GEOLGY OF THE WILLSBORO QUADRANGLE, NEW YORK

By
A. F. Buddington

AND

Lawrence Whitcomb
Temporary Geologists, New York State Museum

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CHARLES C. ADAMS, Director

GEOLOGY OF THE WILLSBORO QUADRANGLE, NEW YORK

BY

A. F. BUDDINGTON

AND

LAWRENCE WHITCOMB

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GEOLOGY OF THE WILLSBORO QUADRANGLE, NEW YORK

BY

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PREFACE

The work on the Precambrian geology of the Willsboro quadrangle was started in the summer of 1936 by Buddington. In 1937 Whitcomb spent a few days in the Paleozoic area and he returned in 1938 to do the geology of that portion of the quadrangle. This report is the result of the combined work of the two authors, each taking the responsibility for his own section with the exception that the petrography of the igneous rocks in the Paleozoic region is by Buddington.

The writers wish to express their appreciation to Dr Charles C. Adams, Director of the New York State Museum, and to the members of his organization for their interest in the work and for assistance that they have given.

Whitcomb acknowledges the aid that he has received from various persons, geologists and others. He is deeply indebted to Dr A. W. Quinn for permission to use a copy of an unpublished field map which was of great assistance in locating outcrops. Dr Rudolf Ruedemann and Dr Josiah Bridge kindly checked the identification of fossils as mentioned in the text. Credit is due to Dr J. M. Stafford, health officer of Essex county, for much information on water resources. Livingston Hatch, town supervisor of Willsboro, supplied data of a helpful nature regarding Willsboro township and his son provided a motorboat for the examination of the Four Brothers islands. C. L. Clark, of Willsboro, kindly gave some interesting facts regarding the operations of the quarry on Ligonier Point that was formerly operated by his family. Buddington is indebted to John Burnham for cordial cooperation. To all the other persons, who can not be mentioned individually, who assisted in this work by their interest or otherwise, appreciation is expressed.
INTRODUCTION

GEOGRAPHIC LOCATION

The Willsboro quadrangle lies in northeastern New York State between $44^\circ 15'$ and $44^\circ 30'$ north latitude and $73^\circ 15'$ and $73^\circ 30'$ west longitude. Part of the quadrangle is in Essex county, New York, and part in Vermont. The boundary line between the two states lies about in the center of Lake Champlain. Only that portion of the quadrangle in New York State is covered by this report.

The area under consideration is in two physiographic provinces as delimited by Fenneman (1928, p. 53-54, 58-59). The portion lying west of Corlear and Willsboro bays and of the north-flowing portion of the Bouquet river forms part of the northeast flank of the Adirondack province; the area to the east (Split Rock mountain excepted) belongs to the Champlain section of the St Lawrence Valley province.

TOPOGRAPHY

There is a marked topographic break between the two provinces, the hilltops along the east border of the Adirondacks standing in the neighborhood of 1000 feet above those of the adjacent lowlands of the Champlain section. The line of junction forms a rather straight well-defined lineament with the exception of the reentrants on the North Branch of the Bouquet river and at Corlear bay. The area within the Adirondacks is hilly with a relief of several hundred feet or more (figure 1). The Champlain section (figure 2) by contrast is very gently rolling and the hilltops decline from an altitude of about 440 feet at the south to about 240 feet at the north. The highest point in the quadrangle is Mount Bigelow (1650 feet), the lowest the level of Lake Champlain at about 100 feet. To the west and south of this quadrangle the mountains are much higher.

DRAINAGE

There is one main river, the Bouquet, with one major tributary, the North Branch, flowing through the area. This river enters the Willsboro quadrangle at the southwestern contact of the Precambrian and Paleozoic rocks, from which point it flows north for about seven and a half miles before turning eastward to pass through the village of Willsboro and so on to the lake.

The North Branch flows eastward out of the Adirondacks and occupies the graben valley floored with Beekmantown limestone, joining the main branch about a mile and a half before it turns eastward.
Figure 1 Precambrian rocks of Adirondack province exposed along west shore of Willsboro bay. East end of Mount Bigelow in distance.

Figure 2 Looking west up valley of North Branch Bouquet river over glacial sand plain on Champlain lowlands with Adirondacks in distance.
In its northward course the main branch of the Bouquet lies close to the fault line scarp which separates the younger and older rocks. In some places as at the point just below the mill dam at Bouquet it is actually flowing along the fault; in others it veers away, but in no place is it known to flow west of the fault unless it cuts across the end of a Precambrian spur just south of the point where it is joined by the North Branch. As the Precambrian rocks at this place are the relatively soft Grenville limestone which would have been easily eroded by the glacier there may be Precambrian beneath the sediments in which the Bouquet has cut its channel. With the exception of stretches at Whallonsburg, Bouquet and Willsboro, the river does not flow on a rock floor and it is the ledges at these three places that led to the establishment of mill dams and the subsequent communities.

The North Branch flows over ledges near the western end of the graben and also about one mile downstream, at which point a dam for an ice pond has been constructed.

Although there are tributary streams coming out of the Adirondacks to the west, there are practically no streams entering the Bouquet from the east. This absence of streams on the eastern or right bank is due to the fact that the greater part of the land to the east drains directly to the lake.

Although a few square miles in the northwestern part of the territory drain into the Ausable river and some small streams empty directly into the lake, the major portion of the area lies within the Bouquet river watershed.

The United States Geological Survey in cooperation with the State of New York maintains a stream gaging station situated on the right bank of the Bouquet river one-half mile southwest of the village of Willsboro.

The drainage area of the Bouquet river above Willsboro is 275 square miles, the large part of which is in the Adirondack mountains. Continuous records published in the Water Supply Papers of the United States Geological Survey are available since July 1923, from which the following information has been taken (U. S. G. S. 1937, p. 134):

The average discharge over a 14-year period is 307 second-feet, that is cubic feet a second past a point. The maximum discharge over the same length of time was about 11,800 second-feet on October 1, 1924, a figure obtained by calculating from the rating curve above 4600 second-feet, and at this time the water stood at an elevation of

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1 The 14-year average was obtained from unpublished data in the Albany office of the U. S. G. S.
10.85 feet on the gage. The minimum flow recorded was 27 second-feet at a gage height of 2.10 feet on September 11, 1932.

On June 19 or 20, 1937, a landslip, described in another part of this bulletin, occurred on the Bouquet river upstream from the stream gaging station and also above the junction of the Bouquet and North Branch of the Bouquet. This landslip caused a bulging of the stream bed, ponding the waters and temporarily cutting off the flow of the main stream. The record sheet for June 1937 was examined in order to see what effect this had on the discharge at Willsboro and in order to try to establish the time of the occurrence of the slip. Unfortunately, the instrument was out of working order for a period of days prior to and after June 19th and 20th and therefore a very interesting record was unavoidably lost.

**CULTURE**

The marked differences in topography of the two parts of the area are reflected in the culture. The Champlain section is largely cleared and used for dairy farms and contains the two main villages of the quadrangle, Essex and Willsboro. In the northwest corner is part of Keeseville, located on a reentrant of the Champlain section. The hills of the Adirondack portion are largely forested, the scattered dairy farms are practically restricted to the larger valleys, and it is in general a sparsely settled area. Lumbering was at one time a major industry, but is now quiescent.

Many summer cottages are built along the shore of Lake Champlain and of each of the larger lakes in the Adirondack portion. The region is well known as an attractive section for summer visitors and tourists.

The Delaware and Hudson Railroad runs north-south throughout the length of the quadrangle. New York State highway 22 is the major motor road through the area and U. S. route 9 cuts across the northwestern corner.

**SETTLEMENT**

The settlement of the Willsboro-Essex district dates back to the eighteenth century. The lake, long a route for the migrations of the Indians, was to become the scene of four military campaigns between the French and English and afterwards the English and Colonials. Along with this series of military invasions and with the building of forts as at Ticonderoga and Crown Point, came the settler.

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1 Much information regarding the history of the region was obtained from Smith, H. P. (1885) and Watson, W. C. (1869).
On June 13, 1737, Sieur Louis Joseph Robart received a grant of land from King Louis XV of France. There is no record of any serious attempt having been made by Robart to settle or develop the region. In 1765 William Gilliland purchased the tract of land from Robart and proceeded to make plans for its settlement. With a party of companions Gilliland sailed up the lake from Canada and stopped off at the mouth of the Bouquet river. Exploration up the river to the falls (figure 5) at the present site of Willsboro finally, after some delay and argument, led to the establishment of a small town site. The house constructed for Gilliland may well have been the first permanent white dwelling on the New York side of Lake Champlain between Crown Point and Canada.

In 1777 General Burgoyne encamped at Willsboro from the 20th to the 25th of June on his ill-fated march to the south. The old military road that ran along the lake was in constant use.

Again in the summer of 1814 General Izard and his army encamped at Willsboro on their way to the Niagara Frontier.

Present-day residents of the region have talked to former inhabitants who could remember seeing the "Redcoats" going along the old road.

The town was at first called Milltown, but on March 7, 1788, it was renamed Willsboro by and for William Gilliland. The township as it was originally bounded included several of the present surrounding townships and extended as far south as Crown Point, having an area of some 900 square miles. As time went on and other settlements developed the size was reduced as outlying areas were removed to become new townships, and Essex township was so constituted on April 4, 1805.

Village of Willsboro

The unincorporated village of Willsboro is the largest community within the bounds of the quadrangle. By 1800 the settlement had begun to show definite signs of permanence and a post office was established in that year. In 1810 a gristmill was constructed and subsequently a sawmill and tannery were built. In 1881 a pulp mill was established by the Champlain Fiber Company, and this plant is still in existence although ownership has changed and it is now the New York, Pennsylvania Company. This mill is the one major industry not only of the village of Willsboro but also of the entire area. When working to capacity it affords employment to about 150 persons. There is a good modern high school (figure 3), a bank and

1 Stafford, J. M. Personal communication, 1938.
numerous stores. Churches of several denominations are represented in the village.

One of the outstanding institutions of Willsboro is the Paine Memorial Free Library, built and endowed in 1930 by A. G. Paine as a memorial to his parents (figure 4). This library with its own brick building, housing a comfortable reading room and stacks for its collection of approximately 5000 volumes, is playing a very important part in the cultural development of the town. The present population of the village is in the neighborhood of 800.

**Village of Essex**

The unincorporated village of Essex is the second largest place in the quadrangle at the present time with a permanent population of about 250 persons. During the summer months the population is greatly increased by vacationists and tourists.

Although second to Willsboro in these days, Essex formerly was the more important. Until 1840 Essex was one of the chief ports on Lake Champlain and was the port of entry for all of the surrounding area. Before the construction of the Delaware and Hudson Railroad, that now supplies the region, material used to be brought across the lake to Essex from the railroad at Charlotte on the Vermont side. In the winter when the lake froze, the supplies were sledded across the ice.

In the early days Essex was famous as a shipbuilding center and many of the boats, both civil and military, that made names for themselves in local history were constructed in the yards at Essex. At one time when two partially completed gunboats were threatened by a British flotilla the townspeople moved them to the south side of Split Rock Point where they were successfully hidden. The British on finding only the spars in the yard left without destroying these spars for, as the commanding officer said, "they could soon get more." The boats were afterward completed and served in the naval engagements upon the lake.

Following the decline of shipbuilding the old properties were transformed into a sash and blind factory, which for years afforded employment to part of the populace.

In 1879 the Essex Horsenail Company Ltd. bought the sash and blind factory, installed machinery and after an outlay of about $45,000 started to produce horseshoe nails. For years this factory was doing an excellent business and was shipping horseshoe nails to all parts of the country and even to foreign ports. These were
Figure 3  Willsboro High School and bank building constructed of Chazy limestone.

Figure 4  Paine Memorial Free Library, Willsboro.
Figure 6 Old mill dam at Whallonsburg. Ledges are Beekmantown limestone.
Figure 7  Falls on Potsdam sandstone at site of old mill dam at Bouquet.

Figure 8  Octagonal schoolhouse at Bouquet built of Potsdam sandstone.
days of prosperity for the village, more than 100 persons being employed in the various branches of the business.

With the closing of the horseshoe nail factory the village was left without any industry. The population has decreased and the main "industry" at present is the summer vacationist.

Essex has several churches, stores and a small free library. An automobile ferry to Charlotte provides the only way for vehicles to cross the lake between the Port Kent ferry to the north and the Lake Champlain bridge at Crown Point to the south.

Several years ago the Essex Fire District was formed and a modern motorized pumper was purchased. Since the formation of the fire district and the purchase of the engine, no fire has gone beyond the premises on which it started. Since there are no hydrants, the water is pumped direct from the lake and the hose will reach any house in the village.

There has been a summer theater group at Essex for several seasons producing plays three nights a week in the Harlan Community House.

**Bouquet**

Bouquet for many years a thriving little community, is now rapidly disappearing. Daniel Ross established a sawmill by the falls in the Bouquet river at this point in 1785 (figure 7), having the year before opened up a store. In 1810 a gristmill was built followed in subsequent years by a rolling and slitting mill and a nail factory producing cut iron nails. All of these industries have now disappeared. The schoolhouse (figure 8), octagonal in shape, built of Potsdam sandstone, is still in use and is an interesting landmark.

**Whallonsburg**

Whallonsburg, founded in 1870, at a dam site (figure 6) had at one time or another a sawmill, sash factory, gristmill, plaster factory, forge and clothing factory. These are now all gone and two stores and a garage represent the commercial remains of this once busy center.

**Port Douglas**

Port Douglas, at the head of Corlear bay in Chesterfield township, is largely a summer colony.

**Keeseville**

As only the outskirts of Keeseville fall within the limits of the Willsboro quadrangle, it is not discussed.
PREVIOUS GEOLOGIC WORK

A review of the early work done on the geology of the Adirondacks has been published by Kemp (1892). He mentions that occasional travelers in the latter part of the eighteenth century left a few notes with casual observations on the geology, and that A. E. Jessup (1821) published a few pages on the "Geology of the Northeast Part of N. Y.," in which he speaks of the secondary and primitive rocks of Lake Champlain and of the primitive trap at "Willsborough" which was visited by Dr William Meade in 1810. The first systematic work in the Adirondacks was begun by Ebenezer Emmons in 1837 as part of the initial work of the New York State Geological Survey and the final results were published in 1842. He classified the rocks of Essex county in general as Primary (Precambrian), Transition (Paleozoic) and Tertiary. Under the Primary rocks he included Hypersthene rock (anorthosite), limestone, granite, hornblende gneiss (metagabbro), gneiss, Trap (Diabase) and porphyry, though he recognized that part of the trap and the porphyry cut the Paleozoic sediments. The Transition rocks comprised the Potsdam sandstone, Calciferous sandrock (Beekmantown), Chazy limestone, Trenton limestone (Glens Falls), and Utica slate (Canajoharie). The Tertiary included the Pleistocene and Recent. The Primary limestone (Grenville), in part, bore such peculiar relations to the other rocks that Emmons erroneously interpreted it as of igneous origin.

For nearly half a century following the publication of Emmons' report there were no further systematic studies of the geology of the Adirondacks until J. F. Kemp entered the field in 1889. During this period of general neglect of Adirondack geology there were, however, a few pertinent papers on specialized topics published; T. S. Hunt (1871) on the mineralogy of the Laurentian limestones, James Hall (1876) on the age of the serpentinous limestones of northern New York, A. R. Leeds (1878) on the lithology of certain rocks of the Adirondacks, C. E. Hall (1879) on Laurentian magnetic iron ore deposits in northern New York, G. P. Merrill on serpentinous rocks (1889 and 1890) from Essex county, N. Y., and J. C. Smock (1889) on the iron ores of New York. Kemp worked on the geology of the eastern Adirondacks; in 1892 C. H. Smyth jr started studies in the northwestern Adirondacks, and in 1893 H. P. Cushing undertook geologic surveys of the northern Adirondacks. These three men each labored for many years on the

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1 Terms used for equivalent rocks in this report.
mapping and interpretation of the geology of the Adirondacks and laid the foundation for all subsequent work.

