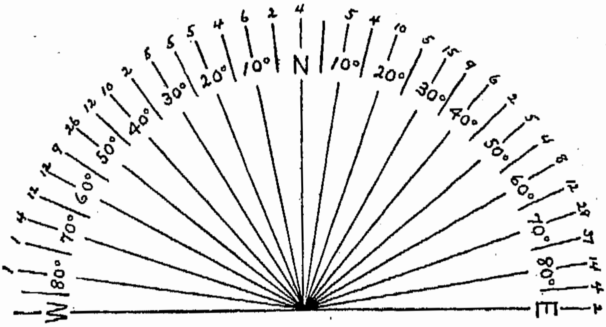

Fig. 6 Diagram, similar to that of the preceding figure, of the joints of the Paleozoic rocks

In the field the majority of the exposures exhibit but two good joint sets, though usually a third quite irregular set is present. With two good sets shown it is the exception that they are at right angles, and it is the east-west set and either the northeast or the northwest set with it, that usually appear. Often all three of these sets appear with lack of only the north-south set, and with the east-west set customarily the most prominent and regular. On bared rock surfaces therefore the joints ordinarily divide the exposure into rhomboidal, rather than rectangular blocks. In plates 15, 20 and 23 joints are well shown.

The limestones of the district exhibit, in general, more abundant, more regular, and more clean cut joints than does the Potsdam sandstone. The limestones moreover are all somewhat soluble in rain water and underground water, the Black River and some of the Lowville beds being preeminent in this respect. The glacial deposits over the district are in rather scant amount, there being much bare rock exposed, and much more only thinly coated with soil. On the bared limestone surfaces the widening of the joint cracks produced by slow solvent action of rain water which passes underground along them, is magnificently shown [pl. 26, 27], most impressively perhaps in the Black River beds but almost equally well in the upper Lowville. In many fields which might otherwise be available for pasturage, the cattle must be carefully excluded, otherwise they fall into, and become tightly wedged in these gaping fissures. During our field work we came by chance upon a poor, stray cow in such plight in the vicinity of Limerick, tightly wedged in a fissure of sufficient size so that the animal's back was well below the ground surface.

Down these widened joint cracks also the streams go underground, so that surface streams are infrequent in the Black River and upper Lowville districts. Beneath, this downward tendency is checked by the less soluble character of the remainder of the Lowville, on the upper surface of which these waters run along, eating away underground channels of considerable size in the soluble layers just above. In their early stages these channels are thoroughly roofed over, but as time goes on the roof tends to disappear, either by caving in because of lack of support by the widened channel underneath, or by slow dissolving away of the rocks above, thus bringing daylight down to the upper part of the tunnel. The matter will receive more detailed discussion when treating of the general drainage, but the details of the process and its varying stages are most excellently illustrated in the region [pl. 35–38]. While it is in many cases impossible to distinguish between preglacial and postglacial solution, it is nevertheless clear that much of this limestone removal is postglacial.

Folds

The rocks of the district exhibit various degrees of folding. The Grenville sediments are closely and intricately folded; the Paleozoic rocks show slight folding of Paleozoic date; and the same rocks

Plate 26

Bared surface of Leray limestone in field 1½ miles west of Sanford Corners, Theresa quadrangle, showing solution along joints. H. P. Cushing, photo, 1907

Plate 27

Bared surface of upper Lowville limestone, 1½ miles south of Sanford Corners, Theresa quadrangle, showing turf-filled joints. H. P. Cushing, photo, 1907

show occasional small surface folds, or buckles, produced since the ice sheet vanished from the region.

Precambric folding. It has been shown that the Grenville beds are now found for the most part in highly inclined condition, dips of less than 45° being relatively rare, while those approaching verticality are common. Averaging the dips of the entire formation would give a result of at least a 55° to 60° dip. It has also been shown that the dip is not everywhere in the same direction but that, with the general direction of strike to the northeast-southwest, the dip, while prevalently to the northwest, becomes at times southeast. The southeast dips prevail over a belt of country some 4 miles in breadth in the Butterfield lake district of the Alexandria sheet. In the country lying south of this belt the dips are all to the northwest. In the other direction the Grenville is badly cut out by the syenite and granite of the Alexandria and Picton bathyliths, but such as remains shows very steep to vertical dips, chiefly to the northwest. The highly tilted condition of the rock series, and these changing dips seem certainly indicative of folding. Moreover many exposures exhibit small folds of exceedingly compressed type, often accompanied by extreme plication. It is reasonable to suppose that these are merely secondary, or minor, folds superimposed upon folds of much larger scale.

In order to demonstrate the presence of these larger folds it is necessary that the order of superposition of the various Grenville beds should be worked out, and in the early stages of the field work it was hoped that this might be done. It is possible that it might have been successfully accomplished had large scale maps, say 4 inches to the mile, been available. But the structure is so complicated, the dips so steep, the folds so compressed, the series so greatly cut out by the igneous rocks, or so modified in character by them, and so much of the territory is yet covered by the Paleozoic rocks, that no certainty as to the Grenville succession could be arrived at with the maps in hand. Certain suggestions may however be made.

Inspection of the maps will show that the Indian river, from Theresa northward to the point where it passes off the Alexandria sheet, follows a broad belt of Grenville limestone, averaging somewhat more than a mile in breadth. Except for being much cut up by granite dikes and stocks, it is quite pure limestone. The dips are steadily to the northwest, and flatter than the usual Grenville dips, averaging about 45°, and hence indicating a thickness of about 4000 feet for the limestone. A few miles to the northward, on the Alexandria sheet, what appears to be a quite similar broad belt of limestone borders the west side of Butterfield lake. It is however so much concealed by overlying Potsdam sandstone that some uncertainty attaches to its extent and purity. But it has a breadth of outcrop quite comparable to that of the Indian river belt, and *seems* to consist chiefly of pure limestone. Its dips are prevalently to the southeast, and somewhat steeper than in the previous case, averaging 60°. This means a thickness substantially the same as in the other case, and strongly suggests that the two are parallel outcrops of the same great limestone belt, and that, since they dip toward one another, the structure is synclinal. If this be the true interpretation then the schists, amphibolites and quartzites which lie between the two limestone belts, rest on the limestone and hence are younger, with the rather massive quartzites about Sixberry and Millsite lakes as the youngest of all; while the schists to the northwest on the Alexandria quadrangle, and to the southeast on the Theresa quadrangle, underlie the limestone and are older. Figure 7 will illustrate the suggested structure.

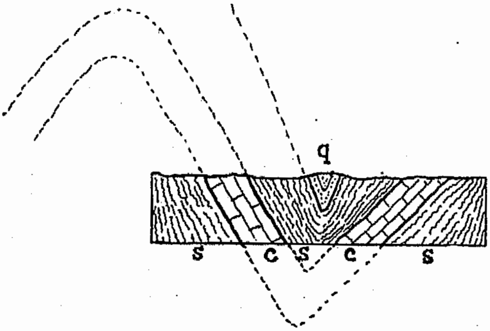

Fig. 7 Section to illustrate the structure suggested by the Grenville rocks, on a scale of 4 miles to the inch; s=schists, c=crystalline limestone, q=quartzite

There are, however, two alternative views in regard to this structure which may be held. It is possible that these two thick limestone masses may be separate beds, the one overlying the other and separated from it by the thickness of schist and quartzite which lies between. This involves the assumption that the series, though greatly tipped, is not folded and hence that no bed is cut by the present surface along more than one line. Since, however, small folds are certainly present in considerable number, the changing dips indicate the presence of greater ones, and as we have here two great lines of limestone outcrop, the rock showing much the same thickness in each, and the two dipping toward one another, this supposition seems improbable in high degree. There seems no direct evidence for it and much against it.

The other alternative is that the structure here is anticlinal instead of synclinal. This is a possible interpretation of it in spite of the fact that the two limestones dip toward one another. Long continued and severe compression may so closely compress rock folds as to cause them to pass into the fan fold type as illustrated in figure 8. Such folds are so pinched that vertical dips prevail centrally, along the axes, and the dips farther away converge toward the axis in the anticlines, instead of in the synclines as in the previous case. In that also the dips flatten in the vicinity of the axis of the fold, and pass from one direction to the other through the horizontal, instead of through the vertical, as in the fan fold. In repeated instances, and in many localities, in the Grenville rocks of northern New York, the writer has observed that change in dip has taken place through the vertical instead of through the horizontal, and this seems to imply a condition of very close folding in the Grenville rocks at many and widely distributed points. In this especial case the dips change from the northwest to the southeast through the vertical in the schists northeast of Millsite lake, but with some comparatively flat dips in the interbanded quartzites north of the lake. At the same time the schists become greatly contorted and puckered. Millsite lake seems to lie closely along the axis of the fold. The section shown in figure 9 was sketched from an exposure ½ mile northeast of Millsite lake.

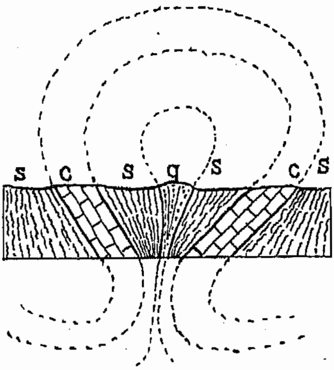

Fig. 8 Section similar to the previous, surface outcrops, dips and scale the same, on the assumption of fan fold structure

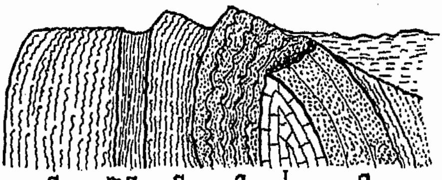

Fig. 9 Exposure of Grenville rocks ½ mile northeast of Millsite lake, showing sharply folded quartzite q-q, with a pinched in thin limestone between the quartzite limbs, l, the quartzite succeeded on the left by hornblende schists, s, and very schistose mica schist ms, the dip being vertical or nearly so throughout

The structure here is definitely anticlinal, though that is no indication of similar structure in the main fold, since minor folds on its flanks must consist of both anticlines and synclines. It will serve, however, as a sample of many similar exposures in the district which show clearly that the series is folded, and that it is closely folded. It also well illustrates the closely compressed conditions, steep dips, and minor folds which prevail in the vicinity of the axis of the supposed fold.

The writer's opinion is that the structure here presented is synclinal, similar to that depicted in figure 7. The discussion, however, serves to present the lack of certainty which prevails, and the possibility that the structure is of precisely opposite character. Either one indicates folding, but one precisely reverses the order of rock succession of the other.

It is also thought probable that the heavy quartzite along the axis of the supposed fold is the same stratum as the even more massive looking quartzite of Grindstone and Wellesley islands. If the structure be synclinal, as supposed, this quartzite is the youngest Grenville formation of the mapped district, but if anticlinal it is the oldest. If these two quartzite belts do represent lines of outcrop of the same quartzite formation, there should be an additional line of outcrop of the thick limestone somewhere between the two, in the near vicinity of the river. This does not appear but its absence is not a fatal objection to this interpretation of the structure, since the Grenville rocks there have been completely cut out by the granite of the Alexandria bathylith, and it is impossible to say what may have originally been there.

In summation it may be said that the Grenville rocks are greatly tilted, suggesting strongly compressive folding, and frequent small folds occur. Two belts of thick limestone and two of thick quartzite suggest a single formation of each in folded condition. Study of the dips suggests that this folding is of a certain type, but it is possible that, owing to very intense compression, the structure is just the reverse of that suggested. It has not proved possible to determine the order of succession of the various formations composing the Grenville, and to use that succession as the key for unraveling the structure, as is the usual method in folded rocks. Instead the attempt has been made to decipher the structure and from that to determine the order of succession, but with only indifferent success.

Paleozoic folding. While the Paleozoic rocks of the district show but a trifling amount of folding, it is of interesting nature and to a certain extent at least is due to the pivotal situation of the region with respect to the early Paleozoic warpings, as has already been shown. In general the rocks lie, in nearly flat attitude, on the worn surface of the sharply folded Precambric rocks. Over most of the district a low, southwesterly dip prevails; locally, however, the dip steepens to 5° or more, and dips occur in all compass directions. A strong westerly dip in the rocks along the Black river just above the bridge at Brownville is well shown in plate 28, and the dip is to the north, into the bank, as well, rock layers on the south side of the river lying some 10 feet higher than their equivalents on the north bank. In plate 24 a rather steep northerly dip in the Black River limestone at Watertown is shown, and in plate 21 a similar easterly dip in the same formation at another locality. These are samples of what is a matter of common occurrence all over the district. The areal mapping plainly brings out the presence of a series of folds which trend somewhat to the east of north. It also shows that the present stream valleys of the region in large part trend with these folds and chiefly follow the anticlines, while the synclines constitute the higher ground between.[1] Examples are the valleys running south from Theresa and from Evans Mills on the Theresa sheet; the French creek valley and the Chaumont valley on the Clayton sheet; and the Clear lake-Butterfield lake-Black creek valley on the Alexandria sheet; but there are many others of minor importance.

In addition to these nearly north-south folds there is a second set, about at right angles to the first, trending somewhat to the north of west, in parallelism with the Frontenac axis which is itself a fold of this group, the axial and most prominent one. Though mostly of minor importance, these folds are likely earlier than the others, and in part at least owe their existence to the warpings and tiltings of the region in early Paleozoic times, when it oscillated up and down, with tipping now to the east and now to the west. The Frontenac axis appears to be the major warp of this series, and the others are minor corrugations, grouped about it and diminishing in importance with recession from it.

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[1] An anticline is the upward folding of rock layers into a long and relatively narrow arch; a syncline, the downfolding into a similar trough. Where erosion has removed the upper portion of such folds a worn off anticline is readily recognized on an areal map since it will show an older rock centrally, followed by successively younger rocks in the same order on each side; while an eroded syncline will show a younger rock in the center, followed by successively older rocks on each side. Thus the French creek valley, south of Clayton, shows Precambric rocks centrally, adjoined by Potsdam on each side, Potsdam adjoined by Theresa and that by Pamelia limestone, and the structure there is anticlinal.

In addition to the evidence which the general stratigraphy of the region furnishes as to the early date of some of this warping, evidence which has been already set forth, it also appears that the Potsdam and Theresa formations are somewhat more folded than are the overlying limestones, implying that they were somewhat folded prior to the deposition of the limestones. This is best shown in the district southwest from Clayton, along the valley of French creek, where the Potsdam is arched up into a prominent dome, even to the extent of bringing up the Precambric. The dome falls away to the south with rather steep dip, there is scant room for the Theresa formation between the south margin of Potsdam outcrop and the Pamelia front just beyond, and this Pamelia inface passes across the line of prolongation of this fold to the south yet shows no sign of being affected by it, being precisely the same cliff of horizontal limestone that it is to the east and west of this line. It is of course possible that a fault lies between, but the faults of the district are infrequent and insignificant, so far as known, so that the supposition seems unlikely, and the evidence seems to clearly point to folding and subsequent wear, during the long time interval between the close of Theresa and the beginning of Pamelia deposition. Evidence of less distinctive character but of the same kind is also forthcoming elsewhere.

Two series of low folds intersecting at right angles result in producing maxima of elevation at the intersections of arches and of depression at trough intersections, with intermediate conditions where trough of one set meets arch of the other. In other words the axes of the north-south folds are themselves folded by the east-west folds, producing elevated domes along the arches, and depressed basins along the troughs. A prominent feature of the areal maps is the considerable number of outliers and inliers of the various formations there shown.[1] The abundant Potsdam outliers on the Precambric are more largely due to the irregularity of the floor on which the formation was laid down, than to the subsequent folding. But

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[1] Along the southern margin of the Theresa sheet are shown a number of patches of Leray limestone, lying to the north of the main line of outcrop of the formation, and entirely surrounded by the older Lowville limestone. The Leray limestone formerly extended over the entire district, and has been worn away from much of it, these representing outlying patches or residuals left behind in this general process of removal, hence known as outliers. Inliers on the other hand are patches of an older rock entirely surrounded by a younger, such as the Precambric by French creek south of Clayton, or the Lowville near Threemile Bay and Threemile Bay creek, on the Clayton sheet. These are much less common than outliers and are strongly indicative of a warped upper surface of the formation constituting the inlier.

Plate 28

Lowville limestone, capped by Leray limestone, at Brownville, extreme southwest corner of Theresa quadrangle. View looking northeasterly, across the Black river and upstream, showing the westerly limb of one of the low folds which characterize the Paleozoic rocks. The water is slack water, back of a dam, hence the river surface is horizontal. H. P. Cushing, photo, 1908

Follows Part IV

in the case of the other formations the great majority of the outliers are owing to wear on rocks of this folded type. The numerous outliers of Leray limestone on the Theresa and Clayton sheets chiefly mark the positions of basins (points of intersection of synclines of both series of folds), the dips being everywhere in toward the center. Similarly the Lowville inliers which Ruedemann has mapped on the Clayton sheet, north of Threemile and Guffin bays, mark the summit of domes (intersections of anticlines) with dip outwardly from the center. In the case of some of the outliers however, those of the Theresa formation on the Potsdam west of Theresa for example, the dome structure instead of the basin structure is exhibited, the outlier showing no prominent inface, and with dip outward from the center. The domed structure often shows excellently elsewhere, as for example in the Theresa formation at Orleans Four Corners (Theresa sheet) where the upper surface of a single massive layer of the formation protudes above the soil as a low, shallow dome, dipping outwardly in all directions. Many other examples might be cited and, owing to the abundance of rock exposures in the district the evidence of these structures is unusually clear, and it is quite certain that these two sets of low, cross folds occur.

Postglacial folds. There are in the district at least a half dozen examples of low folds, or buckles, of the surface rocks, which are of very recent origin. Though they form only a minor structural and topographic feature, they are rather unusual and the interest attaching to them is out of all proportion to their size and frequency. The writer has noted three of them in the limestones, Lowville and Pamelia, and Professor Fairchild has called his attention to two others. In addition at least one occurs in the Potsdam sandstone. The limestone folds seem all to conform to a common type so that a description of one of them, and of the one in the Potsdam, will answer every purpose.

The Potsdam fold occurs 2 miles south of Chippewa Bay, in the northeastern portion of the Alexandria sheet, is near the roadside and easily visible from it. It is 40 yards long, trends n. 28° w., and a view of it, taken at the south end, appears in plate 29. It rises sharply from the surface of an extensive plain, underlaid by nearly horizontal sandstone, with but a scanty soil covering and much bare rock exposed. The fold is of bared rock with beautifully glaciated surface, whose striations demonstrate that the buckling has occurred since the glaciation. The central portion is buckled up about 12 feet. The photograph clearly shows that, owing to compression, the rocks were bent upward until, the elastic limit being exceeded, the fold snapped along the crest, furnishing relief to the bent flanks and permitting them to straighten. In the rock here only a single set of good joints appears, and this runs at right angles to the axis of the fold separating it into a series of transverse blocks. On bending, these seem to have fractured individually instead of collectively, so that the axial fracture does not coincide in the different blocks, but departs from the median line, now on one side and again on the other, as illustrated in figure 10, giving rise to the dovetailing of slabs along the crest, so well shown in the photograph.

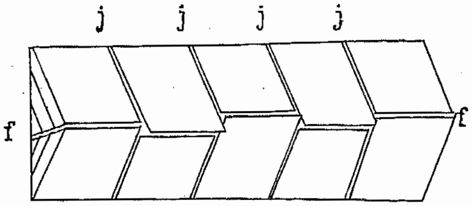


Fig. 10 Plan of fold in Potsdam sandstone, j-j-j=joints; f-f=fracture along crest, illustrating the manner in which the fracture shifts laterally in the different joint blocks, causing overlap of the rock edges along the crest.

One view of one of the folds in the Lowville limestone is shown in plate 30. The greater part of this fold is covered with soil, but centrally it has been stripped and a small amount of rock removed for local use. It seems to have about the same length as the previous one, and to be buckled up about the same amount. Its axis trends to the northwest. The rock is more closely jointed than in the Potsdam fold, and with two good sets present, one of which trends northwest with the fold, as the view clearly shows. Fracture then was unnecessary in this case and readjustment took place by utilization of these northwest joints, and instead of being actually folded, as might be judged from the photographs, the displacement really has the character shown in figure 11, as sketched on the spot.

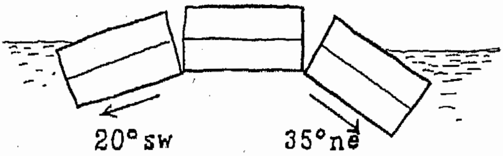
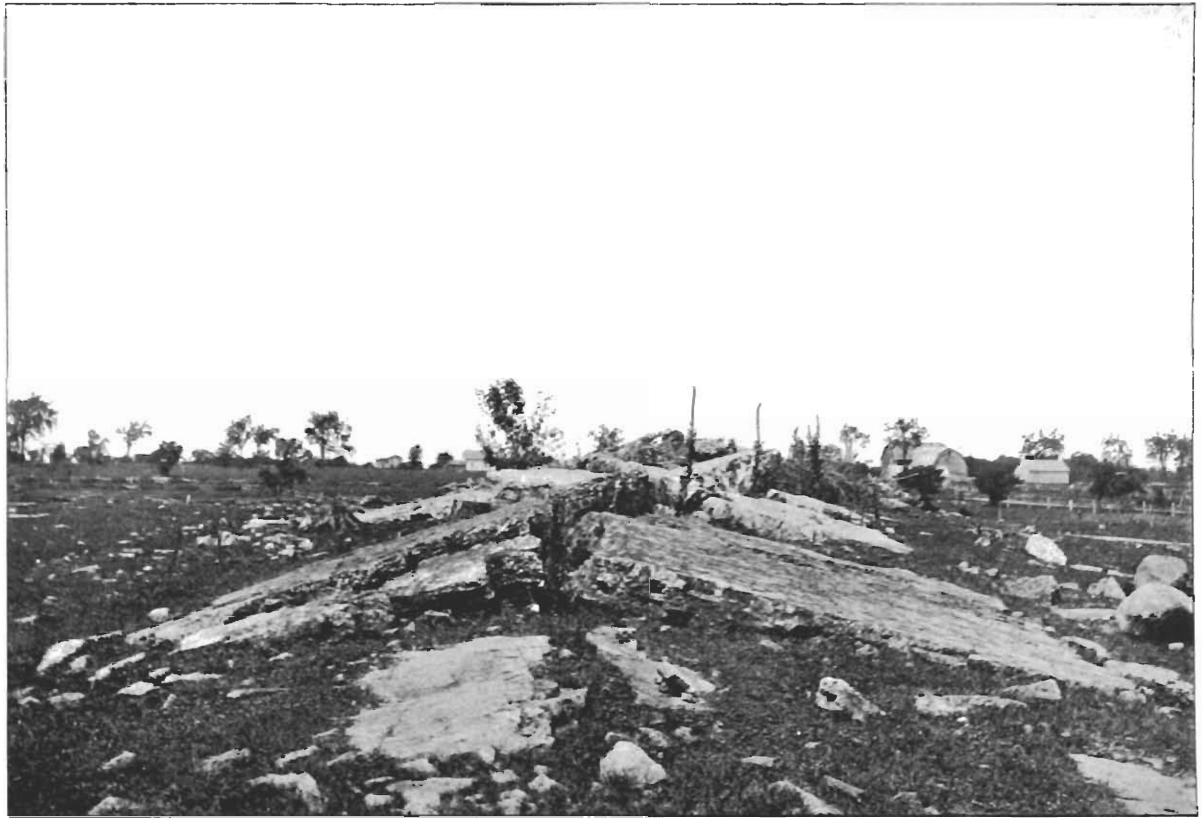


Fig. 11 Diagram to illustrate the arrangement of the joint blocks in the Lowville fold shown in plate 30 The central block lies nearly horizontally, the adjacent ones tipped in the directions and by the amounts indicated.

Small postglacial folds of similar type have been described by a number of authors and from various localities, and they have resulted from several different causes. Gilbert, after seeing some of

Plate 29



Postglacial arch in Potsdam sandstone, 2 miles south of Chippewa Bay, Alexandria quadrangle. The rock surface is glacially polished and shows the later date of the arching. The ruptured crest, and the dovetailing of slabs along the crest are also shown, and the set of cross joints. H. P. Cushing, photo, 1908

Plate 30

Postglacial fold in Lowville limestone, 1 mile west of Sanford Corners, Theresa quadrangle, looking northwest. The prolongation of the arch under cover as a topographic ridge is also shown. H. P. Cushing, photo, 1907

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the limestone folds in this district, as well as others in shales in western New York and Ohio, demonstrated that they were superficial and postglacial, and attributed them to "horizontal expansion of superficial strata, consequent on postglacial amelioration of climate."[1] The writer does not question the correctness of this explanation as applied to the folds in shales and shaly rocks, which Gilbert describes, but is not so sure as to its adequacy in the case of quite massive, rigid limestones such as the Lowville, and is especially doubtful of it as applied to a well cemented, massive sandstone like the Potsdam, which is an exceedingly rigid and resistant rock. Postglacial climate is no warmer than was preglacial climate. Unless therefore the weight of the overlying ice was sufficient to cause some lateral spreading of the rocks, at the same time that it was producing contraction in them by lowering of their temperature, postglacial warming would merely reexpand them to their preglacial condition. There is no question as to the competency of the ice weight to produce lateral spread in shales and shaly rocks. Many shales are known to spread and to give rise to buckles under much smaller pressures, hence the cause suggested by Gilbert would seem ample to account for the results. But the pressure necessary to produce spread in a massive, rigid limestone is quite another matter, and that required in the case of such a rock as the Potsdam sandstone is of a still higher order. The weight of an ice sheet 1 mile thick would be equal to that of from 1700 to 1800 feet of average sedimentary rock. We do not know the thickness which the ice attained over this region but even the supposition that it was much more than a mile thick does not greatly enhance our figures of rock thickness. Are such pressures, even if applied continuously for a long time, sufficient to bring about lateral spreading in such a rock as the Potsdam? So far as known to the writer there are no direct, positive data which warrant a definite answer to this question. It is certain, however, that at such depths below the surface such rocks are abundantly fissured, are often porous, and permit free passage of fluids. This certainly suggests that they are not under sufficient weight to close up cracks.

If, however, this pressure due to the ice load could be reinforced by pressure from some other source in sufficient amount, the necessary lateral spreading could be brought about. A

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[1] Gilbert, G. K. Am. Ass'n Adv. Sci. Proc. 35:227; 40:249.
Am. Jour. Sci. ser. 3, 32:324.
The writer is under great obligations to Dr G. K. Gilbert, J. C. Branner and H. F. Reid for references to the literature and for personal discussion of these folds.

very likely source of such additional pressure is to be found in the well known oscillations of level which the district has undergone preceding, during and since glaciation. The general district has increased its altitude by some 400 feet since the ice disappeared from the St Lawrence valley, and this change is simply the last of a series of oscillations. Furthermore these movements were of the nature of warps, the changes in level not being everywhere the same, but of varying amount. Such warping must bring about compression in some tracts and stretching in others. The contraction produced in the rocks by the cooling of the ice sheet would likely have manifested itself in mere slight widening along the joint cracks, and side compression brought about by warping may have sufficed locally to close up these widened joints. In such case postglacial increase of temperature might well tend to cause buckling of the rocks. The warping is of such nature that it would tend to produce thrust from the northeast, and it is to be noted that these folds trend northwest, as should be the case on this hypothesis.

There at once arises, however, the further question as to whether the compression consequent upon warping may not have been perfectly competent to cause the buckling, entirely independently of any effect which the ice may have had, and this seems to the writer very probable. Dr Reid, in correspondence, states his belief that "we must fall back on the general explanation that movements of the crust are in progress which have produced these bucklings." Dr Branner expresses similar views. In any case, until it has been shown that lateral spreading may be produced in rocks of this resistant type by load no greater than that of the ice sheet, some doubt must attach to the competency of Gilbert's hypothesis as applied to these special cases.

Faults

Faults of considerable magnitude and importance have not been noted in the district, and the fairly accurate areal mapping which the abundant rock exposures render possible, indicates that no such are present, at least in the Paleozoic rocks. Small faults appear, however, in considerable number in all the rocks and are apparently of different age.

In the Precambric rocks. Small faults, with dislocations of from a fraction of an inch to a few feet occur in a great number of localities in the Precambric rocks, as already pointed out by

Smyth.[1] The numerous dikes, chiefly of granite, which everywhere cut the Grenville give every facility for determining their presence. They are in great number but for the most part of very trifling displacement. Similar faulting locally in the Paleozoic rocks suggests that this faulting is of Paleozoic date, but the much greater number of faults noted in the older rocks indicates some Precambric faulting at least, and of this there is direct evidence in some instances. The hand specimen shown in plate 5, lower figure, presents an adequate illustration. The rock is a well banded, acid Grenville gneiss, consisting chiefly of feldspar and quartz and seems certainly a sediment, a metamorphosed shaly sandstone. The bands vary in color from a light reddish to a blackish red, and are very plain, though without sufficient contrast to photograph clearly. They are parallel to the bedding and seem certainly to represent original lamination in the rock. Shearing has occurred, with development of fracture cleavage, principally at a high angle with the bedding, but with secondary fractures which rudely follow it, and along many of the former minute slips of the rock have taken place. These old cracks are now solidly welded up with secondary minerals, black in color, except for an occasional, shining pyrite crystal, and it is this secondary filling which furnishes the evidence for the date of the deformation and gives the chief interest to the rock. Pyroxene, hornblende and black mica (biotite), stated in order of abundance, are the minerals composing the filling, their grain somewhat coarser than that of the rock. They are of the same types as the minerals of the Grenville green schists. They argue for fairly deep seated conditions at the time of the deformation. The fractures show that the rock was above the zone of flow, but the minerals, the pyroxene especially, indicate anamorphic conditions and point to deformation in the lower part of the zone of fracture. Such faulting seems not only of Precambric date, but to have preceded the greater part of the long, Precambric erosion interval. Its date is made quite certain by the numerous dikes of Picton granite which cut the schists, the granite being younger than the filling of the shear zones.

There are also frequent shear zones in the Precambric rocks, zones of no great breadth but of considerable linear extent, along which the rock is shattered into quite small blocks by a multitude of close spaced joints, and along which some faulting has certainly taken place, small slips along many planes. No such shear

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[1] N. Y. State Geol. 19th An. Rep't, pl. 15.

zones have been noted in the Paleozoic rocks, and the deformation which gave rise to them seems certainly of Precambric date, though later than that previously described since the rocks were under less load, hence nearer the surface.

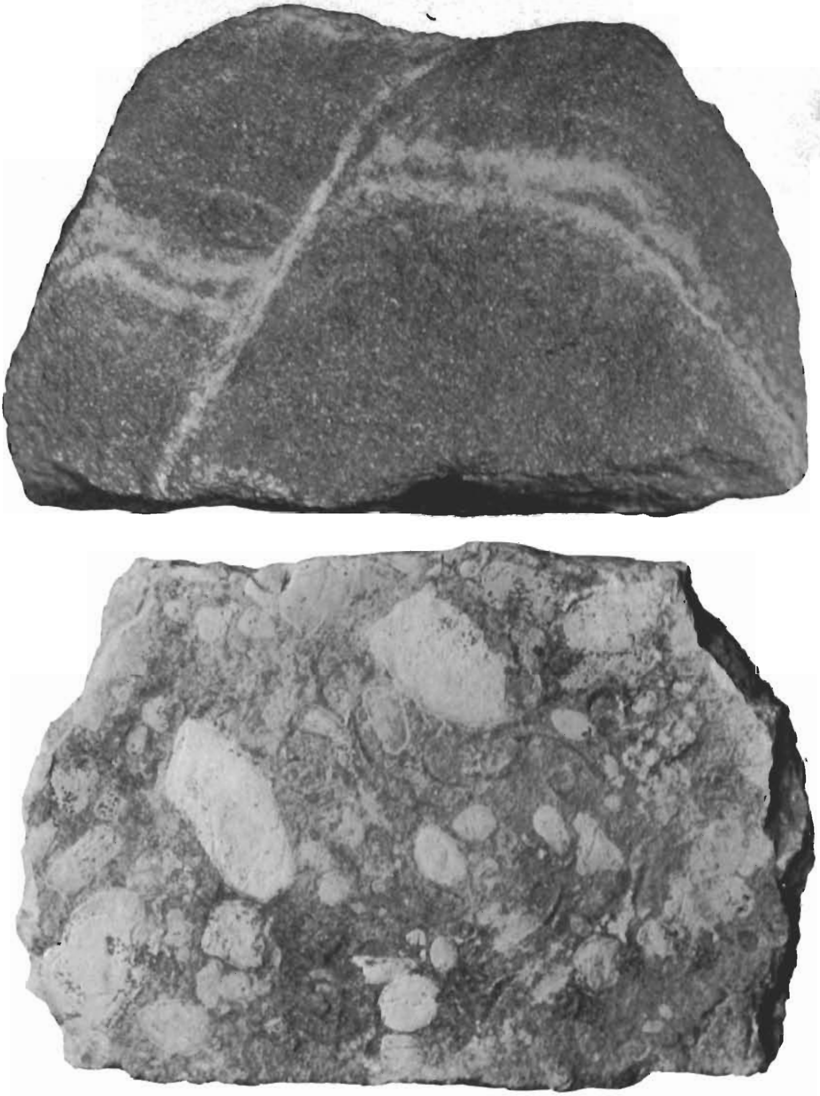
In the Paleozoic rocks. Frequent faults of small throw may be made out in the Potsdam sandstone. The red and white banded stone which constitutes the lower part of the formation on the Alexandria quadrangle is excellently adapted to display them, and a magnificent exhibit of them is given on the bare rock surface of the large Potsdam outlier which lies between the railroad and the north end of Butterfield lake. Here over a considerable area the faults are spaced but a few feet apart, and though the throw seldom amounts to as much as a foot, and is frequently only a fraction of an inch, the combined displacement of the whole must be quite considerable, as there are hundreds of them. For a hand specimen from this locality, showing one of these faults see plate 31, upper figure. All noted are normal faults of slight hade. The fault planes are filled with sand grains in all respects like those of the rock itself and as thoroughly cemented, which would seem to indicate that the faulting occurred before rock cementation was far advanced, so that the grains gave way individually instead of as sandstone fragments, whereas the latter would certainly be the method were faulting to take place in the rock now. Cementation subsequent to the faulting has thoroughly indurated the whole.