Of the many publications on the geology of the Adirondacks and of the adjacent rocks of the Champlain valley the following may be mentioned as particularly pertinent to the geology of the Willsboro quadrangle:

Two papers by Ezra Brainerd and H. M. Seely, *The Calciferous Formation in the Champlain Valley* (1890) and *The Chazy Formation in the Champlain Valley* (1891); *The Trap Dikes of the Lake Champlain Region* by J. F. Kemp and Vernon F. Marsters (1893); *Preliminary Report on the Geology of Essex County* by J. F. Kemp (1894); *The Geology of Essex and Willsboro Townships, Essex Co., N. Y.*, by T. G. White (1894); *The Geology of Moriah and Westport Townships, Essex Co., N. Y.*, by J. F. Kemp (1895); *Faults of Chazy Township, Clinton Co. of N. Y.*, by H. P. Cushing (1895); and also by the same author *Geology of the Northern Adirondack Region* (1905); *Ancient Water Levels of the Hudson and Champlain Valleys* by J. B. Woodworth (1905); *Geology of the Elizabethtown and Port Henry Quadrangles* by J. F. Kemp and R. Ruedemann (1910); *The Champlain Sea* by Winifred Goldring (1920); *Geology of the Ausable Quadrangle* by J. F. Kemp and H. L. Alling (1925); *The Fault Systems of the Northern Champlain Valley, N. Y.*, by G. H. Hudson (1931); *Structural Geology of the Adirondack Anorthosite* by Robert Balk (1931); *Normal Faults of the Lake Champlain Region* by A. W. Quinn (1933); *Stratigraphy of the Trenton Group* by G. M. Kay (1937) and *Stratigraphy and Structure in the Upper Champlain Valley* by John Rodgers (1937). All of these papers have been consulted in the present work.

**SUMMARY OF GEOLOGY**

As previously noted, there are two quite contrasted topographic provinces in the Willsboro quadrangle. This contrast is fundamentally dependent upon the fact that bedrock different both in kind and structure underlies each of the two respective provinces. The bedrock of the Adirondack province comprises a set of rocks that belong to the oldest groups in the earth's crust, the Pre-cambrian or basement complex, and are almost wholly of igneous origin with pronounced mountain type of structure; whereas the rocks of the Champlain section are sedimentary beds of Lower Paleozoic age and relatively flat-lying. The succession of rocks with the oldest at the bottom is shown in the accompanying table.
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GEOLOGIC COLUMN

Pleistocene
- Till, Marine clays and delta deposits
- Lamprophyric dikes
- Trachyte porphyry, laccoliths and dikes
- Canajoharie shale

Lower Paleozoic
- Glens Falls limestone
- Chazy limestone
- Beekmantown limestone and dolomite
- Potsdam sandstone

Intrusive Rocks
- Diabase, as dikes
- Hornblende granite gneiss
- Pyroxene quartz syenite gneiss
- Metagabbro, as dikes and sheets
- Anorthosite and gabbroic anorthosite gneiss

Precambrian
- Impure crystalline limestone and metamorphic equivalents,
  pyroxenic gneiss; pyroxene, garnet and wollastonite skarn layers)

PRECAMBRIAN

Grenville Crystalline Limestone

The very oldest rocks in the Willsboro area are crystalline limestones and their metamorphic equivalents. These limestones are quite minor in volume in this area but are exposed locally at a number of localities. They are interpreted as a member of the Grenville series which elsewhere in the Adirondacks is present in much greater quantity and comprises a varied series of metamorphosed sediments such as quartzite, schist, gneiss etc. The name "Grenville" comes from the township of Grenville in Quebec where similar rocks are well developed and where they were first named. The crystalline limestones are thought to represent sedimentary calcium carbonate muds which have been metamorphosed, recrystallized and modified through the activities of hot solutions accompanying the successive intrusions of magmas which yielded the igneous rocks. The Grenville sediments as a consequence of the intrusion of the magmas were separated and isolated into disconnected layers through movement of magmas along bedding planes, or locally into blocks through disruption and forcible displacement by the magma. The Grenville now exposed in the Willsboro area represents but traces or relics of an originally thick varied series of sedimentary strata and occurs as local included bands within the igneous rocks.

Limestone is exposed at several localities along the railway between Willsboro and Port Douglas, in the south face of Sugarloaf mountain, in the quarry for road material one mile west-southwest of Willsboro and a half mile to the northwest, and along the shore-line from Grog Harbor to Split Rock Point.
Skarn layers and mixed gneisses. Far more common than limestone layers, however, are bands, layers or shreds of dark gneiss or skarn inclosed within gabbroic anorthosite. Their mode of occurrence and local transitional gradation into limestone strongly suggest that they represent bands of limestone which have been replaced by silicates, comprising especially pyroxene, garnet and plagioclase. The replacement is thought to have been effected by hot solutions given off by the gabbroic anorthosite magma at the time of its intrusion. The calcium carbonate of the limestone was in part dissolved and carried off and in part reacted with the solutions to form silicates. These silicate rocks were in turn locally disintegrated, shredded and modified by the gabbroic anorthosite magma. Locally, narrow bands or lenses of white wollastonite or red garnet are associated with the dark pyroxenic gneiss. Several belts of such gneiss and skarn are shown on the map as well as one large area in which shreds of the gneiss are common within the gabbroic anorthosite.

Igneous rocks in general. Five markedly different kinds of igneous rock are present in the Precambrian, each resulting from the intrusion and consolidation of a magma at five different periods of time and all later deformed and metamorphosed to equivalent gneisses. Each magma is interpreted as having consisted originally of a molten solution of silicates (plus minor oxides etc.) approximately equivalent in composition to one of the respective rocks plus a small percentage of water and, to a minor extent, of other compounds normally volatile at relatively low temperatures. Some local and minor modifications of the primary magmas are thought to have resulted from sorting of crystals in the liquid magma during the long period of congelation, incorporation of some material from the older country rock into which the magma was intruded, the activities of dissolved water and other volatiles in effecting the transfer of material as gases from the magma into the country rock, and the squeezing out of the last liquid of crystallization from the interstices of the largely consolidated rock. It is a general principle of chemistry that volatiles, crystalline material and residual liquid from partial crystallization will for such solutions as magmas always be of different composition so that a separation of one from the other will result in a differentiation and the formation of facies differing from the original magma. Many such modified variants are found in this area.

Anorthosite gneiss. Elsewhere in the Adirondacks some geologists have thought that they have found evidence for a granitic
intrusion older than the anorthositic rocks, but so far as the Willsboro area is concerned the latter constitute the oldest proved igneous rock. Anorthosite and gabbroic anorthosite gneiss underlies most of the Precambrian area. It may be seen from figure 9

![Figure 9 Map of the platy foliation in the Adirondack anorthosite massif and the country rock in its vicinity (From Balk, 1931, plate XI). Heavy black line outlines anorthosite massif](image)

that it is but a portion of the eastern part of a great massif of similar rock which occupies some 1200 square miles of the eastern Adirondacks and embraces the area of all the very high peaks. Among all the several hundreds of varieties of igneous rocks which are known from various parts of the world, anorthosite in masses of
the Adirondack type is unique in that it is the only one which is wholly restricted to any particular age, in this case, the Precambrian. Not only are such uniform masses of anorthosite restricted to the Precambrian but they are also characteristically present in large areas of older Precambrian rocks in most continents. A score of anorthosite bodies are found in the older Precambrian areas of eastern North America from Virginia to Labrador. The anorthosite masses form, therefore, in a very special and restricted sense, bodies of "ancient" rock of the earth's crust and are over a billion years old. Anorthosite does, however, occur elsewhere as a differentiated facies of thick gabbroic or noritic sheets which are of an age younger than the Precambrian, but such layers have a different mode of occurrence from the more or less uniform masses of the Adirondack type.

The anorthositic rocks in the Willsboro quadrangle have a distinct platy structure, a foliation or gneissic structure except at the extreme north and south where it becomes somewhat elusive. Systematic plotting of the orientation and arrangement of this structure yields a picture such as that shown in figure 9. It will be noted that the foliation just south of the Willsboro quadrangle indicates an elliptical domical or inverted-basin structure with the platy structure plunging away in all directions from a high at the core. The domical foliation bears a resemblance in its layered character to the upper half of an onion. In the northern half of the Willsboro quadrangle the foliation dips south so that a saddlelike basin structure results in the belt between the Sugarloaf Mountain skarn belt and Mount Bigelow. Shreds and layers of Grenville skarn and limestone layers are locally abundant in the rocks of this saddle and they are interpreted as constituting a portion very near or at the roof of a very large mass of anorthositic rocks. The anorthositic rocks vary from an almost wholly even medium granular rock to one consisting mostly of large plagioclase crystals. The most common facies is one in which a few large fragments of plagioclase up to an inch or more in length occur dispersed through a medium granular groundmass. The larger plagioclases are of such shapes and bear such relations to the groundmass that it can be shown that in part at least if not in whole, the groundmass is a pulp derived by crushing the granulation of an original much coarser grained rock of which the larger plagioclases are mere relics or porphyroclasts.

The major rock of the saddle is a sparsely porphyroclastic medium granular gabbroic anorthosite gneiss which together with
the relics of Grenville skarn, forms a migmatite or mixed rock to a greater or lesser extent. The Mount Bigelow ridge is composed of gabbroic anorthosite in which relics of skarn are not so common, though present. To the south of the saddle area the gabbroic anorthosite with its included Grenville passes into a similar gabbroic anorthosite gneiss in which there is no evidence of relics of Grenville skarn. At the extreme south border of the map this gabbroic anorthosite gneiss grades into an anorthositic gneiss which is more nearly true anorthosite and has in general a larger percentage of unreduced fragments of feldspar and a smaller content of dark minerals. At the north the gabbroic anorthosite gneiss with its admixed Grenville relics of the saddle (2-c) passes rather abruptly into anorthositic gneiss resembling that at the extreme south. The gabbroic anorthosite gneiss of areas 2-b and 2-c is similar to what has been called Whiteface anorthosite elsewhere in the Adirondacks and the anorthositic rock of 2-a approaches in character the Marcy anorthosite of the core of the Adirondacks and is here called Transitional Marcy. The Transitional Marcy anorthosite forms the exposed core of the structural domes and the Whiteface gabbroic anorthosite the flanks and saddle.

**Metagabbro.** The anorthosite and gabbroic anorthosite are cut by small tabular bodies in the form of dikes and sheets of metagabbro. The metagabbro stands out conspicuously as a dark gray to black rock but may in many cases be easily confused with the dark pyroxene skarn bands unless careful study is made. The only considerable masses of metagabbro as distinguished from small dikes and sheets are about a mile northwest of Bouquet and in Split Rock mountain.

**Quartz syenite gneiss.** The next younger igneous rock is quartz syenite gneiss. It is a greenish gray rock on fresh exposure weathering to a brown just beneath the actual gray surface veneer. There are several small sheets intrusive in the anorthosite and the Grenville skarn involved with gabbroic anorthosite near the western border of the quadrangle. These few exposures represent outlying fingers of a type of rock which is much more abundant in adjoining areas and is a major member of the great intrusive complex of the Adirondacks.

**Granite gneiss.** There are two small bodies of pink granite gneiss, one a medium grained variety forming much of Split Rock mountain and intrusive into metagabbro and Grenville, the other a facies with a coarse lenticular gneissic structure about one and one-
half miles south of Butternut pond. These are the only granite bodies sufficiently large to map. Throughout much of the area of the Precambrian, however, there is scarcely any large outcrop which does not contain one or more narrow granitic veinings, or seams, from an inch to a foot wide. Often they are highly schistose and garnetiferous. Locally, though rarely, there are dikes of granite. These granite bodies, like the quartz syenite, are representives of a type of igneous rock that forms in general a major member of the intrusive complex of the Adirondacks.

**Diabase.** In the upper two-thirds of the area of Precambrian rocks there are numerous narrow dikes of black basaltic rock, or diabase. They strike almost exclusively between N.65°-90°E. They may be distinguished from the metagabbro dikes by their freshness, general fine grain except in large dikes, and dense, in part, glassy borders. Most of them are less than three feet in width. Only one large dike was seen; this had a width of 20 feet. Diabase dikes are well exposed in the cuts along the railroad track on the west side of Willsboro bay. Such dikes are common around the borders of the Adirondack massif but are sparse in the core.

The diabase dikes occur within the Precambrian rocks, and exactly similar rocks are apparently not found in the overlying Paleozoic beds. They are therefore thought to be of Precambrian age. They are the youngest Precambrian rocks and have not suffered any regional metamorphism. A series of such dikes can be traced intermittently westward to the Lake Superior region, where their age is determined as Keeweenawan.

**PALEOZOIC**

Following the formation of the youngest Precambrian rocks there was a great interval of millions of years during which erosion took place. At the end of this stage in geologic history the land sank beneath sea level and sedimentary rocks were deposited upon the old eroded land mass.

**Potsdam Sandstone**

The Potsdam sandstone, upper Cambrian in age, is the oldest Paleozoic formation within the region; it is composed of quartz sands and represents the first deposits laid down on the old Precambrian land mass by an invading arm of the sea. The color varies from white through yellows and browns to red. It is stratified in beds from a few inches to two feet in thickness and is often
found to have well-preserved ripple marks on the upper surface of the beds. The best two exposures are at Bouquet, two and a half miles west of Essex, and at Flat Rock camp on Jones point, Willsboro township.

**Beekmantown Group**

The Beekmantown group, representing the oldest Ordovician (Canadian rocks), comprises a great thickness of dolomites and limestones with a few beds of intercalated sandstone. In general gray to blue in color, it varies from exposure to exposure. The thickness of the beds and the lithologic character of the rock are too varied to be covered here (figure 10) but will be discussed in more detail in a later part of this report dealing with the Paleozoic area. Fossils, although scarce, are found at a few localities, the best and most accessible being on the right bank of the Bouquet river below the mill dam at Willsboro, where the gastropod *Lecanospira* occurs in abundance. The subdivision of the Beekmantown and the discussion of the Cassin formation (upper Beekmantown) are reserved for another chapter.

**Chazy Limestone**

Overlying the upper portion of the Beekmantown is the Chazy limestone, a common rock in the region and one well exposed in many quarries in both Essex and Willsboro townships. It is a marine limestone and was deposited in a great down-warped trough which paralleled the present Champlain valley in upper Lower Ordovician time. The beds are generally massive, where seen, and are often separated into individual blocks by excessive weathering along the joints (figure 11). In practically all exposures of the Chazy the coiled gastropod *Maculites magnus* may be seen on the weathered surface of the rock. Although well exposed in many localities the best place to see this formation is in the abandoned quarries on the end of Ligonier point.

**Trenton Group**

The Trenton group is represented in the area by two formations, the lower being the Glens Falls limestone and the upper the Canajoharie shale. They are both marine sedimentary rocks of Middle Ordovician age and are the youngest of the Paleozoic sediments within the area.

**Glens Falls limestone.** The Glens Falls formation is a dark blue to black, dense limestone, the individual beds of which vary
Figure 10. Black chert in Beekmantown limestone below old dam at Whallonsburg.

Figure 11. Weathered surface of Chazy limestone showing solution along joints in gently dipping beds. One mile southwest of Essex.
Figure 13. Glens Falls limestone on south shore of Begg point, Essex.

Figure 13. Canajoharie shale near north end of Willsboro point showing well-developed steeply inclined cleavage and indistinct nearly horizontal bedding.
from an inch to ten or more inches in thickness (figure 12). It weathers to a light gray or black depending on the beds represented. In many places it is remarkably fine grained, in others it is more crystalline, and in some cases, due to the amount of mud that has been mixed with the lime ooze, it has a shaly appearance. The Glens Falls is generally quite fossiliferous and contains a large fauna of invertebrates. The best two places for collecting fossils from the Glens Falls are the south end of Willsboro bay and the shore of Lake Champlain along the southeastern corner of Willsboro township.