The bulk of the formation is rather uniformly colored and hence not so well adapted to display faulting of this type, and it is not certain whether it occurs in it or not.

There are also occasional small faults of a later type in the Potsdam, the fault planes remaining as open cracks, with sandstone fragments in the fault breccias. A small fault of this type appears in plate 12.

In the limestones a few faults have been noted whose throw amounts to several feet. The best example seen by the writer is in the lower Pamelia limestones of the Pamelia inface, 2 miles east of Perch lake. The section here shows the basal, black, fossiliferous limestones, overlaid by a thickness of some 15 feet of thin bedded, earthy limestone, followed in its turn by massive blue limestone with interbedded gray magnesian layers. These upper massive limestones are faulted down against the earthy limestone, the fault bearing n. 30° e, downthrowing to the east and with a throw of some 20 feet.

Plate 31



Upper figure. Hand specimen of faulted Potsdam sandstone, nearly natural size. The rock is red, with white streaks, and the fault plane is filled with white, thoroughly cemented sand.

Lower figure. Hand specimen of basal, Lowville conglomerate from near Depauville (Clayton quadrangle). The pebbles of fine limestone mud, of dove color, weather prominently white, as compared with the remainder of the rock surface. H. P. Cushing, photo

Follows Page 120

Ruedemann has mapped two small faults on the Clayton and Cape Vincent sheets and furnishes the following description:

In Chaumont village (Clayton sheet) is a small outlier of Trenton limestone, immediately to the west of which, and at the same level, is Watertown limestone. The relations are best seen about the viaduct on the Depauville road and along the railway immediately to the east. Under the viaduct is Watertown limestone. Along the railroad is Trenton at the same level, with a cut which shows steeply dipping Trenton, the dip being away from the Watertown and apparently due to drag on the downthrow side of a fault. The fault downthrows to the east, with a throw just sufficient to preserve the small patch of Trenton on the downthrow side. Its trend is substantially parallel to the road, or about northeast.

On Carleton island (Cape Vincent sheet) the presence of a fault cutting off the small western promontory, which consists of Watertown limestone, is suggested by the depression which separates the promontory from the mainland, within which no rock shows, and which is faced by a rock cliff on each side, a high Trenton cliff on the main island side and a lower cliff of Watertown on the other. A small fault along the depression, with downthrow to the east, is thus indicated.

TOPOGRAPHY[1]

The present day topography is the result of erosional forces acting for long ages upon a land surface, which from time to time varied in altitude and which underwent climatic changes. The character of the erosion, and of the resultant topography are also conditioned upon the character, attitude and structure of the rocks comprising the region. We have some slight knowledge of the changes in altitude of the region. The climate has certainly varied much, both in respect to temperature and to humidity, with, in quite recent times, the climatic rigor of the glacial period. The erosional forces, as always, have been in part atmospheric, but chiefly those of moving water and ice.

During paleozoic times the region was, when not submerged, one of low altitude. It was uplifted somewhat at the close of the Paleozoic, and during Mesozoic time seems to have been worn down to a comparatively even surface of low altitude, in common with much of the eastern portion of the continent. During the succeeding Tertiary it participated in the general uplift of the same region, and its present relief is chiefly a product of Tertiary wear.

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[1] By H. P. Cushing.

Paleozoic altitude and climate

During the Lower Siluric the immediate region was from time to time submerged, at other times was above sea level. During submergence there were neighboring lands. It is apparent that all were of low altitude. During emergence there was but trifling wear on the exposed land surface. During submergence the adjacent lands furnished but little land wash, though the Precambric rocks of which they were formed were capable of supplying great quantities of sand and mud under conditions of any freedom of drainage; and they were near at hand and of much extent. A small thickness of sand marks the horizon of the Pamelia-Lowville break, otherwise the formations are unbroken limestone, until the shales of the upper division come in; and these are more indicative of stronger currents in the marine waters, than of especially increased altitudes of the neighboring lands. The succeeding Oswego sandstone seems a continental, rather than a marine deposit and indicates freer drainage and somewhat greater altitude.

But little has been gleaned from the region itself as to climatic oscillations in these early times. The upper Pamelia was marked by a somewhat arid, and perhaps warm climate, as has been seen. Probably the same was true of the Oswego-Medina, though that lies outside our district. The Potsdam climate is a puzzle. Farther east, where the basal Potsdam consists largely of arkose, and where the Precambric underneath shows the same freshness and the same irregularity of surface under the Potsdam that it does here, we have expressed the opinion that the sandstone was a continental deposit, so far as the basal portion is concerned, and that the climate was arid. Here however, with the same character of floor, we have a pure sand deposit, instead of arkose. The unweathered character of the Precambric rocks, the absence of residual weathered material, except in very scanty amount in the most sheltered situations, and the general base-leveled character of the surface, seem to point to long continued wear under conditions of aridity and removal of disintegrated material by the wind. Under those circumstances however the residual products should be arkose, instead of pure quartz sand such as constitutes the Potsdam here. There is much more feldspar in the basal Pamelia sand than in the Potsdam, and even in that it is not in great quantity. We are unable to correlate this quartz sand with conditions of climatic aridity, and equally unable to explain the character of the Precambric surface, and the unweathered condition of the rocks, satisfactorily to ourselves, on any other basis.

During the remainder of the Paleozoic we know but little concerning the region here, except by comparison with other regions more or less remote from it. It may have been somewhat submerged during the Siluric, but certainly, for most of the time, it was a land area, and the small amount of wear which it experienced indicates that, for most of the time, its altitude was low.

Amount of erosion

The total amount of rock thickness which has been worn away since the region became a land area, can not of course be exactly determined, though it is thought that it can be approximated. To the south the Trenton limestone is overlaid by the Utica and Lorraine shales, and these by the Oswego sandstone and Medina shale and sandstone. These are all sufficiently near to make it in high degree probable that they were laid down over our district, especially since the source of their sediment must have been to the north and east. It is regarded as unlikely that they had any greater thickness here than they now show toward the south, but they may have been as thick. We have no evidence that any formations later than the Medina were ever deposited here, and even if so, the thickness would seem to have been small and the submergence brief. If therefore we allow to these formations the full thickness which they show to the south, we are likely exaggerating their thickness here and allowing a margin to account for any possible later formations which may have existed.

The deep wells which have been drilled at various points between this district and the Syracuse region, give the data desired. In the Monroe well at Baldwinsville the drill went through 1740 feet of sandstone (Medina-Oswego) and shale (Lorraine-Utica), reaching the top of the Trenton at 2240 feet. If we assume them to have been deposited over our district in the same thickness, and add the thickness of underlying rock (Potsdam-Trenton) we get 2600 feet as an outside measurement of the Paleozoic thickness here originally. In all probability this is considerably too high. There were 1200 feet of sandstone and 500 feet of shale above the Trenton in this well, and the full thickness of both was passed through by the drill. In the wells further north, as in Orwell and Central Square, less sandstone appears but the shales thicken to 700 feet. Since no certainty is possible our purpose is best subserved by a generous estimate, and an original thickness of 3000 feet of Paleozoic rocks here will be assumed. Where Precambric rocks are now at the surface, 3000 feet is regarded as the outside limit of the thickness of overlying rock which has been worn away, from the close of the Siluric to the present. Where the various members of the Paleozoic form the surface rocks, erosion is correspondingly less, and since the Precambric is at the surface over but a small fraction of the region, the general erosion has been less than that figure. Considering the great length of time involved, this represents no great erosion, and seems to point to land of no great altitude for much of the time. It seems to be further demonstrable that at least one half of this erosion took place in Tertiary time, which argues all the more strongly for general low altitude during the preceding ages of the Mesozoic and later Paleozoic.

Original drainage

As uplifted at the close of the Siluric, and following the deposition of the Oswego sandstone, our area became the marginal portion of land masses to the north and the east, and in all probability possessed a gentle slope to the southwest. The original streams must have followed down this slope to the margins of the later Paleozoic water bodies of central New York, thus flowing in the direction of the rock dip, and at right angles to the strike. Having taken position they would commence to carve valleys, whose possible depth would depend upon the altitude of the land. Streams of this type are called consequent streams. With valley cutting in progress, tributaries to these original streams commence to develop, beginning as gullies in the valley sides, and steadily cutting headwards. Obviously they form most readily where the valley walls are weakest, and tend to remain in the weak rock belts, following their strike, hence with courses which make substantially a right angle with those of the original streams. Such streams are called subsequent, since their development must wait on that of the consequent streams. With a belt of weak rocks to follow, these subsequent streams may eventually become the chief streams of a region, diverting or " capturing " the headwaters of the old consequent streams. The Utica and Lorraine shales constitute such a weak rock belt in this region, with the great Ontario valley eaten out along it, the Adirondack highland blocking its extension further east.

With chiefly low lands, drainage adjustments would go on but slowly, and the drainage may have been considerably modified from time to time by tilting of the land, under these low altitude conditions. With the passage of time, however, it has come about that the chief streams of the region are now in subsequent position, and there is little trace of the old consequent streams, though the streams running westerly, out of the Adirondacks, seem to represent the old heads of such streams.

Tertiary uplift

Evidence derived chiefly from without the district indicates that our region, in common with much of eastern North America, was worn down to a comparatively smooth surface (peneplain) of low altitude by the close of Mesozoic time. It then experienced considerable uplift, erosion was renewed and streams cut and widened considerable valleys in the weaker rock belts, while the more resistant rocks retained in considerable measure their original altitude, and give us the remnants of the old plain. Elevations of over 1500 feet are found on the Watertown sheet, immediately south of our map. On the Port Leyden sheet, next south, the altitudes reach almost 2000 feet, the district there forming a low plateau, capped by the resistant Oswego sandstone, between the Ontario lowland to the west and the broad valley of the Black river to the east. East of the valley the levels rise within a few miles to 2000 feet, in the westerly edge of the Adirondack platform, and from there continue to slowly rise eastward. The Adirondack highland, and the Oswego sandstone plateau, are regarded as remnants of the old peneplain surface, which as uplifted, was given a slight tilt toward the west, while the deep valleys of the region have been cut since the uplift and give some measure of its amount. Unless later rocks in considerable thickness have been worn away from the surface of the Oswego sandstone plateau, the amount of wear there has been very slight; yet this small thickness of removed rock represents the general erosion over the entire region from the close of the Ordovicic to the close of the Cretaceous, a wear so slight as to be only compatible with low altitude of land when the length of the time interval is considered.

Tertiary drainage

The Tertiary uplift of the region gave to the land an altitude in excess of that of the present. A partial measure of this excess is the difference in level between the Tertiary valley bottoms and those of today; but we do not know the depth of valley filling in this district and hence can not state the excess. Even before the uplift the streams had likely become adjusted to much their present relation, namely consequent streams flowing westerly and northwesterly out of the Adirondack region, and southerly and southwesterly out of the Canadian Precambric region, and these streams diverted by the large subsequent streams in the Black river, St Lawrence and Ontario valleys; the Black along the overlap of the sedimentaries on the crystallines, the Ontario valley on the thick shales, and the St Lawrence on the limestones of the depressed trough, with bordering Potsdam and Precambric on both sides; hence each on a relatively weak rock belt. In these positions the Tertiary successors dug out their valleys. They mostly flowed as they do now, the important exception being in the case of the Ontario-St Lawrence drainage. The fold, or warp, of the Frontenac axis crosses this drainage line in our district. Even before being worn down to the Precambric this would make a natural rock barrier to the drainage, since the lower Ordovicic rocks are more resistant than the upper, and hence form a divide or col between waters flowing northeast, down the present St Lawrence valley, and waters passing west through the Ontario valley, the Black river forming the chief stream of the immediate region, as it now does. All writers on the district have considered that, in Tertiary times, the Black river turned westward into the Ontario valley. Wilson especially has considered the drainage of the immediate region in some detail in a most excellent paper, with much of which we are in entire agreement.[1] He points out that the St Lawrence lacks a definite channel in the Thousand Island region, going over the Frontenac axis at its most depressed point. With this we agree, but we do not coincide with his view that the Black river, in its course across the mapped area, is closely in its preglacial channel (the river below Carthage is here referred to). We are however in doubt as to where this preglacial channel was. Fairchild disagrees entirely with the view that the preglacial waters of the Black river went westward, and turns them into the St Lawrence valley below the col. His views are presented on pages 141–145. I dissent somewhat, preferring the view that the drainage went into the Ontario basin, but must frankly admit that I have not discovered the precise route followed, so that it seems to me that opinion in the matter must be held in abeyance, pending discovery of the actual old channel.

If the Frontenac axis formed a divide here in Tertiary times such divide should run across our district toward the Adirondacks, as a divide between streams going north and those moving

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[1] Geol. Soc. Am. Bul. 15:236-42.

west. The presence of this divide, with its sharply cut ravines heading against it on both sides is to us one of the most interesting features of our district. It is most unfortunate that the maps of the quadrangles next east are not available so that it could be further traced in that direction. Inspection of the Alexandria and Theresa maps will show plainly its course across them. In the low grounds near the St Lawrence the ravine heads are not prominent, though the two lateral ravines into Cranberry creek valley from the east are good examples. But at Browns Corners, 4 miles southeast of Alexandria Bay, is seen the head of the first of a series of sharply cut valley heads with northeast trend. The next is at Plessis, dropping down sharply into the Clear lake-Mud lake-Butterfield lake valley, with a secondary sharp drop at the head of Butterfield lake. One and one half miles southeast of Plessis, on the extreme south margin of the Alexandria sheet, is the head of the Hyde lake-Hyde creek-Perch river valley, on the other side of the divide, belonging to the southwest drainage. Just east are two sharply cut ravines heading on opposite sides of a low pass across the divide, the valley of Crystal lake, which is tributary to the Mud lake valley, and the valley without present drainage, followed by the railroad and leading south into the Indian river valley on the Theresa sheet. This valley is somewhat more blocked by drift than the others and seems to have held a shallow lake. The Millsite lake and Sixberry lake valleys also head sharply against the divide on the north. They are however of somewhat abnormal type. Most of the other valleys mentioned commence as distinct but shallow, rock-cut trenches, which, after a short course, suddenly deepen to gorges with walls from 40 to 100 feet high. The Clear lake and Hyde lake valleys nicely illustrate this type. The lakes are at the heads of long valleys leading away from the divide. The Crystal lake, Sixberry lake and Millsite lake valleys, on the other hand are short valleys, tributary to others at the side, and they deepen almost at once, instead of having the preliminary shallow course. The view of the head of Crystal lake valley [pl. 34] gives an excellent idea of the general character.

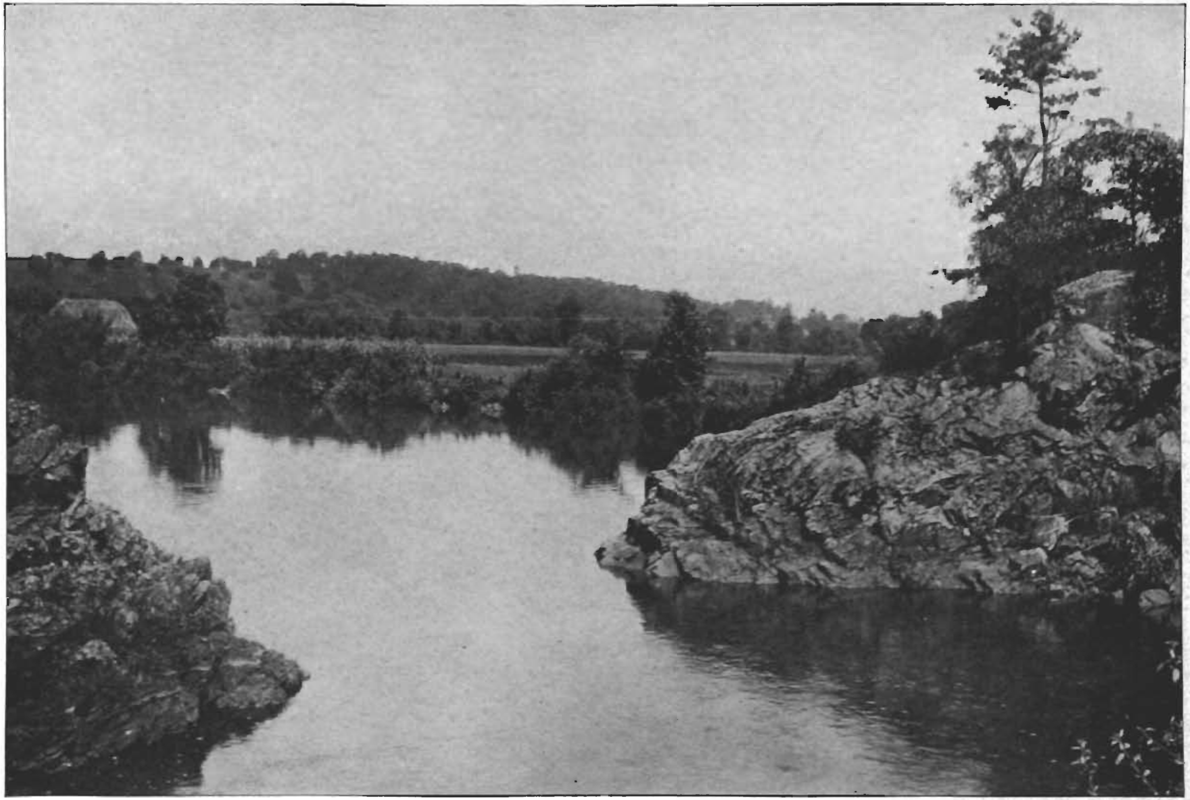
Passing to the Theresa sheet, attention is at once directed to the considerable and deep valley, leading north past Theresa, the valley into which the modern Indian river breaks at that point, with production of falls and short gorge [pl. 32]. The valley itself heads 3 miles further south. Two miles to the west is the Hyde creek-Perch river valley, running southwest and heading on the Alexandria sheet, as we have just seen. This parallel, but northerly-flowing Theresa valley plainly heads several miles south of the original line of the divide, in other words has pushed it south out of line by headward cutting of its valley. Its ability to do this was no doubt conditioned upon the weak resistance of the Grenville limestone belt there. Once the Potsdam was cut through, rapid headward cutting of the stream would be possible. From the present valley head a shallow valley runs southwest to Perch lake, and it seems clear that formerly this valley headed along the old divide, and was diverted, bit by bit, by the more advantageously situated stream flowing the other way. The minor tributary valleys from the east and west, between Theresa and the north margin of the sheet, are southerly trending valleys, southeast or southwest, and hence adjusted to a southerly, rather than a northerly flowing stream. The northerly flowing stream slowly captured and reversed the headwaters of the south stream, extending its capture through a distance of from 4 to 5 miles.

Northeastward from Theresa are a number of valleys heading sharply against the Potsdam mass which there forms the divide, and leading away from it to the southwest. These are located on belts of Grenville limestone, or of weak schist, and therefore are broader and less ravinelike than most of such valleys in the district. They are, however, comparatively narrow, distinctly rock walled, and with present flat-bottomed floors owing to drift deposits.

Here, in the northeast corner of the Theresa sheet, the divide runs off our maps to the east, and with maps of that district not yet available, its further course can not be traced. It, today, rises steadily in altitude in that direction, and is, as in Tertiary times, the divide between waters flowing north to the St Lawrence and west to the Ontario valley.

The Indian river of today, from Theresa south to the great bend north of Evans Mills, is flowing in reversed direction through what was then the valley of a small stream heading near Theresa and flowing south. Wilson's view is that at the bend it was tributary to a southwest stream, occupying the valley now followed by Indian river above the bend; and that their combined waters flowed south through the present West creek valley to the Black river. With our disbelief in the presence of the Black river there at that time, coupled with the fact that the West creek valley seems both to widen, and to deepen,

Plate 32



The smaller of the two gateways at Theresa through which the Indian river passes into the preglacial valley. The rocks are steeply dipping Grenville schists. H. P. Cushing, photo, 1907

Follows [illegible]

northward, we are in doubt as to the correctness of this view. Certain it is, however, that the present course of Indian river is a patchwork of various preglacial valleys, the modern character of the course being most excellently shown at Theresa where the river drops 80 feet, from a shallow valley into a much deeper one, entering this on its east side 3 miles below its valley head, with cutting of a short, postglacial gorge in the old valley side.

Plateaus, terraces, scarps

With the streams cutting down valleys and exposing rock formations of varying age and resistance in their valley walls, and with the slow widening of the valleys, the stronger rock beds of the region tend to outcrop in cliff form, the scarps running across country in the direction of strike, and curving up the consequent valleys in the direction of dip. The stronger cliffs result where a more resistant rock overlies a considerably less resistant one, the more rapid wear of the underlying rock tending to keep a tolerably steep and precipitous cliff front. Where the differences in resistance are less, or where rapid changes in resistance occur, involving no great thickness of rock, low, subdued scarps are produced.

Furthermore, where an overlying formation is weaker than that beneath, rapid wear is checked at the upper surface of the lower rock, the upper rock is stripped away from it and a flat bench of varying breadth is produced, separating the cliff fronts of the upper and lower formations. In the large way, ignoring minor complicating factors, the general topography of our district is of this type: flat platforms developed on the surfaces of the hard layers, and cliff fronts which mark the descent from one rock platform to the next, the cliff fronts facing toward the old land area, in this case to the north, hence often called infaces.

The most prominent cliffs, and the broadest platforms of the district are those of the Potsdam sandstone, as it usually has considerable thickness, is the strongest or most resistant of the Paleozoic rocks, and more enduring than much of the Precambric, on which it rests. The Precambric topography has already been described, and this does not need repetition. The Potsdam is thickest where the underlying Precambric is weakest, the bulk of the remaining Potsdam rests on these weaker rocks, this being notably true in the case of the outliers. Potsdam cliffs from 20 to 60 feet high are abundant throughout the district, and are absent only where the underlying rock is granite and the Potsdam very thin. Broad Potsdam platforms are well shown on both the Theresa and Alexandria sheets.

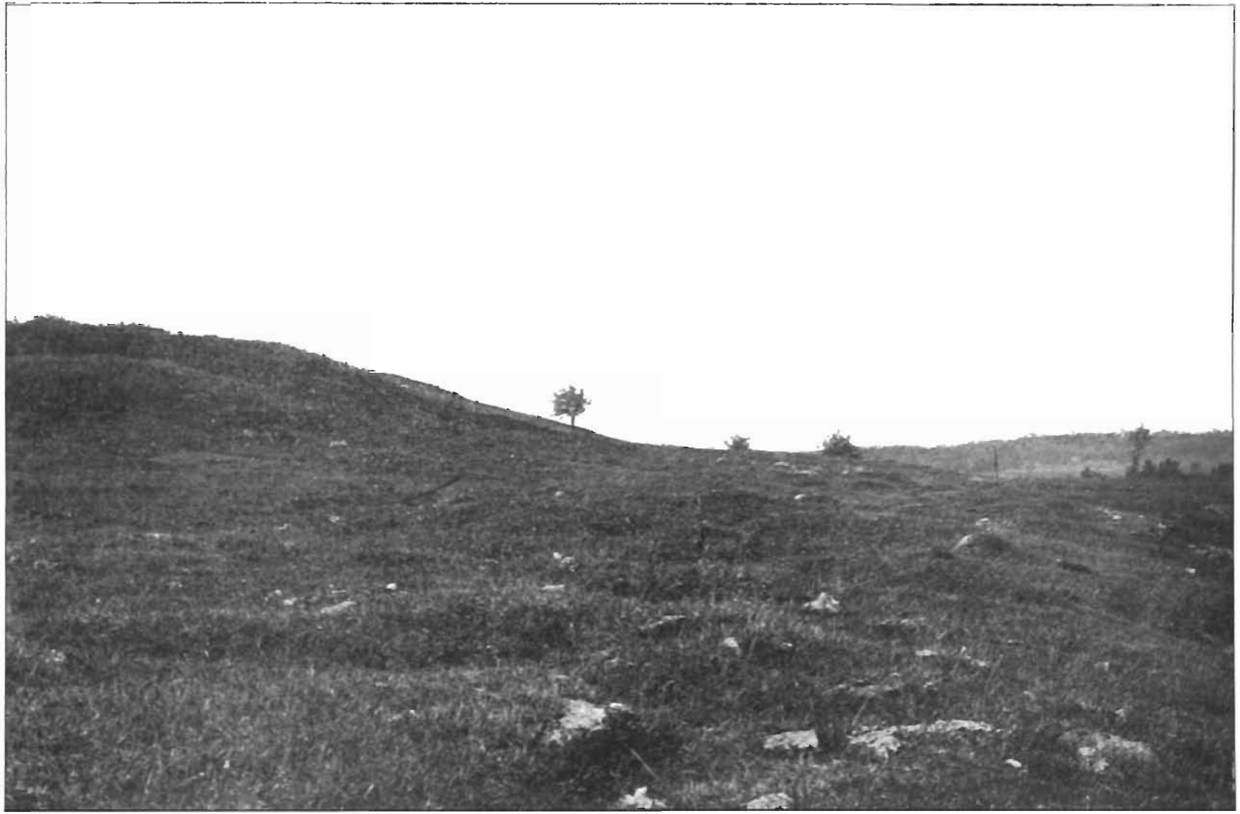
Though the Potsdam as a whole is strong, the uppermost beds, together with the sand beds in the basal Theresa, form a weak combination, in which the massive bed of the Potsdam summit is relatively strong. The overlying Theresa is also stronger than this weak zone, and hence the Theresa edges form rather prominent infaces, with these weak beds at their base; not infrequently also the strong summit bed of the Potsdam forms a narrow platform of its own, part way up the inface [pl. 33]. The Theresa rocks weather to iron stained crusts and their exposed edges have a thin bedded look, giving these infaces a peculiar and unmistakable look of their own. Above the base the Theresa shows rather rapid alternations of thicker and thinner bedded layers, the former somewhat more resistant, so that low infaces of these various layers are frequent throughout the Theresa country.

The sandy basal layers of the Pamelia formation, some 25–30 feet thick, constitute the weakest zone within our map limits, and are readily stripped away from the Tribes Hill underneath, while the overlying limestone is more resistant, so it is not surprising that the Pamelia cliff front is one of the most conspicuous topographic features of the district, a feature which the contour maps clearly bring out. In front lies a flat Tribes Hill platform. The cliff ranges from 20 feet to more than 100 feet in hight, but is usually from 50 to 60. Higher up in the formation the occasional very massive limestone beds form frequent low infaces of their own, as in the case of the Theresa formation. The Lowville differs but little from the Pamelia in resistance, and has no zone of weakness at its base, hence is not fronted by a prominent inface of its own, and is the only formation which lacks one. It has its own minor fronts, but these are of the same order of magnitude as those of the upper Pamelia beneath.

The Leray is a thin formation, but because of the massiveness of its beds, and the abundance of chert in its lower portion, it everywhere forms infaces with distinct characters of their own, of which the curious blocky type of weathering is the most conspicuous [pl. 20]. The 7 foot tier above also has a front of its own.

The thin bedded Trenton limestone is considerably less resistant than the Watertown, hence the Watertown platform in front of the Trenton inface is comparatively broad, especially when the small thickness of the formation is taken into consideration. Notwithstanding the weakness of the Trenton, its inface to the south of the Black river is far the highest and most commanding of the

Plate 33



North face of Theresa escarpment, 1¼ miles southeast of Clayton, looking west. Theresa dolomite on left, upper surface of Potsdam sandstone on right and in foreground. H. P. Cushing, photo, 1908

(Follows p. 150)

region. Only a little of this is within the map limits, in the extreme southeast portion of the Theresa quadrangle. Such Trenton as there is north of the river shows itself in rounded hills without prominent inface and this is its normal and usual character. The high cliff referred to is unusual and due to proximity to the Black river.

Minor modifications of these general features are produced because of the low folds of the Paleozoic rocks. The discussion of these has shown how low domes and shallow basins are thus produced in the rocks, resulting in the formation of outliers and inliers of the various formations, with their local infacing or outfacing cliffs; resulting also in a lobation of the general formational infacing fronts. As Ruedemann has stated these lobes are most conspicuous in the Leray fronts, an additional cause being there at work to accentuate them. Nevertheless they are primarily due to the folding, the other infaces showing similar, even though less conspicuous lobes. The topographic maps show these general features excellently.

The lowlands of our region today are chiefly the result of the stream wear during the Tertiary. The prominent rock infaces and platforms of the various formations are owing to the considerable differences in level between the low grounds and the adjacent uplands, and terrace broadly the ascents from the one to the other. These features, together with those of the drainage outlined above, were substantially what they are now at the end of Tertiary time. There are few northern regions in which the general topography is so little changed, and has its Tertiary features so little masked by subsequent Pleistocene changes as is the case here.

Lakes

The group of lakes in the southeastern portion of the Alexandria quadrangle, together with a few more of the same type in the district to the eastward, constitute one of the very interesting features of the district. Their interest arises in part from their localization; they are abundant in this restricted area and are scarce or lacking elsewhere. In some features they resemble the much more abundant, and more widely dispersed, lakes of central Ontario, as described by Wilson; in one respect they are sharply contrasted with them.

Wilson describes the Ontario district as characterized by a prominent cuesta front at the north edge of the Paleozoic limestones, overlooking the Precambric areas to the northward. The drainage is to the southwest and passes from the Precambric into the Paleozoic limestone country, the streams deeply notching the cuesta front as they pass into it. Of the lakes he says: "In most cases the upper parts of these valleys, near where they pass through the cuesta front, form the basins of long, narrow lakes. The water seems in some cases to be held back by a drift dam, which partly blocks the lower part of the valley. Certainly in some cases, in all probability in most cases, the present lake basin is a rock basin and the existence of the present lake is due either to warping or possibly to differential erosion by ice.[1]"

In this district of Wilson's the Potsdam and Theresa formations are absent, the Pamelia, or Lowville, resting on the Precambric, forming a single cuesta front that is more prominent than those in our district. The lakes on the Alexandria sheet have their beds either on Precambric or on Potsdam, and the limestone front is more or less remote. They nestle in the extreme upper portions of the valley heads on the north side of the divide which runs through the region, and has just been described. They are in the extreme upper portions of the valleys of north-flowing streams, instead of occupying a special position in the valleys of southerly streams, as in the case of the Ontarian lakes, and in this lies their chief difference from those. Hyde lake, in the northern portion of the Theresa sheet, conforms more nearly to the Ontarian type, though in Potsdam instead of Precambric, and Perch lake seems the shallow remnant of another lake of similar type. The Alexandrian lakes, however, differ as specified, and herein lies also the reason for their localization. The old divide runs into higher ground passing eastward, and the relations of the rocks shift. The streams there rise in the Precambric and run northward into the Paleozoic rocks of the St Lawrence valley, while our lake valleys here commence in Potsdam and run north into Precambric.