**Canajoharie shale.** The Canajoharie shale, which rests upon the Glens Falls limestone, is a shaly facies of the Trenton in which the amount of mud has so increased that it has a different lithology and contains a different fauna than the underlying Glens Falls. In the two northern areas of Canajoharie a slaty cleavage has been developed by the folding of the beds and this feature is very helpful in recognizing the formation (figure 13). In the southern exposure the slaty cleavage was not developed and it is not so easily distinguished from the Glens Falls limestone; however, the trilobite _Triarthrus becki_ is found in all outcrops and may be used as a guide fossil for the Canajoharie.

**Paleozoic Intrusions**

Following the deposition of the Canajoharie shale the area was subjected to one or more periods of igneous activity during which sills and dikes of igneous rock were injected into the Precambrian and Lower Paleozoic rocks. As the Canajoharie shale has been cut by these intrusions they are obviously younger than the Canajoharie, but it is not definitely known how much younger they are or how many periods of intrusion there actually were. A later portion of this paper will discuss the location, character and possible age of the various types of intrusive rocks.

**PLEISTOCENE**

The Pleistocene glacial deposits, which cover a large part of the lowlands, were deposited upon the older rocks following a long interval (hundreds of millions of years) during which time the underlying rocks were faulted, subjected to erosion and finally overridden by the great ice sheet.
This blanket of Pleistocene material so completely buries the bedrock, over large portions of the Paleozoic areas, that the geology must be inferred from the few scattered outcrops that are available.

During the period of deglaciation of the Champlain valley, till was deposited upon the eroded surface of the underlying rocks. As the glacial front withdrew still farther to the north there was a marine invasion and a great arm of the sea extended through what is now the Champlain valley. In this seaway marine clays and sands were deposited to further mask and obliterate the underlying surface. Goldring (1920, map 2, opp. p. 180) has shown that portions of this seaway were of brackish water, which caused a diminishing and dwarfing of the marine fauna. The clays of this postglacial arm of the sea being deposited in other than fresh water do not show the varved character (seasonal banding) that would be present had they been formed in fresh water. The streams flowing from the Adirondacks have in some instances built great deltas such as that of the Ausable, largely on the Plattsburg map, and Bouquet and North Branch of the Bouquet on the Willsboro quadrangle.

**GEOLOGY OF THE PRECAMBRIAN**

**GRENVILLE CRYSSTALLINE LIMESTONE, MIGMATITES AND METASOMITES**

Crystalline Limestone, Skarn Layers and Mixed Gneisses

No special detailed study was made of the normal Grenville crystalline limestones. In considerable part, however, the limestone is interpreted as having been replaced by silicates to yield skarns or metasomites and gneisses, which were subsequently intimately penetrated or replaced by plagioclase-rich veinings to yield migmatites. Such penetration of the skarns on a larger scale by gabbroic anorthosite magma yielded mixed gneisses or migmatites.

The origin of the skarn layers and mixed gneisses is best interpreted in the light of the relationships found in the junction zone between gabbroic anorthosite and limestone, and the conditions at three such localities will be described in some detail.

About seven-tenths of a mile north of the railway tunnel north of Rattlesnake mountain there is exposed in a cut alongside the railway limestone with a gabbroic anorthosite lens having a maximum width of several feet. The anorthositic rock has in general 10–20 per cent of augite, and is still richer in augite near its termination. Adjacent to the anorthosite there is usually a half inch of skarn
consisting predominantly of green augite with some associated enstatite and accessory apatite, magnetite, sphene and quartz. Adjoining the pyroxenic band are several inches of reddish brown garnet, then limestone with a very large amount of disseminated pyroxene, followed outward by normal crystalline limestone. Locally there is a black skarn layer with very thin lenticular veinings of plagioclase; the dark mafic minerals comprising augite and brown hornblende with accessory magnetite. This latter rock superficially resembles a foliated gabbro in appearance, but appears definitely to be a facies of the limestone country rock locally replaced by pyroxene and hornblende, and with the development to a minor extent of anorthositic veinings.

A half mile south of the tunnel an exposure shows anorthosite with thin layers of limestone. Between the anorthosite and the limestone there is a two-foot band of very mafic skarn with a variable amount of thin veinings of aplite. The mineral composition of a typical specimen is shown in table 1.

At the road material quarry, a mile west-southwest of Willsboro, there are gabbroic anorthosite sills in crystalline limestone which are spatially related to and in contact with masses of garnet and pyroxene developed in limestone. Locally the sills are adjoined by pyroxenic amphibolite skarn layers resembling foliated gabbro.

These three localities serve to show that skarns are developed by the replacement of limestone at contact with members of the anorthositic series; and that the skarns are variable in composition, with some consisting predominantly of augite, some of garnet, and others of augite and hornblende with some plagioclase. Enstatite, magnetite, apatite and sphene are common accessory minerals and may be locally abundant. The skarns locally show a development of thin feldspathic lenses presumed to be genetically related to the anorthositic intrusions.

Rocks of similar character to the skarns just described also occur on a large scale wholly inclosed within gabbroic anorthosite, and though usually not associated with limestone are by analogy interpreted as in large part representing complete metasomatic replacements of limestone beds caught up in a gabbroic anorthositic magma.

A belt of such skarn more or less injected by anorthosite extends from a point about two miles southwest of Willsboro across the south slope of Sugarloaf mountain on to the Ausable quadrangle. It is about a quarter of a mile wide and more than six miles long. Rock exposures are found on every hill crossed by the belt, and in
every case interbanded rocks are found in the southern portion which comprise massive red garnet-rich rock, green pyroxene granulite, local bands of white wollastonite, layers of dark green pyroxene-garnet-oligoclase or andesine skarn, and thin sills of gabbroic anorthosite. The northern half consists largely of dark pyroxene skarn and pyroxene-plagioclase gneiss with local intrusive sheets of olivine metagabbro. A quarter of a mile to the north there is another similar but narrower parallel band. On Sugarloaf mountain, and to the west on the Ausable quadrangle, the belt includes many beds of crystalline limestone in addition to the other types of rock mentioned. A similar narrow belt of skarn and gneiss layers, with interbeds of crystalline limestone, extends for some seven miles south from Brown point, with a tongue southward towards Warm pond.

Northwest of Bouquet there are layers of garnet and pyroxene skarn associated with anorthosite and in turn inclosed in metagabbro. At one locality about one and three-fourths miles northwest of Bouquet limestone is associated with the skarn. This area probably represents the faulted southeastern extension of the Sugarloaf belt. Just east of the center of Butternut pond, there is also a narrow band of garnet and pyroxene skarn with sills of gabbroic anorthosite and intercalated layers of limestone. The presence of the crystalline limestone in these belts is considered very suggestive and appropriate for the character of the original rock from which the skarns and gneisses were derived. There are locally a few thin layers of amphibolite in the limestones which appear to be independent of contact metasomatism by solutions from the anorthositic magma. These may represent recrystallized impure calcareous argillaceous beds or less probably mafic tuffs.

Table 1 shows the composition of some of the skarns, artieritic migmatisites and gabbroic anorthosites, mafic from assimilation, which occur in the contact zones between crystalline limestone and border facies anorthosite or are included within anorthosite. Since there is so much variability, the ratios merely give some idea of the kinds of rocks which may be found. The compositions of the nearly uniform red garnet, white wollastonite and green pyroxene layers, respectively, are not shown.

All the skarns and mafic gneisses have a foliation and in general a granoblastic (recrystallized granular) texture. The feldspar is usually largely aggregated in thin flat lenses parallel to the foliation. As the amount of feldspar increases, the rocks take on more and more the aspect of artieritic migmatisites. Those, in particular, in which
quartz accompanies the plagioclase to a noteworthy extent, have the appearance of arteritic migmatites or injection gneisses.

The typical included thick dark skarn layers in the anorthosite are in general mafic rocks in which augite is practically always a major mineral, with garnet, hornblende and hypersthene associated in widely varying ratios, and plagioclase varying from a few per cent to one-third of the rock. Iron oxides are nearly always present, locally in considerable amounts. Apatite is uniformly present, often to the extent of 1 per cent or more. Rarely is there any sphene. Locally there is a trifle quartz as discrete grains. The garnet is locally in part poikilitic with intergrowths of quartz. Potash feldspars are commonly spare or absent, except to a small extent in the arteritic migmatites. The plagioclase is variable, ranging from $\text{Ab}_{80}\text{An}_{20}$ in the more obvious arteritic veinings to labradorite in some of the uniform amphibolite layers inclosed in anorthosite.

All gradations can be traced between red skarn composed rather uniformly of garnet or of dark green pyroxene skarn, on the one hand, and anorthosite, on the other, in the contact zones. Much of the dark green pyroxene is probably the variety, salite.

An excellent example of such intergradation between garnet skarn and anorthosite is shown in the road metal quarry just north of Pokamoonshine State Park, just off the west border of the Willsboro quadrangle on the Ausable area. Here are layers of garnet skarn up to several feet thick. The gradational facies range from skarn in the incipient stages of mineralization with a few apparently isolated lenses or crystals of feldspathic material (figure 14) and a facies with many thin flat lenses of the feldspathic aggregate, to skarn with veinings of anorthosite and anorthosite with thin included layers of skarn or with relics of disintegrated skarn rather homogeneously distributed.

The gradation from pyroxene skarn to anorthosite is excellently shown in the outcrops about 1.7 miles southwest of Willsboro bridge, southwest of the road forks. The least feldspathic skarn (6020) consists of mafic minerals with less than 10 per cent plagioclase. The latter occurs in thin flat lenses parallel to the foliation. With increase in feldspar (6020-a) the rock has the appearance of an arteritic migmatite. This grades into gabbroic anorthosite with included lenses of amphibolite (280-c), or into gabbroic anorthosite with the skarn quite homogeneously disintegrated so as to yield a uniform mafic facies (6020-b) which forms a three-foot sill in the skarn.
Another aspect of gradation between gabbroic anorthosite and pyroxene skarn is well shown in the pasture at the north end of Rattlesnake mountain. The gabbroic anorthosite here locally contains small knots or nodules of pyroxene coccolite, or has an inhomogeneous messy appearance as if it had ratherilly digested some skarn, or contains numerous phantomlike xenoliths which are angular in shape and more mafic than the normal anorthositic rock.

The composition of the arteritic migmatites is variable. The coarser veinings usually consist almost wholly of andesine or andesine labradorite, and are certainly related to the anorthosite. The arteritic migmatites, like the skarns, usually show a concentration of apatite. The finer aplitelike veinings all have the appearance of white anorthositic veinings, but some are composed of quartz and oligoclase and others of oligoclase, microcline and quartz. The oligoclase commonly varies between An19 and An25. Such variations are present in the migmatites inclosed in the gabbroic anorthosite at Brown point. The rock here is cut by numerous garnetiferous granite veinings, but the writer could find no connection between them and the aplite granite of the migmatite. Neither could he find evidence that the migmatite was older than the anorthositic rock. The plagioclase of the veinings at this locality is a sodic andesine. Some of the potash-feldspar bearing aplite veinings may then questionably be considered to have been generated by the gabbroic anorthosite magma itself.

**Gabbroic Anorthosite Modified by Incorporation of Skarn**

As previously stated, and as indicated by the preceding descriptions, the gabbroic anorthosite develops a migmatitic facies both locally and over large areas as a result of incorporation of skarn. This is manifest in many different ways. The migmatitic anorthosite may have long thin tabular layers of skarn up to several feet thick; irregular schlierenlike mafic inclusions either isolated as a string of lenses, or in tabular forms resulting from dismemberment of formerly uniform skarn layers; a few isolated nodules or knots of pyroxene or garnet, or salite and garnet, or saussuritized plagioclase; a phantom-breccia or nebulitic structure; bands of an inhomogeneous appearing coarsely porphyritic or phacoidal more mafic anorthosite with a few very small schlieren (figure 15), bands with a marked nodular structure; facies which are quite uniform but coarser than normal and more mafic; and facies which are locally finer than normal and more mafic. At a number of localities, as along the road one mile west of Hadley pond and a mile west of
Figure 14. Andesine grains (white) in garnet skarn (dark). The andesine is interpreted as a replacement of skarn and genetically related to the anorthositic magma. Quarry opening just north of Pokamooshine camp, Ausable quadrangle.
Figure 15. Porphyroclastic gabbroic anorthosite. Dark streaks are richly garnetiferous, relics of disintegrated skarn. West of Hadley pond, Willsboro quadrangle.
the south end of Warm pond, included layers of skarn are complexly crumpled and locally pulled apart. The foliation of the inclosing anorthosite is parallel to that of the inclusions, indicating an initial primary magmatic structure.

Such rocks occupy most of the area between the Sugarloaf skarn belt and Mount Bigelow.

In the accompanying table the composition is given of several examples of anorthositic gabbro of rather uniform character and the product of assimilation of skarn by gabbroic anorthosite. A characteristic or peculiar feature of the migmatitic facies is the frequent occurrence of relatively high apatite and quartz, locally the presence of sphene or biotite, the occasional hedenbergitic or strongly titani-ferous character of the pyroxene, and rarely the predominance of hornblende over pyroxene. Hornblende is much more common in the skarn rocks than in the associated anorthositic intrusives. The average sample A-2 represents the normal gabbroic anorthosite (A-1, table 2) slightly modified by incorporation of skarn to yield anorthositic gabbro. The latter is richer in garnet and shows a higher ratio of hornblende to pyroxene as compared with the original rock.

Balk (1931, p. 347-49) has described mafic layers in the anorthosite along the railroad south of Brown point and (p. 350) a mafic layer on the highway about one mile east of Long pond, as lens-shaped amphibolitic gabbros. He further describes (p. 351) streaks, scattered clusters and lenses of amphibole, augite and biotite in anorthosite along the southeastern slope and top ledges of Rattlesnake hill as gabbros "in statu nascendi." The layers of mafic material are interpreted by the present writer as skarn and the gabbros "in statu nascendi" as skarn shredded and disintegrated by gabbroic anorthosite. The composition of the layer a mile east of Long pond is given in the table (No. 76). It does not have the composition of a gabbro. Balk has also described some of the true metagabbros on the Willsboro quadrangle, but apparently failed to recognize the widespread presence and the significance of skarn layers formed from limestone within the anorthositic rocks.
### Table 1

Mineral Composition, in Per Cent, of Migmatites, Skarns, Mafic Gneisses, Arteritic Migmatites and Gabbroic Anorthosite Mafic from Assimilation

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<th>Plagioclase</th>
<th>Potash Feldspar</th>
<th>Hypersthene</th>
<th>Augite</th>
<th>Hornblende</th>
<th>Garnet</th>
<th>Magnetite and Ilmenite</th>
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* Also 1.5 per cent prehnite.
† The gabbroic anorthosite through incorporation of skarn has actually acquired the composition of anorthositic gabbro.
Road cut about 2 miles NW of Willsboro, included layer several feet thick in gabbroic anorthosite.

6020 and 6020-a  1.7 miles SW of Willsboro, included layers in gabbroic anorthosite.

22-a  1.1 miles WSW of Willsboro, included layer in gabbroic anorthosite.

280-c  1.8 miles SW of Willsboro, included layer in gabbroic anorthosite.

173-a  Quarry at NW side of Augur lake, included layer in gabbroic anorthosite.

179-b  NE of quarry on east side of Butternut pond, mafic gneiss in contact zone between gabbroic anorthosite and limestone.

43-a  ½ mile south of tunnel east of Rattlesnake mountain, 2 feet of artaritic migmatite between gabbroic anorthosite and limestone layer.

112d, a, and b  R.R. cut at Mile Post 148, Brown Point. Layers of artaritic migmatite included in gabbroic anorthosite.

245-a  Quarry just north of Pokamoonshine park, Ausable quadrangle.

483  Diorite adjacent to included limestone layer, 21/2 miles NE of Cross, Ausable quadrangle.

6020-b  Three-foot sill in skarn, 1.7 miles SW of Willsboro.

301  Sill in limestone, just west of railroad track, 2 1/5 miles north of Willsboro R.R. station.

349  Gabbroic anorthosite with shreds and layers of skarn, ¾ mile north of Bouquet.

36-a  Gabbroic anorthosite, mafic from assimilation of skarn, north end of Rattlesnake mountain.

A-2  Rough average composition of gabbroic anorthosite, mafic from assimilation, based on 20 thin sections selected at random along section 21/2 miles across the strike from Long Pond outlet to 11/2 miles NW of Willsboro.

ANORTHOSITIC SERIES

Facies of Anorthositic Rocks

The anorthositic series of rocks (table 2) on the Willsboro quadrangle range in composition from true anorthosite to mafic gabbro. The predominant members are gabbroic anorthosite and locally, where this is modified by considerable incorporation of Grenville skarn, an anorthositic gabbro.

Kemp (1898, 57-58) described as the Whiteface type of the anorthositic series a medium granular facies which contained more dark silicates than the rock of the core of the main body of the anorthosite, a milky white feldspar, and which in its type locality on Whiteface mountain has a strong foliated structure. In 1910 (p. 35) he further noted that it shows evidence of crushing and granulation. Such rock is typically a gabbroic anorthosite with 10-25 per cent mafics. On several published quadrangle maps, the term Whiteface facies has been used somewhat in the sense of a formation name for rock which is predominantly such as that described by Kemp but which may also carry interbands of more feldspathic or more gabbroic types. Balk (1930, p. 291) described the Whiteface type as always foliated and not more mafic than typical anorthosite, but
this is not in accord with prevailing usage. Miller (1919, p. 17-20) defined as the Marcy type of anorthosite a very coarse-grained, light to dark bluish gray rock consisting very largely of basic plagioclase feldspar. He described as an important facies of the Marcy anorthosite, one in which dark bluish gray labradorite individuals, from a few millimeters to an inch or more across, stand out conspicuously in a distinctly granulated groundmass of feldspar which in the fresh rock varies from light gray to pale greenish gray. In practice the term Marcy has also been used by Miller to some extent in the sense of a formation name; for he writes, locally the amount of dark-colored minerals rises to 15 to 25 per cent. Such rocks, however, would not be true anorthosite. The foliation of the Marcy facies is in general elusive or absent, except in the more gabbroic varieties.

The characteristic anorthosite of the core of the anorthositic massif, which constitutes a belt through Mount Marcy and Santanoni, and St Regis mountains, is a massive to indistinctly gneissoid rock composed in general of 90 per cent or more of plagioclase crystals (andesine-labradorite) averaging an inch or more in length, the Marcy facies. The border facies of the anorthositic massif, however, are more variable in composition, in general more mafic, and the minerals have in part or in whole been crushed and recrystallized to a medium granular aggregate with sparse to abundant relics (porphyroclasts) of original larger feldspars, so that the rocks usually have a distinct foliation. The members of the anorthositic series of rocks of the Willsboro quadrangle belong wholly to the border facies.

The border facies of the anorthositic rocks often show a structure called "Block Structure" by Balk (1931, p. 358) (figure 16), in which there are rounded or lens-shaped to angular blocks of anorthosite surrounded by anorthositic rock of slightly different character. They commonly vary in size from a few inches to a few feet, but Balk cites one block over 30 feet in diameter on Rattlesnake mountain. The groundmass is generally more mafic than the blocks; but locally, though rarely, the reverse occurs. Block structure is particularly well shown in the Willsboro area at many places in the Bigelow Mountain sheet, south of Brown point, west of Warm pond, and locally at numerous other localities.

**Regional Variations in Willsboro Quadrangle**

The rocks of the area 2-a on the geologic map are in general intermediate in character between typical Marcy facies and typical Whiteface facies. They consist in large part of a sparsely porphyro-
clastic medium granular rock with an elusive foliation. Locally there are bands in which large porphyroclastic plagioclases form one-half to one-third of the rock, the remainder being a granular groundmass, largely the product of comminution of primary large plagioclase grains. There are some bands of true anorthosite (less than 10 per cent mafics), but much of the rock carries slightly more than 10 per cent mafics, and in general it is strictly a gabbroic or noritic anorthosite. The predominance of recrystallized white granular plagioclase, and the usual content of mafics greater than 10 per cent, ally this rock with the Whiteface facies; whereas the elusive foliation, almost universal presence of blue porphyroclasts, locally constituting up to half the rock, the content of mafic minerals in general only slightly exceeding that of true anorthosite, and the relative sparseness of garnet, ally it with the Marcy facies. For purposes of distinction it will be called here Transitional Marcy anorthosite. There are no evidences of relics of Grenville skarn in these rocks. The size of the porphyroclasts makes it difficult to determine under the microscope the correct composition of the rocks without the study of a very large number of thin sections. This has not been done, and data on this matter are therefore inadequate.

The rock of area 2-b on the geologic map, south of the Sugarloaf Mountain skarn belt, like the Transitional Marcy anorthosite shows no relics of Grenville skarn. The texture also is similar, except that in general the rock is more dominantly granular and porphyroclasts are slightly less abundant. The predominant rock, however, is definitely somewhat more mafic than that of the Transitional Marcy anorthosite and may be quite accurately termed Whiteface facies. The major rock by far is a medium granular gabbroic anorthosite gneiss with over 10 per cent mafics and sparse plagioclase porphyroclasts up to an inch or more in length. Interbanded with this are layers of white mafic poor granular anorthosite and local facies somewhat richer than normal in mafics, also bands in which porphyroclasts form a third or more of the rock. Block structure is common.

The mineralogical composition of a number of specimens of rock from this area are given in table 2.
### Table 2
Mineral composition of rocks of the anorthositic series

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**Gabbroic Anorthosite and Anorthositic Gabbro (Whiteface Facies)**

**Intimately Associated with Relics of Skarn (Area 2-c)**

**Geology of the Willsboro Quadrangle**

45
394 1½ miles WSW of Whallonsburg.
144 Trembleau mountain.
159 Prospect hill.
559 ½ mile NW of Port Douglas.
135 ½ mile NE of Port Douglas.
132 1½ miles SW of Port Douglas.
156-c 1½ miles W of Port Douglas.
175 1½ miles SW of Prospect hill.
A-1 Average of 21 thin sections of rock from across 2-mile section NE of Reber.
Minerals secondary after feldspar are counted as feldspar, and those secondary after mafic minerals are counted separately.
416-a East Bouquet mountain.
341 ½ mile ESE of Payne mountain.
392 1½ miles SW of Whallonsburg.
397-a 1 mile W of Whallonsburg.
410 1½ miles NW of Whallonsburg.
329 1 mile W of Payne mountain.
336 ½ mile N of Whipple mountain.
413 West end of Bouquet mountain.
414 East end of Bouquet mountain.
A-2 Average of 20 thin sections of Whiteface gabbroic anorthosite which con-
tains included layers and shreds of Grenville skarn, along section for
2½ miles southeast of Long Pond outlet towards Willsboro, and north of
road.
173-c NW end of Augur lake.
201 1 mile E of Mount Bigelow.
130 2½ miles SE of Prospect hill.
1 ½ mile SE of SE end of Long pond.
14 1 mile S of S end of Long pond.
112-c Brown point.
83 1 mile S of Brown point.
25 Long Pond outlet.
192 1 mile NW of Long Pond outlet.
236 1 mile W of N end of Long pond.
9-b 1½ miles W of Willsboro.
188 ½ mile E of Butternut pond.

In the structural saddle area between Mount Bigelow and the
Sugarloaf Mountain skarn belt at the south, and in a belt along the
north side of Mount Bigelow, the rock is in general a gabbroic
anorthosite gneiss with many small shreds, nodules or relics of mafic
material, some thin included layers of skarn and locally much evi-
dence of nebulitic breccia structure, all interpreted as arising from
the disruption and disintegration of skarn layers. The widespread
ubiquitous presence of these relics of the Grenville series thus serves
to distinguish the rocks of the area 2-c from that of the gabbroic
anorthosite area (2-b) which shows no relics of skarn. The rock of
2-c otherwise is similar to the gabbroic anorthosite of the belt 2-b.
The gabbroic anorthosite, where intimately associated with skarn
bands, often develops locally, however, facies which are distinctly
more mafic than normal and may become as mafic as true gabbro.
Another difference is that the gabbroic anorthosite gneiss of this
area shows almost consistently and on the average a much higher
ratio of hornblende to pyroxene than any of the other anorthositic
rocks of the Willsboro quadrangle. Block structure is common in the gabbroic anorthosite gneiss. The rock of this belt (2-c) is interpreted as in a broad sense a migmatite of border facies gabbroic anorthosite and Grenville skarn and limestone, occurring very close to the roof of the anorthositic massif. Thin sheets of quartz syenite in the western part, and small veinlets and thin sheets of granite throughout, are much more abundant in this zone than in any other facies of the anorthositic rocks.

The Mount Bigelow belt of gabbroic anorthosite gneiss deserves special mention. It appears to form a thick sheet which was intruded into the Grenville limestone. There are often thin shreds or lenses of amphibolite or skarn present and local facies of gabbroic anorthosite showing a structure characteristic of that arising from assimilation. The rock of the sheet as a whole, however, has distinctly less evidence of metamorphosed Grenville than the rock to the north and south, where in the northeast there are bands of skarn with local lenses of limestone sufficiently large to map separately, and many bands and relics of skarn too small to map appear in the anorthosite above and below the Bigelow sheet in its western and northwestern extension. The rock of the western part of the Bigelow sheet, as shown on the ridge of Bigelow mountain, is in large part a coarse porphyroclastic gabbroic anorthosite gneiss less completely granulated than the borders. The porphyroclasts (andesine grains up to an inch or more in length) often form one-third or so of the rock. Garnet is usually conspicuous. At several localities block structure is common. Most of the northeastern part of the Bigelow sheet is a medium granular gabbroic anorthosite gneiss.

Parallel to the skarn belt running south and southwest from Brown point there is a belt of a coarse porphyritic gabbroic anorthosite with conspicuous block structure, many large and small fragments of anorthosite in a more mafic groundmass. The rock shows only slight to moderate deformation and granulation. The plagioclase phenocrysts form the bulk of the rock, which is slightly more mafic than normal. It forms the northeast side of the Bigelow sheet and is a half mile wide at the north, and extends for a couple of miles to the south where it thins out.

Local Development of Gabbro and Mafic Gabbro

Rarely there is a local development of a gabbroic or mafic gabbro facies, as may be observed in a road cut about a mile south of Brown point. This rock type is characterized by a high ratio of augite and ilmenite-magnetite to plagioclase. The plagioclase, however, is
similar to that of the normal anorthositic facies. The gabbroic facies of the anorthositic series differs from the younger metagabbros in the absence of olivine.

**Pegmatitic Members of Anorthositic Series**

In a sector between radii two miles northwest and two miles southwest of Whallonsburg, the anorthositic rocks carry narrow veinings of pegmatitic nature. In part these are conformable with the foliation and in part they transect it. The veinings are coarse gabbro or anorthositic gabbro consisting of andesine-labradorite and pyroxene with accessory iron oxides. A little sulphide is also present. The veins are rarely over three feet wide and commonly narrower. Where the rock is strongly deformed and granulated there are beautifully developed coronas of garnet around the mafic minerals. The grain of the undeformed rocks and the inherited pattern of the granulated facies indicate a grain size of two inches or more for much of the pegmatite. In addition to the pegmatite veins there are also veinings, commonly not over an inch or so wide, composed of augite, garnet, magnetite and ilmenite, locally with several per cent of apatite. Garnet-rich veinlets facing fractures are present in many outcrops.

**Composition of Plagioclase and Its Variations**

The compositions of more than a score of plagioclases were determined by means of the indices of refraction. The plagioclase of the Whiteface type, without skarn inclusions in the area for a distance of two miles to the northeast of Reber, varies between Ab₅₅An₁₄₅ and Ab₅₀An₅₀ with an average of about Ab₃₂An₄₈. That of the gabbroic anorthosite mafic from assimilation in the section southeast from Long Pond outlet to 1.3 miles northwest of Willsboro varies from Ab₆₂An₂₈ to Ab₅₆An₄₄, with an average of about Ab₆₀An₄₀. Anorthositic rock involved with skarn in the belt through Sugarloaf mountain also shows a similar plagioclase. The most calcic feldspar found was Ab₄₈An₅₂ from a very coarse Marcy facies one and one-half miles southwest of Whallonsburg. The most sodic plagioclase is that of thin anorthositic veinings in skarn which may range from Ab₆₉An₃₁ to Ab₆₀An₃₄. The plagioclase of the anorthositic rocks intimately associated with skarn is thus definitely commonly more sodic than normal. It is also the case, however, that granitic veinings are more common in such associations, and this therefore raises the question as to whether the more sodic character of the plagioclase is the result of modification of a normal plagioclase by thermal solu-
tions related to the granitic magma. The uniformity and narrow range of composition of the plagioclase of the gabbroic anorthosite which is involved with skarn, and the generally more sodic character of the plagioclase of the thin anorthositic veinings in skarn, however, indicate that their more sodic character is in major part, at least, a primary development. There is no independent evidence, except very locally, that there has been introduction of quartz and alkali feldspars by thermal solutions from granitic magma into the anorthositic rocks. The more sodic character of the anorthositic rocks of the migmatite and assimilation facies may reasonably be ascribed, in part at least, to modification of their magma through the agency of volatiles or hyper-fusibles derived from the main anorthositic bodies. Their origin as residual solutions, more sodic because of removal of early more calcic crystals, is a possibility where there has been a contemporaneous increase of mafic minerals of primary origin, but there are many examples where this has not occurred.

The plagioclase of the coarse pegmatitic facies seems in general to be that of the country rock in which the vein is present.

**METAGABBRO**

A series of metagabbro sheets and dikes is present intermittently in the whole outer portion of the Westport anorthosite dome and in the immediately adjacent metamorphosed Grenville rocks. The metagabbro layers inclosed in the granite of Split Rock mountain, the mass of metagabbro a mile northwest of Bouquet, and the swarm of dikes and sheets extending northwest from Bouquet, form part of this zone. Another swarm of metagabbro dikes occurs within the anorthositic gneiss north of the Bigelow ridge, and are very conspicuous on Trembleau mountain. Sheets are also numerous locally in a belt one-half mile wide along the west side of Willsboro bay north of Rattlesnake mountain. They are rare in a broad belt striking northwest from the border of the Precambrian near Willsboro, through Long, Warm and Butternut ponds, and are absent in the southwest corner of the quadrangle in the vicinity of Payne and Whipple mountains.

The metagabbro appears in part to be conformable with the folia-
tion of the anorthositic gneiss, and in part to be disconformable. The belt of metagabbro bodies northwest of Bouquet is about two to two and one-half miles wide, has a length of six and one-half miles on the Willsboro quadrangle, and extends on to the Ausable area. In the Bouquet mountains the metagabbro masses, though in general striking parallel to the foliation of the inclosing anorthositic gneiss,
in part at least dip steeply and transect the gently dipping foliation of the country rock. To the northwest along the belt most of the bodies seem to be conformable, though some discordant dikes are also found. In the hills west of Whallonsburg there are only a few metagabbro masses, and they are nearly vertical and crosscut both the strike and dip of the foliation.