Most of the lakes seem to be in rock basins, Crystal, Sixberry and Millsite certainly are, and Butterfield probably is. Crystal lake is entirely in Potsdam though its bed may be on the Precambric, and is walled by high and continuous sandstone cliffs, with the sharply cut valley head but a short distance back from the lake margin [pl. 34]. Sixberry, Millsite and Butterfield are partly walled by Potsdam, with characteristic cliffs, and with valley heads cut in Potsdam, but with their beds in Precambric [pl. 54]. The beds of the two latter are in large part in Grenville limestone. Six-

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[1] *Op. cit.* p. 217.

Plate 34

Head of Crystal lake, 2½ miles south of Redwood, looking north down the lake. Cliff of Potsdam sandstone, characteristic basin wall, seen at right. Compare plate 51. H. L. Fairchild, photo, 1908

Plate 35

Bared surface of Tribes Hill limestone, 1 mile west of Lafargeville and close to the point from which plate 15 was taken. The joints run n. 70° e. and the view shows that some solution takes place along them even in this rock; in fact the stream is now flowing below ground and breaks out as a large spring at the base of the rock wall shown in plate 15. H. P. Cushing, photo, 1908

berry is surrounded by quartzite and granite and there is no known evidence of limestone in the bed.

Whether these basins were dug out by ice, or have resulted from warping, we are unable to say. In either case we can not see why no lake was formed in the valley which heads at Browns Corners, and is of identical type with the others. The extreme head of a valley up which the ice was moving would seem an unlikely place for it to dig. Solution of limestone may have aided in the formation of some of the basins. Though we are unable to account for them to our satisfaction, their localization seems to us unquestionably due to the localization of the especial type of valley heads in which they occur.

Underground drainage

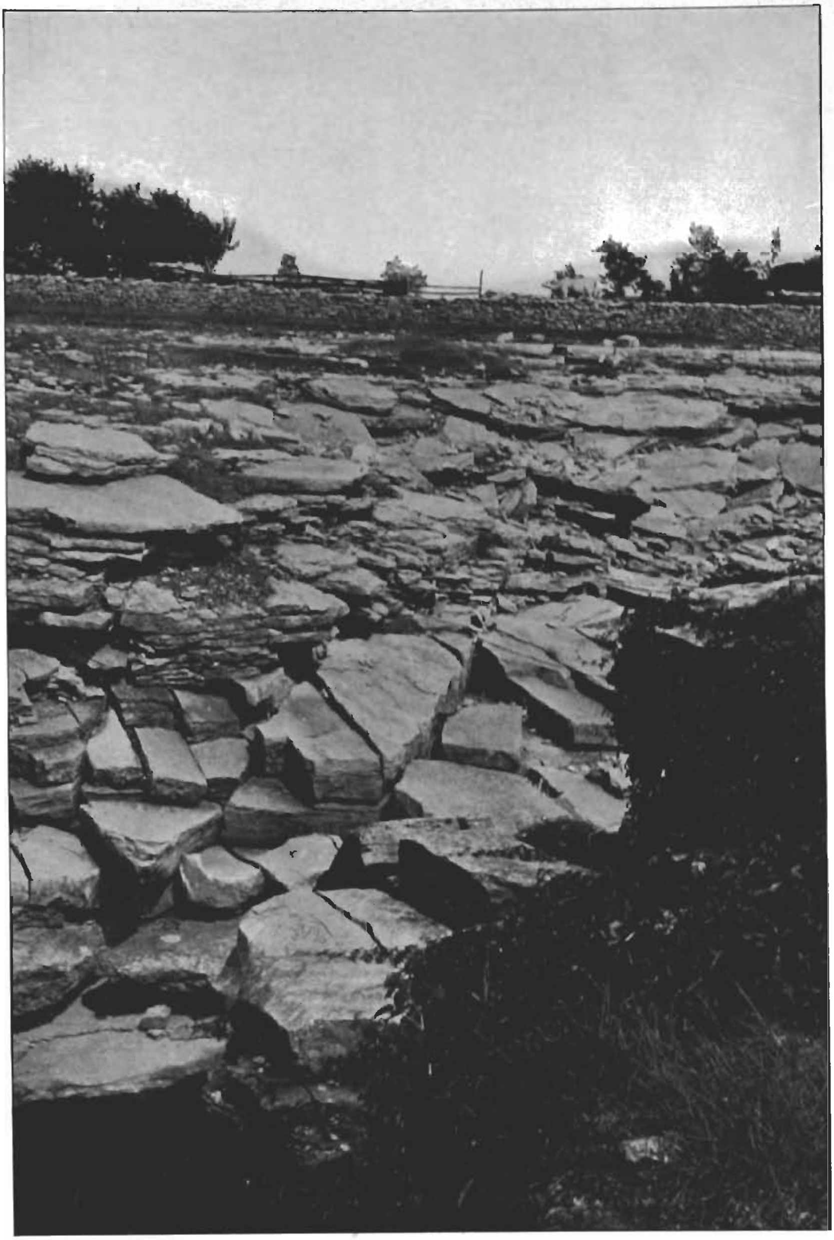
It has previously been shown how, in the more soluble limestones of the district, chiefly the Black River and upper Lowville, rain water widens the joint cracks by solution, and much of the surface water of the district passes down through these fissures to underground flow [pl. 26 and 27]. The Leray limestone is more soluble than the Lowville and the chief underground drainage of the region is in Leray districts, the underground waters running along on the upper surface of the Lowville, slowly enlarging their channels by solution. But there are also underground waters in the Lowville the upper beds of which are more soluble than those beneath. Even in the Theresa formation similar action is at times seen. In plate 35 may be seen bared Theresa surfaces in the bed of a brook, with joints considerably enlarged by solution, sufficiently so to allow the water of the creek to entirely disappear through them, to emerge a few yards away at the base of the cliff shown in plate 15, the cliff being part of the rock wall of a somewhat filled Tertiary valley, that of the Chaumont river. During the spring floods the underground channel can not care for the entire flow, and part of it remains at the surface, flowing over the rock exposed in the view. In the Leray and Watertown limestone districts are many stream beds of bare rock, totally dry throughout the summer, with their waters underground, but showing plainly the incapacity of the underground channel to care for flood waters, which flow in part at the surface, and keep the beds thoroughly washed out. Examples of such are the creek coming into the Black river from the south at Felts Mills (southeast corner of Theresa sheet), and the bed of Philomel creek near Brownville. Much underground water comes into the Black river, all across the district.

With enlargement of the underground tunnel the roof tends to cave in, at first where thinnest, followed by gradual lengthening. In most cases the cover is thinnest toward the stream mouth and caving in begins there and works slowly upstream. In the case of the creek at Felts Mills, just referred to, the map shows Lowville limestone in its bed for a half mile above its mouth, beyond which the Leray forms the bed rock. In the Lowville for part of its course the stream is above ground, and the point where the formational contact crosses the stream marks the point of emergence from underground, and the slow upstream working of the roof cave in. In plate 36 is a rather unsatisfactory view of the caved roof of a small stream, unsatisfactory because no position of the camera which looked upstream could be obtained, and we are here merely looking across from one bank to the other, with the nearer bank somewhat hiding the view of the opposite one. The stream is a small one, fed by the underground waters of a Leray promontory of no great extent, but its waters emerge from well down in the Lowville, (which alone appears in the plate) and can be seen in the extreme lower left-hand corner. The caving extends many yards upstream and amounts to some 20 feet in hight at the lower end.

Plate 37 gives an interesting illustration, on a small scale, of another feature. The view shows a Lowville platform, surfaced by a resistant layer of somewhat less solubility, and, on the right, the point of emergence of a small, wet weather stream, flowing in a shallow underground channel in the more soluble material underneath. The stream course then curves across the foreground and passes backward and toward the left, its course margined by the projecting edge of the hard layer, which has otherwise been removed from the channel with the exception of the fragment left as a tiny "natural bridge" on the left.

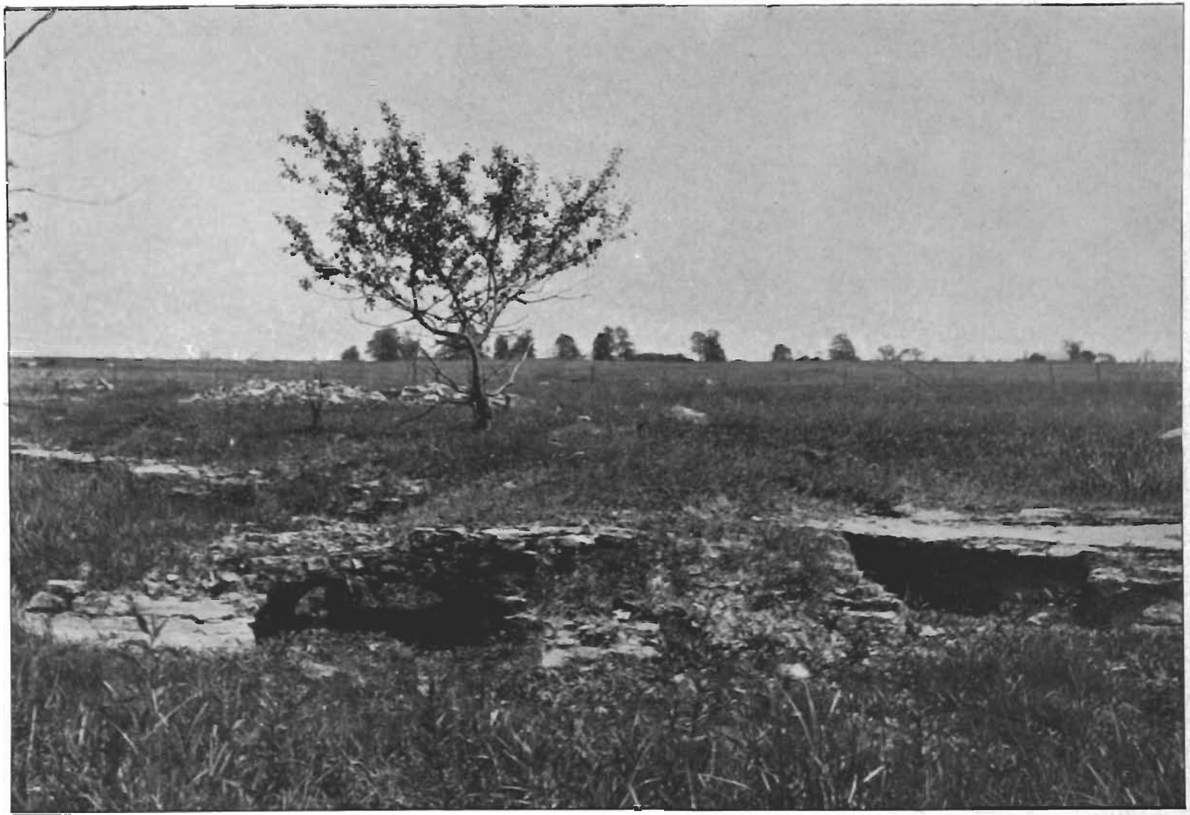
As already pointed out by Ruedemann, in his account of the Lowville inliers in the Leray limestone, very interesting underground features are shown in the Perch river valley about Limerick (Clayton sheet). The rock structure there seems to us to be anticlinal, with the Leray limestone at Limerick marking the site of a sag, and the Lowville inlier, just south, the site of a dome of the anticlinal crest. North of Limerick increased southerly dip transfers the stream from the Lowville to the Leray horizon, south of it diminished south dip transfers the stream back to the Lowville again, the point of transfer being marked by a fall [pl. 23] as is the rule in the streams of the region when passing

Plate 36



Caved-in roof of a small underground stream in Lowville limestone, nearly 3 miles west of Sanford Corners, Theresa quadrangle, looking north. A good position for the camera could not be obtained so that the view does not exhibit the conditions clearly. The issuing stream shows in the lower left-hand corner. H. P. Cushing, photo, 1907

Plate 37



A less soluble, overlying a more soluble layer of Lowville limestone. A small cavern in the latter and covered by the former shows on the right, and a miniature "natural bridge" left in the wearing away of both shows on the left; 3 miles northwest of Sanford Corners. H. P. Cushing, photo, 1907

Plate 38

Perch river emerging from beneath a limestone wall after flowing underground for ¼ mile. Note the sunken appearance of the limestone of the wall. H. P. Cushing, photo, 1908

from the Leray to the Lowville. But when increased south dip brings down the Leray again, at the south end of the inlier, the formation appears as a wall across the valley, and the stream follows the Lowville underground, though its course is marked by a depression in the surface of the Leray above. After flowing underground a short distance the river reappears at the surface, or more strictly the surface comes down to the river level, owing to caving down and removal of the Leray. In plate 38 this emergence of the stream is shown. It quickly passes again underground. The process seems definitely the enlargement of an underground channel by solution until the roof becomes unsupported, sags and caves in where thinnest, with succeeding gradual extension of the caving in process, both up and down stream. About Limerick the Leray limestone forming the stream walls is shown in all stages of disturbance due to this undermining process. The view in plate 23 shows the process in an early stage, and that in plate 39 in a much more advanced stage, the Leray here being in a condition for which Ruedemann's term of "scrambled" is so absolutely applicable, that we can not refrain from utilizing it.

In plate 40, a view of the stream above the falls at Limerick, we seem to have a direct exposition of what the character of the stream is when underground. It seems distinctly a solution, not a corrasion, channel following the joints in beautiful, zigzag fashion. The chief part of the course shown in the view is on a northwest joint, but in the foreground, and also in the background, it is along a set of north joints. It seems to us highly probable that the stream was formerly underground here. Unquestionably the channel is due to solution along, and guided by, the joints. The locality is so suggestive that it is a pity a longer portion of the stream's course can not be photographed. A contrasting view, that of plate 41, shows a limestone surface (the same limestone) corraded and etched by surface solution and wear.

The influence of the low folds in the Paleozoic rocks in causing falls in the streams which more or less directly flow down the dip, has just been noted in the case of the fall at Limerick. The course of the Black river across the south margin of the map furnishes a fine illustration of a stream whose fall is precisely that of the dip, and along which, owing to variations in the amount of dip, repeated falls occur over identically the same rock horizon. The river here has cut a shallow valley in rock, in postglacial times, and the chief falls in this part of its course are at Felts Mills, Black

River village, Watertown, Brownville and Dexter; and at each locality use is made of the water power. Every one of the falls is over the massive Leray limestone into the Lowville beneath, as well shown in Ulrich's excellent panoramic view of the main fall at Watertown [pl. 42]. There are minor falls of the same type between the chief localities. Below the fall the river flows along in the Lowville until the steepened dip on the western limb of an anticlinal fold carries the overlying Leray limestone down to, and beneath, the water surface, forming the bottom of a shallow, synclinal trough [*see* pl. 28 for such steepened dip at Brownville]. In this the dip flattens, and then becomes low east, bringing the Leray base back to stream level, and giving opportunity for development of the fall as the water passes on to the less resistant Lowville beneath, the fall so begun slowly cutting back up stream with gradual increase in hight. Down stream the river remains on the Lowville under the general low anticlinal arch, until the drop of its western limb again puts the Leray limestone beneath the river level, with repetition of the previous conditions and another fall where the limestone comes back again. Because of the westerly dip the western limb of the anticlines is steeper than the eastern, and the river cuts the bottom of each syncline at substantially the same horizon. The diagram [fig. 12] will illustrate the conditions, which are somewhat exceptional, better than can be done verbally.

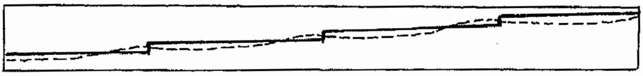


Fig. 12 Diagram illustrating the rock structure which gives rise to the successive falls in the Black river, the heavy line representing the river bed with three falls, and the sinuous dotted line the base of the Leray limestone, showing how, due to the folding each fall is over the same rock horizon as its predecessor. Dips and fall of river much exaggerated

PLEISTOCENE GEOLOGY[1]

History

A brief outline of the Pleistocene history and its relation to the earlier time is given on pages 23 and 24.

At least three distinct episodes are recognized in the recent geologic history of our region. These are (1) burial under the ice sheet, (2) burial under standing waters, (3) renewal of the exposure to the atmosphere.

Glaciation. The glacial theory has long since passed into the category of accepted fact. That our area has been subjected to

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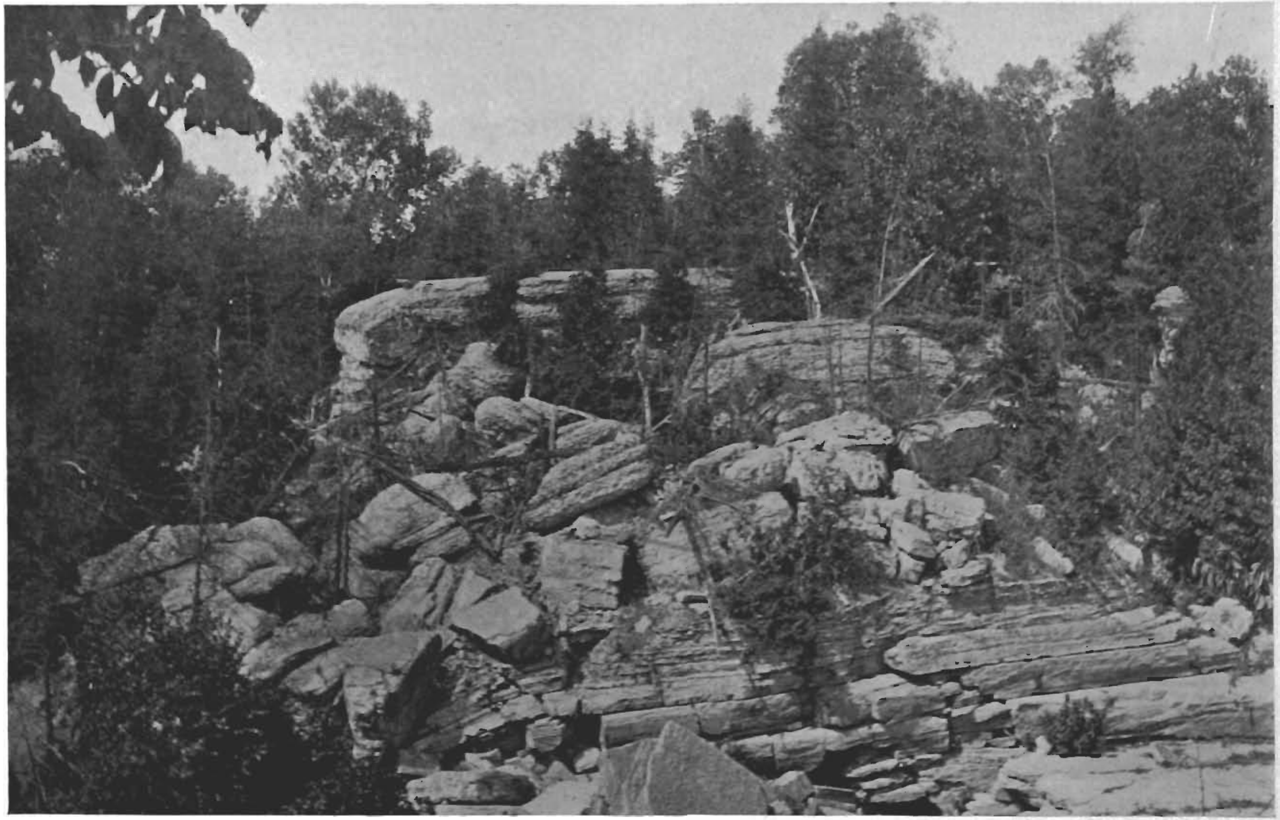
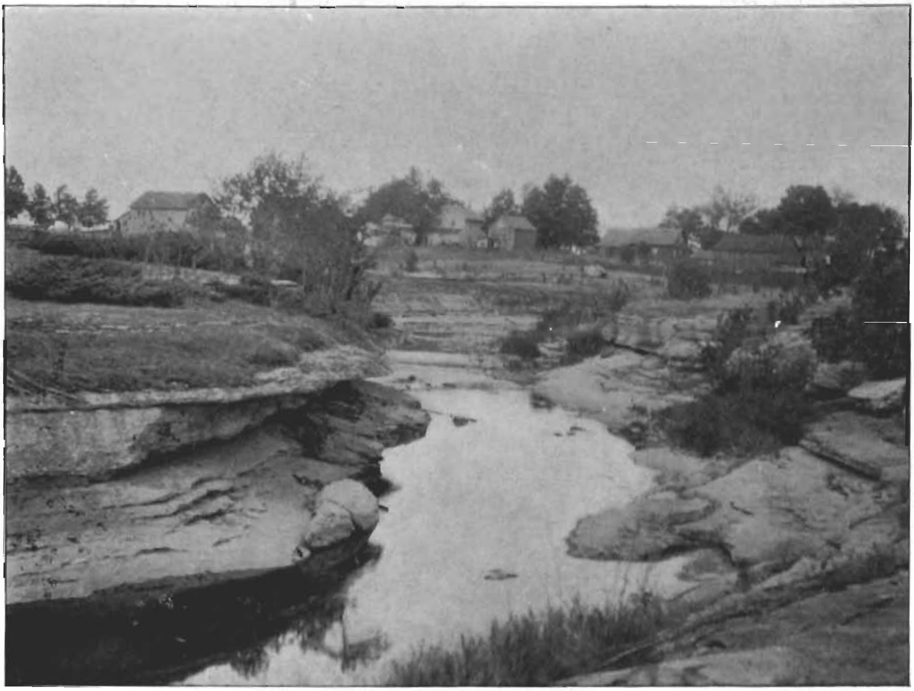
[1] By H. L. Fairchild.

Plate 39



Leray limestone overlying Lowville, banks of Perch river at Limerick, near the point at which plate 21 was taken. Shows the Leray breaking up and working down the bank, owing largely to solution of the Lowville beneath. H. P. Cushing, photo, 1908

Plate 40

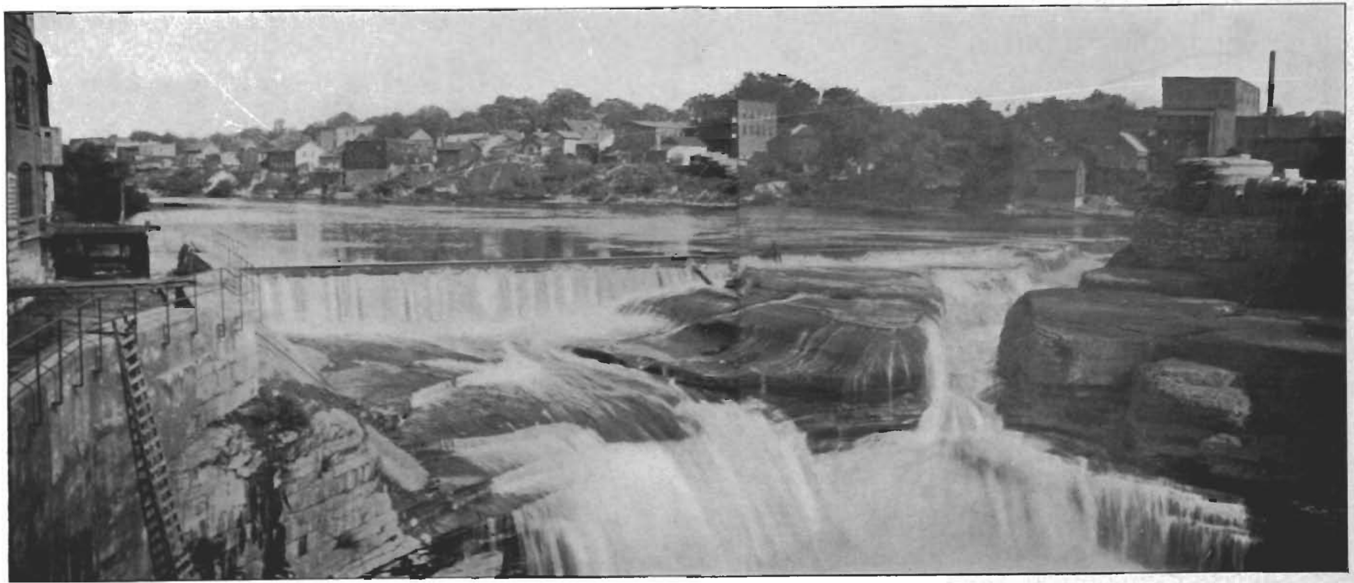


Perch river above the falls at Limerick, Clayton quadrangle [*see* pl. 23]. The rock is Leray limestone and the stream course here follows enlarged joint cracks, first one set and then another. The enlargement seems wholly owing to solution and likely was formerly an underground channel. Looking northwest and upstream. E. O. Ulrich, photo, 1908

Plate 41

Stream erosion of Leray limestone, west edge of Watertown; north bank of Black river. Looking south. H. L. Fairchild, photo, 1908

Plate 42



Fall in the Black river at Watertown; river falling over the lower bed of the Leray limestone into the Lowville beneath. E. O. Ulrich, photo, 1908

the rubbing and grinding action of a continental ice sheet has long been recognized, and now it seems almost certain that instead of only one there have been several ice invasions of the territory. Students of glaciation find evidences of multiple glaciation in the Mississippi basin, in Canada, in New England and in Pennsylvania. It seems impossible that New York should have escaped occupation by ice sheets that buried surrounding territory. In the Mississippi basin the glacial epochs have been named as follows, in order of time: Jerseyan, Kansan, Illinoian, Iowan, early Wisconsin and later Wisconsin. While there is some doubt as to the validity of the Iowan yet the multiplicity of the glacial invasions seems to be a fact. The intervals between the glacial stages, the interglacial epochs, are believed to have been long periods of temperate climate. It seems possible that our present time of release from glacial conditions may be only a warm interval between the latest ice invasion and another invasion to come in the near (geologically) future.

This matter of multiplicity of ice invasions is here emphasized for the reason that the glacial features of our district seem to require for satisfactory explanation the work of more than a single ice sheet. The glacial phenomena will be described in proper order.

Submergence. *Lake Iroquois.* As the latest glacier waned and the front receded and moved northward the ice was replaced by a body of water, the glacial lake Iroquois. This great lake, held in the Ontario basin by the ice barrier blocking the St Lawrence valley, and with its outlet at Rome to the Mohawk-Hudson, laved the receding ice front continuously over all the area described in this paper. An important effect of this condition, which the reader should hold in mind, is that all the materials left by the waning ice were laid down beneath the Iroquois waters, and are consequently more or less modified by the water action.

The present altitude of the Iroquois beach east of Watertown is 733 feet. The only point on the entire area covered in this paper which is sufficiently elevated to reach the Iroquois plane is the extreme southeast corner of the area, as shown at the bottom of the Theresa sheet, [pl. 44]. Here the nose of the Rutland promontory brings the 800 foot contour on the map and the Iroquois shore line is a steep cliff on the limestone scarp. On account of the postglacial uplift and northward tilting of the region the Iroquois plane, and all later water planes, rise to the north. On the parallel of Redwood it is estimated that the Iroquois water surface was about 800 feet, and at Chippewa Bay toward 900 feet. The depth of water over the plain at Watertown was 200–250 feet, at Lafargeville about 350 feet, and over the plains at Chippewa Bay about 550 feet.

Eventually the ice barrier weakened in the St Lawrence valley and the Iroquois waters found a new outlet north of the Adirondacks which was lower (at that time) than the old outlet south of the Adirondacks by the Mohawk valley. One point of escape was the "Covey Hill gulf," precisely on the international boundary between New York and Canada, about 4 miles northeast of Clinton Mills.[1] The Covey gulf is a great V-shaped gorge in hard Potsdam sandstone, leading north of east, and it carried the waters of the second stage of Iroquois, or the Hypoiroquois, over to some lower level in the Champlain basin. From aneroid measurements it is estimated that the altitude of the head of the gulf is about 850 feet, or perhaps somewhat higher, but when the gulf was made the district was at least 460 feet lower than it is today, and must have been lower than the Rome outlet, which is now 430 feet. It appears that the Covey gulf outlet was not much lower that the Rome outlet, perhaps 50 feet and possibly 100 feet. It might seem as if the Covey gulf outlet represented sufficient length of time for the lake waters at that level to produce recognizable features along favorable stretches of the shore line, and such may yet be found. Dr Gilbert has suggested that possibly the Covey gulf was chiefly cut by a more ancient glacial outflow and that the Hypoiroquois may have done little work beyond clearing out the old gorge.

As the ice front melted back this second stage of the glacial waters of the Ontario basin found yet lower escape along the north side of Covey hill, between the ice wall and the rock slope. This third phase of the Iroquois waters must have been short-lived, with rapidly-falling levels, the river flow only terracing the sandstone slope. It is thought that the final effect of this down-draining of the glacial waters was to bring them into confluence with the oceanic waters which then occupied the Champlain basin and are called the Champlain (Woodworth's Hochelagan) sea. The supposed extension of the sea-level waters into the Ontario basin is known as Gilbert gulf.[2]

Gilbert gulf. If our present conception of the history is correct the sea-level waters covered nearly all the territory comprised in our five quadrangles. On the north slope of Covey hill the Champlain beaches have an altitude of at least 460 feet, which is the measure of the amount of land uplift in

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[1] For description and illustrations of this outlet see paper by J. B. Woodworth, Ancient Water Levels. N. Y. State Mus. Bul. 84. Ebenezer Emmons and G. K. Gilbert had noted the feature.

[2] Gilbert Gulf (Marine Waters in Ontario Basin). Fairchild, H. L. Geol. Soc. Am. Bul. 17:712-18.

that district since the ice left that locality. The Gilbert plane declines to the south and southwest and on the south border of our area the beaches are 390 feet [pl. 45]. North of Lafargeville [pl. 46] strong beaches lie at 440 feet, and 2 miles southeast of Redwood a bar is found at 450 feet altitude [pl. 47].

It has not seemed practicable to make maps for this writing to show all the Gilbert shore lines of the area, but the strongest shore features are indicated on the maps, plates 45–47. These are wave-built bars and spits and wave-washed limestones. Some of these features are shown in the halftones, plates 48–53. The southeast portion of our area, being the southeast diagonal half of the Theresa sheet, was mostly above the Gilbert waters. The submerged parts are such as lie below 400 feet at the south edge of the sheet and below 440 feet at the north edge. It will be seen that this is the low ground north and northeast of Brownville, the valley of Perch river, the low ground about Theresa and the valley of Indian river. All the rest of the region was under the full Gilbert level except the three limestone hills northwest of Dexter; the limestone plateau between Stone Mills, Depauville and Lafargeville; the limestone plateaus north of Depauville; the boulder-kame hill 2 miles north of St Lawrence corners, known as the "Hogback"; and the group of boulder-moraine hills north of Lafargeville; one being cut by the edge of the Theresa sheet. These areas which received wave action so as to leave beach records are mostly shown in the plates 45, 46 and 48.

While all surfaces between the highest Iroquois and the Gilbert planes have been wave-swept by the subsiding waters, and many patches of bared rocks are found at various levels, no beach phenomena have been noted between the two planes. All the high level shoreline features in our district are confidently referred to the sea-level waters.[1]

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[1] Since this paper has been in type Prof. George H. Chadwick discovered heavy beaches and deltas of Lake Iroquois in St Lawrence county, and also extensive deltas inferior to the Iroquois plane and of uncertain relationship. In August 1910 we examined these features and carried the study northeastward into Canada.

The Iroquois plane is now definitely known at several points, the farthest east being at Chateaugay with altitude 975 feet. On the international boundary at Covey hill the full-hight plane is not much above 1000 feet. The head of Covey gulf, the outlet of the lower or Second Iroquois, is about 980 feet.

A recent survey on the Canadian side of the boundary gives us precise altitudes for the sea-level beaches (Gilbert gulf), which have at Covey Hill post office a hight of a least 523 feet.

These altitudes are entirely consistent with the figures and facts relating to the Iroquois and Gilbert gulf water planes given in this report.

From the Iroquois to the Gilbert levels the waters fell with comparative rapidity by the removal of the ice dam. The apparent lowering of the Gilbert waters was on the contrary by the very slow uplifting of the land out of the sea-level waters. This rising of the land must have been so slow as to give opportunity to the waves at all minor levels to produce shore line phenomena, and many such are found. However, such proofs of the presence of standing waters are missing over long stretches of even the summit plane, which emphasizes the well recognized fact that absence of clear wave work does not necessarily prove the absence of standing waters.

But while beach phenomena may be lacking or weak over wide stretches we find other evidences of the waters. Either by the lowering of the Iroquois waters over the higher ground or by the lifting of the lower ground through the Gilbert waters all the land surfaces have been brought into the zone of wave action and subjected to erosion or deposition by the agitated waters. In consequence the steep slopes, the projecting rock masses, tables and knobs, have been more or less cleared of their drift and specially of the finer material, which has been shifted to lower levels. The broader plateaus and plains have been smoothed and the lower grounds, valleys, basins and hollows, have been more or less filled or silted with the detritus, sand or clay, washed from the higher ground. This action explains two striking characters of the region, the areas of bare rocks and the silt-filled basins, which will be discussed later.

Conclusive proof that the lower waters were confluent with the sea would be the finding of marine fossils. Such have not yet been found in the Ontario basin, though they are abundant in the Champlain and St Lawrence valleys, and marine shells have been found as far west as Ogdensburg.

Atmospheric erosion. The whole region, above the Ontario level, has long been subjected to a renewal of the atmospheric agencies. The length of time is unknown, but is not equal for all the area. For the lower plains, near the present lake, the time must somewhat exceed the life of Ontario; while for the higher ground, above the Gilbert levels, the time must cover not only the life of Ontario but also that of Gilbert gulf. If we estimate the life of each of these water bodies as 10,000 years it may give some fair conception of the duration in years. For lands above the reach of Lake Iroquois its length of life must be added to the time of exposure, at least another 10,000 years. It is likely that these figures are too small rather than too large.

Physiography

Glacial diversion of the Black river. The history of the Black river is not only the most interesting problem connected with the evolution of the physiography of the region but specially important as it may supply the key to Tertiary drainage of the entire area.

In only the middle portion of its course has the present Black river any pronounced valley. The headwaters and upper section, about 30 miles long, lie on the crystallines of the southwest slope of the Adirondacks, with no conspicuous valley. The lower section, below Carthage, has only a shallow postglacial channel. The great valley begins at about Forestport and extends northwest to Carthage, a distance of more than 40 miles, and steadily deepens and widens northward. At Glenfield or Lowville, near the middle part of the valley, the altitude of the river is 740 feet, while the great ridge on the west, separating this valley from the Ontario, rises to 2000 feet, and the breadth of the valley is at least 10 miles on the 1300 foot contour.

Former writers have regarded the Black river as the trunk stream of the early drainage which headed the Ontario valley.[1] It appears to the writer that that view is a mistake and that quite the opposite is the fact, that the Black river was the headwater of the St Lawrence drainage, at least for New York State.

Plate 43 shows the present hydrography of the region and the divide between northward and southward streams of the Ontario-St Lawrence valley. Plates 44 and 47 show portions of the divide on the larger scale of the topographic sheets. On plate 43 the heavy, broken line south of the Black river marks what was the preglacial divide between Ontario and St Lawrence drainage before the Black river was forced by the interference of the ice sheet across the divide. The light, continuous line indicates the present and shifted divide. It is apparent that below Great Bend the river has peculiar and anomalous relationship, and that the divide leading east up the Adirondacks slope is newly established.

In discussion of this problem the theoretic evolution of the drainage will be considered first and then the recent history and the present features.

The Black valley was initiated and developed, at least as early as the Tertiary uplift, along the contact or overlap of the Ordovicic sedimentaries on the ancient crystallines. The west wall of the

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[1] Specially the paper by A. W. G. Wilson, Trent River System and the St Lawrence Outlet. Geol. Soc. Am. Bul. 15:211-42. Pages 236-38 refer to our district. With the entire article excepting the point of the Black river relationship we are in hearty accord.

great valley shows all the strata from the Pamelia to the Oswego sandstone. The east wall of Precambric rocks is deeply buried under sand plains or delta deposits accumulated in glacial waters.[1] The axis of the deepening and north leading valley migrated westward, down the slope of the basal crystallines and against the outcrop of the sediments.

The great ridge dividing the Black and Ontario valleys now terminates abruptly in the Rutland promontory with a limestone scarp about 400 feet high. The point of this promontory is shown on the lower edge of plate 44, south of Felts Mills and Black River villages. A glance at the Watertown sheet will show how the river below Felts Mills clings to the foot of the scarp. A moment's thought will make it evident that these thick limestones did not originally end here, but must have extended far north, overlying the district toward the St Lawrence. It seems perfectly evident that the stratigraphic relations and the erosional conditions which produced the Black valley above Carthage must once have extended much farther northward, and the Tertiary river probably had its course northward along what is now the east slope of the St Lawrence valley, in continuation of the Forestport-Carthage valley. The problem is therefore narrowed to the question of the time of the removal of the Trenton limestones north of the Rutland promontory, and the date of the diversion of the river from its northward into its westward course.

A singular physiographic feature of the region is the northward or rather northeastward direction of all the heavy streams north of the Black river. These all flow along parallel with the St Lawrence, and in some sections at even lower levels. In normal stream development the tributaries should flow toward the trunk stream. The Indian, Oswegatchie, Grass, Raquette and St Regis are more or less independent of the St Lawrence and are not normal tributaries. Their courses have probably been modified, straightened and their parallelism emphasized by repeated glaciation, but the latest ice erosion has certainly been insufficient to produce such channels. Their direction is in precise opposition to the glacial effect and also in opposition to the postglacial uplift of the region. It is in harmony with and in continuation of the Black valley, curving eastward around the uplifted mass of the Adirondacks. It seems altogether likely that these stream courses were developed by north leading drainage having practically the same stratigraphic

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[1] See a paper by the writer, Glacial Waters of the Black and Mohawk Valleys. N. Y. State Mus. Bul. *In press.*

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relation as that which initiated the Black valley. The only features which are not in harmony with the above theory are the southward course of a section of the Indian river, above Evans Mills, and of the Oswegatchie above Oxbow. These are probably due to glacial diversion, similar to that of the Black below Great Bend, but for better knowledge we must await the topographic sheets.

Professor Cushing suggests that north from Felts Mills the preglacial divide might have swung west from the present course, passing south of Perch lake, through Depauville and south of St Lawrence corners. The wider valley of the Chaumont north of Depauville and the northward course of French creek favor this view. It is quite possible that Prewisconsin glacial erosion has caused a northward migration of the portion of the divide that was transverse to the ice flow, but the latest ice work seems to have been too weak. We may not appeal to forced stream flow during the last ice recession, as the region was then buried under Iroquois waters. The northward uptilting of the area tends of course to divert sluggish drainage into southward flow, but alone this could not be a very effective factor.

Passing now to certain specific data and features connected with very recent history, the reader should note again the intimate relation and parallelism of Black river to its northward flowing neighbors [pl. 43], after which a glance at plate 44 will show the cause of the separation and the character of the barrier. At Great Bend and Felts Mills the river has cut into the south side of its own delta, that was built in Lake Iroquois. Along much of that stretch rock is seen in the bed of the river, beneath the steep wall of the delta deposits. North of the delta the ground is 100 feet or more lower than the river, and all draining northward. At Felts Mills the river has an altitude of 580 feet, while only 1½ miles north, and simply across the delta divide, is Pleasant creek, a tributary of Indian river, at only 520 feet altitude. The fall from Black river to Indian river by Pleasant creek is 200 feet in about 6 miles. Further up stream, at Great Bend the river has a large meander in the delta and the facility for northward flow may be even better than at Felts Mills, but the topographic survey has not covered the district.

The suggestion is natural that possibly a rock barrier is buried under the delta, which would be an effective barrier to north escape of the river if the delta were removed. Fortunately we have specific data. Mr F. A. Hinds, the well known hydraulic engineer of Watertown, has pointed out the important fact that the drainage of the great sponge of sand plain, on which is located the military camp, is not into the Black river but north into the Indian river.[1] Along the north side of the sand plain huge springs gush out along the contact with the impervious drift, while such are entirely wanting on the Black river side. It is certain, therefore, that if the delta at Felts Mills and Black River were not there the river would plunge northward. It is equally certain that before the ice invasion, and the deposition of the delta and moraine barrier, the river did flow northward. The only condition which could produce southward flow would be a northward uplift 20 or 30 feet per mile greater than we have today, which is extremely unlikely for this district. As long as any of the St Lawrence valley drainage passed north the Black river went with it.

The westward course of the Black river from Great Bend is due to glacial diversion. The river is on rock and with no proper valley. It is in a postglacial channel. Moreover, there is no south leading valley in the Watertown district sufficient for a large river. If there were the Black would be in it today as there is no heavy drift barrier to block drainage in the district south of Watertown.

The later history is quite clear. During not only the advance and retreat of the latest ice sheet but probably that of earlier ice sheets the Black valley high-level waters were forced westward and southward around the Rutland promontory. High on the slopes at Copen-

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[1] Extracted from report of Frank A. Hinds to the Water Board of the City of Watertown, June 29, 1908.

. . . the entire country slopes toward the north and west and away from the bank of the river which is the highest part.

The Pine Plains is a sheet of very clean sand from 50 to 75 feet thick and covering an area of from 25 to 40 square miles. The sand is so porous that all the rainfall sinks directly into it and forms a natural reservoir at the bottom. This ground water has a slow movement in the direction of the slope but does not become exhausted during the dry season as the constant character of the springs at its edge proves.

While the water of the river opposite the (U. S. military) camp is 100 feet below the surface of the plains, there is an impervious bed of clay and rock underlying the sand which is from 30 to 50 feet above the river. This clay may be seen in many places along the bank, though in others the sand has run down and covered it over. Five miles to the west the sand plateau stops and the clay substratum continues as the surface soil of the country; but here it is 100 feet lower than where it commences at the river brink under the camp.

This northwesterly slope of the subsoil determines the direction or flow of the underground water and accounts for the fact that there are but few and comparatively small springs flowing into the Black river from under the plains, while those along the western border of the sand are more copious and gather into several creeks or brooks of noticeable magnitude which flow westerly into the Indian river. The few springs along the Black river bank are where the underground water spills over the easterly upper edge of the clay stratum, but they are comparatively few and small . . . the water which emanates from under the Pine Plains does not get into the Black river to any extent worthy of attention.

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hagen and Champion are the glacial channels [*see* footnote p. 142]. The Rutland Hollow is a capacious valley cut obliquely across the nose of the promontory, parallel in direction with both higher and lower glacial channels of Black valley outflow, and was undoubtedly given its form and dimensions by glacial drainage. When the Black valley waters were lowered into Lake Iroquois the Black river built its delta in the lake northwest of Carthage, partly banked against heavy moraine. When Lake Iroquois was lowered into Gilbert gulf the Black river found its ancient course obstructed by the delta and moraine deposits and was compelled to follow around the rock promontory in the path of the stronger shore currents in the lake. West of Watertown the river dropped its detritus in the sea-level waters (Gilbert gulf), and when these waters were lowered by the land uplift the river pursued its chance course over the rock toward the retreating water body.

To epitomize: It seems certain that the earliest drainage which we can locate must have been along the weak zone of the overlap of the sedimentary rocks on the Precambric, in north and northeast continuation of the Black valley. Preceding the latest ice invasion the Black river probably flowed north. Just what may have occurred during the Tertiary uplift and the earlier Pleistocene we do not know. It is possible that there are unsuspected elements in that long history, but there is no discovered reason for any preglacial southward drainage across the divide as mapped in plate 43. The really uncertain factor is the glaciation earlier than the Wisconsin epoch. The writer is inclined to credit to glaciation earlier than the Wisconsin considerable influence in producing the parallelism of the rock forms and the drainage lines along the St Lawrence depression; and the bluntness and roundness of the Rutland promontory; and the cutting of the Rutland Hollow.

Topographic features. *Parallelism.* The topographic elements of the area have a conspicuous parallelism, about northeast and southwest, in accordance with the St Lawrence valley and river. On the Clayton and Theresa sheets this shows clearly in the stream and valley courses and in the trend of the plateaus and rock hills. On the Alexandria and Grindstone sheets the parallelism appears in the elongation of the rock knobs and the form of the lakes and the islands in the river. This character prevails down the valley far beyond our district, as shown by the river courses which instead of flowing directly to the St Lawrence follow along in parallel courses [pl. 43].

The genesis of this prevailing orientation probably involves factors which cover the entire geologic history of the region. In an earlier chapter Professor Cushing has shown that during the time of the earliest sedimentation in the region there was alternately a tipping to the northeast and the southwest, the fulcrum of motion lying across our district, initiating what is called the Frontenac axis [p. 95]. The broad depression of the valley is thought to be partly the result of sagging, accompanied by jointing, one main trend of joints having fair agreement with the trend of the valley. Cushing also shows that some slight folding occurred in Paleozoic time and stronger folding in Precambric time which probably had some directive influence on the drainage [p. 108–115].

The larger existing features and general stream directions were developed during Tertiary time under subatmospheric erosion. During Pleistocene time the St Lawrence valley, being closely in line with the spreading flow of the ice sheet over the region, served as a trough for the advancing and the waning ice lobes. We do not know the number of ice invasions but it seems quite certain that the latest, or Wisconsin, ice sheet was preceded by others of probably greater effectiveness in erosion. The striking parallelism of the minor features of the topography is probably due in some degree to repeated glaciation, the alternation of ice flow of the glacial epochs and the stream erosion of the interglacial epochs mutually assisting or guiding each other.

Dominant types. The topographic features in the sedimentary rocks are naturally an expression largely of the stratigraphic characters. This has already been discussed in a former chapter by Cushing [p. 121–136]. In the present connection we have to consider the topography in its relation to the glacial and glacio-aqueous history.

Leaving out of account for the present the localized and scanty moraine deposits, we may distinguish two dominant types of the surface relief in the area, (1) the rounded rock hills or knobs of rather striking relief in the northern part of the area, in the district of Potsdam and Precambric rocks, and (2) the broad level stretches which characterize the southern half of the area, where the rocks are well stratified.

Rock knobs. In the northern part of the area, covered by the Grindstone and Alexandria sheets and the northeast part of the Theresa sheet, the crystalline rocks and the lower Potsdam appear commonly in the form of knobs or bosses, singly or in clusters and chains, as illustrated in plates 6 and 7. Cushing has shown [p. 54]

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that the knobby surface of the crystallines is the immensely ancient erosion surface of the Precambric land area, which had been buried under Potsdam sediments and only recently uncovered. Ice erosion seems to have had very little influence in shaping the surface, merely rounding and smoothing the knobs.

The major axes of the knobs are roughly parallel with the valley and the ice movement, but the relation to the latter is mostly casual and not genetic. The struck or northwest side commonly shows more erosion, but frequently the difference is not evident. As a rule the crystallines have not retained their striae and polish as well as the Potsdam sandstones.

Plains of erosion. The broad plains, either rock or rock floored, are regarded as the product of long eras of atmospheric erosion with later glacial planing and a finishing touch of wave smoothing. They are found in districts where the sedimentary rocks are persistent in considerable thickness so as to cover the Precambric and the lower and irregular Potsdam. Broad tracts of this class consisting of upper Potsdam occur south of Chippewa Bay and toward Alexandria Bay. Theresa dolomite forms the plain north of Chippewa Bay and covers large areas on the parallel of Plessis and Clayton. South of the parallel of Lafargeville the plains and plateaus are limestones.

The earlier ice sheets seem to have lifted or plucked away the weathered and weak superficial layers of these stratified rocks down to some firm, less jointed and more resistant bed; but the flatness and smoothness of these level stretches is partly due to the latest action, the leveling action of the shallowing waters. The glacial drift is commonly thin on these plains and patches of bare rock are very frequent, sometimes acres in extent, specially on the Potsdam. A good example is seen at Plessis; which village was formerly called "Flat Rock." On the highways rock frequently occurs in unexpected manner and often forms the wagon track for considerable distance. Although glacial polish and striae occur frequently on the Potsdam the majority of exposures have either lost their smoothness or were never severely rubbed. On the other strata glaciated surfaces are not common.

These plains have been trenched by stream erosion and many of the valley walls are yet steep, those of Chaumont river for example. The differential erosion of the several strata has produced scarps or benches about the margins of the higher plains which are frequently striking features of the landscapes and sometimes are persistent for long distances. These have been described in a former chapter in connection with the stratigraphy [p. 129]. The valley and scarp topography is certainly older, at least in great part, than the latest glaciation.

Plains of deposition. Flat stretches of detrital deposits occupy the valleys and basins in the northern part of our area and the lowlands in the southern part. They are broadly developed over the southwestern part of the area, covering nearly all of the Cape Vincent sheet and a large part of the inferior levels of the Clayton sheet. Doubtless the more elevated of these detrital plains have rock floors, those about Lafargeville and Clayton for instance, but the rock is masked; while the valley and basin fillings are deep clay.

These plains are chiefly clay, though sometimes sandy silt and occasionally sand. They represent the distributing and leveling work of standing waters, Lake Iroquois and Gilbert gulf, and are described with reference to origin in a later chapter, page 156. The best example of the sand plains may be seen 3 miles southwest of Theresa, crossed by the Clayton branch of the New York Central Railroad between Theresa Junction and Strough. Beyond this, both east and west of Lafargeville, the plains are clay. From the trains on the Cape Vincent branch of the railroad the clay plains may be seen spread far and wide, as flat as a prairie, all the way from Limerick to Cape Vincent, with a few interruptions of rock or of till ridges.

The more extensive, upland clay plains shade off into till, while some of the valley clays are conspicuously pitted, as if deposited over ice [p. 158, pl. 47].

Lake basins. Perhaps the most puzzling of the physiographic features are the basins or basinlike valleys with steep rock walls. These are more striking in the district of Potsdam and Precambric rocks of the Alexandria quadrangle, where they hold an interesting group of lakes, the only lakes in our area, excepting Hyde and Perch lakes on the Theresa quadrangle. The five lakes of our area, near Redwood, shown in plate 47, are only the western members of a large group. Some basins without lakes and some steep-walled valleys in limestones on the Theresa and Clayton sheets are probably of similar genesis.

Two facts in connection with these basins are specially to be noted, the steep, scarplike rock walls and the very small amount of glacial drift. These features seem abnormal in a district that has been subjected to probably repeated glaciation. While these depressions are mostly oriented in general harmony with the physiographic alinement of the region, having a northeast-southwest atti-

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tude, which very likely was partly controlled by early glaciation, yet a significant number are transverse. Some basins in the vicinity of Alexandria Bay [pl. 47] and others south of Clayton [pl. 46] do not conform to the prevailing direction, and the basins of the Redwood lakes are so irregular in form as to rule out ice erosion as the dominant agent. It seems certain that these basins, like the scarp borders of the plateaus, are due to atmospheric agencies with only small and indeterminate glacial effects; or that they certainly antedate the latest ice invasion. One would naturally suppose that the scraping ice sheet would have rubbed the transverse valleys full of drift. In some valleys and against some scarps the amount of drift is sufficient to be noticeable, but it only masks the foot of the cliffs. In many relatively deep depressions the drift is scarcely perceptible, though some may be buried under the lake silts which occupy the valley bottoms.

Besides the lack of drift filling is to be noted the absence of preglacial talus accumulations. In places the Potsdam is so freely jointed that the cliffs break down under the frost quite rapidly and heavy block taluses occur which are evidently postglacial; but in most cases there is little or no talus, specially outside the Potsdam rocks. In the case of the limestone walls solution might be sufficient agency to remove the products of weathering, and this might also apply to the Precambric Grenville limestones which form some part of the basins of the Redwood lakes; but such removal can not apply to the almost imperishable Potsdam sandstone. The older fragmental deposits produced by the recession of the cliffs have been removed, most likely by the glacial ice, but without leaving much drift in their place.

The lack of drift in the basins and over the plains clearly implies a lack of drift burden in the latest ice sheet. The cause of this will be discussed later [page 172]. The small abrading power of the ice was probably due to its lack of tools, and evidently it did not have sufficient power of "plucking" or removing blocks in mass to destroy or even seriously cut the steep ledges and scarps which stood across its path.

One suggestion in partial explanation of the somewhat contradictory features, is that stagnant ice occupied the strong depressions over which the upper ice moved by shearing. This would fairly account for the absence of heavy drift in the basins and valleys and the protection of the walls. Another suggestion takes account of the fact that when the latest ice sheet disappeared from this area the front was faced by about 400 feet of water in the Redwood district. Just what that condition implies in its effects on the ice and the drift is uncertain. We do not know whether the ice melted back as a steep, high front under the dissolving influence of the water, or whether it melted as a thinning sheet, partially protected by its scanty drift, until it was lifted by the water and rafted away.

To epitomize: We conclude that the basins and stronger valleys were excavated by weathering and stream erosion in preglacial or interglacial time, with perhaps some help from early ice erosion; and that the latest ice sheet had little effect beyond clearing out the debris which it found.

Glacial deposits

Introduction. General features. Compared with areas to the southward the area under description has very scanty drift, and has suffered little recent ice erosion. The area did not lie in the zone either of dominant deposition or dominant erosion of the latest ice sheet. Over large portions of the area the rocks are nearly bare, and even in the districts where the drift cover prevails the rock appears frequently and unexpectedly. The amount or depth of drift increases southward but the only heavy moraine lies in the southeast corner of the area [pl. 44].

In considering the character and distribution of the drift it is necessary to emphasize again the fact that during the ice recession the whole area was submerged in the waters of Lake Iroquois, and this was followed by the sea-level waters of Gilbert gulf. The marginal drift was all deposited under subaqueous conditions, and wholly subjected to the distributive action of the shallowing waters.

Over the northern part of the area, where the rock foundation is either Potsdam or Precambric and the land surface irregular, the scanty drift is largely in the depressions, due specially to the work of the shallow waters. Over the southern districts, where the limestones form wide plains or plateaus, the drift is usually a veneer giving the broad stretches flat or gently rolling surfaces. Because of the lack of drift the preglacial valleys are still open, and one of the characters of the region is the valleys and basins with steep rock walls and silt-plain bottoms. The valleys of French creek and Chaumont river are open down to Ontario level; and the Perch lake valley is filled to only 70 feet over Ontario. The open character of these southern valleys is to be only partly explained by the stream erosion of the clays which constitute the bulk of the drift. The existence of the Redwood lakes in the northern district is an evidence of lack of drift filling.

The normal and common form of drift in regions of glaciation, the stony clay or clayey mixture of rock rubbish known as "till," is widely found but in relatively small amount. The larger drift masses are of three kinds: sandy or "kame" areas; boulder moraines; and pitted clay plains. The extensive plains of water-laid clay are regarded as glacio-aqueous deposits, and are described in a later chapter.

Till. In the northern portion of the area, where the rocks are Potsdam and crystallines and arenaceous materials prevail, the scanty till is sandy and stony. In the southern district where the strata are wholly limestone these give a clayey texture to the drift sheet.

The superficial till is usually incoherent and yellow or yellowish gray in color. In a few places a compact, hard, blue or blue gray till may be found which is regarded as the product of ice action earlier than the Wisconsin. The most massive exposures of the blue till are found south of our area, at Watertown [p. 166].

No drift masses that could be definitely recognized as drumlin have been noted in our territory, though they do occur over the line on the south, north and south of Watertown. Some molding of the till surfaces suggest drumlinizing of the drift, but apparently the till was too scanty to be rubbed into definite drumlin masses.

Moraines. One heavy moraine lies in the southeast corner of our area, between Black River and Evans Mills, mapped in plate 41. This is the only mass of drift of notable size in the limestone district. In the northern part of the area, where the Potsdam sandstone and the knobby crystallines give irregular surface and rather sharp relief, patches of rough and stony drift that may be regarded as morainal are quite frequent; but the only grouping which merits the name of moraine belt lies about Clayton and eastward north of Lafargeville, shown in plate 46. In general it may be said that the peripheral or morainal drift is not collected in well marked lines but is scattering, patchy and indefinite. In districts where the Potsdam prevails at the surface, with scarps and ledges that supplied very coarse material the ice-piled blocks are liable to be confused with the postglacial debris from frost fracturing of the jointed sandstone. As the Gilbert waters have rinsed away the lighter drift from the higher masses it is not easy to readily distinguish the ice-heaped blocks from the frost fracture piles; the frost work having, of course, also affected the ice deposits.

In some places the morainal character of the drift is clearly expressed by the well known features of irregular surface, mound and basin topography, but over most of the area the morainal element has been discriminated by one or the other of two features; unusually stony patches or kettles. Very stony fields with heaps of boulders and stone fences, specially if containing considerable percentage of nonlocal rock, have been diagnosed as moraine. Discrimination is needed, for in a district of ledges, scarps or cliffs, specially of the quartzitic Potsdam, the ground may be strewn with rubbish from the native rocks which is not strictly morainal, or peripheral to the ice sheet, even if glacial. This criterion of stoniness is often equivocal and in such cases is usually disregarded.

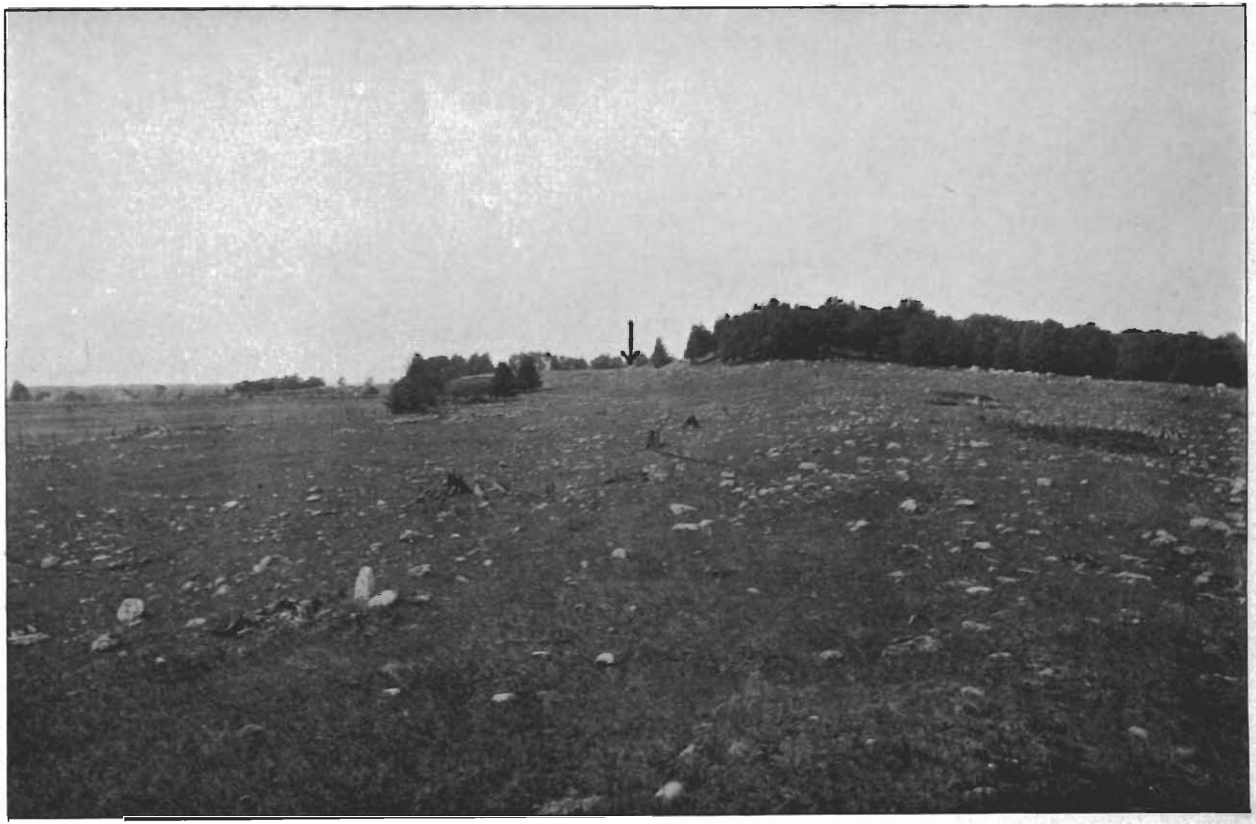
In districts of clayey till the occurrence of kettles or inclosed basins in the drift is interpreted as indicating ice margin deposits, and sometimes they may correlate with stony tracts. Over limestone floors small sinks may simulate kettles, but over the sandstone and crystallines this deception can not occur.

The above description will suggest how difficult if not quite impossible it would be to accurately map the morainal deposits over the entire area, and this is not attempted. The heavier morainic masses are shown in plates 44–47.

Boulder moraines. Plate 47 shows the larger portion of the Black river moraine, which continues southwest to and beyond Watertown. On this map conventional signs indicate lines and ridges of block moraine. Some of these have high relief and are striking features in the landscape. One photograph is given in plate 56. The character of the ridges as bare limestone blocks is partly the result of wave work of the falling waters of Lake Iroquois. The Black river delta built in the lake was banked against the moraine and partly buried its southeastern border. From the trend of these ridges it is apparent that the ice flow constructing them was from the northwest, and that the ice margin was spreading or deploying on the plain.

The great massing of limestone blocks with very few crystallines could hardly have been effected by the earlier ice movement from the northeast or north, as the limestone formations do not extend far in that direction. The change in direction of flow enabled the ice to sweep up the rubbish left on the limestone tract on the northwest, and perhaps the new direction of impact, changing from southwestward to southeastward, gave the ice a more effective grip for

Plate 48

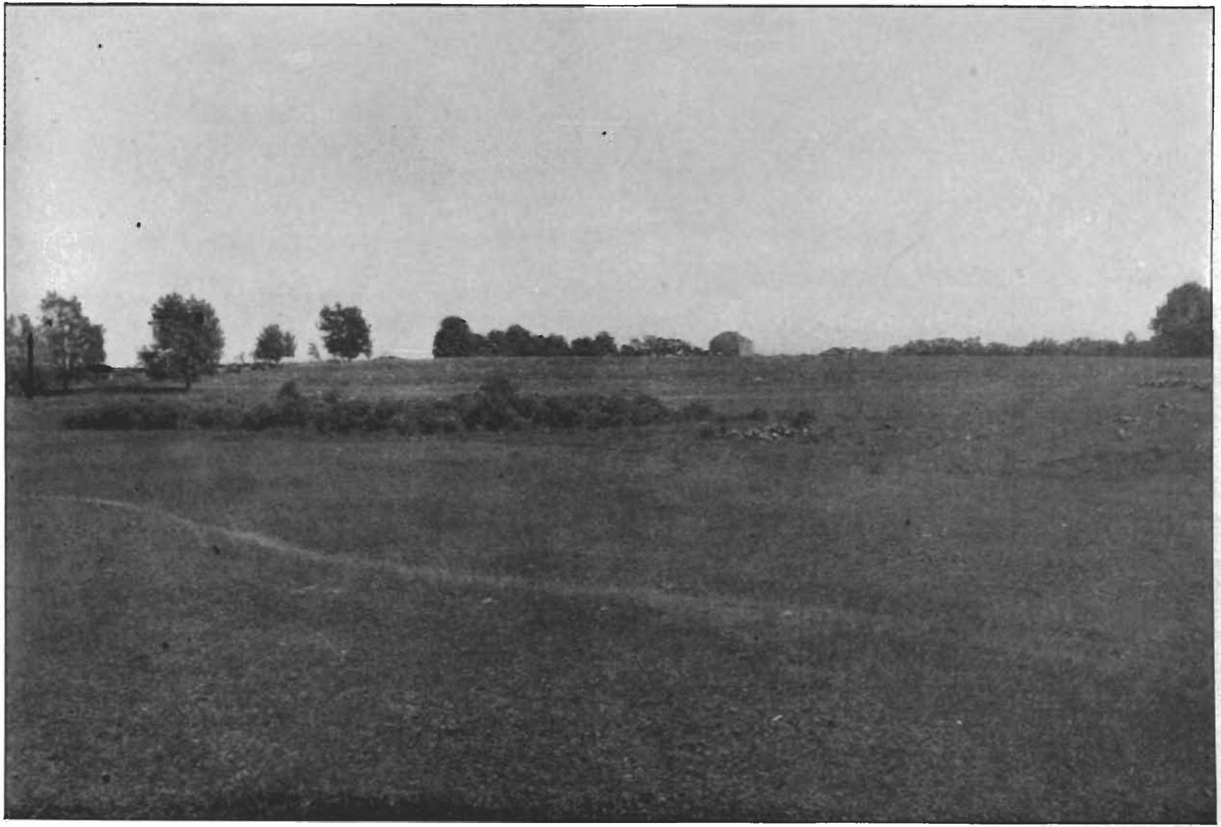


Gilbert Gulf bar south of Pine Grove hill, 4 miles northeast of Lafargeville. Looking north. Altitude about 420 feet. Arrow shows position of camera in plate 49. H. L. Fairchild, photo, 1908

Plate 49

Gilbert Gulf beach, Pine Grove hill, 4 miles northeast of Lafargeville. View facing southeast. Altitude of wave work about 440 feet. Arrow shows position of camera in plate 48. H. L. Fairchild, photo, 1908

Plate 50



Gilbert Gulf shore, north side of Haller hill, 2 miles north (by east) of Lafargeville. Looking east of south from the sixth bar from the summit. Bar basin in foreground. Arrow shows position of camera in plate 51. H. L. Fairchild, photo, 1908

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plucking on the limestone ledges; which previously had been attacked from the northward.