On Trembleau mountain and the hills northwest of Port Douglas, the foliation of the anorthositic gneiss has in general a west-northwest strike with a gentle southerly dip. This is crossed by a swarm of metagabbro dikes striking north-northwest and dipping gently to steeply east. This belt (in part on the Plattsburg quadrangle) of dikes with a north-northwest strike is exposed for three miles in length and a mile in width. To the south the strike of the dikes swings to the southwest, and they become conformable with the foliation of the anorthositic gneiss on the north side of Bigelow mountain. An example of a metagabbro dike in anorthositic gneiss may be seen in the quarry alongside the main highway about one-half a mile north-northeast of Augur lake. At the south end, and on the east side of the hill marked by the “T” of Chesterfield on the map, there is a dike of metagabbro with relations excellently exposed in a vertical section 15 feet high. The strike of the dike is parallel to the foliation of the anorthositic gneiss, but the foliation of the anorthositic dips gently south, whereas the dike is nearly vertical (80°S.). The dike itself has a foliation parallel to that of the anorthositic gneiss.

At the north end of Rattlesnake Mountain ridge there is a crosscutting dike of metagabbro, and on the spur running to the railroad tunnel there are many metagabbro sheets 5 to 20 feet thick conformable with the foliation of the anorthosite. Two of these were noted at one place to be connected by a crosscutting dike. A metagabbro sill, in turn cut by a younger diabase dike, is exposed in several road cuts about two miles south of Brown point.

Local flexuring of the foliation of the anorthositic gneiss is paralleled by similar warping of conformable metagabbro sheets, indicating that both have been deformed together.

The metagabbro dikes and sheets vary from an inch or so to 200 feet in width, but are commonly between 5 and 50 feet. They usually can not be traced for more than 100 feet in length. Locally the dikes fork and contain lenses of the anorthositic gneiss; rarely small offshooting dikes are found which also transect the foliation of the country rock; rarely angular inclusions of anorthositic gneiss occur within the metagabbro. Just west of the road near the creek 1.7 miles southwest of Willsboro, a metagabbro mass is in part parallel to the
Figure 16 Block structure; lens of white anorthosite in groundmass of coarse anorthositic rock (From Balk, 1931, plate VI).

Figure 17 Metagabbro dike (dark) crosscutting platy foliation of gabbroic anorthosite. One-third mile southwest of Bouquet.
foliation of a band of pyroxene gneiss, and in part crosscuts it at right angles. Figure 17 shows a photograph of a specimen from the contact of a discordant dike and the anorthosite wall rock. The metagabbro crosscuts the foliation but is almost parallel to the linear structure of the anorthosite which pitches but slightly in the plane of foliation.

The evidence for discordant relationships of some of the metagabbro bodies to the country rock has been especially emphasized because of the interpretation by others (Balk, 1931, p. 308) that all metagabbro bodies in the anorthositic rocks are conformable with the structure of the latter.

The metagabbro, as indicated by the name, has resulted from metamorphism of gabbro, and a description of the variations in texture and mineralogy will be found in the chapter on dynamo-thermal metamorphism.

**QUARTZ SYENITE AND ASSOCIATED GRANITE**

There are within the anorthositic rocks several small sheets of granitic type which are related to the pyroxene quartz syenite series so extensively developed farther to the west. Associated with the quartz syenite locally is a reddish granite which may in part be a metamorphosed facies of the quartz syenite or may belong to the younger granites.

A green, strongly foliated, phacoidal hypersthenite quartz syenite gneiss forms the west face of hill 1480 about one and three-fourths miles south of the south end of Butternut pond. It consists of about the following percentages of minerals: oligoclase 52, microcline 16, quartz 14, hypersthenite 10, hornblende 4, augite 1, magnetite 1½, and accessory biotite, garnet, apatite, zircon and pyrite. The quartz syenite is involved with amphibolite to the south. A medium granular dike of green augite quartz syenite gneiss in the hill one-half a mile north of Payne mountain consists of microperthite 53, plagioclase 2½, quartz 32, augite 5, garnet 3.5, magnetite 3, and accessory hornblende and zircon. A nearly red facies of the felsic rock consists of about 54 microcline, 3 plagioclase, 32 quartz, 3 hornblende, 6 garnet, 2 magnetite and accessory zircon. Green quartz syenite gneiss and pink medium-grained granite gneiss, with included layers of amphibolite, underlie the valley north and northwest of Sugarloaf mountain. A garnetiferous augite quartz syenite sheet several feet thick is present in the gabbroic anorthosite 1½ miles southeast of Prospect hill. A fine-grained syenite composed of microperthite, about 20 per cent pyroxene (mostly augite), and several per cent of magnetite,
forms a two-foot dike cutting a metagabbro dike in gabbroic anorthosite at the north end of rise 800 at the north end of Rattlesnake Mountain ridge.

**GRANITE**

Granite gneiss is the major rock of Split Rock mountain. It is a fine-grained (a trifle less than 1 mm) pink hornblende granite gneiss intrusive into metagabbro and much involved with it. Coarse hornblende syenitic pegmatite veins with only a little quartz are commonly present. Their syenitic character is probably related to phenomena connected with the intrusion of the granite into metagabbro. The mineralogic composition of a specimen of granite gneiss from the road about a mile west of Split Rock point consists of the following percentages of minerals: microperthite 56, quartz 32, plagioclase 4, hornblende (in part chloritized) 7, and accessory zircon, apatite and magnetite.

The road metal quarry near the east side of Butternut pond is in a strongly foliated pink granite gneiss with phacoidal structure, and locally is deeply weathered. The two major minerals are microperthite and quartz. Mafic minerals are rather minor in amount. A little more than 1 per cent of chlorite is present, but it is uncertain what the primary mineral was.

Small garnetiferous fine-grained granite sheets, dikes, veins and lenses are found here and there throughout the anorthositic rocks, except for local areas such as that for a couple of miles north and northeast of Reber. Commonly they are not over several feet wide, and are strongly foliated and recrystallized.

About one and one-third miles northwest of Willsboro bridge on the east face of the hill, south of the road, there is a sheet of pink garnetiferous granite with angular inclusions of the gabbroic anorthositic gneiss. In thin section the granite is found to consist of a granoblastic aggregate of microcline, plagioclase and quartz, with much garnet poikilitic with quartz, and accessory hornblende, magnetite, a trifle biotite and apatite and zircon. In some of the garnet granite veins augite is also present. Garnet may form up to 20 per cent of the garnetiferous granite. Locally the granite veins are schistose and mylonitic, and the banding of the gabbroic anorthosite may be offset along them.

Rarely a coarse granite pegmatite lens cuts the anorthositic rocks. On the top of Bigelow mountain there is a 20-foot vein of granite pegmatite with hornblende crystals four to six inches in length.
DIABASE

The texture of the diabase dikes ranges from medium grain in the heart of wide dikes to dense and glassy in very narrow dikes and in the chilled selvedges of dikes. In thin section the texture is seen to be predominantly doleritic as distinguished from ophitic. A noteworthy feature is the common occurrence of a few amygdules filled with carbonate, chlorite or quartz, and the occasional presence of miarolitic cavities. The latter are characteristically lined with terminated orthoclase crystals projecting into the cavity, the latter being filled with successive crusts of chlorite and calcite or calcite alone. Some miarolites are lined with orthoclase and quartz and associated with accessory biotite, apatite and magnetite. The apparently glassy facies are seen in thin section to be largely devitrified with a microfibrous texture. The black color arises from the abundance of margarites or strings of microscopic opaque iron oxide. Locally the monoclinic pyroxene is in arborescent intergrowths with the plagioclase.

There are two varieties of the diabase, an olivine diabase and a nonolivine-bearing variety. The olivine, where present, is in euhedral phenocrysts. The major minerals are calcic plagioclase and monoclinic pyroxene. In many dikes a little enstatite is present. In others there is a little biotite. In all varieties there are accessory opaque oxides in skeletal growths and small crystals, and a trifle apatite. The biotite occasionally occurs as a corona around the magnetite and ilmenite, presumably as a reaction product between the iron oxides and the plagioclase. The plagioclase appears to be predominantly labradorite, though there is a variation from bytownite to andesine. The monoclinic pyroxene varies from a slight pink to greenish. Some crystals show a very faint pleochroism. The pyroxene is probably titaniferous.

Many of the dikes show secondary alteration. The plagioclase and pyroxene may be altered to carbonate and/or chlorite, and the olivine to serpentine with magnetite particles.

STRUCTURE

Foliation

Practically all the Precambrian rocks show a well-defined platy foliation or leaf structure along which the rocks tend to break. This is due in part to the dimensional orientation of certain of the mineral grains or grain aggregates parallel to planes, and in part to a differentiation whereby alternate laminae or flattened lenses are com-
posed of different minerals. When this foliation is plotted on the map, it is seen that in the southern half of the map there is an anticlinal structure whose axis strikes northwest through Reber, and pitches to the northwest. The foliation of the northern third of the Precambrian area in general strikes west-northwest and dips south. In the southern part of this northern area, however, it exhibits several crumple structures which form subordinate anticlinal and synclinal structures pitching south-southwest. The belt northwest from Willsboro, through Long, Warm and Butternut ponds, constitutes a saddle between the northeast flank of the Reber anticline and the generally southerly dipping rocks of the Mount Bigelow range.

The relationship of the foliation of the rocks of the Willsboro quadrangle to that of the anorthosite massif as a whole, as worked out by Balk, is shown in figure 9. It is there seen that the Reber anticlinal structure is but the northern prong of a larger dome-shaped structure, which may be called the Westport dome.

**Linear Structure**

In the plane of the foliation there is usually a linear structure, evidently due in part to a dimensional orientation of inequidimensional grains or aggregates parallel to a line, and in part to a streaking arising from the concentration of different proportions of different minerals in definite linear streaks. The concentration of the dark minerals in such pencils often indicates the linear structure. The linear structure is plotted on the map and, on the Reber anticline is seen to be parallel to its axis and to pitch in the same direction as the fold. In the northern part the linear structure is parallel to the subordinate crumple structures which may be called the Westport dome.

The relationship of the linear structure of the anorthositic series of the Willsboro quadrangle to the linear structure of the main anorthosite massif is shown in figure 18 as worked out by Balk.

**Origin of Gneissic Structures**

The foliation of the igneous rocks is interpreted by some geologists as having been formed wholly as the result of differential flowage in the magma during a stage when it contained appreciable proportions of crystals. The alignment of minerals is ascribed to friction caused by relatively stationary walls along which the magma moved. Other geologists believe that upon this primary foliation of the magmatic
stage there has been superimposed the effects of plastic flowage in solid rock at a time many millions of years subsequent to the complete consolidation of the anorthositic and syenitic intrusives. The secondary foliation arising from the plastic flowage is in general conformable with the primary foliation. Similar alternative interpretations have been offered for the origin of the linear structure; one group of geologists believing it corresponds to flow lines developed during the magmatic stage, and another group believing it was developed during a secondary deformation long after the rocks were solid. In either case the foliation and linear structure are interpreted as phenomena of differential flow, whether developed by viscous flow during a magmatic stage or by plastic flow of the solid.

Fracture Systems

The major joints of the igneous rocks of the quadrangle tend to lie in certain well-defined sectors or parallel to certain preferred directions.

A set of joints striking in a general north-northeast direction is uniformly present in strong development throughout the Precambrian rocks. They vary locally between N. 10° W. to N. 15° E. (usually N. 0°–15° E.) or between N. 10°–30° E.

Another major set of joints strikes in a general east-west direction, varying between N. 60° E. and N. 80° W. These are most strongly developed in the southwest ninth of the quadrangle, where their strike averages in general between N. 80°–90° E., with in general a steep dip (70° or greater) to the south. Northeast of Reber they average N. 75° E. with a steep southern or vertical dip. In the northwestern ninth they are less strongly developed with a strike averaging about N. 80° E. and with local steep north dips.

A set rather uniformly, but not so strongly, developed ranges between N. 45°–60° W. or N. 30°–50° W.

Locally along the west central and southwest border of the quadrangle there is a set of joints striking N. 50°–50° E.

The major joint systems maintain their appropriate trends independent of wide variations in the strike and dip of the foliation and in the strike of the linear structure.

The history and dynamics of the formation of these joint systems are not clearly evident. Indications of a very early system of north-northwest to northwest fractures are found in the strike of the meta-gabbro dike swarms of the Trembleau and Bouquet Mountain belts. The fractures occupied by granite pegmatite veins also indicate a younger set whose directions and relationships were not studied.
Figure 18 Map of the flow lines (linear structure) and joints in the Adirondack anorthosite and its vicinity (From Balk, 1931, plate XII) Heavy arrows show generalized direction of linear structure.
The Precambrian diabase and basalt dikes occupy a set of east-west joints (average about N. 75° E.). Post-Ordovician normal faulting is strongly developed with north-northeast to northeast strikes both in this area and in the eastern Adirondacks as a whole. The north-northeast set of joints is independent of wide variations in the strike of the foliation and of the linear structure in the Willsboro area. This set of joints, or one with a more northerly or more northeasterly direction, is widespread throughout the Adirondacks. It has been referred by Balk (1931) (figure 18) to an origin as “Regional tension joints” arising from compression in the same general direction. Acceptance of this must be held in abeyance, however, until more data are available. Certainly in the eastern Adirondacks it is to be expected that this set of joints was accentuated during the period of post-Ordovician faulting.

The east-west joint system in the southern half of the Precambrian area is approximately at right angles to the linear structure, and many of the joints dip steeply south, whereas the linear structure pitches gently north. In the northern part the west joints are also approximately at right angles to the linear structure, and in part dip steeply north against the southern pitch of the linear structure. To this extent the joints have the character of “cross joints.” There is a difference of about 40° between the strike of the linear structure in the south and the north, however, which is not matched by an equivalent swing in the strike of the joints. Locally there is a still greater change in the strike of the linear structure with the strike of the joints remaining constant. The east-west joints are regional in character.

**DYNAMO-THERMAL METAMORPHISM**

**General Statement**

One of the problems of major interest in the Adirondack geology is the relative importance of primary and of secondary structures in the igneous rocks. The earlier workers, including Cushing, Kemp, Newland and Smyth, believed that regional orogenic stresses played a very large part in producing and controlling the foliation and linear structure within the igneous rocks as we now find them, although recognizing that there may have been an earlier primary structure of magmatic origin. Miller (1916), on the other hand, advocated the hypothesis that the foliation of the igneous rocks was primary and formed by flowage with concomitant crushing during the progress of intrusion and consolidation of the magma under the impulse of efforts to shoulder aside blocks of the Grenville. Balk (1931) has more
recently similarly further developed the idea that the movement of the magma during the intrusion and consolidation was itself responsible for the induction of the foliation and linear structure. The writer believes that the evidence for the development of metamorphic mineral facies, the pattern and relationships of the foliation, the relationships of the linear structure, and the relic lenses of relatively undeformed rocks, all indicate that most of the Precambrian rocks (the younger diabase and certain granite pegmatite veins excepted) of the Willsboro area have undergone dynamo-thermal metamorphism and plastic flowage.

**Metamorphic Facies Development of Anorthositic Rocks**

The degree to which the metabasalt and quartz syenite sheets are conformable with the foliation of the anorthositic rocks indicates that the foliation of the latter must have originated in part at an early date and that there may have been a foliation of primary origin. Locally in the anorthositic rocks to the south and southwest of the Willsboro area, there are lenses of Whiteface anorthosite showing both a primary texture of crystallization and a primary foliation, so that there seems to be convincing evidence that the anorthositic rocks possessed a primary foliation.

All of the rocks of the anorthositic series of the Willsboro area, however, when studied in thin section, are found to be composed largely of a mosaic of mineral grains characteristic of a granoblastic origin. Furthermore, some bands show all gradations between a coarse Marcy type of anorthosite, with feldspars averaging more than an inch in length with only a small amount of peripheral crushing and veinlets of crushed material traversing the large feldspars, to rock which is wholly granulated. Locally the Whiteface facies shows inherited relics of an ophitic texture, the scale of which indicates a primary grain of about a half a centimeter or more but not greater than a centimeter, although the rocks in general now have a grain of not more than 1 or 2 mm. The Whiteface facies commonly carries a few large phenocrysts or porphyroclasts. These also appear to be an inheritance from a primary coarsely porphyritic texture, for the porphyroclasts in many cases are still almost euhedral and locally more calcic than the groundmass.