The massing or localization of the drift, so unlike anything elsewhere in the southern half of our area, suggests that it was the accumulation produced by a readvance of the ice margin, and was followed by a retreat of the ice front to the latitude of Clayton, where the glaciers made another stand, or readvance, with accumulation of another belt of heavy boulder moraine (or boulder kame) in the Clayton-Lafargeville-Redwood moraine.

Boulder kames. The glacial deposits with sharpest relief and, outside the Black river moraine, the most conspicuous masses are the detached or isolated hills of boulders and cobbles which fall in this class. With little attempt to classify the drift forms these would be called bouldery moraine, but on account of the predominance of water-worn materials in the hills and on their flanks, and their isolation, it is thought best to distinguish them as a form between true moraines and typical kames. They stand out isolated, apart from any line or ridge of moraine, being the most striking hills of their neighborhoods. One known as the "Hogsback" lies 1½ miles northeast of St Lawrence and 4 miles southwest of Clayton and is over 100 feet high. Four smaller but conspicuous conical hills lie in chain, in the line of ice flow, in esker-kame fashion, forming the river front of Prospect Park, west of Clayton. These are shown in plate 46. The same map shows the striking group of cobble hills 2 miles north of Lafargeville, having an east-west distribution and somewhat morainic aspect, which have supplied the materials for the best display of Gilbert bars in the entire area [pl. 49–53]. On the edge of this map and reaching over on the Alexandria sheet [pl. 47] is another prominent hill, called Pine Grove hill, 5 miles northeast of Lafargeville and nearly 4 miles southwest of Plessis. Very heavy cobble bars of Gilbert waters are thrown north and south from this hill, shown in plates 45, 46. A pit for gravel has been dug on the summit of the hill. Yet another hill of this kind is shown on plate 47, ¾ mile northwest of Redwood. There is a chain of similar hills all along the north side of Grindstone island.

From the large amount of rounded or water-transported materials in these hills, their isolation and their form and alinement, it appears that they were built, at least in larger part, by torrential streams. And as all the area was buried under deep waters of Lake Iroquois during the ice waning it would appear that the streams must have been surficial to the ice sheet and have poured down the steep ice front, into the standing waters. This genetic relationship throws them into the category of water-laid marginal drift, and they are essentially kames. The inclusion of huge angular blocks, apparently contributed directly by the ice, along with the very coarse and largely unassorted materials constituting the bulk of the hills, proves their close contact with the ice front.

The stony composition of these hills has been made more evident by the wave erosion of the waters in which they were buried, the finer materials being swept away from the sloping surfaces. There is a general lack of clayey or adhesive material.

The amassing of such large piles of blocks and boulders, which are only sparsely distributed over adjacent ground, is an interesting illustration of the peculiar mechanical operations of the waning ice sheet, which invites speculation as to the precise genetic processes. The boulder kames hold a considerable percentage of far-traveled fragments, Potsdam and crystallines, which argues against a basal position in the ice of the rock materials, in which case they would be mostly of local derivation. The streams which carried the boulders must have had high gradient, which argues for superglacial flow. This and the unassorted structure of the conical piles argues for a steep frontal slope of the ice at these points. The glacial rivers, like land streams, doubtless had their tributaries, and valleys in the ice, down the walls of which the stones rolled to the streams; so that a river would gather up the rock rubbish from a large area of the ice sheet, and eventually concentrate it in a detrital cone in a notch at the ice margin.

Kames. Deposits of sand and gravel contributed by glacial drainage are well displayed in a number of localities, and several kame areas retain their relief as hills and knolls despite the erosional and leveling action of the standing waters. Indefinite patches of sand are rather frequent and would be much more numerous on our maps if the wide stretches of country between the highways were all examined.

The southernmost and earliest of the kames of the area are in the Black river district, shown on plate 44. Two patches lie south of Felts Mills, close to the limestone scarp. Small patches are west of Black River, and large surfaces north of Sanford Corners and a mile southeast. The sand plain on West creek, south of Evans Mills, marked on the map as correlating with Gilbert waters, may be partly or chiefly kame instead of delta. A kame area of decided relief and glacial character lies 2 miles southwest of Evans Mills.

Plate 51

Gilbert Gulf shore, north side of Haller hill. Looking west from position indicated by arrow in plate 50. Three lower bars and two bar basins in the view. H. L. Fairchild, photo, 1908 [illegible] 1954

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Plate 52

Gilbert Gulf shore, east side of Haller hill. Looking southwest from 420 foot bench. Wave work on bouldery drift. H. L. Fairchild, photo, 1908

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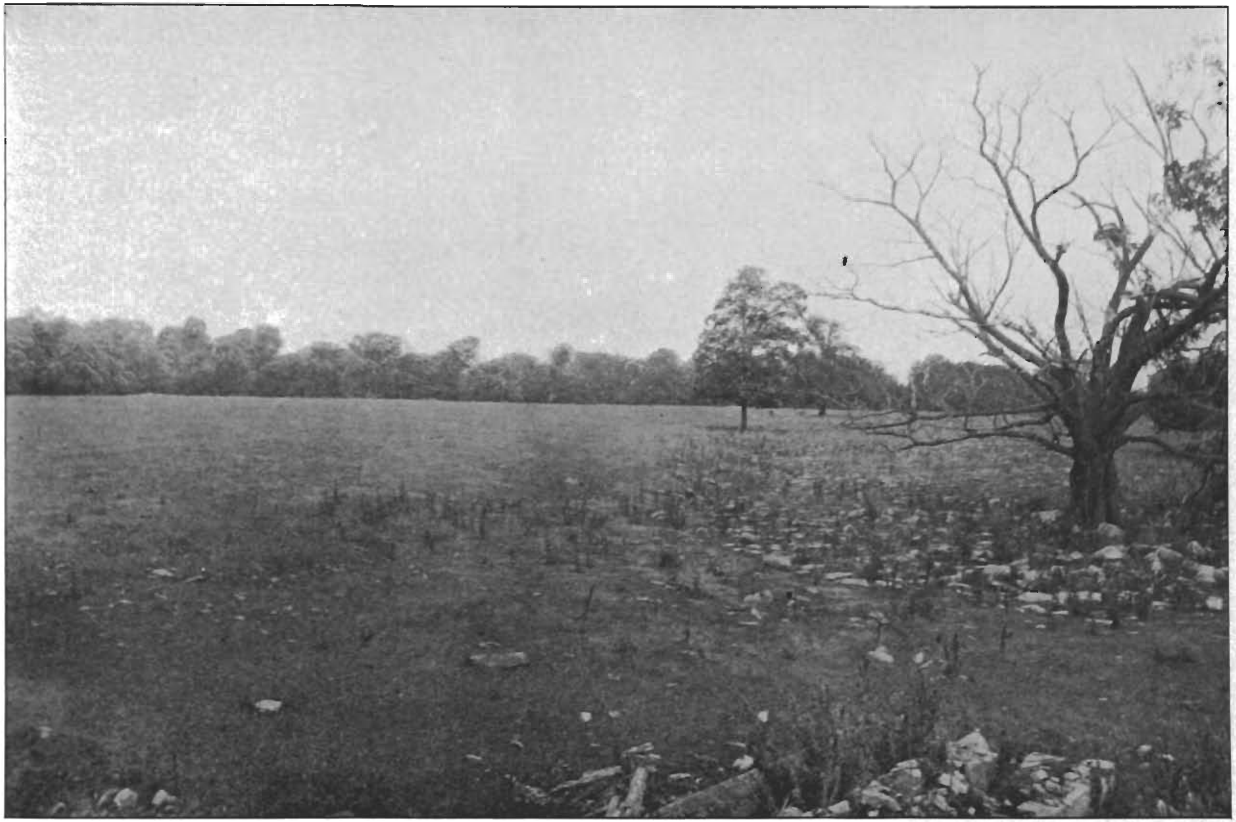
Plate 53



Gilbert Gulf shore, 3 miles west of Lafargeville. Looking northwest. Showing limit of wave work and removal of drift from the limestone. H. L. Fairchild, photo, 1908

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Northward toward Theresa are several extensive sand tracts which are not covered by our maps. East of Strough is a level sand area of 2 or 3 square miles, traversed by the Clayton branch of the New York Central Railroad, which seems to have been mostly leveled by Gilbert waters, but which retains some kame topography along the railroad. Another tract is at Theresa Junction and eastward on both sides of Indian river, and up the river on the west side. Other areas occur: one 2 miles south of Strough, and one a mile south of Theresa. Other tracts, or extension of those noted above, may occur out of sight from the roads.

On plate 46 a series of sand areas are shown extending from St Lawrence northeast toward Clayton, which are related to the Prospect Park boulder kames. Other small sand tracts are marked on this map, and also on plate 47.

Some of these sand areas have not only been modified by the submerging waters but have been worked on by the winds. The dune characters in some cases rather obscures the glacial origin. Some tracts are fine, clean sand, with basins or swampy intervals, like the Theresa Junction area. It would appear that these sands were laid in glacial waters over or among stagnant ice blocks; subsequently modified by the lowering waters; and lastly acted on by the winds.

Eskers. Plates 46 and 47 exhibit several series of kame knolls lying in definite chains in the same direction as the ice movement, some of them blending into true eskers. One stands on the flood plain of Indian river; another close to the St Lawrence river, 4 miles southwest of Alexandria Bay; and two parallel chains 3 miles northwest of Lafargeville. The mapping somewhat overemphasizes the directness and regularity of these esker-kames. The line of sand between the Hogsback and Prospect Park, southwest of Clayton, should probably be regarded as eskerlike, while the four Prospect Park boulder kames, and the Hogsback also, are parts of the chain; that is, they are all deposits made under variable conditions by a single glacial river.

True eskers, gravel ridges of fair continuity and uniformity and lying in line with the ice flow direction, are regarded as deposits in the beds of full loaded glacial streams, either subglacial or superglacial. The true kames are the short lived deltas of the streams, at their debouchment. Only the streams or their deposits which lie in the line of the ice movement could survive. As the ice front recedes the kames may bury or mask the less massive upstream or esker ridges.

Considering their relation to the ice sheet, the kames are essentially morainal in so far as they are peripheral or marginal to the ice sheet. Eskers, specially if of great length, are longitudinal, or parallel to the ice movement, and correspond to drumlins of the ice-laid drift. The esker-kames noted above are not quite typical of either class, and are therefore all the more instructive. In the field these four or five chains are distinct and clean-cut features.

It should be borne in mind that all these detrital deposits were formed when the ice front was bathed by several hundred feet of water of Lake Iroquois. The streams which drained the ice sheet may have flowed in tunnels beneath the ice (subglacial), or in trenches on the ice (superglacial), or rarely within the ice (englacial). To enter the standing water with sufficient force to carry detritus the subglacial streams must have been under considerable head or hydraulic pressure.

The various differences in these water deposits must be sought in the variation of the glacial drainage in its complex relation to the inclosing ice and to the receiving waters, and to the amount and kind of rock debris at different depths in the ice and within reach of the streams.[1]

Glacio-aqueous deposits

Clay plains. The largest in volume and the most extensive of the deposits due to glacial agency, direct or indirect, are the clay plains which were spread by the Iroquois and Gilbert waters. Except where in the Black river district the moraine and delta occupy the ground the prevailing drift of practically all the territory south of the parallel of Lafargeville is this clay; and also large areas of the lower ground north of this line. With exception of some till and thinly till-masked rock ridges all the lower ground of the Cape Vincent sheet and the southwest half of the Clayton sheet is clay. East of Clayton and east and west of Lafargeville the plains are clay, blending into till, or eastward at Strough into sand. Excellent views are afforded of these prairielike plains from the railroads to Clayton and Cape Vincent. In the northern district the clay occupies only the valleys and hollows, where the

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[1] The reader who wishes to pursue the study of water-laid drift will find a philosophic discussion by R. D. Salisbury in Glacial Geology of New Jersey. Final Rep't, 5:113–45.

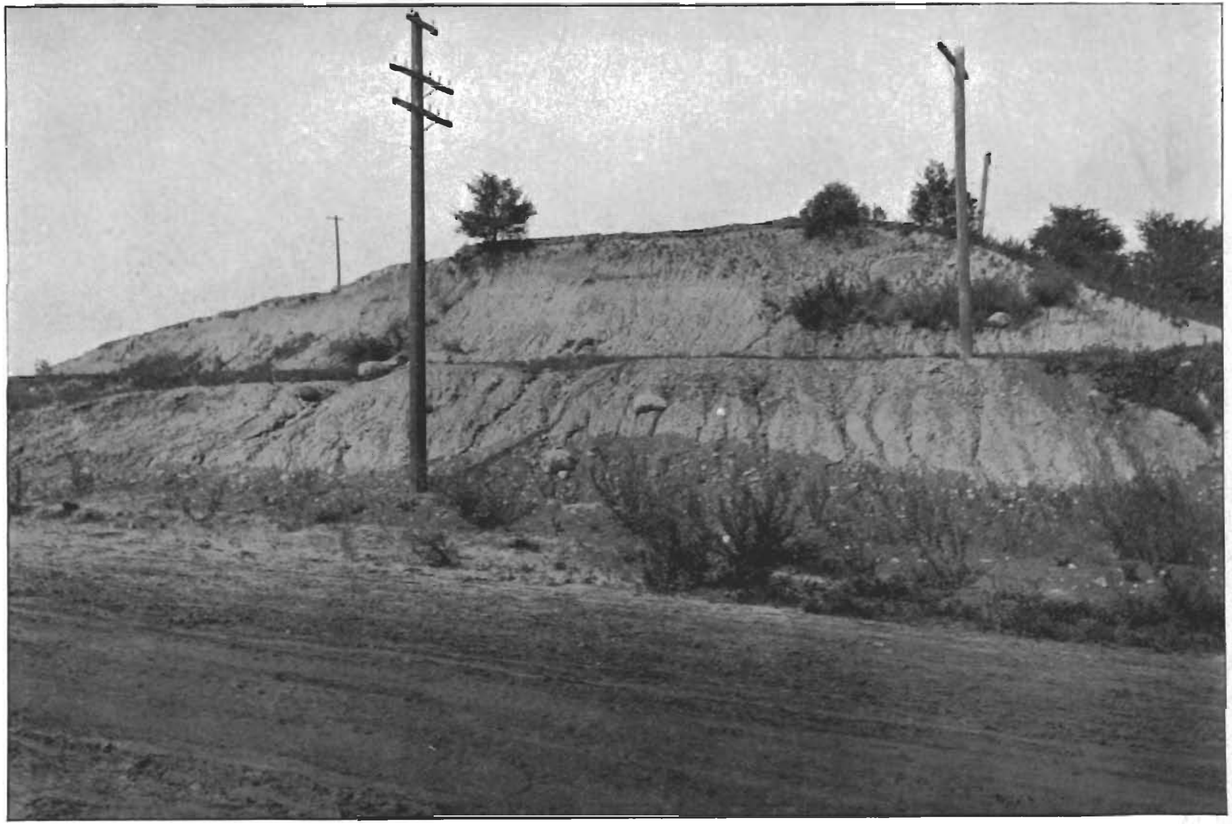
Kames of Central New York are briefly described by the present writer. Jour. Geol. 4:199–59. *See also* Am. Geol. 22:177–80; Am. Ass'n Adv. Sci. Proc. 47:278–81.

On eskers, favoring their superglacial position, *see* an article by W. O. Crosby, Am. Geol. 30:1–39.

Plate 54

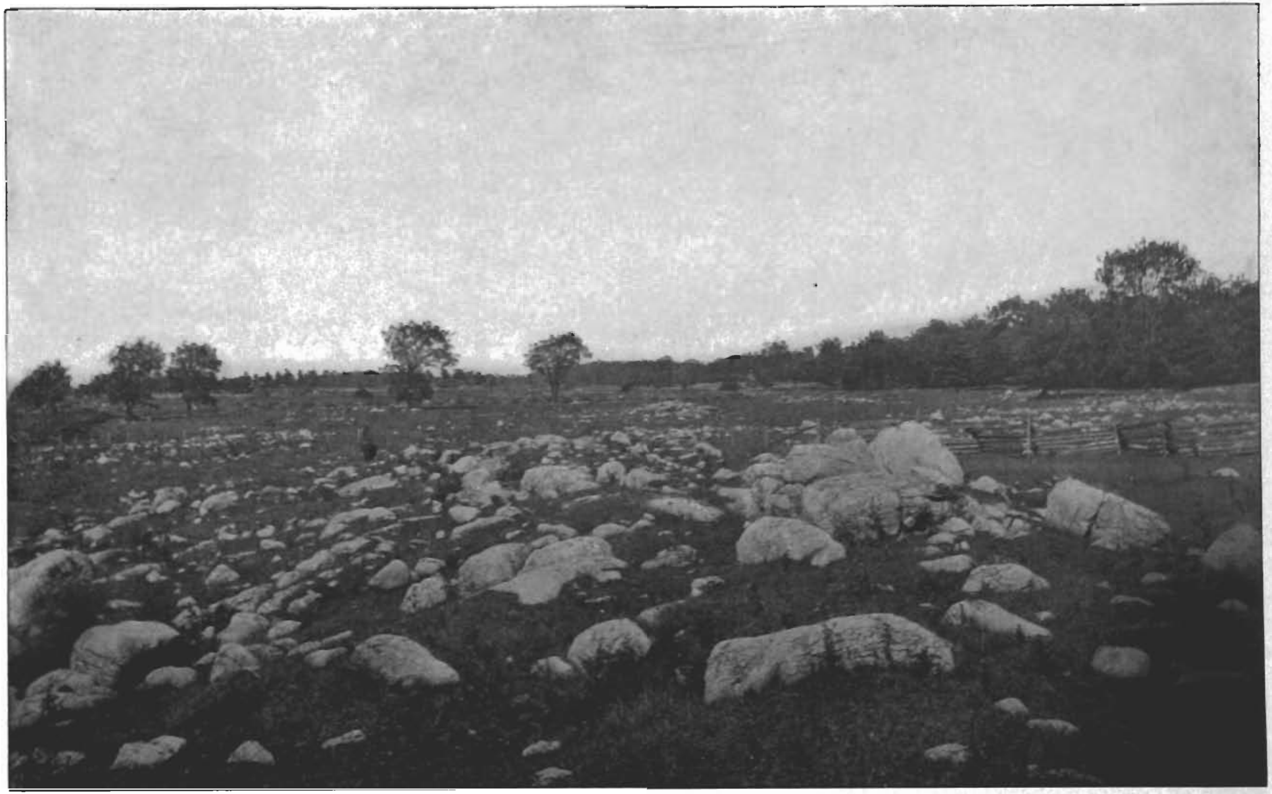
Head of rock-walled basin of Sixberry lake, 2½ miles southeast of Redwood. Looking south. H. L. Fairchild, photo, 1908

Plate 55



Lake silts capping hard, blue till. West edge of Watertown, north side of Black river. Cutting for R. W. & O. R. R., Cape Vincent branch. Looking northeast. H. L. Fairchild, photo, 1908

Plate 56



Boulder moraine, 1½ miles west of Black River. Looking northeast, lengthwise of the ridges. Blocks are limestone. H. L. Fairchild, photo, 1908

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smooth clay fillings, as meadows or swamps between the rock bluffs or among the rock knobs, make striking contrast [pl. 29].

The clay is evidently the rock flour of the glacial mill, sifted by the standing waters. Its glacial relationship is shown by the fact that in some localities it shades into ordinary clayey till; by its inclusion of boulders and cobbles, probably ice rafted; and by its composition which is decidedly calcareous.

In many exposures the clay rests directly on glaciated rock [pl. 57] with no mass or visible layer of till or stones intervening. In the gullies or storm-wash hollows a few cobbles or boulders are commonly found, derived from the mass of the deposit, but they do not seem perceptibly more common at the base. The bed of the creek where plate 57 was taken was filled with cobbles from the clay ravine. At the top of this section the lamination was destroyed, but the crushing appears to be very localized, and has rarely been noted elsewhere. However, the structure does not often appear, as the exposed clay quickly loses its lamination and forms a rough, crackled skin over the slope, as shown in plate 58. It is only where the clays are freshly exposed that the lamination becomes evident.

In plate 58 the numerous white fragments scattered over the slope are calcareous concretions, discoid or irregular in form. Evidently they represent concentration of the lime that was originally disseminated in the deposit, but the clay still retains enough of the carbonate to effervesce very freely in weak acid. The latter is true of all the clays tested, except in some cases the topping layers, 1 or 2 feet thickness. The lack of carbonate at the surface may be due to postglacial leaching, and perhaps to original lack of carbonate since the latest beds may have been deposited from well washed material, the ice being far removed to the northward.

Some sections do not contain the lime concretions. This is the case with a great exposure 1½ miles east of Clayton where the river has undercut the bank, giving a section 15 to 18 feet high. The lower part is beautifully laminated, the upper part with older exposure showing the characteristic mottled or crackled skin and some small lime particles. The east end of the clay section exhibits some crumpling of the beds. All these clays effervesce freely.

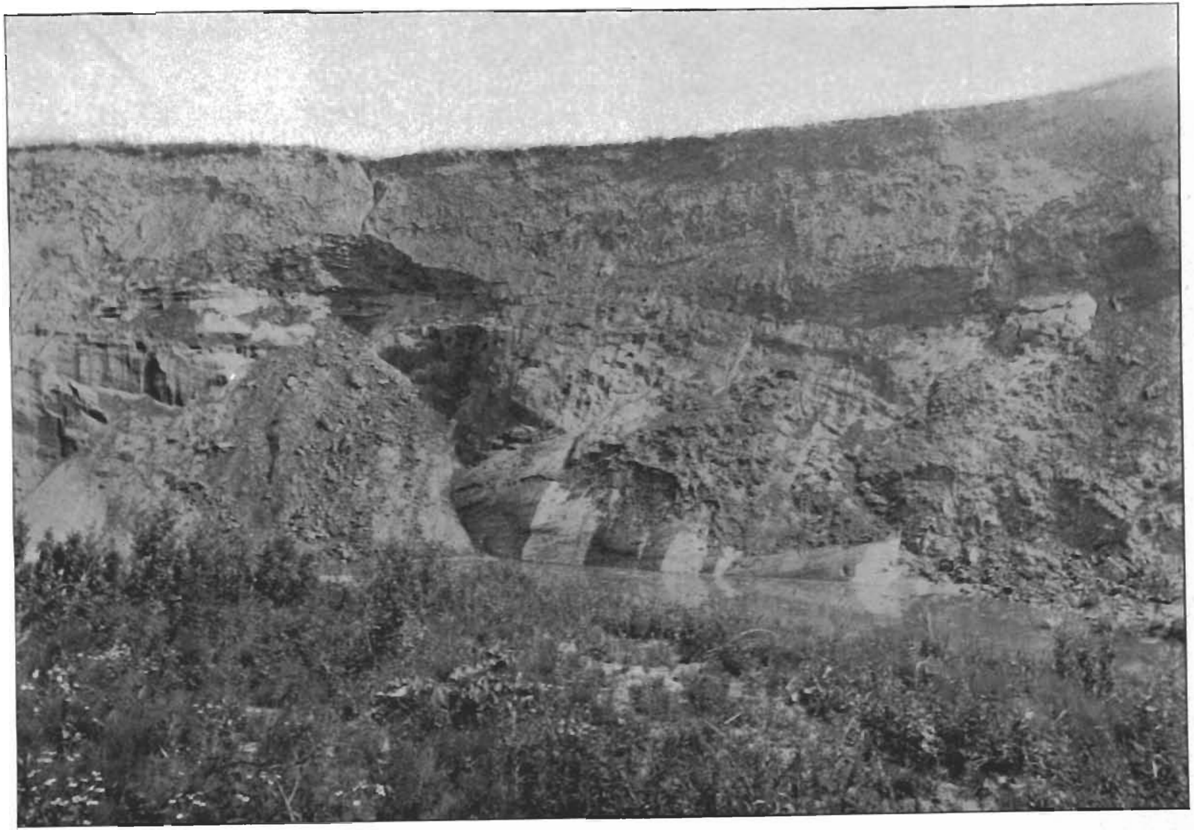
The volume of this clay over the area increases southward, over the limestones, but the total seems excessive in proportion to the scanty drift of other materials. It is possible that the genesis and history of the clay is more complex than would at first appear. Apparently it is all Postwisconsin, for if it were partly the deposit of ice of earlier invasion we should expect to find the deeper and older beds of somewhat different quality, more or less crushed by overriding of the ice; and tills interbedded between the older and the newer clays. No such features have been seen. In the few sections observed reaching to rock the clay reposes directly on the smoothed rock, and the deposit is similar and homogeneous from bottom upward, and very finely laminated. The cases of crumpling which have been noted are probably explicable by the grounding of icebergs, or perhaps by the thrust of the accumulating weight of clay on weaker borders of the deposit.

An explanation of the large volume and extent of the clay seems to lie in the consideration of the lake conditions at the front of the waning ice sheet and the mechanical factors working there. In ordinary glacial drift or till the coarse materials remain in mixture with the clay (rock flour) matrix. But the agitated deep water in which all the deposits of our area have been laid down have screened out the coarse from the fine, dropping the coarse near the ice front, and have carried the fine material away by itself farther from the ice front into the more quiet water. It should be understood that the deposits as a whole were accumulated from south to north, following the departing ice front. In other words they grew backward. It is possible that either by lifting or by toppling the breaking ice kept the water agitated and so facilitated its sifting action. The materials contributed by the glacial streams were already under assorting action. Lack of strong, continuous currents, as rivers, or as in tidal seas, prevented the far removal of the silt, and the muddy waters dropped their clay burden over the bottom not far in advance of the ice front. Subsequently the lowering waters scraped the silt which had been dropped on the higher surfaces down into the lower grounds and hollows. As there was no break in the existence of the standing and lowering waters, and consequently no pause in the depositional process, so we find continuity and uniformity in the deposits.

Pitted clays. In the hollows or basins of the Alexandria Bay district [pl. 47] are found deposits of clay which are pitted with basins or kettles. In some instances the silt forms merely mounds and ridges with intervening swales and swamps, a good example being seen 3 miles north of Redwood.

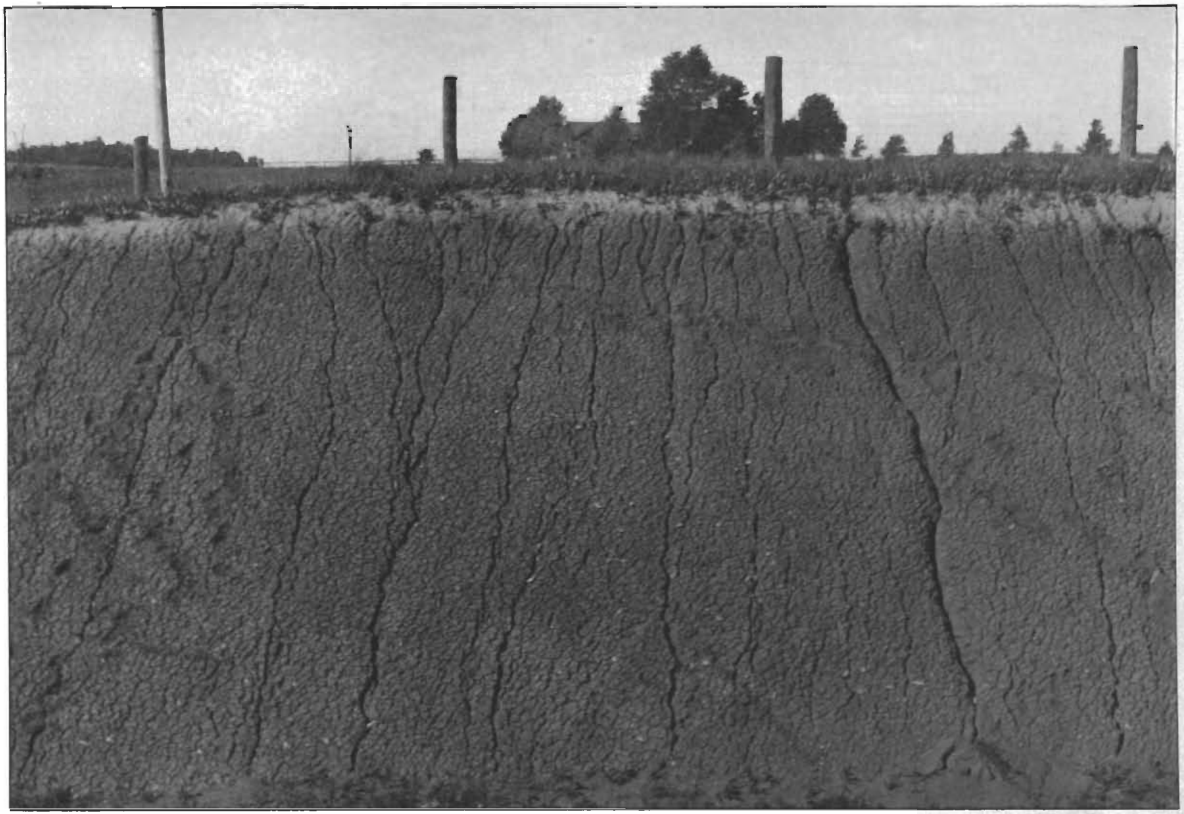
These pitted clay fillings blend on the one hand into till, and on the other into the smooth or merely eroded clay plains. The explanation of their origin seems to be the deposition of the silts over grounded ice or anchored ice blocks. Apparently the ice masses were not melted until the silt deposition was ended.

Plate 57



Silts on glaciated rock, 2 miles southeast of Clayton, by railroad bridge. The rock is Potsdam sandstone; the lower part of the section is sand. The fragments resembling stones are clay masses from the upper beds. Compare plate 58. H. L. Fairchild, photo, 1908

Plate 58



Glacio-lacustrine clay, Dexter. This is the prevailing low-level deposit. An adhering film of the weathered clay hides the lamination. The white particles are lime concretions. Compare plate 57. H. L. Fairchild, photo, 1908

The pitted clays are a link between the ice marginal deposits and the open lake deposits. They might be classed with the morainal or peripheral drift, since they were associated with remnants of the ice front, but the aqueous origin is here regarded as the more important element.

Glacial erosion

General character. The abrasional work of the glacier in this area is more conspicuous in the northern district where the hard Precambric and Potsdam rocks are in high relief and the drift is mostly in the hollows. Over the southern district where horizontal limestones form the floor the ice erosion was probably greater than farther north, but the evidences are more concealed. The origin of the plains, plateaus and mesas, by preglacial weathering, glacial planing and stream trenching, has been discussed in a former chapter [p. 146].

The more vigorous erosion on the limestones is shown by flutings or ribbing, the lighter and later, by striation and polish. The Potsdam and crystalline knobs seem to have been little more than " sandpapered " by the latest glaciation. The broader surfaces of the more horizontal Potsdam shows effective abrasion in spots only. The impression made on the observer is that glaciation of an earlier ice invasion was vigorous but that the latest ice sheet was comparatively ineffective.[1]

Striations. *Occurrence.* The limestones exhibit few striae, as will be inferred from the lack of arrows on the maps of the limestone districts [pl. 44–47]. It is uncertain whether this should be chiefly attributed to the failure of the latest ice to generally abrade the rock surface, due possibly to clayey character of the subglacial drift in this district, or to the obliterative effect of solution and weathering. The limestones are readily attacked by atmospheric waters, as proven by the very numerous areas of solution structures and open joints [p. 133, pl. 26–27, 35]. But in many places the fresh removal of clay or clayey till that would seem to be sufficient protection to the rock reveals unglaciated surface, though usually firm and even, as if a glaciated surface had lost its smoothness. This feature is emphasized by the finding in the same locality surfaces

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[1] Unfortunately we have no standard or measure of the intensity of ice abrasion or erosion, or glaciation in general. When a writer says that the drift is scanty or abundant, that erosion has been great or small, he expresses merely his own conception of relative intensity, based on his observational experience. It is apparent that different observers might have different opinions, according to the range of their work and their mental attitude. Moreover, the view of the same student might vary with increasing experience and changing emphasis on the various elements or factors.

recently exposed with perfectly preserved polish. While it is possible that this difference in surface characters may be the effect of differences in present conditions of drainage and solution, though improbable, it seems more likely that we have here another illustration of multiple ice work.

In the Potsdam areas the impression is given of general ice abrasion by the frequent patches of polish and striae; but the unscored surfaces far outnumber the striated. Here, again, we have the uncertainty as to the degree of weathering and destruction of the latest glacial records, because exposed surfaces, apparently of identical quality of rock and equality in exposure exhibit partly highly polished and partly unscratched surfaces. The fact of a general grinding and smoothing of the rock is clear, but quite certainly not by the latest ice sheet.

Direction [*see* pl. 44–47]. Near the St Lawrence the average direction of striae is about parallel with the river. Leaving out the extreme and aberrant marks they may be generalized as follows: at Chippewa Bay, s. 25° w.; Alexandria Bay, s. 25–40° w.; Clayton, s. 40–50° w.; eastward from the river and from the axis of the valley the striae are more variable and swing more southerly. About Redwood some striae are s. 40° w., probably representing the stronger flow of the deeper ice, but a great number range within s. 10–20° w. About Theresa the greater number lie within s. 10° w. and s. 10° e. East of Chaumont the striae are s. 35° e.; at Evans Mills, 10–20° east of south and at Sanfords Corners, 30° east of south. The Leraysville moraine [pl. 44] clearly shows the southeasterly push of the latest ice in the district. This easterly swing of the ice in the eastern part of our area was due to the well known spreading or radial flow of a lobation in the ice front. As the ice sheet waned the last portion resting over the area was a broad lobe occupying the St Lawrence depression and having spreading flow toward the east side of the valley. Along the east side of our maps the most westward striae represent the general direction of the maximum flow while the eastward striae are later scratches by the ice margin.

Curved scorings. A remarkable example of curved scorings may be seen on a broad, flat, smoothed surface of Potsdam sandstone 2½ miles east-southeast of Alexandria Bay, about ½ mile west of three corners. The bare area lies in the track and on the north side of an abandoned highway, on land of John Bogert. The locality is indicated by three converging arrows on plate 47, and one photograph is given in plate 59.

Plate 59

Curved glacial scorings on planed Potsdam sandstone, 2½ miles eastsoutheast of Alexandria Bay. Looking downstream, south 56° west. The scorings curve to south 44° west. H. L. Fairchild, photo, 1908

FOLLOWS PAGE 50

A considerable area of planished rock is covered by striae which have various directions, from s. 56° w. to s. 16° w. Apparently the markings with the more westerly trend are the older and prevailing ones over most of the surface, the later and more southerly abrasion having softened the older groves and given a cross polish. But the later motion is also represented by a few strong chatter bands which quite obliterate the older scorings where the latter are crossed.

The curved markings lie in a belt about 10 feet wide and over 50 feet in length now exposed. The scorings are strong, clean-cut, and perfectly parallel. At the north end they lie for several yards perfectly straight, with direction 56° west of south, then they gently curve, southing with steady uniform curvature until the direction is s. 42° w. The curving is still continued where the belt of scorings passes under the turf on the south side of the wagon track. The strong furrows may not be confidently traced throughout the entire length of the curve in distinct individuality, as later abrasion has somewhat obscured them in places, but they are practically continuous and retain their relation and character. The belt of curved scorings is exceptional to the general striae of the broad surface and surrounding bare patches, the prevailing direction being s. 30–35° w.

The curving lines have no angularity and show no hesitation nor pauses or spasms in the ice motion. In one place a few of the strong scorings in a narrow strip exhibit a perceptible variation from the true curvature, or a tendency to straightness, but taking the belt as a whole the curvature and the parallelism of the lines appear to the eye to be true. The radius of the curve is about 60 or 70 feet. The chord of the exposed belt, including about 15 feet of the straight beginning of the scorings, is 54 feet; and the ordinate is 23 inches.

This glaciated surface is the northern side of a broad rock plain, with no apparent cause in the surrounding topography for the deflection in the ice flow. A narrow valley lies near on the north, across which is a somewhat higher plain. The map, plate 44, shows the general topography.

A significant fact is that the curving belt of scorings, even at the southern deflected end, so far as uncovered, is much more westerly in trend than the prevailing ice movement, not only in the immediate locality but in the great area.

Chatter marks and gouges. The innumerable exposures of the Potsdam sandstone, often of large extent, coupled with the very hard and brittle texture of the rock, furnish many excellent examples of the effect of the dragging pressure and the percussive force of the boulder-shod ice. The rock is too hard to accept much furrowing or mass removal on the flat surfaces, but its brittleness favors the production of fractures due to compression and to striking force. Of these features two classes will be briefly described.

The hard boulders held as planes and hammers in the bottom ice have produced two kinds of curving fractures, one class convex upstream or toward the boulder, the other convex downstream or concave toward the boulder. Those with the concavity facing downstream, that is to say, with the convexity toward the producing tool, fall under the category of "cones of percussion" or "chatter marks." Many excellent examples of these concentric fractures are seen, some of large size or up to 10 inches of arc and forming from one quarter to one third of the circle. Sometimes the parallel concentric fractures are closely crowded, several within an inch, but are usually somewhat more open, three or four or less to the inch. Figure 13 is traced from a "rub" taken by the road near the house of William Northrup, 3 miles northwest of Redwood and 3 miles east of Alexandria Bay, and about ¾ of a mile northeast of the curved scorings described above. In this case 11 fracture lines lie within 4 inches along the axis of the curvature, most of them being

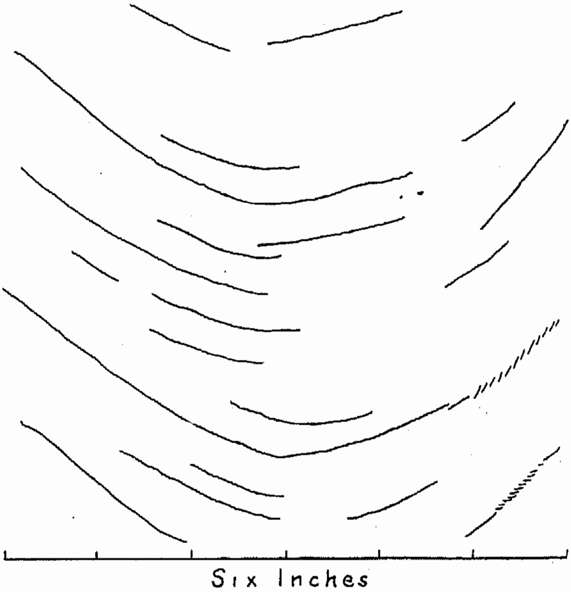

Fig. 13 Chatter fractures

short. The longer lines have an arc of 6 inches or a radius of about 3½ inches.

Another excellent illustration of the chatters is on the highway 3 miles north of Redwood on the road to Chippewa Bay, at the point indicated on plate 47. Several very large examples occur in the middle of the street in Redwood village, just below the Dollinger House. Smaller examples are so very numerous that no notebook record was made of them. Fine examples occur with the curved scorings.

The chatter fractures dip so steeply into the rock that rarely is there any flaking of the surface rock. In many instances no axial grooving or crushing of the rock is visible, the appearance being as if the rock had been abraded and resurfaced and polished so as to leave merely the clean-cut concentric fracture lines. Such abrasion is more than possible but is very slight, as early striae having the direction of the axes of the chatters are not obliterated. Commonly there is some evidence along the axial line of the pressure by the unsteady or chattering tool.

The other class of fractures, having the concavity facing upstream toward the tool, are much less regular or true than the chatter fractures. In both classes the cracks dip downstream or away from the point of the tool, but in these gouge fractures the angle of dip is much less than in the chatters, and commonly there is considerable flaking of the rock or removal of the feather edges of the surface rock. These cracks fall in the class of "concentric gouges" or "disruptive gouges" of earlier writers.[1] The action seems to have been a sort of drag or pull on the surface of the rock by pressure of a boulder with broad area of contact, but without pounding or percussive force. The process was a plucking by dragging pressure.

These gougings are not as common as the chatters, and only two good localities were noted. One of these is ¾ mile south of the county line between Jefferson and St Lawrence counties, on the west road to Chippewa Bay. The other occurrence is on the road east of Goose bay and on the south side of Crooked creek valley. The first mentioned is on the south end of a plain, the latter on a surface facing north, where the ice was pushing against an upslope.

The gouge fractures are rarely true circular curves, in which cases they may be mistaken for chatters, but commonly they are irregular

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[1] A full description and discussion of these singular phenomena connected with glacier mechanics is given in Professor Chamberlin's paper Rock Scoring of the Great Ice Invasion. U. S. Geol. Sur. An. Rep't 1888. p. 216–40. Reference to other writings is there given.

in both form and relation. They lack concentric parallelism, in other words are not in regular series; and they are not always transverse or normal to the line of motion of the tool, as shown by the band of crushing or gouging. Figure 14 shows these characters.

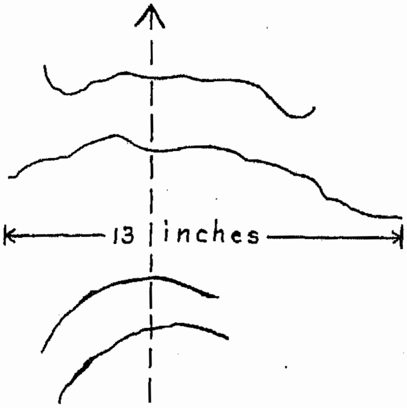

Fig. 14 Gouge fractures

To summarize: the gouge or dragging fractures would seem to be the effect of a steady dragging motion of a boulder with large contact surface, while the chatters are the product of unsteady, percussive or pounding movement of points of boulders or small contact surfaces.

Limestone flutings. Over large districts in the southern part of the limestone area the rock surface is worn into series of parallel, cylindrical ridges of several feet diameter, separated by equally regular troughs or hollows. These features which can be attributed only to ice erosion are illustrated in plates 60–63. As the amount of erosion and the direction of the ribs and ice movement are inconsistent with the work of the latest ice sheet the discussion of the topic is deferred to the next chapter.

Prewisconsin glaciation

Theoretic considerations. In the preceding pages several features have been mentioned as difficult of explanation or inconsistent with the conception of a single ice invasion. The facts and argument favoring the view of multiple glaciation will be summarized here.

If the generally accepted conclusions of glacialists, that the northeastern states have been repeatedly glaciated since Tertiary time, are well founded, it is quite impossible to except or exclude New York from all ice invasions earlier than the latest, or Wisconsin. The several glacial epochs recognized in the Mississippi valley have been named on page 137. The very old drift of New Jersey and southeastern Pennsylvania is believed to be as old, certainly, as the Kansan, and probably represents the Preaftonian, which is now sometimes called the Jerseyan when referring to the eastern region. The drift of northwestern Pennsylvania lying in advance of the Wisconsin drift, is believed to be as old at least as the Kansan. For an ice sheet to so expand as to reach either northwest or southeast Pennsylvania without trespassing on New York seems impossible. Hence we are forced to the belief, apart from any evidences on the ground, that the State has been more than once in the climatic condition of Greenland at the present time.

If the State has been overrun by ice sheets more than once it seems rather strange that geologists have not recognized the phenomena and discriminated the records. It must be admitted that we now lack the evidence afforded by multiple till sheets, separated by temperate climate deposits such as are found in the Western States. With attention directed to this subject it is probable that some conclusive proofs will be discovered.

But while no single fact or class of phenomena yet found furnishes conclusive proof of more than one ice epoch, we have a variety of indirect evidences, and many features are well explained only on that supposition, and several lines of study converge toward that conclusion. Moreover, to attribute all the glacial phenomena to a single ice sheet involves inconsistencies, such as the evidence of impotence in erosion of the latest ice, with indication of vigorous erosion formerly; and the lack of glaciation surfaces on ice-shaped rock as well protected as places showing hairline striae and polish.

The glacial features of the Thousand Islands region which are not satisfactorily referred to the latest ice work probably can not be attributed to an ice sheet as ancient as the Kansan, but would seem to be the effect of some recent ice epoch. Whether it was one of the later Prewisconsin invasions or only an early Wisconsin episode we may not now decide.

Anomalous physiography. South of our area, in the central part of the State, many channels of ancient drainage are found which are not Postwisconsin. In the area under discussion these features do not occur because the whole region was drowned in deep water during the ice recession. But the region has its own peculiar topographic features that are difficult of full explanation under the conception of a single ice transgression. The valley, basin and scarp topography has already been briefly discussed [p. 146]. Other points will be touched on below, but a full discussion of the difficult problem requires more fieldwork specially directed to the particular features.

Old till. As far as the writer is informed, the first one to recognize Prewisconsin till in New York was F. B. Taylor. In the summer of 1905 he directed attention to the very compact, resistant, stony, blue till in the bottom of the deep valleys southeast of Buffalo, which he confidently pronounced older than the overlying and prevailing Wisconsin drift. Subsequently the writer noted other occurrences of similar till. In 1907 Frank Carney published an account of what he regarded as old till in the Keuka valley.[1]

No soil zones or forest grounds lying between the supposed old till and the superfical till have yet been found, to prove the fact of an interval of deglaciation, though such finds may be expected. The writer has noted very sharp distinctions between the two tills, with incorporation of the lower into the upper. An important locality is along the new cuttings for the shortened tracks of the Delaware and Hudson Railroad west of Schenectady, between Kelly station and Duanesburg. Here an incoherent, yellow till, capped with gravel, directly overlies a very hard, dark blue till. The contrast between the two is very striking and the line of separation is very distinct in some sections; while in places the older blue till has been plowed up and masses have become incorporated in the yellow till. The blue till retains its color and consistency even when exposed for considerable time to the weather, masses which have lain in the field over the winter being only partially disintegrated. The writer was told that the steam shovels were able to cut the blue " hardpan " with much difficulty and very slowly.

The blue till has a very different composition and derivation from the overlying and oxidized yellow till. It is impossible that an ice sheet, producing from its burden of ground-up shale and limestone the hard blue till, should suddenly cease to deposit this and at once lay down a yellow oxidized till of entirely different origin. We have here good proof of at least two distinct episodes in ice work.

The writer has not noted in our Thousands Islands area any example of tills comparable to the old, blue tills farther south, though Cushing thinks that he has seen them. But they probably do occur just south of the boundary, in the northern part of the city of Watertown. Here begins a group of drumlins that extends southward. In the mass of the drumlin forming the dome-shaped hill north of the Black river, and in the small drumlin ridge in the northwest corner of the city, where the Dexter electric line crosses

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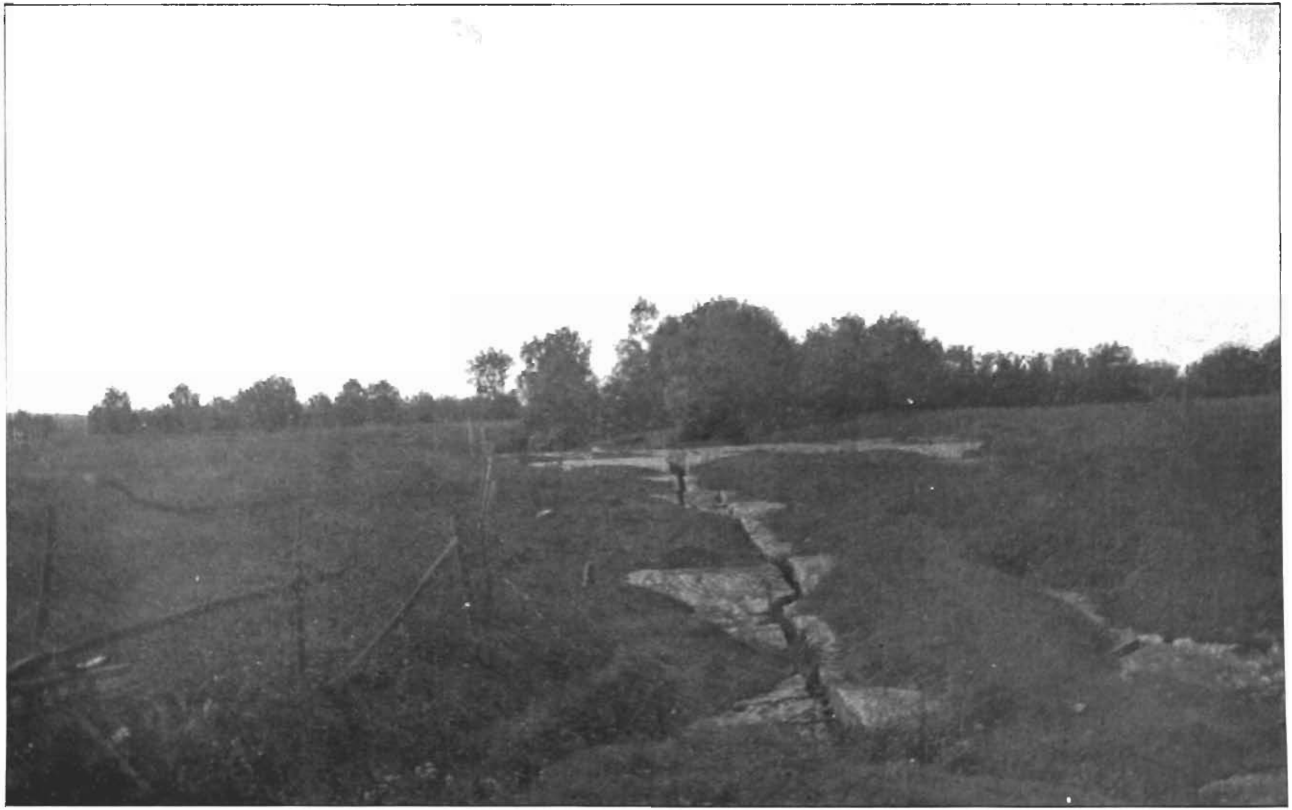
[1] Pre-Wisconsin Drift in the Finger Lake Region of New York. Jour. Geol. 15:571-85.

Plate 60



Postglacial weathering. Open joint across limestone ribs, 1½ miles east of Dexter. Looking northwest. H. L. Fairchild, photo, 1907

Follows page 151

the Cape Vincent branch of the New York Central Railroad, a hard, gray blue till appears that is very unlike the prevailing drift of the northward area. The latter exposure is shown in plate 52. The resemblance of this drumlin till to the "old" tills farther south is as close as might be expected when the differences in latitude, source of the material, etc. are considered. However, we must recognize that the drumlin till was subglacial, deposited beneath the ice and under tremendous grinding pressure; while the surficial drift of the area was dropped in standing water, and is consequently incoherent, sandy, inclined to yellow or gray colors, and carry few striated or abraded stones. The production of masses of subglacial drift or drumlins is a sort of work which the later ice did not do north of Watertown, at least to noticeable extent, and it is doubtful if it did such work at Watertown. However, the drumlin till is inconclusive, until we know if the Watertown drumlins are the work of the latest ice or of some earlier invasion. This Watertown till is not in valley bottoms or deeply buried, but in hills above the levels of the plain.

Limestone ribbing. Over the southern part of the Clayton quadrangle the limestones frequently exhibit series of parallel ribs or flutings, a sort of washboard structure on a vast scale [pl. 60–63]. These ribs positively have no genetic relation to the joint structure of the rock. They are pronounced convexities, often quite cylindrical but commonly rather flat, with a breadth from crest to crest, or across the base, from 2 to 10 feet; the usual breadth being 3 to 5 feet. The hollows between the ribs are usually filled with drift or soil, but when cleared they show quite cylindrical troughs of uniform width and fair curvature, and parallelism with the ribs. By solution-weathering the sides of the flutings are rarely steepened and the bottoms perforated by solution holes, as in plate 63.

Within any single exposure these flutings are strikingly parallel [pl. 61] and are approximately so over the whole region, having a direction about s. 45° w. Scores of them have been measured with that direction, over all the area between Dexter and St Lawrence village. The extreme variation in direction is s. 40° w. for the heavy ribbing east of Dexter, and s. 50° w., south of Dexter, shown in plate 63. Two other localities toward St Lawrence gave the latter compass direction.

Speaking broadly the flutings have lost all their glacial surfaces, retaining only the erosional form, for their origin by ice erosion of the limestone seems certain. In a very few cases a suggestion of the heavier scorings are preserved, and some minor flutings on the ribs. The ribs which have been long exposed have been so corroded by weathering that one might question even their glacial origin. But those flutings also which are only recently uncovered have lost their glaciated surface, though they may show the perfect polish of a later glaciation oblique to the ribbing. This fact is important with reference to the age of the ribbing.

In plate 61 we see a typical example of the ribbed limestone, the locality being the west side of a hollow several rods west of the railroad station at Threemile Bay. The ribbing is s. 45° w. The three ribs in the foreground at the lower right corner have been strongly cut and polished by an ice flow having direction s. 55° w. This change of 10 degrees in direction is not unusual for the same ice sheet, and taken alone would be weak evidence of dual glaciation. The important fact here is that the later ice movement has scored and polished the ribs obliquely, striking them on the east faces, and the later polishing is perfectly preserved though apparently has been exposed as long as other portions of the ribs where no glaciation is visible. The ribs are being freshly uncovered by the wash on the slope, but the only glaciation seen is that oblique to their direction. The only reasonable inference is that the ribs have lost the glacial surface by old age weathering and that the oblique polish is from a later ice rubbing. The ribs are rough and corroded where not cut by the more westerly planing, and it is certain that the lack of striae and polish on the ribs can not be due to merely recent weathering.

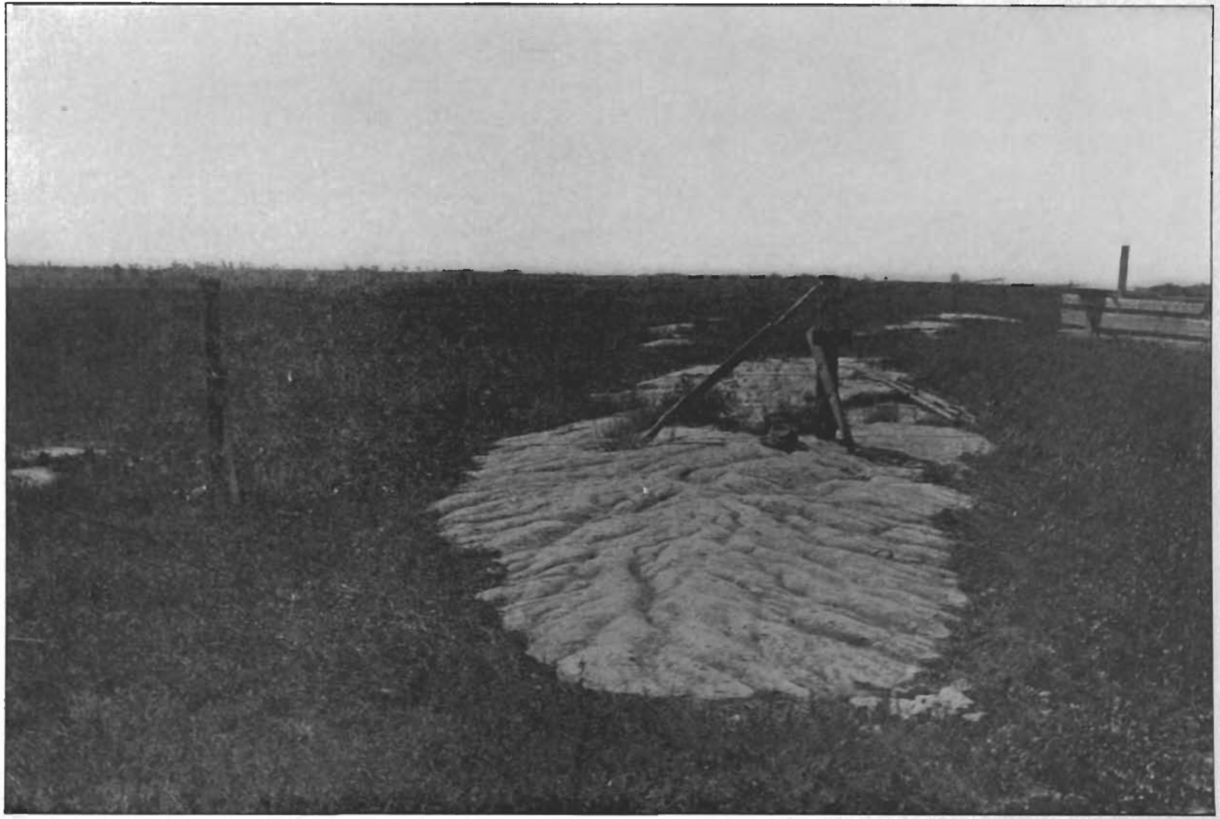
The ribs and hollows have no fixed relation to the joints of the rock. In the locality of plate 61, while the ribbing is s. 45° w., the joints, so far as they have any dominant trend, are s. 75–85° w. Nowhere are the joints so true and parallel as the ribbing. Only occasionally do joints appear in the furrows but they commonly lie boldly across the ribs and are frequently opened widely, as in plate 60, where some joints are a foot wide and 10 feet deep. The removal of the clays of the latest deposits from the ribbed surface shown in plate 60 has been chiefly by subterranean drainage through these open joints. It seems very unlikely that these open joints were produced with their present size and form since the last glaciation and beneath several feet of the Dexter clay [pl. 58]. The joints certainly are the product of atmospheric weathering and solution, and it seems a safe inference that they represent a time of long exposure antedating the last ice work.

These exposed ribs east of Dexter, visible on the north side of the electric line, lie in a hollow in the clay, as shown in plate 63,

Plate 61

Glacial ribbing in limestone, Threemile Bay station. Looking north 35° east. Compare plates 62 and 63. Direction of ribs s. 40° w. Recent glaciation in lower right corner, s. 55° w. H. L. Fairchild, photo, 1908

Plate 62



Weathered rib of limestone, 1½ miles west of Brownville, south side of Black river. Looking southwest. Compare plates 61 and 63. H. L. Fairchild, photo, 1908

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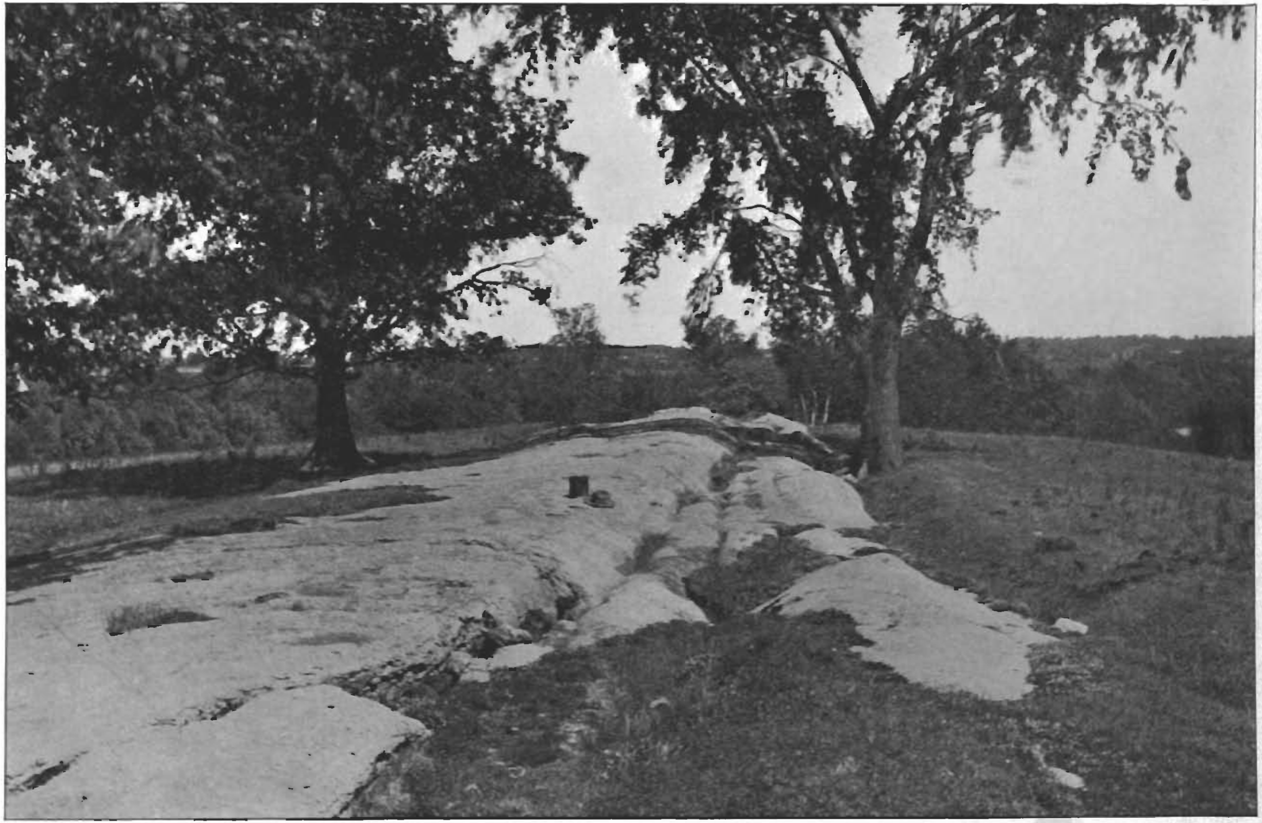
Fig. 2

Plate 63



Glacial flutings in limestone, ½ mile southeast of Dexter. Looking n. 50° w. Compare plates 61 and 62. Directions of ribs s. 50° w. H. L. Fairchild, photo, 1908

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the hollow being produced partly by the washing of the clay cover down the wide solution joints. On the sides of the hollow the ribs are being newly uncovered by the storm wash and the tramping of cattle, but no trace of glacial polish was seen, the new surfaces being similar to the longer exposed surfaces of the middle of the ribs. Masses of chert standing 2 or 3 inches above the limestone surface prove a long period of solution of the rock surface, which seems impossible beneath the present clays in the short time involved. Enforcing this conclusion is the fact that only a number of rods distant, in the gutters of the electric road under similar clay cover the same limestone shows elegant glaciation. But while the ribbing is s. 40° w. the preserved glacial scorings are variable, ranging from s. 50° w. to s. 10° e.

These two examples of the ribbing, which can be multiplied, will give illustration of the quality of the evidence they offer in favor of at least dual glaciation in recent time. These flutings are widespread, remarkably uniform in direction (generally s. 42-45° w.), symmetrical and true in form. They can not be attributed to weathering, nor jointing, nor wave work, nor water corrosion, all of which have left conspicuous records in the district. Undoubtedly the ribbing is old glacial, and it represents a glacial abrasion vastly more energetic than the similar work of the latest ice sheet.

Weathered surfaces. The considerable weathering which the limestones have suffered is shown in plates 23, 26, 27 and 63. Doubtless some part of this corrosion is postglacial, specially on the more exposed patches and on cliff edges where the rock was not buried by the drift; but it must not be assumed that these etched, corroded and open-jointed surfaces were all left smooth and glaciated by the latest ice sheet, as that is the question under discussion.

The uncovering of corroded surfaces which have been under clay that would seem to have been sufficient protection from the postglacial weathering, as illustrated in plates 61 and 62, argues strongly for nonglaciation of such surfaces. The conditions shown in plate 60 seems to prove that great open joints existed in the limestones previous to the deposition of the glacial clays.

Probably many of the deeply corroded surfaces were recently buried under ice or lake deposits which have been swept off by the wave erosion of the standing waters and the subsequent and now acting storm wash. Without more special study on the ground it is impossible to estimate the amount of postglacial weathering. In some places it seems very small, and where slightly covered practically nothing. Such cases give the impression of slight corrosion since the ice removal. On the other hand the existence of broad surfaces of exceedingly rough and open-jointed rock, from which the farmers have to fence their cattle, and the location of which would seem to have been favorable to glaciation, give the suggestion of large postglacial weathering. The critical question is, were the latter surfaces glaciated by the latest ice sheet? It would appear that a duration and intensity of postglacial weathering which has not destroyed the glacial polish on the limestone ribs shown in plate 61 could not justly be held responsible for the open joints and rough surfaces shown in plate 60, where a deep clay cover has been removed chiefly by washing down into the open joints and being carried away by subterranean flow.