With the exception of a few local lenses, all the anorthositic rocks of the Willsboro area are here interpreted as having undergone crushing, recrystallization, and in part reconstitution, under conditions of regional dynamothermal metamorphism. The least metamorphosed rocks (transitional facies 2-a) are those nearer the cores
of the Westport and Port Kent domes, and they carry little or no garnet; whereas the more thoroughly reconstituted rocks (2-b) commonly carry garnet. It may also be noted that whereas the facies with little or no garnet may carry considerable hypersthene there is commonly (though there are exceptions) little or no hypersthene in the reconstituted garnetiferous facies. Locally augite granules are found on the borders of hypersthene, and it is thought that on reconstitution augite, garnet, and magnetite are formed at the expense of hypersthene and the calcic molecule of the plagioclase. Hornblende is also more common in the reconstituted facies. Locally porphyroblasts of garnet and augite up to a centimeter in diameter are found.

Metamorphic Facies Development of Metagabbros

The metagabbros best show the results of metamorphism and will be discussed in some detail.

The texture of the metagabbro varies from a coarse-grained facies with feldspars averaging about one-half an inch in diameter and with a well-preserved ophitic pattern, through a medium-grained, wholly recrystallized, strongly gneissic foliated rock, to a very fine-grained granulitic or granoblastic gneiss. The coarse diabasic rock with but little granulation of the minerals forms the core of the larger masses, the medium-grained gneiss the core of medium-sized dikes, and the fine-grained rock occurs exclusively in the narrow dikes and at the borders of the metagabbro bodies. It definitely has such relationships as to suggest that it originated in the first instance as a quickly chilled facies. There are all gradations between the almost uncrushed diabase and the wholly recrystallized granulated gneiss.

The original diabasic texture is excellently shown by the cores of the metagabbro masses of Split Rock mountain and a number of dikes on Trembleau mountain, both on the Willsboro and Plattsburg quadrangles. A fine one is exposed on the east side of the hill just south of Port Kent, and another in a road cut one-half a mile south-east of Sugarloaf mountain. Excellent examples of wholly recrystallized dikes are exposed in road cuts along the northeast-southwest road about one and three-fourths miles northwest of Bouquet, and along the road about two miles south of Brown point.

Most of the metagabbro masses, both dikes and sheets, show a well-defined foliation parallel to their walls. A few of the discordant dikes, however, show a foliation conformable with that of the country rock, and therefore at an angle to their walls. One such dike was noted one and three-fourths miles west-southwest of Brown point,
and another two and one-half miles southwest of Willsboro. The foliation parallel to the walls of discordant dikes is attributed to movement of anorthositic rock as blocks parallel to the plane of the dikes; and the foliation across the discordant dikes, to granulation, reconstitution and recrystallization consistent with forces producing the similar and conformable foliation of the inclosing anorthositic rocks.

All the metagabbro shows profound changes in the mineralogy as a product of reconstitution during metamorphism. A number of variations in the mineralogic facies are given in table 3.

No unaltered or nongarnetiferous gabbro has been found in the Willsboro area. The least altered facies of the metagabbros with similar age relationships are found in the northwest Adirondacks, where they consist of labradorite, augite, hypersthene and olivine, with accessory magnetite and ilmenite and a little apatite.

The garnetiferous metagabbros of the Adirondacks in general vary from a facies in which the plagioclase is labradorite to one in which it is oligoclase, depending upon the degree of reconstitution. No labradorite facies have been identified from the Willsboro quadrangle. They appear to be largely, if not wholly, restricted to a belt of less intense metamorphism to the northwest. Labradorite is the predominant plagioclase in both the garnetiferous and nongarnetiferous metagabbros of the Santa Clara quadrangle (Buddington, 1937, p. 28). On the Willsboro quadrangle the least altered facies are the cores of dikes with ophitic texture which commonly belong to an andesine-olivine-pyroxene-garnet facies with only a trifle ilmenite and magnetite.

The granoblastic facies are finer grained and show a more intense reconstitution than the ophitic textured rocks. The plagioclase varies from a sodic andesine to oligoclase, and often there has been a slight unmixing and segregation of potash feldspar from the plagioclase into small interstitial grains. Olivine is rarely present; ilmenite and magnetite together form a major member of the mineral assemblage except where hornblende is the predominant mafic. Locally hornblende is the major mafic mineral. In the ophitic gabbros the garnet occurs in a corona structure around the mafic minerals or as partial replacement of the plagioclase; whereas in the granoblastic rocks it forms euhedral to subhedral grains, commonly with a little poikilitic quartz.

The writer has unpublished chemical analyses to prove that the change in mineralogy is dependent upon the character of the metamorphism, since the bulk chemical composition for all the meta-
The ungranulated, unrecrystallized plagioclase is dusty with clouds of microscopic inclusions, and is interpreted as having undergone a change in composition without a change in form from primary labradorite to andesine. In the granoblastic facies there are two alternative lines of modification for the mafic minerals, one leading to augite, hypersthene, iron oxides, and garnet, the other to hornblende and garnet. The corona structure and the changes which may be traced by the various facies suggest that for the pyroxenic line of development a major element in the reconstitution has been a reaction of the calcic molecule of the plagioclase with the olivine to yield hypersthene, augite, and garnet, on the one hand, and a more sodic plagioclase, on the other. In the incipient stages of metamorphism a little green spinel may be present. More intense reconstitution results in a reaction of part of the hypersthene with the anorthosite molecule of the plagioclase to form augite and a still more sodic plagioclase, with at the same time a recrystallization and segregation of iron and titanium oxides from the pyroxenes to form magnetite and ilmenite. A trifle quartz is also commonly present in the granoblastic facies.

In the hornblende line of development olivine similarly reacts with the calcic molecule of the plagioclase to yield hornblende, garnet and a more sodic plagioclase. Spinel is also found locally. The hornblende also forms at the expense of the augite. The alternative development of a pyroxene or a hornblende facies may be interpreted as dependent on the amount and character of thermal solution (gas or liquid) present at the time of reconstitution. The hornblende-rich rocks are wholly in the border zone of the anorthositic series where there are layers of skarn and Grenville, where granitic intrusions are more numerous, and where conditions are such as to warrant the inference that the rock formations were of such a character as to permit more ready access to thermal solutions than the more homogeneous anorthositic rocks.

A slight amount of thermal solutions must have been present also, however, to facilitate the reconstitution of the pyroxenic facies, for there has been a slight migration of certain constituents from the metagabbro into the wall rocks to form thin garnetiferous selvedges to numerous metagabbro sheets within the anorthositic country rock. There also appears to be a concentration of apatite and ilmenite in the border facies of a number of the metagabbro dikes.

The maximum intensity of metamorphism is uniformly found in the border zones of the masses and in the small sheets.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Andesine (40-60)</th>
<th>Andesine (3-30)</th>
<th>Oligoclase (3-20)</th>
<th>Clinopyroxene</th>
<th>Oliven</th>
<th>Hypersthene</th>
<th>Hornblende</th>
<th>Ilmenite and Magnetite</th>
<th>Garnet</th>
<th>Biotite</th>
<th>Potash Feldspar</th>
<th>Quartz</th>
<th>Apexite</th>
<th>Pyrite</th>
<th>Spinel</th>
<th>Carbonate</th>
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<tr>
<td>510-b</td>
<td>53.1</td>
<td>...</td>
<td>...</td>
<td>5.1</td>
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<td>14.9</td>
<td>1.4</td>
<td>2.1</td>
<td>19.3</td>
<td>3.5</td>
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<tr>
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<td>37.</td>
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<td>...</td>
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<td>11.2</td>
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<td>14.6</td>
<td>0.3</td>
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<td>0.6</td>
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</tr>
<tr>
<td>56-b</td>
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<td>...</td>
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<td>6.7</td>
<td>5.3</td>
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<td>2.2</td>
<td>1.0</td>
<td>20.5</td>
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</tbody>
</table>

**Ophitic Metagabbro; Andesine, Olivine, Pyroxene, Garnet Facies**

**Granoblastic Gneissic Medium-Grained Metagabbro; Andesine, Pyroxene, Garnet, locally Hornblende, Magnetite Facies**
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Carbonate</th>
<th>Spinell</th>
<th>Pyrite</th>
<th>Apatite</th>
<th>Quartz</th>
<th>Potash</th>
<th>Biotite</th>
<th>Garnet</th>
<th>Mackrite</th>
<th>Hornblende</th>
<th>Aegirine</th>
<th>Hypersthene</th>
<th>Olivine</th>
<th>Andesine (an 60-65%)</th>
<th>Andesine (an 45-50%)</th>
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<tbody>
<tr>
<td></td>
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<td>1.0</td>
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<td>24.5</td>
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<td>39.8</td>
<td>38.6</td>
<td>44.7</td>
<td>40.9</td>
<td></td>
<td>9.0</td>
<td>7.8</td>
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<td>6.0</td>
<td>8.0</td>
<td>3.0</td>
<td>34.0</td>
<td>1.0</td>
<td>27.0</td>
<td>2.0</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

* A little potash feldspar as antiperthitic intergrowth in plagioclase.
510-b East side of hilltop just south of Port Kent, Plattsburg quadrangle. Core of large dike.
6022 ½ mile SE of Sugarloaf mountain.
280-b 1.7 miles SW of Willsboro bridge. Core of dike.
6004 West side of Jay mountain, Ausable quadrangle; center of thick sheet.
56-b North end of Rattlesnake Mountain ridge.
353 1½ miles NW of Bouquet.
564-b 2 miles south of Brown point, on road.
280-d Same locality as 280-b; schistose metagabbro at north end of sheet.
6025 2½ mile SW of Bouquet; border of dike.
510-d Same locality as 510-b; border of dike.
142-a 1½ miles north of Port Douglas; wall of dike.
142-b Same locality as 142-a; core of dike.
5641 1 mile WNW of Elizabethtown Post Office.
80-a 1½ miles south of Brown point on railroad.
275-d Split Rock mine, Port Henry quadrangle.

Metamorphic Facies Development of Felsic Rocks

Syenite and quartz syenite gneiss are insufficiently represented on the Willsboro quadrangle to warrant detailed consideration of their metamorphism. There is a marked contrast in the mineralogy of the granite gneiss of Split Rock mountain and the strongly foliated dikes and sheets within the anorhostic rocks. In the Split Rock mountain granite the feldspar is almost wholly microperthite and the rock shows only a moderate amount of granulation and recrystallization, whereas in the strongly foliated rock the feldspar is finely granulated and recrystallized to plagioclase and microcline, with only a slight amount of plagioclase as intergrowth in the microcline and with a considerable percentage of garnet. The latter necessitates the introduction of considerable iron so that there must have been thermal solutions moving through the rock at the time of metamorphism.

Evidence for Plastic Flow

The evidence of extensive and intensive recrystallization and reconstitution of most of the Precambrian rocks of the Willsboro quadrangle (a few granite pegmatite and the younger diabase dikes excepted) indicate to the writer that the present foliation and linear structures are secondary developments in connection with plastic flowage under conditions of great depth, relatively high temperatures (probably over 600° C.), and great stress.

The local and the general broader regional pattern of the foliation is consistent with formation by orogenic tangential forces, acting upon rocks which in large part possessed a primary foliation.

Examples have been described in the foregoing pages where meta-gabbro dikes transect the foliation of the inclosing gabbroic anorthosite but themselves have a foliation consistent with that of the
country rock. Similar relationships have been observed in the case of numerous discordant granitic veins. Conditions where the same foliation traverses country rock and dike, without respect to the contacts of the latter, are indicative of a secondary origin for the foliation.

The linear structure is in general parallel to the axes of the folds, as is the common case in crystalline schists and in the Grenville rocks of the Adirondacks. In the rock of the Reber anticlinal structure there is a narrow belt about four miles long, striking north-northwest through Reber, in which platy foliation is indistinct or indistinguishable and linear structure is pronounced. This belt coincides with the crest of the nose of the anticlinal structure and is consistent with what is to be expected in flexure folds, since the relative amount of movement between the layers or shear on the foliation planes is at a minimum on the crest and in the trough.

Local small lenses of relatively little deformed rock, such as that in the road cut about one-half a mile southwest of Brown point and another in the quarry just south of where Phelps brook crosses the main road on the Elizabethtown quadrangle, give clues as to the nature of the primary rock. On such bases, the Whiteface facies is thought to have originally been in large part much coarser grained than it now is, though not so coarse as the typical Marcy. It may also have had large phenocrysts, now occurring as large porphyroclasts. In part the original rock was a coarse gabbroic anorthosite.

POSTDEFORMATION RECRYSTALLIZATION AND REPLACEMENT

Locally throughout the anorthositic rocks the plagioclase is slightly to moderately saussuritized, with clinozoisite a conspicuous major element, and the mafic minerals are altered to chlorite, epidote, zoisite, carbonate etc. Locally also at many localities the plagioclase is partly altered to prehnite. These alterations affect the recrystallized and reconstituted minerals and are postdeformation.

Locally the anorthosite is completely saussuritized, as in the hill three-fourths of a mile west-northwest of Whallonsburg, or wholly replaced by prehnite, as in the second railroad cut south of the railroad bridge south of Burnhams Siding. The latter is located where the highway and railroad approach each other most closely, about one mile north of the railroad tunnel and three miles north of the Willsboro railroad station. The country rock is Grenville limestone with several sheets and lenses a few feet thick of altered gabbroic anorthosite. The plagioclase of these sheets is almost wholly
replaced by a granular white prehnite. The altered rock has the appearance and texture of ordinary gabbroic anorthosite. It is adjoined by a narrow layer of skarn composed predominantly of augite, locally with thin veinings of plagioclase, and locally with bands of garnet. The skarn has the relationships of a contact metamorphic deposit, but the prehnitization is later, as proved by the fact that the plagioclase of the skarn is also replaced by prehnite. The prehnite occurs both as fine, fibrous to lamellar aggregates, interpreted as replacement of plagioclase, and with a druselike structure in which terminated crystals of prehnite project into druse fillings of quartz or of quartz and prehnite. Epidote is locally found facing fractures in granite pegmatite, and the saussuritization and prehnitization is considered to be the product of hydrothermal alterations genetically related to late stages of consolidation of the granitic magmas.

GEOLOGY OF THE PALEOZOIC DISTRIBUTION

The Paleozoic areas of the Willsboro quadrangle all lie on the eastern flank of the Adirondack mass and because of the difference in hardness of the rocks are at a lower elevation than the Precambrian. The largest area makes up the eastern half of Essex and Willsboro townships and is a continuous belt about 13½ miles long and averaging three miles in width. In addition to this large area there is about a square mile of Potsdam at Port Douglas at the head of Corlear bay, a small patch of Potsdam at Keeseville, and two small outliers of Potsdam in the Precambrian, one just south of the sign "Cinder Limit" along the railroad at the southwestern corner of Willsboro bay and the other in a stream bed just south of the Essex-Willsboro town line. Schuyler island and the Four Brothers islands in Lake Champlain are areas of Canajoharie shale.

The greatest difficulty encountered in this study has been the lack of outcrops. The whole region was overridden by the Pleistocene glacier and a large portion submerged under a postglacial marine invasion with the result that the larger part of the area is covered with unconsolidated Pleistocene sediments. With few exceptions outcroppings of bedrock are confined to the shore of the lake or the valleys of the major streams. Due to this scarcity of outcrops there are large areas where the bedrock geology is inferred, often from very sketchy information and it is possible to interpret the data in more than one way. In all such cases the area has been considered
in its relation to the whole region and what seems the most probable interpretation has been chosen.

On the map the areas of known outcrops, or of regions where the outcrops are sufficiently numerous and closely spaced to justify the assumption of continuity, have been given a solid pattern, and all other portions, where the geology is mapped by inference, have been portrayed by an open pattern thereby distinguishing between the known and the unknown.

**PRELIMINARY STATEMENT OF FORMATIONS**

There are five Paleozoic sedimentary formations recognized and mapped within the district covered by this report. The oldest is the Potsdam sandstone and quartzite of upper Cambrian time and the youngest the Canajoharie shale of upper Middle Ordovician time. The stratigraphic column in ascending order follows:

```
Ordovician  

<table>
<thead>
<tr>
<th>Trenton group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chazy limestone</td>
</tr>
<tr>
<td>Beekmantown limestone and dolomite</td>
</tr>
</tbody>
</table>

Cambrian  
Potsdam sandstone
```

These beds were deposited in the western trough or "Chazy basin" of Ulrich and Schuchert (1902, p. 639–40), a long narrow down-warped area bounded on the west by the highlands of the Adirondack mountains and on the east by the "Quebec barrier" which separated it from the more easterly trough or "Levis channel."

During Cambrian and Ordovician times there was an alternating oscillatory movement between these two troughs with the result that neither one has a complete section and the lithology and fauna of the two do not check. The western trough with which this report deals connects to the south with the Lower Mohawk trough (Cushing and Ruedemann 14, p. 140–41) and contains the more normal series of beds (Ruedemann 1929, p. 410–11).

**POTSDAM**

The Potsdam sandstone was originally described by Emmons (1838, p. 215) as follows:

This rock is a true sandstone, of a red, yellowish red, gray, and grayish white colours. It is made up of grains of sand, and held together without a cement. Intermixed with the silicious grains are finer particles of yellowish feldspar, which do not essentially change the character of the sandstone, but they show the probable source from which the materials forming it were originally derived, viz.
some of the varieties of granite. Unlike, however, most of the sandstones, it is destitute of scales of mica. The colouring matter of the rock is evidently oxide of iron, but unequally diffused through it, giving it intensity or deepness of colour in proportion to its quantity. In some places it is almost wanting, which makes it, when pulverized, a good material for glass.—The grains and particles in its composition are generally angular, but where it takes the character of a conglomerate, as it does in the inferior layers, they are frequently rounded. The thicker strata exhibit an obscurely striped appearance, owing to prevalence of certain colours in the different layers.

As seen in this area the Potsdam is a medium-grained sandstone with the quartz grains cemented by silica. It weathers white and in many shades of yellow and brown and in one outlier, west of the Bouquet river near the Essex-Willsboro town line, it is dark red in color. The individual beds vary in thickness from two inches to two feet and are sometimes topped by beautifully developed ripple marks. Cross bedding is present in some localities. In most places the cementation is so complete that the rock may well be considered a quartzite. Although the Potsdam is known to have some conglomeratic layers where the rock is made up of rounded pebbles none of these beds was seen in place although cobbles of such lithology were found along the shore.

Although no fossils were found in the Potsdam sandstone in 1938 a faunal list by Van Ingen appended to the paper by White (1894, p. 232) lists the brachiopod *Obolella prima*, Conrad and Hall as having been collected at Bouquet.

**BEEKMANTOWN GROUP**

**Beekmantown Formation (Restricted)**

The Beekmantown formation or group has been subjected to considerable revision since the name was first given by Clarke and Schuchert in 1899 (p. 877). Their original description is as follows: “Beekmantown limestone (new). The Calciferous sandrock of Eaton and authors generally. This formation took its original name from sections in the Mohawk valley, where the rocks are without fossils. At Beekmantown, N. Y., the normal fauna is finely developed and the rock section essentially complete.” By this statement the authors made the Beekmantown equivalent to the Calciferous of early reports; since then further work has restricted the name to the upper part of the old Calciferous.

In 1890 Brainerd and Seely published their classic work on the Calciferous of the Champlain region and for the first time sub-
divided the formation into five zones that they lettered A–E and they described their type section at Shoreham, Vermont, as follows (Brainerd, E. and Seely, H. M., 1890, p. 2–3):

A. Dark iron-gray magnesian limestone, usually in beds 1 or 2 feet in thickness, more or less silicious, in some beds even approaching a sandstone. Nodules of white quartz are frequently seen in the upper layers, and near the top large irregular masses of impure black chert, which, when the calcareous matter is dissolved out by long exposure, often appears fibrous or scoriaceous.

Thickness 310 feet.

B. Dove-colored limestone, intermingled with light gray dolomite in massive beds; sometimes for a thickness of 12 or 15 feet no planes of stratification are discernible. In the lower beds, and in those just above the middle, the dolomite predominates; the middle and upper beds are nearly pure limestone; other beds show on their weathered surfaces, raised reticulating lines of gray dolomite.

Thickness 295 feet.

C. 1. Gray, thin bedded, fine grained, calciferous sandstone, on the edges often weathering in fine lines, 40 or 50 to the inch, and resembling close grained wood. Weathered fragments are frequently riddled with small holes, called *Scolithus minutus* by Mr. Wing. .................................................................60 ft.

2. Magnesian limestone in thick beds, weathering drab...100 ft.

3. Sandstone, sometimes pure and firm, but usually calciferous or dolomitic .................................................................70 ft.

4. Magnesian limestone like no. 2, frequently containing patches of black chert.................................................................120 ft.

Thickness of C.................................................................350 feet.

D. 1. Blue limestone in beds 1 or 2 feet thick, breaking with a flinty fracture, often with considerable dolomitic matter intermixed, giving the weathered surface a rough, curdled appearance; becoming more and more interstratified with calciferous sandstone in thin layers, which frequently weathers to a friable, ocherous rotten stone .................................................................80 ft.

2. Drab and brown magnesian limestone, containing also toward the middle several beds of tough sandstone.......................75 ft.

3. Sandy limestone in thin beds, weathering on the edges in horizontal ridges one or two inches apart, giving to the escarpments a peculiar, banded appearance. A few thin beds of pure limestone are interstratified with the silicious limestone.................................120 ft.

4. Blue limestone in thin beds, separated from each other by very thin, tough slaty layers, which protrude on the weathered edges in undulating lines. The limestone often appears to be a conglomerate, the small inclosed pebbles being somewhat angular and arenaceous. .................................................................100 ft.

Thickness of D.................................................................375 ft.
E. Fine grained, magnesian limestone in beds 1 or 2 feet in thickness, weathering drab, yellowish or brown. Occasionally pure limestone layers occur, which are fossiliferous, and rarely thin layers of slate. Thickness 470 feet.

Total thickness .................................. 1800 feet.

Subsequently division A and the lower part of division B which underlie a definite unconformity were removed by Clarke (1903) and placed in the Little Falls. The upper part of division B and all subsequent divisions were left in the restricted Beekmantown. In 1905 Cushing (p. 363) placed the upper part of D and all of E in a new formation, the Cassin, thereby again restricting the Beekmantown. Rodgers in 1937 (p. 1576) found "a significant unconformity 35 feet below the base of division B, and this break seems to correspond with the break above the Little Falls in the Mohawk Valley." Because of this new information Rodgers proposed a new unit, the Whitehall Formation, to take the upper 35 feet of division A and all of division B. Division C in its entirety and the lower part of division D are therefore all that is left in the Beekmantown in its restricted sense.

Cassin Formation

The Cassin, as noted above, consists of the upper part of division D and all of division E of Brainerd and Seely. It is distinguished by the presence of fossil gastropods of the genus *Eccyliopterus*.

Subdivision of Beekmantown

Although an attempt was made to subdivide the Beekmantown on the basis of Brainerd and Seely's classification it was not particularly successful. There are certain places where some of the zones may be tentatively recognized and these will be discussed but in many other localities it was impossible to carry the work to this degree of refinement.

As outcrops are much scattered, with nothing approaching a complete section, and as many outcrops were glaciated surfaces showing stratigraphically only a few feet, enough detail for subdivision could not be obtained.

At two localities, one the right bank of the stream below the mill dam at Willsboro and the other the left bank a quarter mile below the junction of the North Branch, *Lecanospira* was found in profusion. A specimen from below the Mill dam at Willsboro was sent to Dr Josiah Bridge in 1937, who reported,¹ "The piece of rock

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¹ Letter of July 2, 1937.
contains a number of specimens of *Lecanospira*, and it is very evident that it is from the main *Lecanospira* zone of the Beekmantown. This is Upper C or Lower D of Brainerd and Seely's classification, and the form appears to be the same as that figured by Whitfield as *Ophileta complanata.*” *Lecanospira* was not observed at any other Beekmantown outcrop.

In the bed of the North Branch of the Bouquet river near the fault *P-P* the stratigraphically highest strata contained two or three 18-inch beds of quartzite and along the outcrop west of the road, just north of the intersection of faults *A-A* and *H-H* a similar persistent bed of quartzite was found within the Beekmantown. These beds are suggestive of Brainerd and Seely's D2. “Drab and brown magnesium limestone, containing also toward the middle several beds of tough sandstone.” As the including calcareous beds on the North Branch answer the first part of this description and as they fall in correct stratigraphic position with regard to the *Lecanospira* zone it is believed that the correlation is valid.

About halfway between the outcrop on the Bouquet near the junction of the North Branch, which is the *Lecanospira* zone, and the most western outcrop on the North Branch just mentioned which is believed to be D2, near an ice pond, the Beekmantown contains masses of black chert which might place these beds in zone C4. Similar black cherts are found by the Mill dam at Whallonsburg (figure 10) and at the point just north of the place where fault *K-K* enters the lake.

Along the shore of the lake a quarter mile south of the Beekmantown-Chazy boundary on the east shore of Willsboro point the Beekmantown was found to be fossiliferous carrying the Cassini fauna. This is the only known outcrop of this character.

As the area is so badly broken up by faults, as the outcrops are so scattered and as so few of the subdivisions could be recognized with any accuracy it has not been deemed wise to show the subdivisions of the Beekmantown on the map, and the Cassin which is undoubtedly present in at least one locality is not shown as a separate formation.

Van Ingen in the appendix to White's paper (1894, p. 232) previously mentioned, lists *Ophileta uniangulata*, Hall as having been found in the Calciferous (Beekmantown). During the present study the many specimens of the gastropod *Lecanospira* sp. were found. This is obviously the same gastropod as that reported by Van Ingen as recent work has placed many of the forms of *Ophileta* in the genus *Lecanospira*. 
The Cassin beds of the Beekmantown yielded the following:

_Eccyliopterus triangulatus_ (Whitfield)
Asaphid fragments

**CHAZY**

The Chazy limestone was named by Emmons in 1842 (p. 107) with the following description:

To the calciferous sandrock, succeeds the Chazy limestone. As a whole, it is a dark, irregular, thick-bedded limestone. At Chazy, it contains many rough, irregular, flinty or cherty masses, which have been found in places once occupied by a species of stone coral. It appears to have been a Columnaria; but generally the columns are so obscure and broken, that it is difficult to determine the nature of the fossil. The mass is not uniformly of the character described. At Essex the beds are more regular, and it presents externally a better aspect, and forms in consequence a better building stone. As a limestone, it is purer than the calciferous. The principal foreign matter is silex in the form of chert, which is mostly collected in those points where the stone corallines are imbedded. It is free from those brown earthy spots so common in the limestone below, and also from the masses of calcareous spar which appear almost characteristic of the calciferous sandrock.

The position of the Chazy limestone is clearly determined at Chazy, lying between the calciferous and the birdseye limestone. This rock is wanting in the valleys of the Mohawk and Black river.

There are three well marked fossils, which first make their appearance in this rock: the Maclurea, a Trochus, and the Columnaria. Besides these, there are numerous small fossils, which the irregular bedding of the rock partially conceals.

The entire thickness of this rock is not far from one hundred and thirty feet. It is developed at numerous localities along Lake Champlain, particularly at Essex, Essex county, and at Chazy in Clinton county. It appears to be less constant in the series composing the Champlain group, than several others; still, as it occurs in a mass of so much thickness, and at so many places, it appeared to be necessary to notice it as a distinct rock, inasmuch too as it differed materially from the masses below and above it, in its fossils and in its structure.

It is of particular interest to note that Emmons at this early date was cognizant of the relatively local distribution of the Chazy.

Among the outstanding contributions to the literature dealing with the Chazy limestone is the work of Brainerd and Seely (1888) and the work of Brainerd (1891), who measured the section of Valcour island and thereby established a classic section. His subdivisions are given below (Brainerd 1891, p. 295–96) also (Cushing, H. P., 1905, p. 365–67):
Group A (Lower Chazy)

1. Gray or drab sandstone, interstratified with thin (or sometimes thick) layers of slate, and with occasional thin layers of limestone at the base, containing *Camerella (?) costata* Bill. .......................... 56 ft.

2. The slaty sandstone gradually passes into massive beds, made up of thin alternating layers of tough slate and nodular limestone, containing undetermined species of Orthis and Orthoceras .................. 82 ft.

3. Dark bluish gray, somewhat impure limestone, in beds of variable thickness; often packed with *Orthis costalis* Hall, which occurs with more or less frequency through the whole mass. Other fossils are: *Lingula huronensis* Bill., *Harpes antiquatus* Bill., *H. otta-waensis* Bill. (?), *Illaenus acritatus* Hall (I bayfieldi Bill.), *Lituites* sp. (?) ...................................................... 110 ft.

4. Gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams, the bedding being uneven. Many layers consist of crinoidal fragments, largely of *Paleacystites teniradiatus* Hall. Near the middle of the mass for a thickness of 10 feet, some of the fragments and small, ovoid masses (*Bolboporites americanus* Bill.) are of a bright red color ................................................................. 90 ft.

Making for the total thickness of A .................................................. 338 ft.

Group B (Middle Chazy)

1. Impure, nodular limestone containing *Maclurea magna* Les .................. 25 ft.

2. Gray, massive, pure limestone, abounding in crinoidal fragments .............. 20 ft.

3. Bluish black, thick bedded limestone, usually weathering so as to show pure nodular masses enveloped in a somewhat impure lighter colored matrix; everywhere characterized by *Maclurea magna*. Near the middle of this mass for a thickness of about 30 feet, the fossils are silicified and of jet-black color. The more important besides Maclurea, are species of Strophomena, Orthis and Orthoceras ......................................................... 210 ft.

4. Dark, compact, fine grained limestone, with obscure bedding, weathering to a light gray. Fossils are infrequent, but at a single locality were collected *Orthis perveta* Con., *O. platys* Bill., *Leptaena fasciata* Hall, *Asaphus canalis* Con., *Cheirurus polydorus* Bill., Harpes sp. und., *Illaenus incertus* Bill., *Lichas migansensis* Bill., *Sphaereocrinus parvus* Bill., and several undescribed species ........................................... 20 ft.

5. Bluish black limestone like No. 3, but less pure, containing *Maclurea magna* Les., *Orthis perveta* Con., *Strophomena incrassata* Hall, *Orthis disparilis* Con., or *O. porcia* Bill. ........................................... 75 ft.

Total thickness of B ........................................................................ 350 ft.

Group C (Upper Chazy)

1. Dove-colored, compact limestone, in massive beds, containing a large species of Orthoceras, *Placoparia (Calymene) multicosta* Hall, *Solenopora compacta*, and a large Bucania ........................................... 60 ft.

2. Dark impure limestone, in thin beds, abounding in *Rhynchonella plena*; at the base a bed 4 or 5 feet thick is filled with various forms of Monticulipora or Stenopora ........................................... 125 ft.

3. Tough, arenaceous magnesian limestone, passing into fine grained sandstone ................................................................. 17 ft.

Total thickness of C ........................................................................ 202 ft.