The amount of recent weathering is conspicuously greater in locations where the surfaces have been subjected to wave wash of the Iroquois and Gilbert waters, this being specially effective in both solution and mechanical removal of the limestone.

Old planation surfaces. If the ribbing on the limestone was in existence before the last ice invasion then, of course, the limestone plains and plateaus were formed previously; and it has already been stated that the broader topographic features are confidently believed to antedate Wisconsin glaciation. An ice sheet with sufficient vigor to do the plucking and planing necessary to give the limestones and Potsdam sandstones their breadth of flatness should leave abundant evidence in glaciated surfaces; and the limestone ribbing is a relic of such effective erosion. Again, the general lack of glacial polish is the fact which requires explanation.

The plains of Potsdam sandstone present the same question. Over broad surfaces of the very firm, hard, insoluble sandstone, either bare or practically unprotected by any impervious cover, only a minor part exhibits striae or polish. Certainly it was once all vigorously glaciated, for in no other way could the level, even, firm surfaces be produced. From hasty examination it is impossible to confidently decide whether the patchy scoring and polishing is due to weak recent glaciation on an old weathered surface, or to retention of polish under present weathering. The former alternative, recent partial smoothing on an old weathered surface, is more in harmony with the general body of fact; and it seems more probable that the recent ice sheet failed to generally polish the old weathered surface than that patches with finest polish and hairline striae should be so perfectly preserved while surrounding surfaces with apparently identical physical conditions have lost all traces of recent glaciation.

Weak erosion of the Wisconsin ice sheet. It will be seen that the critical point in this study is the erosional impotence of the latest ice sheet. With this established then at least dual glaciation of the region must be accepted.

The principle is recognized by glacialists that intensity of ice erosion depends on pressure, velocity of the bottom ice, and its armament or tools. The glacier can do its most effective work of abrasion when the basal ice is only moderately charged with rock rubbish, and that of hard texture. A heavy burden of subglacial drift serves to diminish the plasticity of the ice and so reduce the velocity of flow; while at the same time it acts as protection or a buffer for the subadjacent rock. For this reason rapid corrasion is a self-checking process.[1] On the other hand it is certain that clear ice can not abrade the bed rock at all. A moderate load of hard tools is the most effective for abrasion.

The first ice sheet that transgressed our region found it deeply covered with the residual product of millions of years of weathering, and could do no effective erosion until not only the sheet of geest (regolith) on our area had been removed but also that lying on the region northward into Labrador and Canada which was swept by the southward ice flow. The theoretical stages would be as follows: (1) the scraping away of the decay product and bearing it far southward, as no very heavy moraines lie near our area; (2) vigorous erosion during the phase of favorable load, with harder tools from the plucking of the fresher rocks; (3) weak abrasion by the clearer ice after the glacier had swept its floor and reduced the asperities in its path.

On the postulate of a single ice invasion of the Thousand Islands region it is necessary to assume that after the ice had removed the abundant product of Prepleistocene weathering it used its medium load of debris to plane the hard Potsdam and to plane and deeply flute the limestone, but at the same time failed to rub down the scores of comparatively abrupt cliffs and scarps which opposed its motion. Here we find another inconsistency. Without further discussion it will be understood that the assumption of a single glacial epoch involves serious contradictions and difficulties in the explanation of the phenomena of the region.

Assuming dual or multiple glacial epochs the features and history are fairly clear. The accumulations of long eras of rock weathering

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[1] Geol. Soc. Am. Bul. 16:26.

were swept southward by the earlier glaciation. Later ice work with more abrasive power planed the harder stratified rocks, grooved the limestones, modified the topographic forms by softening the scarps and rock knobs and straightening the drainage lines. One or more long interglacial epochs partially restored the characteristic atmospheric-erosion forms of the Theresa and Pamelia scarps and cuesta fronts; reexcavated the valleys and basins; and destroyed the surficial glaciation on the sandstones and limestones. The latest ice sheet finding the northward region denuded of rock debris and smoothed by the earlier glaciation was unable to arm itself for effective erosion and thus handicapped was competent only to weakly abrade in places. It is possible that while the deglaciation interval in our district produced some weathering effects the northward (Labrador) region was continuously snow-covered and the ice was not able to pluck a new supply of granitic tools.

Undoubtedly there were important differences in the behavior and mechanical effects of the several ice sheets, due to differences in rate of accumulation and velocity of flow; of depth and pressure; of temperature and rate of waning; and these combined with, and an effect of, climatic variations.

It would have been entirely proper in this writing to have assumed multiple glaciation and confidently to have explained the singular features of the area on that basis. Perhaps the method of argumentation which has been used is somewhat confusing to the reader, but he will better appreciate the complexities of the study and its consequent fascination.

ECONOMIC GEOLOGY[1]

While the district under consideration is bordered on the east by an area in which hematite, pyrite, galena and talc have been, or are being, mined, none of them have been found in anything like workable quantity within the limits of the map. The ferruginous quartz schists of the Grenville are present in quantity but are very lean ores indeed. One mile north of Theresa on the Red lake road a small opening has been made on a hematite mass which occurred as a direct replacement of Grenville limestone. The material was a finely crystalline, scaly, specular iron, and was of great purity, but there were only a few tons of it. While therefore the deposit was of interest as a clear and pretty example of replacement of the sort, it had no economic value.

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[1] By H. P. Cushing.

Small masses of barite are not infrequent in the Grenville limestone, but none were seen of any size or importance. An old opening was made on a coarsely micaceous limestone contact zone, 2 miles north of Theresa, but no mica of merchantable size and quality was forthcoming.

The only mineral industry of the district that has any present or prospective value is the quarry industry. Stone has been and is being quarried for road metal, for paving, for flagging, for lime, and for construction. Various Precambric rocks, the Potsdam sandstone, and the Pamelia, Lowville and Black River limestones have all been quarried in varying degree for one or the other of these purposes.

Road metal

Road improvement is going on hereabout, as elsewhere in the State. About Theresa, Grenville limestone has been chiefly used, though a small quarry has been opened in very impure limestone cut up by granite, which furnished very variable, and hence not very good material. The limestone from the other quarry makes a very good macadamized road, as would apparently much of the Grenville limestone of the district.

About Alexandria bay various experiments have been tried with road metal. The Laurentian granite gneiss of the vicinity has been used, and of course given poor satisfaction. To a small extent Pamelia limestone has also been used, and has not proved very satisfactory, probably because of the variability of the different layers used, pure limestone and magnesian limestone probably being mixed together. At present a considerable stretch of road north of Browns Corners is being macadamized with Grenville amphibolite, obtained 1 mile west of Redwood, surfaced with Grenville limestone, which, as we saw it being obtained, was of poor quality. The amphibolite was slightly soaked with, and cut by granite, so that the material was not as uniform as is desirable, but the quantity of granite is so slight that the lack of uniformity is not prominent, and the amphibolite itself is quite undecayed, firm and strong. It seems on the whole likely to prove quite adaptable to road-making purposes. Its composition is quite similar to that of trap, and in all probability it will bind in similar fashion.

Potsdam sandstone has been used as a road rock to a small extent. It is absolutely unfitted for such use, and the worst rock that could be selected for the purpose.

In the southern part of the mapped district the Lowville, Black River and Trenton limestones have been used on the roads, and all serve the purpose very well.

The rock of the district best fitted for road metal has, as yet, not been utilized at all, namely that of the trap (diabase) dikes. There is no better road metal known than trap, provided it be unrotted, and the wide dikes which occur on Grindstone island are capable of furnishing a considerable supply of material, much of which is certainly quite fresh. The material is in large demand for road-making purposes.

On the country roads to the eastward of Alexandria Bay, on which travel is light, the easily rotting, aluminous phases of the ferruginous quartzite (Grenville) have had considerable use for surfacing the roads, and answer the purpose satisfactorily.

Granite quarries

During the past season both the Picton granite and the Laurentian were being quarried in the district. The former rock has been intermittently quarried on Grindstone island for a number of years and has been considerably used for structural and ornamental purposes, both locally and at a distance. For uses for which pronouncedly red granites are serviceable it compares very favorably in appearance and quality with the other red granites of the country. There is much quite uniform material available, and large sized blocks can be quarried. In 1908 none of the Grindstone island quarries were being worked, though quarrying was actively in progress on Picton island, where the chief quarries of today lie.

On the mainland, a short distance west of Alexandria Bay, active quarrying operations are in progress in the Laurentian granite gneiss. At the location the rock is fairly uniform and free from inclusions, and is being quarried for paving blocks, which are being shipped to Chicago for use. Transportation to the various cities on the Great Lakes is of course cheap, and the rock seems well adapted to the purpose for which it is being used.

Sandstone quarries

Various small openings have been made in the Potsdam sandstone here and there in the district, for very local building and flagging purposes. Just beyond the Alexandria sheet edge, to the east, in the town of Hammond, the Potsdam forms a long scarp, at the base of which the railroad runs, and the rock here is quarried largely for paving blocks. It is fairly evenly and thinly bedded here, mostly of red color, well indurated, and quite well adapted to the purpose. The same would be true of much of the Potsdam of the adjacent portion of the Alexandria sheet, were it as conveniently situated as regards transportation.

Limestone quarries

There are many of these in the district, quarrying the Pamelia, Lowville and Black River limestones, both for structural purposes, and for burning for lime. The massive 7 foot tier of the Black River is largely quarried, the large solid blocks obtainable rendering it an exceedingly serviceable material for heavy masonry construction, much more so than the thinner bedded Lowville and Pamelia limestones. Some of the beds of the upper Lowville are also fairly thick, make very serviceable stone where construction is less massive, and hence are quarried in many places. Most of the Pamelia is much thinner bedded, and the thicker beds are mostly separated from one another by much thin bedded material. Nevertheless the formation contains some good stone, and there are numerous quarries in it all the way from Leraysville to west of Clayton, which, however, chiefly serve a local use in the northern part of the mapped area. It is not so largely quarried and used as the upper Lowville. The dove limestones of the upper part of the formation should, it would seem, make an excellent cement rock.

A single quarry has been opened in the impure, thin beds of the upper division, a few miles south of Clayton, and the stone used for flagging in Clayton. Owing to the joints only medium sized slabs can be obtained, but otherwise the rock is fairly smooth surfaced and makes a very respectable flagstone.

The quantity of limestone in the district available for these various uses is enormous, and the nearness of water transportation bespeaks a considerable future for the industry.

PETROGRAPHY OF SOME PRECAMBRIC ROCKS[1]

It is proposed here to treat, in somewhat more detail than seemed suitable in the general account, of certain of the Precambric rocks with discussion of chemical analyses. While some of the igneous rocks of northern New York have already received detailed study, more especially the syenites and certain gabbros, others have been comparatively neglected, notably the granites. For the purpose of

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[1] By H. P. Cushing.

somewhat atoning for this neglect, analyses have been prepared of four samples of granites of the region, as shown in the following table:

	1	2	3	4	5	6
SiO_2	76.56	76.41	73.33	73.10	70.13	66.59
Al_2O_3	12.95	12.41	13.55	14.29	15.47	14.54
Fe_2O_3	.16	1.01	.58	1.04	1.52	2.42
FeO	.37	.50	1.53	1.04	1.05	2.43
MgO	.24	.46	.45	.53	.85	1.18
CaO	1.30	.78	1.66	1.18	1.60	2.15
Na_2O	3.90	3.34	5.01	3.08	3.72	3.08
K_2O	4.23	4.33	3.12	5.36	4.39	5.62
H_2O+	.25	.34	.45	.54	.48	.46
H_2O-	......	.13		.07	.01	....
TiO_2	.06	.03	.17	.18	.30	.81
ZrO_2	......	.02	......	......	......	....
P_2O_5	......	......	......	.03	......	.40
Cl	.04	......	......	.03	.05	.03
F	.03	.01	......	.02	.09	.06
S	.02	.01	......	.02	.07	.08
MnO	.02	.06	.04	.07	.08	.23
BaO	.02	......	......	......	.05	.17
	100.15	99.84	99.89	100.58	99.86	100.25

NOTE. Cr_2O_3 and CO_2 absent in nos. 1, 4, 5 and 6.

1 White (bleached) granite near limestone, 1 mile north of Redwood (5K10, Alexandria sheet), from a small boss of Laurentian granite gneiss. Analysis by E. W. Morley.

2 Morris granite of Long Lake quadrangle, one of the later granites of the region. N. Y. State Mus. Bul. 115, p. 511.

3 Laurentian granite gneiss from the Methuen bathylith of central Ontario. F. D. Adams, Jour. Geol. 17:17.

4 Laurentian granite gneiss of the Alexandria bathylith, ¼ mile south of Alexandria Bay (6E5, Alexandria sheet), analysis by E. W. Morley.

5 Laurentian granite gneiss of Antwerp bathylith, 2 miles east of Theresa (16M4b, Theresa sheet), chosen for analysis because of apparent slight digestion of amphibolite. E. W. Morley, analyst.

6 Picton granite, from a quarry 1 mile southeast of Grindstone, Grindstone island (2F3, Grindstone sheet). Analysis by E. W. Morley.

That the granite gneisses hold abundant amphibolite inclusions in various stages of digestion, so that the rock is quite variable in composition, has already been stated. The rock of analysis 4 was carefully selected as representative of the normal, acid phase of the rock, free from amphibolite contamination. It is a quite normal, rather acid granite, and comparison with analysis 3 shows close agreement except that the relative proportions of the alkalies are reversed in the two. Calculation of its norm gives the following result:

Or	31.69		Class 1, persalane
Ab	26.20		
An	5.00	95.29	Order 4, britannare
Co	1.50		
Qz	30.40		Rang 2, toscanase
Hy	2.46	4.44	Subrang 3, toscanose
Il & Mt	1.98		

The rock of analysis 5 was not the normal acid granite gneiss of the locality where it was collected, but somewhat darker colored, more basic in appearance, and the field relations definitely suggested that it had soaked up some amphibolite. Nevertheless the analysis shows that this contamination is in slight amount, and the rock is to be classified in the same group as its predecessor, as its calculated norm shows.

Or	26.13		Class 1, persalane
Ab	31.44		
An	7.51	93.85	Order 4, britannare
Co	1.83		
Qz	26.94		Rang 2, toscanase
Hy	2.50		
Il & Mt	2.70	5.49	Subrang 3, toscanose
Py	0.29		

The mode of these rocks differs so little from the norm that it is not thought worth while to present the calculation. Both rocks consist chiefly of feldspars and quartz, with biotite as the principal additional mineral, a little magnetite, and trifling amounts of apatite, zircon, titanite, muscovite and pyrite. These minerals taken together only amount to about 6% in the first case and 8% in the second. In each case the surplus of alumina in the norm, calculated as corundum, is in just the proper amount to combine with the magnesia to form biotite.

Bleached granite

The rock of analysis 1 is from the margin of a small granite boss-cutting limestone, north of Redwood, which we regard as being of Laurentian age, and is a fresh sample of granite whitened by adjacent limestone. It is a somewhat more acid rock than the preceding. Unfortunately no samples which seemed satisfactory for analytical purposes could be obtained from the adjacent red granite of the same boss, and this white granite stands as the only border rock of any of the granites which has been analyzed. The field relations of all the granite masses indicate that their border zones, and the dikes which run out from them, are more acid than the general mass of the rock, higher in quartz and with much less biotite and magnetite. Now the granite cuts and sends dikes into all the Grenville rocks, all of this more acid phase, yet it is only in the case of adjacent limestone that the border and the dikes become white. In the schists and quartzites they remain red, though equally acid with the white. In so far then as the higher silica and lower iron of the white granite are concerned, the rock is believed to be merely an average representative of the general, more acid border rock, it being confidently held that much of the red, border granite or dike granite would show equivalent acidity, and like diminution in iron, and that the color change is in no way concerned in these differences. Though no chemical analyses are available, study of slides of these acid red granites gives results in close accord with the analysis of the white, and many of them show almost no biotite and magnetite in the rock, hence they are much poorer in iron than the rock of analysis 4, though with feldspar equally as red in color. Slight differentiation has taken place in the granite, producing more acid borders and dikes, and these bleached only by limestone.

The rock classes as a toscanose, as do the others. Yet it is close to the border line between orders 3 and 4, as shown by its close similarity in composition with the red, Morris granite of analysis 2, which falls in order 3 and is an alaskose.

There is every reason to believe that the coloring matter of the red feldspar is ferric oxid; in fact in some of the thin sections, minute, red hematite scales are readily made out with high powers. In casting about for some chemical explanation of the bleaching of the feldspar, chance put me in communication with Dr W. F. Hillebrand, who most generously furnished me such data as he had at command. He writes as follows:

> Many years ago, in Denver, I had occasion to analyze a zeolite that was colored red by iron oxid. On ignition the red color disappeared entirely and almost pure white resulted. This was undoubtedly due to a combination between the iron oxid and the silicate material. My impression is that the zeolite was a calcium-aluminum silicate. Since then I have seen in the *Chemical News*, vol. 84, p. 305, a reference to the decolorizing effect of alumina on ferric oxid when the two are ignited together . . .

> Now on hearing of your problem it occurred to me that such an effect might be represented by the bleached dikes in limestone. The idea was that, under the influence of the intrusions, the limestone may have become decarbonated to a slight extent, thus facilitating action with the ferric oxid of the feldspar. The explanation does not, however, satisfy me, for one might expect perhaps that the feldspathic material intruded at the elevated temperature would have already acted on its iron oxid, and hence not show color; still it may be that the silicate molecule of the feldspar is far more resistant than the zeolite and limestone in respect to ferric oxid, which might thus be in independent existence with the feldspar at high temperatures.

Dr Warth's article in the *Chemical News* deals with the blowpipe ignition of mixtures of alumina and ferric oxid in various proportions, in which the color invariably changed from red to white when small amounts of iron were used, while a brownish tint was obtained when the proportions were larger. Incidentally it was also shown that the alumina prevented reduction of the iron to the magnetic oxid.

A sample of finely crushed and sorted red granite was ignited by us for three hours over a Bunsen flame in a platinum crucible. The portion in close contact with the sides and bottom became white, while the bulk of the material, in more central position and hence less strongly heated, retained its red color. This we take to indicate that, with sufficiently high temperature, even in feldspar, the red color will disappear, and that the presence in rocks of alkali feldspar colored red by ferric oxid shows that, under the conditions of congelation, the temperature was not sufficiently high to bring about this color change. We then mixed a small quantity of powdered limestone with another charge of the crushed granite, and ignited in the same crucible over the same burner for the same time. Not only was the feldspar of the entire charge bleached, but the bleaching seemed complete at the end of one hour. Finally we ignited a third charge, in which a very thin coating of limestone was spread over the top, but not mixed with the granite as in the previous case, and here again the bleaching was prompt and absolute. It is not intended to imply that the cause of the bleaching was the same in both cases, but only that, in the presence of lime, decoloration took place more readily and at a lower temperature; precisely what the field relations had indicated for the granite in place. There is also here, it seems to us, a hint at the reason why red coloration is a common feature in alkali feldspars, and not in lime soda feldspars.

The amount of ferric oxid in the red feldspar is undoubtedly very trifling, so that, if chemical combination has taken place and the lime has entered into the reaction the quantity involved is so small that it would be a comparatively insignificant feature in the complete rock analysis. It is to be noted that the lime is somewhat higher in analysis 1 than in 4, but, while it is possible that this is owing to lime taken up from the limestone and going into combination with the iron of the feldspar, it must be remembered that the variation is well within the limits of variation which all the bases show in the general granite mass, hence it is absolutely unsafe to generalize in regard to it. We may have a combination of lime, iron and alumina in a spinellike mineral, though lime does not, in general, occur in spinel; or a small amount of anorthite may be formed, with the iron replacing alumina. The iron may perhaps be reduced, forming an iron aluminate, the iron reduced to the ferrous condition, though it would seem as if this would likely give a green color to the feldspar. Warth argues that his color changes need not mean chemical combination of the two oxids but rather a diffusion of one in the other. Hillebrand, however, is quite confident that combination takes place. He says, " It is unquestionable that both lime and alumina decolorize and combine with ferric oxid when they are heated together." Though this chemical question must be left indefinite, it does seem to us certain that the red color of the feldspar may be made to disappear merely by sufficiently high and prolonged heating, that the presence of lime facilitates the process, lowering the necessary temperature, and that with our feldspars here the temperatures were not sufficiently high to discharge the color, or rather to cause the feldspars to crystallize with the iron combined, rather than as free hematite, under the conditions prevailing at the place and time of solidification; though they were high enough to cause the combination to take place when in the vicinity of limestone and under its influence.

The only difference in the mineralogy of the two rocks is the presence in the white rock of occasional, scattered, small black tourmalins, which in general do not appear in the other, though they are locally present even there. They would seem attributable to the presence of mineralizers in the border phase of the granite, and in the dikes they occur in the red granites adjacent to other rocks than limestone, such as quartzite for example, and seem to have nothing whatever to do with the color change. It seems to us that the chemical analysis gives no suggestion whatever as to the cause of this change.

Picton granite

The specimen of Picton granite analyzed was selected as an average representative of the rock, and bears out the impression gained in the field that as a whole it is less acid than the Laurentian granites where uncontaminated by Grenville material. It seems less quartzose, and always shows considerable hornblende, which is relatively scarce in the granite gneiss. The thin section shows it to be fairly rich in accessory minerals, titanite and apatite especially being frequent and fairly coarse, the former particularly so. Some pyrite is present, zircon also, little hematite inclusions in the feldspars, and ilmenite or rutile needles in the quartz. A few minute tourmalin crystals also occur. The green hornblende is altering to biotite, and there is additional biotite in the rock as well. For the feldspars, microperthite, microcline, microcline-microperthite and oligoclase are all present in considerable amount, and all with strongly marked characters. A good deal of micropegmatite, some of it quite coarse, is also to be seen. Altogether, in its minor mineralogy, the rock presents considerable contrast to the granite gneiss.

The norm of the rock is a follows:

Or....	33.36	89.00	Class 1, persalane
Ab....	26.20		Order 4, britannare
An....	8.62		
Qz....	20.82		Rang 2, toscanase
Hy....	4.48	10.64	Subrang 3, toscanose
Mt....	3.48		
Il.....	1.52		
Py....	0.15		
Ap....	1.01		

It thus falls in the same rock group as the granite gneisses, but is much nearer the border of the group than they are. The greater variety and abundance of the femic and alferric minerals, hornblende, biotite and titanite, would cause the mode to depart somewhat more widely from the norm than in the previous cases, the lime to form titanite being deducted from the anorthite, releasing alumina for the biotite and diminishing the quartz percentage.

The dike phases of this granite range more acid than this, but with this exception it is thought that the average of the rock composition is well represented by the analysis. The composition is toward the basic end of the granites, hence it is not surprising that slight variations toward further basicity should give rise to rock with little quartz, like that south of Clayton along French creek. Except for this the petrographic agreement is so close in all details that there seems no question as to the identity of the two rocks.

Alexandria syenite

In the previous description of this syenite it has been stated that an augen gneiss adjoins it on the south which was taken by us in the field for a gneissoid, border phase of the rock, but that Smyth dissents from this view. In the field this border rock appears much the more basic of the two, but closer examination shows the presence of much quartz, and chemical and microscopic investigation shows it to be much more acid than the syenite. Analyses of each follow, with two analyses of the general Adirondack green syenite, thought to be represented in this district by the Theresa syenite, (of which no analyses have been made) for purpose of comparison with them.

	1	2	3	4	5
SiO_2	58.99	59.70	63.45	66.50	66.59
Al_2O_3	19.22	19.52	18.38	15.66	14.54
Fe_2O_3	2.83	1.89	1.09	1.75	2.42
FeO	2.83	4.92	2.69	2.21	2.43
MgO	1.25	.78	.35	1.18	1.18
CaO	3.41	3.36	3.06	2.15	2.15
Na_2O	4.33	5.31	5.06	3.74	3.08
K_2O	5.64	4.14	5.15	5.02	5.62
H_2O+	.35	.52	.30	.40	.46
H_2O-	.04			.05	....
TiO_5	.01	.....	.07	.71	.81
P_2O_2	.59	.....	.....	.59	.40
Cl	.10	.....	.....	.06	.03
F	.40	.....	.....	.05	.06
S	.08	.....	.....	.18	.08
MnO	.14	.9	trace	.03	.23
BaO	.09	.....	.....	.05	.17
	100.30	100.23	99.60	100.33	100.25

1 Alexandria syenite, 3½ miles north of Redwood (8K2, Alexandria sheet). E. W. Morley, analyst.

2 Tupper syenite (laurvikose), N. Y. State Mus. Bul. 115, p. 514.

3 Loon Lake syenite (pulaskose), N. Y. State Mus. Bul. 115, p. 514.

4 Augen gneiss associated with Alexandria syenite, 2 miles west of north of Redwood (6J2, Alexandria sheet), E. W. Morley, analyst.

5 Picton granite, repeated from previous column of analyses.

Norm of Alexandria syenite, analysis 1:

Or....	33.36	87.15
Ab....	36.68	
An....	11.12	
Co....	1.85	
Qz....	4.14	
Hy....	5.00	11.30
Mt....	4.18	
Fl....	0.78	
Ap....	1.34	

Class 1, persalane
Order 5, Canadare
Rang 2, pulaskase
Subrang 3, pulaskose

The rock itself contains considerable green horblende and biotite which, together with the accessory magnetite, titanite, apatite and pyrite, constitute about 15% of the rock, (elsewhere they run up to 25 or 30%, carrying the rock into the dosalane class) meaning of course that some of the lime, alumina and potash calculated with the salic minerals of the norm are in the hornblende and biotite. Microcline, microperthite and oligoclase are all present in some quantity, plagioclase being somewhat in excess. Some of the microperthite is secondary after oligoclase. The rock has beautiful cataclastic structure, showing much more crushing than the Picton granite. Chemically it is seen to be very close to the green syenites of similar silica percentage, the chief difference being in the higher magnesia and in the relative proportions of ferric and ferrous iron and of the alkalies. The higher magnesia expresses itself mineralogically in the formation of hornblende and biotite, instead of the pyroxenes of the green syenite. The general rock is somewhat more basic, and with a higher percentage of ferromagnesian minerals than the normal green syenite.

The augen gneiss of analysis 4 is a much more acid rock, a toscanose, suggesting caution in attempting to account for it as a phase of the syenite. The analysis is so close to that of the Picton granite of the last column as to be almost grotesque. Quite certainly it has no relation whatever to the Picton granite, though mimicing it so closely chemically. The green syenites of the region show wider range of variation than that shown in this case, nevertheless the intrusion here is of such comparatively small size that variation in composition to this amount would be quite unusual. Hence the analyses rather tend to reinforce Smyth's conclusion that we really have here two separate small intrusions, side by side.

Mineralogically the augen gneiss consists of quartz, feldspars and biotite, with accessory magnetite, titanite and apatite, and small amounts of hornblende, muscovite, zircon and pyrite. The femic minerals constitute 15% of the rock analyzed. The feldspar is chiefly microcline and oligoclase, though with some microperthite. Both feldspars occur as augen, with trains of granulated material running away from them, between which are foliae of quartz, feldspar and biotite. To a considerable extent the quartz and biotite seem to have resulted from recrystallization of feldspar.

The certain Alexandria syenite runs into very gneissoid and micaceous border phases, which lie between its massive core, and the augen gneiss beyond. These varieties are much more micaceous, and much more quartzose than the massive portion, and in them also much biotite and quartz have resulted from feldspar recrystallization. They are thus very similar to the augen gneiss. It was this apparent gradation from one rock to the other in the field which gave us the impression that the whole represented a single intrusion. It is a matter of very minor importance in the local geology, and must for the present be left as undetermined.

Granitized amphibolite and amphibolitized granite (soaked rocks)

Practically all observers who have worked in Laurentian areas, have seen and recorded the evidences, which meet one on every hand, of the attack of the granite upon the amphibolite inclusions, large and small, which occur nearly everywhere, and are often abundant. The action consists of an injection of granite into the amphibolite, at first along the foliation planes, from which the granite spreads out more or less into the adjacent rock, injecting itself between and inclosing the grains, but with the distinction between the two materials still sharp. In later stages this sharpness disappears, the two materials seem to merge, or fade into one another, and as a final stage a rock is produced which seems a true mixed rock, in which a distinction between the two elements is no longer possible, and whose origin would be problematic except for the occurrence of the less advanced phases of the change. Needless to say the granite must be very thoroughly molten in order to produce these mixed rocks. It was our purpose to investigate these rocks somewhat thoroughly chemically. Unfortunately however no material which seemed to us sufficiently fresh to warrant chemical investigation was obtained from rocks which seemed distinctly intermediate. A beginning was made, however, by the investigation of two rocks, one a granite slightly tinctured with amphibolite, and the other an amphibolite slightly soaked by granite, and their analyses appear herewith. Each, in the field, was classified as plainly a soaked rock, in which the constituents were merged. Each was also merely a phase in a gradual increase in amount of soaking, plainly to be traced in the field, and the two samples were chosen from among many because of unusual freshness.

	1	2	3	4	5
SiO_2	73.10	70.13	56.58	51.42	50.83
Al_2O_3	14.29	15.47	15.54	17.42	18.64
Fe_2O_3	1.04	1.52	3.80	3.64	2.84
FeO	1.04	1.05	5.41	5.14	5.97
MgO	.53	.85	2.77	5.11	4.90
CaO	1.18	1.60	4.56	6.76	7.50
Na_2O	3.08	3.72	2.91	3.74	4.22
K_2O	5.36	4.39	4.25	3.33	1.83
H_2O+	.54	.48	.80	.74	1.40
H_2O-	.07	.01	.10	.09	
TiO_2	.18	.30	1.71	1.25	1.10
ZrO_2	......	......	.01	.01	....
P_2O_5	.03	......	.87	.71	....
Cl	.03	.05	.12	.13	.03
F	.02	.09	.14	.10	....
S	.02	.07	.44	.23	.01
MnO	.07	.08	.09	.16	.10
BaO	......	.05	.08	.13	.11 CO_2
	100.58	99.86	100.18	100.11	99.48

NOTE. Cr_2O_3 and CO_2 absent.

1 Laurentian granite gneiss of Alexandria bathylith, from column 4 of original table.
2 Laurentian granite gneiss of Antwerp bathylith, slightly soaked with amphibolite, column 5 of original table.
3 Amphibolite, somewhat soaked by granite, from railroad cut 4 miles north of Redwood (8L2a, Alexandria sheet). E. W. Morley, analyst.
4 Amphibolite, from same railroad cut (8L2B, Alexandria sheet). E. W. Morley, analyst.
5 Amphibolite described by Adams as representing the extreme stage in the alteration of crystalline limestone into amphibolite by contact action of the Glamorgan bathylith, Jour. Geo. 17:2.

It is not thought that the amphibolite of analysis 4 is an altered limestone, but rather a member of the schist series, though likely a calcareous shale, even perhaps an impure limestone. In any case its similarity in composition with the amphibolite described by Adams from Maxwells Crossing is quite striking, the somewhat higher magnesia and potash being the most prominent differences.

Adams also shows, in his valuable paper, the similarity in composition of his contact amphibolite with other amphibolites, even some of igneous origin. It would seem therefore that we are reasonably safe in assuming that analysis 4 will not depart widely in composition from most of the amphibolites of the region, no matter what their origin.

The analyses of the two granites have been already discussed. No. 2 does not depart widely from no. 1 in composition, and might well represent a simple variant of the magma. Its field relations, however, preclude that supposition and it is to be noted that, when compared with analyses 1 and 4, it represents an intermediate stage in every single important constituent. On the basis of the silica percentage a mixture of six parts of analysis 1 and one part of analysis 4 would almost give a rock of the composition of analysis 2. Calculated on that basis the following result is arrived at:

	1	2	3	4
SiO_2	70.13	70.05	56.58	56.62
Al_2O_3	15.47	14.73	15.54	16.66
Fe_2O_3	1.52	1.42	3.80	3.01
FeO	1.05	1.63	5.41	4.14
MgO	.85	1.18	2.77	3.97
CaO	1.60	1.99	4.56	5.53
Na_2O	3.72	3.17	2.91	3.58
K_2O	4.39	5.08	4.25	3.79

In column 1 are given the percentages of the soaked rock shown by analysis, and in 2 the calculated percentages on the basis stated above. They seem to us to be sufficiently alike in every constituent to afford a strong probability that the field relations were correctly interpreted, and that the rock is a true soaked rock. The greatest variation between the two is in the alkali percentages, and these are just the ones which vary most in the general granite masses. The total amount of alkalies, however, is much the same in each, 8.11% in the first case and 8.25% in the second.

The granitized amphibolite is not so definitely a soaked rock as the other, since the amount of granite in it is so small, that it is an impregnated, rather than a mixed rock. Nevertheless the granite is thoroughly disseminated through it, though granitizing it in patches rather than uniformly. Column 3 gives the rock percentages of this amphibolite, and column 4 a calculated mixture of granite and amphibolite in the ratio of 24% of the former and 76% of the latter. The agreement in this case is not so close as in the former one, but in large part the differences can be ascribed to the fact that the granite here is not normal, but of the pegmatitic type, higher in mineralizers and in iron, and poorer in alumina, lime and magnesia than the normal rock. Comparison of analyses 3 and 4 seems definitely to suggest this, the iron being higher in the granitized rock than in the amphibolite, and the lime and magnesia much lower. It is thought that if an analysis of the neighboring granite was available for use in the computation, the agreement would be much closer. But the result is somewhat disappointing, and the importance to be assigned to the discrepancies a debatable matter, likely to vary with the personal equation of the reader. Considering all the circumstances the agreement seems to us as close as could be hoped for, and indicative of the correctness of interpretation of the field evidence, namely, that these are true mixed rocks.

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New York State Education Department

New York State Museum

JOHN M. CLARKE, Director

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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.

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Report	*Price*	*Report*	*Price*	*Report*	*Price*
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16	1	20	.50	[*See* Director's annual reports]	

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See first note under Geologist's annual reports.

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Entomologist's annual reports on the injurious and other insects of the State of New York 1882–date.

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Report	*Price*	*Report*	*Price*	*Report*	*Price*
1	$.50	10	$.35	18 (Bul. 64)	$.20
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5	.25	12	.25	20 (" 97)	.40
6	.15	13	*Free*	21 (" 104)	.25
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				25 (" 141)	.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), 60th (1906), in volume 2 of the 61st (1907) and 62d (1908) 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. *To advance subscribers, $2 a year or $1 a year for division (1) geology, economic geology, paleontology, mineralogy, 50c each for divisions (2) general zoology, archeology and miscellaneous, (3) botany, (4) entomology.*

Bulletins are grouped in the list on the following pages according to divisions.

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Clarke, J. M. Limestones of Central and Western New York Interbedded with Bituminous Shales of the Marcellus Stage.
Wood, Elvira. Marcellus Limestones of Lancaster, Erie Co., N. Y.
Clarke, J. M. New Agelacrinites.
—— Value of Amnigenia as an Indicator of Fresh-water Deposits during the Devonic of New York, Ireland and the Rhineland.

52 Clarke, J. M. Report of the State Paleontologist 1901. 280p. il. 10pl. map, 1 tab. July 1902. 40c.
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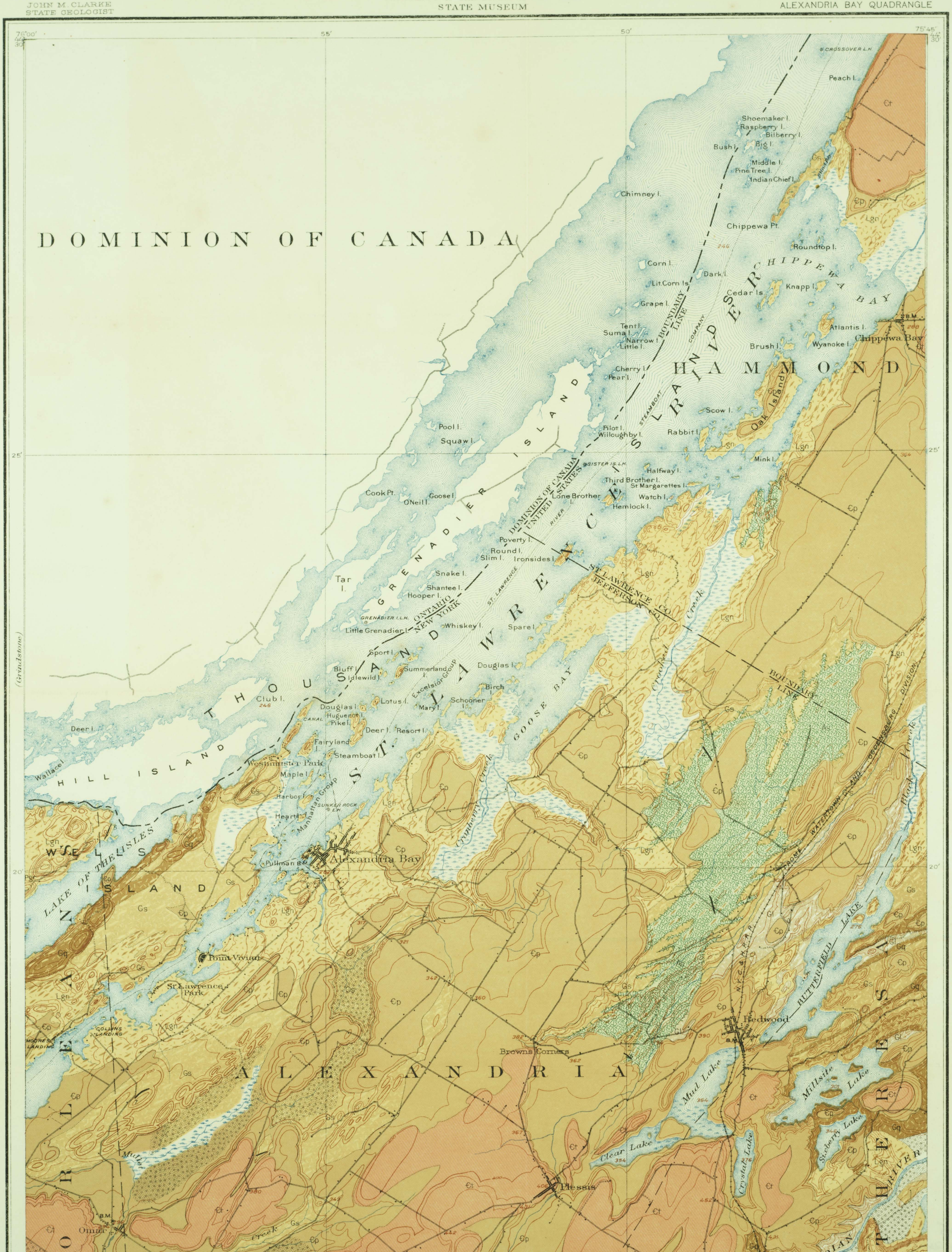
Geologic maps of the Alexandria Bay, Cape Vincent, Clayton, Grindstone and Theresa quadrangles

Plate 43 Hydrography of the Thousand Islands region

EDUCATION DEPARTMENT
JOHN M. CLARKE
STATE GEOLOGIST

UNIVERSITY OF THE STATE OF NEW YORK
STATE MUSEUM

BULLETIN 145
ALEXANDRIA BAY QUADRANGLE



LEGEND

Sedimentary Rocks

PLEISTOCENE

▨ Glacial deposits, concealing boundaries.

UPPER CAMBRIC

Ꞓt Theresa formation Sandy, magnesian limestone, with beds of weak sandstone.

Ꞓp Potsdam sandstone. Red, white and buff sandstone with some coarse conglomerate.

PRECAMBRIC

Gl Grenville limestone. Generally coarse, white crystalline limestone.

Gq Grenville quartzite. Coarse and fine, pure and impure quartzites and quartz schists.

Gs Grenville schists. Comprising amphibolites and all other Grenville rocks except quartzites and limestones.

Gs Gl Grenville rocks, cut by numerous dikes from the igneous rocks.

Igneous Rocks

PRECAMBRIC

Diabase dikes, of late Precambric age.

As Lgn Various igneous rocks holding frequent inclusions of the Grenville rocks.

As Gp Alexandria syenite, Picton granite, of early Precambric age but younger than the Laurentian.

Lgn Laurentian granite-gneiss.

Scale $\frac{1}{62500}$
1 ½ 0 1 2 3 4 Miles
1 ½ 0 1 2 3 4 5 Kilometers
Contour interval 20 feet.
Datum is mean sea level.

Geology By H. P. Cushing,
1907-08.
Wells Island by C. H. Smyth, Jr.,
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EDUCATION DEPARTMENT
JOHN M. CLARKE
STATE GEOLOGIST

UNIVERSITY OF THE STATE OF NEW YORK
STATE MUSEUM

BULLETIN 145
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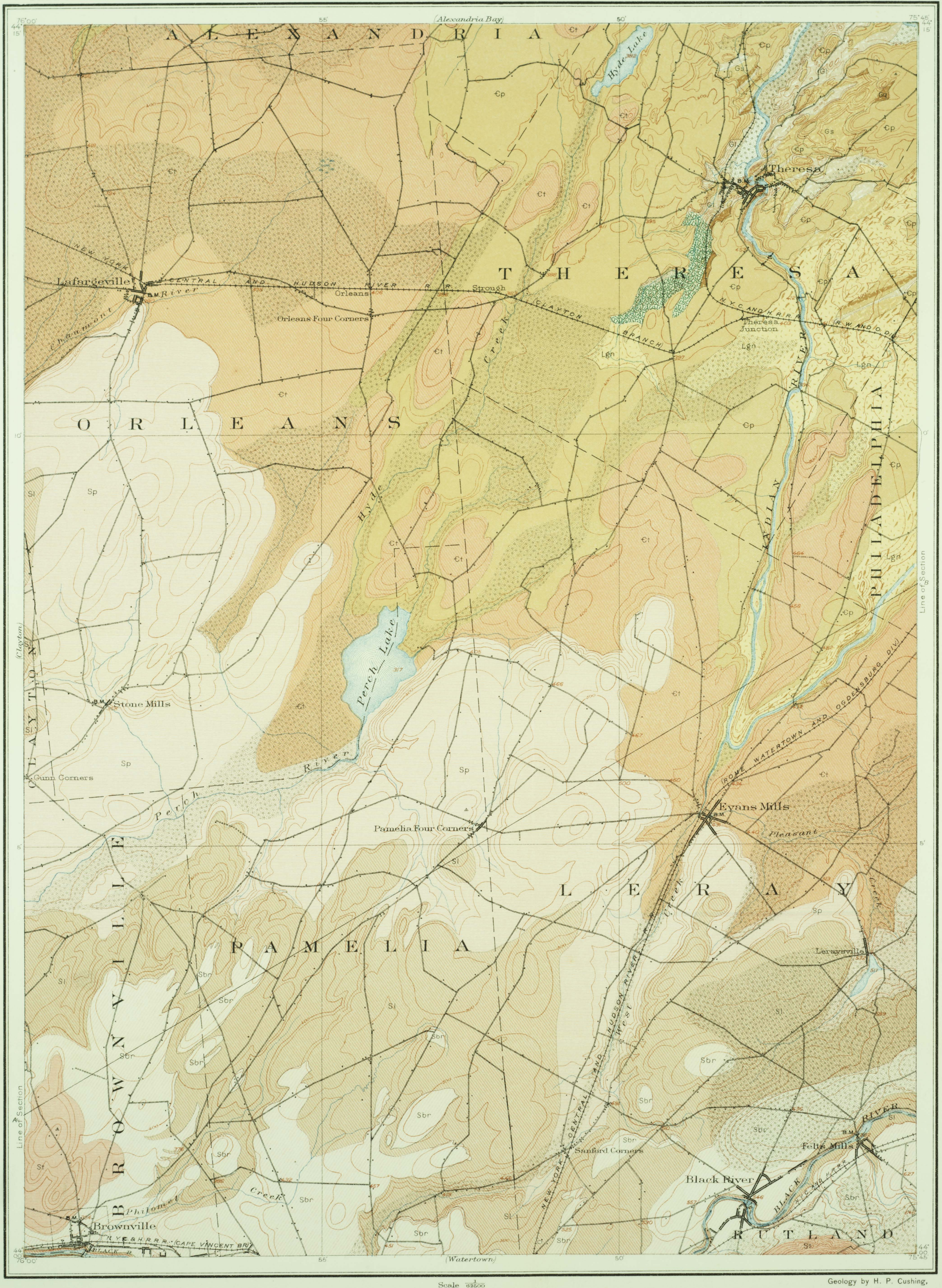

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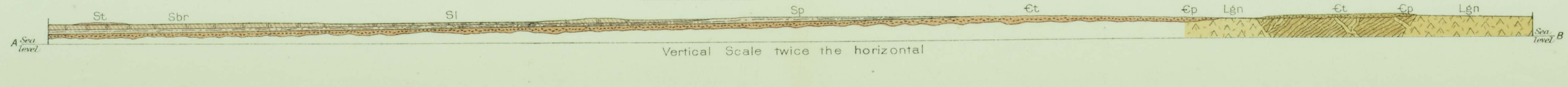
Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.



Vertical Scale twice the horizontal

LEGEND

Sedimentary Rocks

Symbol	Description	Period	Era
▨	Pleistocene deposits. As overprint on other rocks where boundaries are concealed, and mapping uncertain.	PLEISTOCENE	
St	Trenton limestone. Gray and black, mostly thin-bedded limestones.	LOWER SILURIC	PALEOZOIC
Sbr	Leray and Watertown limestones Massive, black limestone, often cherty.		
Sl	Lowville limestone. Dove and blue limestone.		
Sp	Pamelia limestone. Gray and white, impure magnesian limestone, alternating with blue and dove limestone.		
Єt	Theresa and Tribes Hill formations. Sandy, calcareous dolomites, alternating with coarse, weak sandstone beds.	UPPER CAMBRIC	
Єp	Potsdam sandstone. White, yellow, gray, red and black sandstone, with local conglomerate.		
Gl	Grenville limestone. White crystalline limestone, with a local, bluish, less crystalline phase.		PRECAMBRIC
Gq	Grenville quartzite. Coarse and fine, pure and impure, quartzites and quartz schists.		
Gs	Grenville rocks other than limestone and quartzite; various schists with thin limestone bands.		
Gl Gs	Grenville rocks cut to pieces by dikes from the granite-gneiss.		

Igneous Rocks

Symbol	Description	Era
Ts	Theresa syenite. Early Precambric but younger than the granite-gneiss.	PRECAMBRIC
Lgn	Laurentian granite-gneiss holding numerous inclusions of the Grenville rocks.	
Lgn	Laurentian granite-gneiss.	

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CAPE VINCENT QUADRANGLE

LEGEND

St — Trenton limestone. Black and gray, mostly thin-bedded limestone.

Sbr — Watertown and Leray limestones. Massive, black limestone, cherty in the lower (Leray) member.

Sl — Lowville limestone. Dove and blue dove limestone, both thick and thin-bedded.

LOWER SILURIC

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

Contour interval 20 feet
Datum is mean Sea level

Geology by R. Ruedemann
1908.

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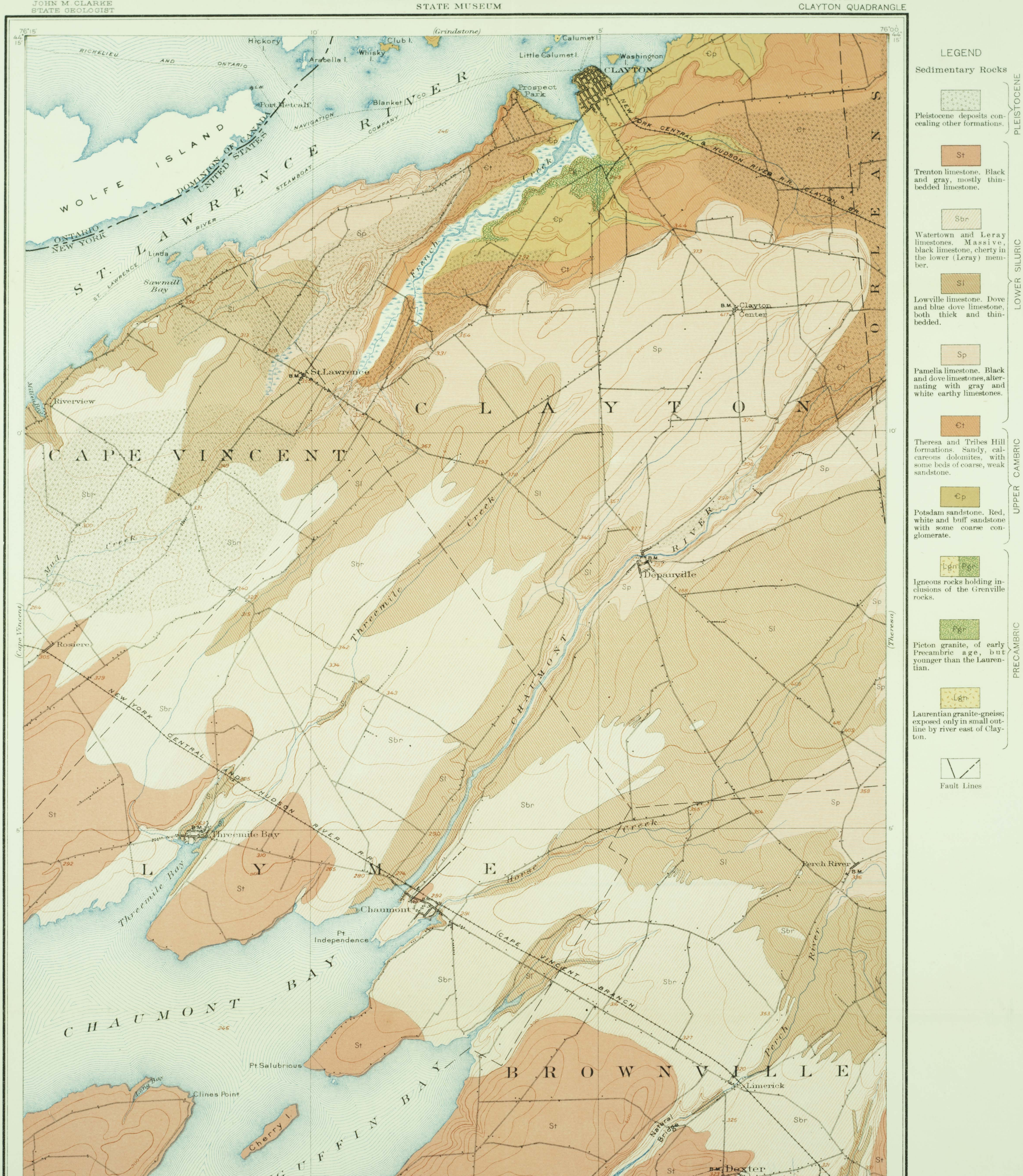
CLAYTON QUADRANGLE



LEGEND

Sedimentary Rocks

PLEISTOCENE

Pleistocene deposits concealing other formations.

LOWER SILURIC

St — Trenton limestone. Black and gray, mostly thin-bedded limestone.

Sbr — Watertown and Leray limestones. Massive, black limestone, cherty in the lower (Leray) member.

Sl — Lowville limestone. Dove and blue dove limestone, both thick and thin-bedded.

Sp — Pamelia limestone. Black and dove limestones, alternating with gray and white earthy limestones.

UPPER CAMBRIC

Ɛt — Theresa and Tribes Hill formations. Sandy, calcareous dolomites, with some beds of coarse, weak sandstone.

Ɛp — Potsdam sandstone. Red, white and buff sandstone with some coarse conglomerate.

PRECAMBRIC

Lgn Pgr — Igneous rocks holding inclusions of the Grenville rocks.

Pgr — Picton granite, of early Precambric age, but younger than the Laurentian.

Lgn — Laurentian granite-gneiss; exposed only in small outline by river east of Clayton.

Fault Lines

Geology by H. P. Cushing (northeast half) and
R. Ruedemann (southwest half),
1908.

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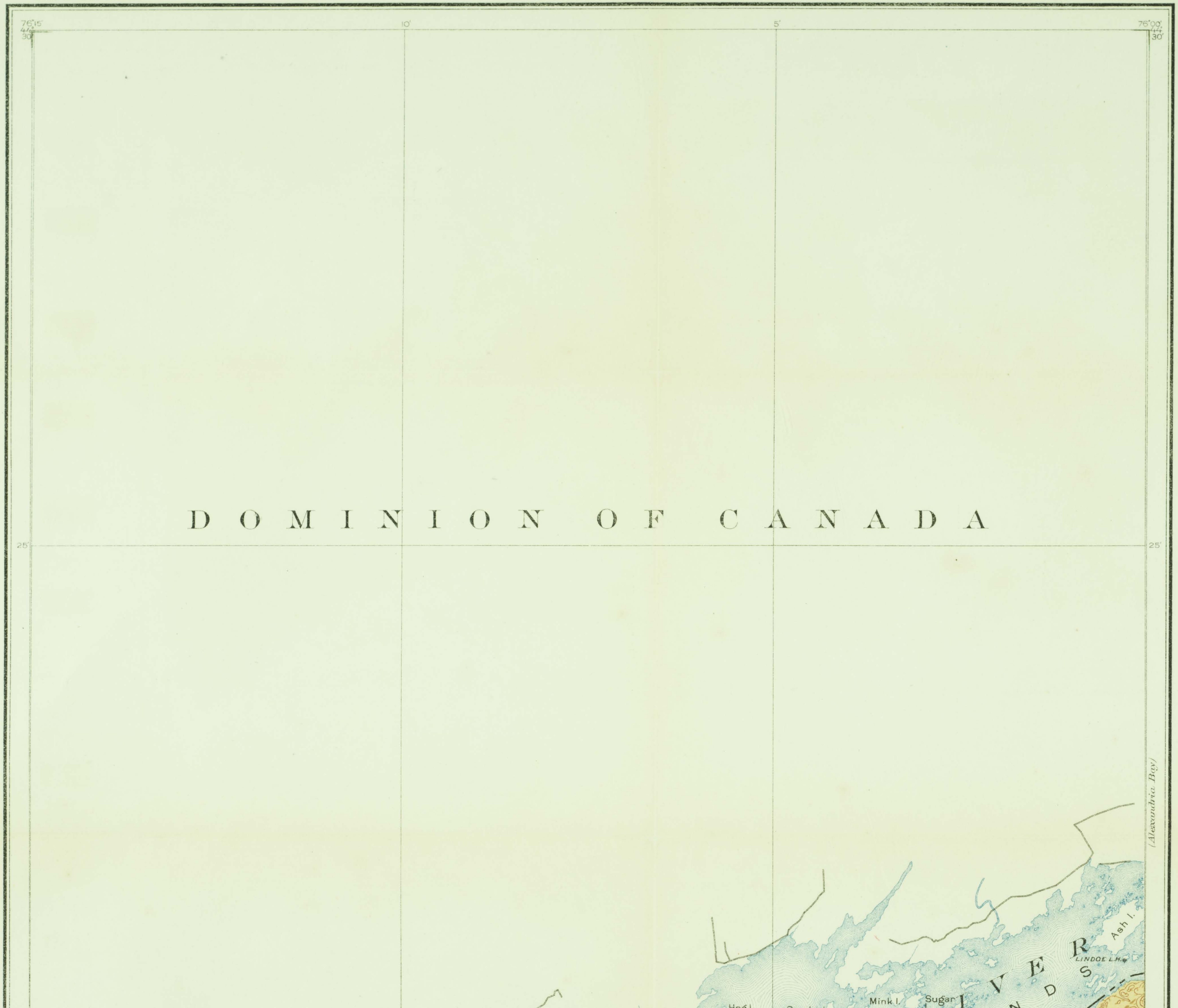
BULLETIN 145
GRINDSTONE QUADRANGLE



LEGEND

Sedimentary Rocks

PLEISTOCENE

Glacial deposits as overprint, where underlying rock is widely concealed.

UPPER CAMBRIC

Ct Theresa formation. Sandy, blue gray, dolomite, weathering to rotten stone, with some interbedded weak sandstone.

Cp Potsdam sandstone. Red, white and buff quartz sandstone, with some coarse conglomerate.

PRECAMBRIC

Gs Grenville schists. Variable rocks, comprising all Grenville rocks, except quartzite and limestone.

Gq Grenville quartzite. Coarse and fine, pure and impure quartzites and quartz schists.

Gg Gs Grenville rocks cut by numerous dikes of the igneous rocks.

Igneous Rocks

PRECAMBRIC

2 4 Diabase dikes.

Pgr Lgn Igneous rocks containing inclusions of the Grenville rocks.

Pgr Picton granite. Coarse red granite with fine-grained phases; younger than the Laurentian.

Lgn Laurentian granite-gneiss.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

Geology by H. P. Cushing and C. H. Smyth, Jr.
1908.

HYDROGRAPHY OF THE THOUSAND ISLANDS REGION

H. L. FAIRCHILD

1909

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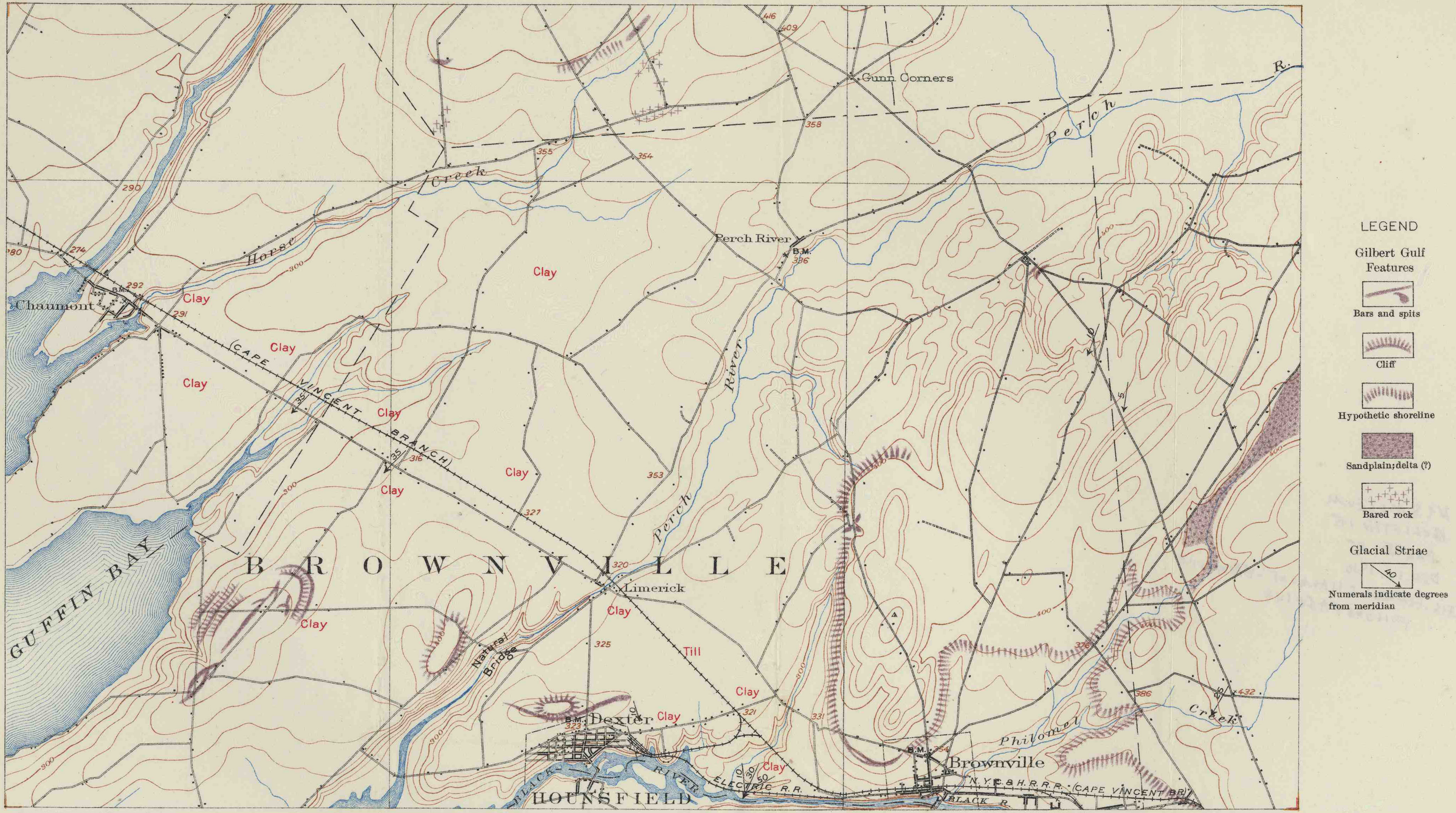

Parts of Clayton and Theresa sheets

H. L. Fairchild, 1909.

PLEISTOCENE FEATURES: CHAUMONT-BROWNVILLE DISTRICT

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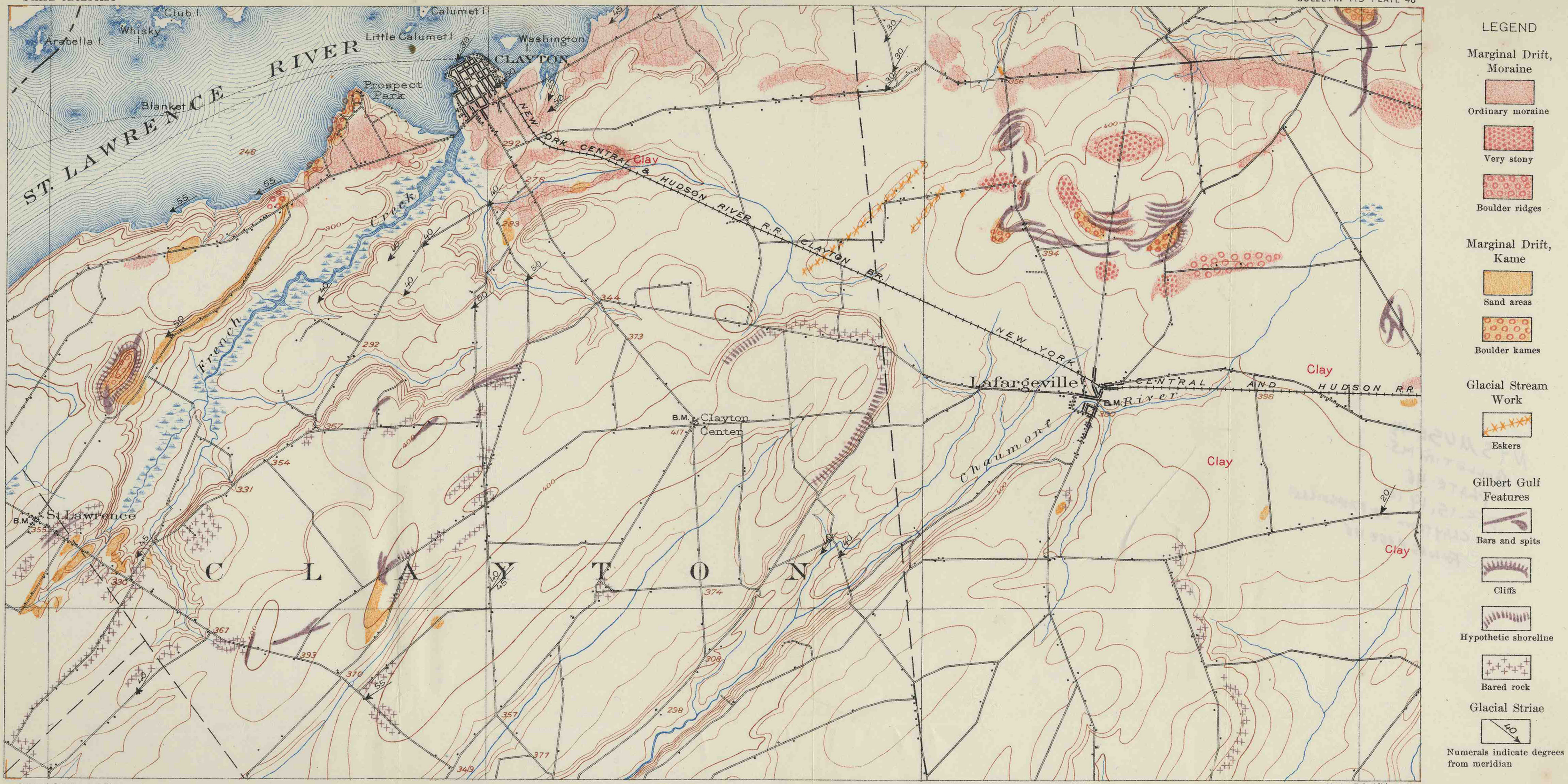
BULLETIN 145 PLATE 46



Parts of Clayton and Theresa sheets

PLEISTOCENE FEATURES: CLAYTON-LAFARGEVILLE DISTRICT

H. L. Fairchild, 1909.