Aggregate thickness of the Chazy on Valcour island .......................... 890 ft.
The work of Raymond (1906, p. 569-71) has shown that at Crown Point, N. Y., to the south, only division B of Brainerd and Seely’s classification is present and that the Chazy sea which invaded the Champlain valley from the north did not reach this point during Lower or Upper Chazy time. As all sections of the Chazy as exposed in the Willsboro area contain the gastropod *Maculurites magnus*, which is characteristic of this middle portion, it may be safely assumed that here also only division B is represented. Cushing (1905, p. 368-69) proposed the three substage names Day Point, Crown Point and Valcour for Brainerd and Seely’s groups A, B and C. Upon this basis the Chazy at Willsboro and Essex would belong to the Crown Point substage.

Van Ingen’s (1894, p. 232) faunal list for the Chazy as given in White’s paper is as follows:

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maclurea magna</td>
<td>Leseur</td>
</tr>
<tr>
<td>Orthoceras sp.</td>
<td></td>
</tr>
<tr>
<td>? Monticulipora lycopodites</td>
<td>Vanuxem</td>
</tr>
<tr>
<td>Orthis borealis</td>
<td>Billings</td>
</tr>
<tr>
<td>Orthis imperator</td>
<td>Billings</td>
</tr>
<tr>
<td>? Orthis costalis</td>
<td>Hall</td>
</tr>
<tr>
<td>? Orthis perveta</td>
<td>Conrad</td>
</tr>
<tr>
<td>Orthis platys</td>
<td>Billings</td>
</tr>
<tr>
<td>Strophomena incrassata</td>
<td>Hall</td>
</tr>
<tr>
<td>Strophomena alternata</td>
<td>Conrad</td>
</tr>
<tr>
<td>Solenopora compacta</td>
<td>Billings</td>
</tr>
<tr>
<td>Stenopora fibrosa</td>
<td>Goldfuss</td>
</tr>
<tr>
<td>? Ophileta complanata</td>
<td>Vanuxem</td>
</tr>
<tr>
<td>Lithites sp.</td>
<td></td>
</tr>
<tr>
<td>Bolboporites americanus</td>
<td>Billings</td>
</tr>
<tr>
<td>Camerella varians</td>
<td>Billings</td>
</tr>
<tr>
<td>Camerella sp.</td>
<td></td>
</tr>
<tr>
<td>Asaphus sp.?</td>
<td>fragments</td>
</tr>
<tr>
<td>Trilobite fragments</td>
<td></td>
</tr>
<tr>
<td>Zaphrentis</td>
<td></td>
</tr>
<tr>
<td>Encrinal columns</td>
<td></td>
</tr>
<tr>
<td>Globular masses containing as nuclei</td>
<td></td>
</tr>
<tr>
<td>minute lamellar foraminiferal skeletons</td>
<td></td>
</tr>
</tbody>
</table>

The forms collected during this work were:

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maclurites magnus</td>
<td>Leseur</td>
</tr>
<tr>
<td>Maclurites magnus Opercula</td>
<td></td>
</tr>
<tr>
<td>Lophospira rectisiriata</td>
<td>Raymond</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stromatocerium sp.</td>
</tr>
<tr>
<td></td>
<td>Brachiopod fragments</td>
</tr>
</tbody>
</table>

**TRENTON GROUP**

The two upper formations of the Paleozoic sequence in the Willsboro quadrangle, the Glens Falls limestone and the Canajoharie shale, are members of the Trenton group. The history of the Trenton group is long and complicated and as it has been admirably treated in a recent paper by G. M. Kay (1937) only a brief discussion will be included in this report.

**Glens Falls**

The oldest member of the Trenton group represented in the region under discussion is the Shoreham member of the Glens Falls limestone of middle Trenton age which is equivalent to the basal portion of the Sherman Fall in the standard section of the Trenton group. This limestone occurring in beds up to 10 inches in thickness of dark blue to black fine-grained limestone, which
weathers gray to blue-gray, carries Cryptolithus tesselatus and Prasopora orientalis which are excellent guide fossils (figure 12).

Van Ingen (1894, p. 232-33) lists a considerable fauna from the Trenton as follows:

- *Bellerophon bilobatus*, Sowerby
- *Trinucleus concentricus*, Eaton
- *Asaphus gigas*, DeKay
- *Calyxmenia senaria*, Conrad
- *Ceramus pleuroxanthemus*, Green
- *Dalmanites calicophalus*, Hall
- *Ambonychia bellistriata*, Hall
- *Tellinonyxa dubia*, Hall
- *Strophomena alternata*, Conrad
- *Strophomena deltoidea*, Conrad
- *Spathorhynchus planumbonum*, Hall
- *Orthis pectinella*, Emmons
- *Orthis borealis*, Billings
- *Orthis testudinaria*, Dalman
- *Platystrophia biforata*, Schlotheim
- *Leptaena sericea*, Sowerby
- *Leptaena sericea*, large, finely striate, ventricose form
- *Lingula quadrata*, Eichwald
- *Lingula curta*, Conrad
- *Lingula sp.?*
- *Trematis terminalis*, Emmons
- *Monticulifera lycopodites*, Vanuxem
- *Monticulifera branching species*, delicate
- *Ptilodictya* sp. undet
- *Stenopora fibrosa*, Goldfuss
- *Orthoceras*, sp. undet
- *Endoceras proteiforme*, Hall
- *Graptolite*, gen. and sp. undet
- *Lamellibranch*, fragment
- *Encrinal columns*
- *Nucula levata*, Hall
- *Subretopora (intricaria) reticulata*, Hall
- *Alga*

The fauna collected in 1938 is as follows:

- *Cryptolithus tesselatus* Green
- *Calymene senaria* Conrad
- *Asaphid fragments*
- *Diplograptus amplexicaulis* (Hall)
- *Lingula cf. curta* Conrad
- *Sowerbyella sericeus* (Sowerby)
- *Dalmanella sp.*
- *Nucula levata* Hall
- *Ambonychia orbicularis* (Emmons)
- *Sinuites cancellatus* (Hall)
- *Pleurotomaria* sp.
- *Orthoceras* sp.
- *Prasopora orientalis* Ulrich
- *Unidentified Bryozoa*

Canajoharie

The Canajoharie shales which overlie the Glens Falls limestone have very much the same lithology as the Glens Falls except that the beds become thinner and the rock becomes more argillaceous or shaly. In some parts of the area a well-developed slaty cleavage has been produced which gives a distinctive character to the rock (figure 13) but as this is not uniformly so throughout the region it cannot be relied upon exclusively and fossils must be considered. The Glens Falls always carries Cryptolithus and Prasopora. The Canajoharie does not have them but does have the characteristic trilobite *Triarthrus becki* by which it may be recognized. According to Kay (1937, p. 271) *Triarthrus becki* is confined to the upper or Fairfield member of the Canajoharie.

Graptolites which were collected from the shore section of the Canajoharie just north of Cannon Point were sent to Ruedemann for identification. He writes¹ that they are *Climacograptus spinifer*

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¹ Ruedemann, R. Letter of November 15, 1938.
but that they are "somewhat different from the typical expression of the species in having larger and broader terminal spines, the same as in the *C. bicorns* of the Normanskill, while in general habitus it is more like *C. typicalis* and *C. spinifer." He continues, "This seems to indicate to me that the Cannon Point spécimens are on the transition line from *C. bicorns* to *C. spinifer* and that the horizon may be far down in the Canajoharie shale."

*Triarthrus beckii* was collected from this same locality and Kay, as mentioned above, places this trilobite in the upper Canajoharie. It therefore seems as if there were some doubt as to the exact horizon within the Canajoharie that is represented.

The fauna listed by Van Ingen (1894, p. 233) was limited to two forms, *Triarthrus beckii* Green and undetermined Graptolites.

A faunal list given by Ruedemann (1921, p. 112) for the Canajoharie exposure on Willsboro point is as follows:

<table>
<thead>
<tr>
<th>Mesograptus mohawkensis Ruedemann</th>
<th>Triarthrus beckii Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leptobolus insignis Hall</td>
<td>Primitiella unicornis (Ulrich)</td>
</tr>
<tr>
<td>Dalmanella rogata Sardeson</td>
<td>Aparchites minutissimus (Hall)</td>
</tr>
<tr>
<td>Liospira sp.</td>
<td></td>
</tr>
</tbody>
</table>

The 1938 collection yielded the following fauna:

<table>
<thead>
<tr>
<th>Triarthrus beckii Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lingula cf. curta Conrad</td>
</tr>
<tr>
<td>Diplograptus amplexicaulis (Hall)</td>
</tr>
<tr>
<td>Climacograptus spinifer Ruedemann</td>
</tr>
</tbody>
</table>

POST-CANAJOHARIE IGNEOUS ROCKS

The Post-Canajoharie igneous rocks of the Lake Champlain region have been described in some detail by Kemp and Marsters (1893) and by Hudson and Cushing (1931, p. 81-113). Those of the Willsboro area, insofar as observed, comprise two groups: light colored aphanitic to porphyritic aphanitic varieties including trachyte (bostonite), rhyolite and keratophyre; and dark gray lamprophyric types including camptonite, augite camptonite or fourchite, and diabasic facies.

Trachyte Porphyry (Bostonite)

The most common of the felsic varieties of the igneous rocks is trachyte porphyry (bostonite). According to Kemp and Marsters, dikes of trachyte porphyry are found at Split Rock point, on the shore about a mile and a half north of Essex, on the banks of a stream just east of the highway bridge about two and one-fourth miles north of Essex, and in the quarries at Willsboro point. Small laccolitelike sheets of trachyte porphyry, inserted more or less conformably with the bedding, are found in the vicinity of Cannons point and one mile southwest of Essex.
These trachytic rocks were originally described by Kemp and Marsters (1893, p. 18) as bostonite, based on their mode of occurrence in part as dikes, their trachytic texture and leucocratic character. In thin section they show the presence of some interstitial quartz, and Johannsen (1937, Vol. III, p. 26) has grouped them as quartz-bostonites.

The compound porphyry sheet with interlayers of slate near Cannons point outcrops along the shore for a distance of about three-quarters of a mile and extends for about half a mile to the west beneath the grounds occupied by the Crater Club. The rock in general is a reddish brown (deep brownish vinaceous) color with a felsitic groundmass containing a few pink feldspar phenocrysts 2–5 mm in length. The phenocrysts are arranged in a rude flow structure parallel to the bedding of the inclosing slates. On the shore the mass is seen to have essentially conformable relations with the bedding of the slates, though locally containing thin included layers of the slate, and thickening and thinning by crosscutting the bedding of the slates for short distances. The rock weathers with a rough platy structure or fissility which is also parallel to the bedding and flow structure. The sheet strikes about N. 60° W. and dips gently north. The rock at the contact with the slate has, for a few inches, a very dense nonporphyritic texture. The lowest part of the mass, about two-fifths of a mile south of Cannons point, contains many rounded inclusions of Potsdam sandstone and a subordinate number of Paleozoic limestone fragments, as may be seen in many of the porphyry blocks lying on the shore. The western end of the porphyry mass is masked by drift, but the absence of float suggests that it pinches out rather sharply in the first valley to the west or is cut off by faulting.

The uppermost sheet, about 0.3 mile north of Cannons point, is about five feet thick (figure 19). It is a pale buff color with an almost dense texture and sparse, small phenocrysts.

In thin section the normal rock is seen to consist of small idiomorphic feldspar laths with a crude flow structure. The feldspars of both the phenocrysts and the groundmass are practically all a potash variety. Plagioclase phenocrysts are rare. Kemp and Marsters have shown that the feldspars must be largely anorthoclase, as indicated by the chemical composition of similar rock from the Vermont side. There is probably slightly less than 10 per cent of quartz, which is interstitial to the groundmass feldspars, and which in small part is in micrographic intergrowth with the feldspar. There are sparse minute zircons and a sprinkling of magnetite grains, but no
other primary mafic minerals to be found. There are locally a few disseminated grains of pyrite and numerous microscopic limonite spots throughout. In some of the trachyte, apatite crystals are common as an accessory mineral.

**Rhyolite Porphyry**

On the south side of Whallon bay, about half a mile southeast of the road junction, a reddish brown porphyry is exposed along the shore for about 50 yards (figure 21). It has a flat-lying, barely distinct, banded structure, and a platy fissility on weathering which indicates that it is a sheet conformable with the bedding of the limestone. The rock, on examination in the hand specimen, appears in no way different from the trachyte porphyry of the Crater Club mass. Locally it also contains rounded inclusions of Potsdam sandstone. In this section it is found to contain a few microphenocrysts of quartz 0.3 to 0.5 mm in diameter. The crystals show borders partly corroded, partly crystal facies, and partly intergrowth with the groundmass. The groundmass consists of a very fine micrographic intergrowth of potassic feldspar and quartz with a little interstitial quartz. The feldspar phenocrysts are idiomorphic and almost wholly potassic feldspar.

**Keratophyre**

About a mile southwest of Willsboro there is a pale buff aphanitic dike of keratophyre which strikes west-northwest and cuts both the Precambrian Whiteface anorthositic rocks and the Beekmantown limestone, which are in contact with each other along a great fault at this place.

In thin section the rock is found to consist of plagioclase laths with trachytic texture, with about the same amount of interstitial quartz as in the trachytes and with rare plagioclase phenocrysts. There are also rare amphibole phenocrysts now replaced by iron oxides and numerous microplates of sericite (altered biotite?) in the groundmass. Apatite crystals are common as an accessory mineral. The rock is weathered and there are some calcite and considerable limonite.

**Camptonite**

About two-fifths of a mile southwest of the highway crossing of the river at Bouquet, west of the road there is a narrow dike of dark gray aphanitic lamprophyre in the border facies anorthosite. In thin section the rock is found to consist of idiomorphic feldspar
Figure 19  Five-foot sill of trachyte porphyry (bostonite) on north shore of Cannon point underlain by Canajoharie shale.

Figure 20  Two and one-half-foot camptonite dike cutting Chazy limestone in Gardiner's Quarry, Essex.
Figure 21  Sill of rhyolite porphyry at south end of Whallon bay.

Figure 22  Augite-camptonite dike with oriented fragments of Precambrian anorthositic rock on south headland of Indian bay, Willsboro point. Country is Canajoharie shale.
laths and long columnar hornblendes with interstitial miarolitic fillings of calcite and chlorite. The feldspar is predominantly plagioclase but subordinately a potassic feldspar. The latter occurs as rims around the plagioclase and as separate individuals. The hornblende is strongly pleochroic from deep brown to a pale yellowish green, with an extinction angle of about 15°, and is probably allied to barkevikite. Magnetite is common as minute crystals throughout the rock, and there are occasional apatites. The plagioclase is full of crystal needles and is partly altered. Euhedral crystals of potash feldspar project into a few of the miarolite aggregates. There are a few minute augite crystals, and a number of serpentine aggregates probably secondary after olivine crystals. In finer-grained bands the hornblende occurs both as microphenocrysts and as microlites in the groundmass. The rock is a camptonite.

Kemp and Marsters (1893, p. 44) refer dikes north of the fault south of Essex and in the limestone quarries southwest of Essex to camptonite (figure 20). A three-foot dike of camptonite is also present between Essex and Willsboro about two miles north of Essex. In this dike the microphenocrysts are largely of augite, whereas the groundmass consists predominantly of brown hornblende needles and plagioclase. Another camptonite dike occurs at Willsboro. It differs from the normal camptonite in being of a light color with conspicuous phenocrysts of brown hornblende and augite in the core of the dike. The groundmass in thin section shows a large amount of carbonate and carbonate alteration.

**Augite-Camptonite**

A remarkable dike is excellently exposed on the south headland of Indian Bay (figure 22). The dike consists in the central part of gray aphanitic groundmass with a multitude of rock fragments of various compositions, and finer-grained aphanitic dike borders an inch to two feet wide, quite free of fragments. The breccia portion of the dike is three to six feet wide. The dike strikes N. 8° E. and dips 61° SW. The breccia fragments are predominantly plates of Whiteface gabbroic anorthosite gneiss dimensionally oriented parallel to the strike and dip of the dike, but with their foliation oriented at random. The next most abundant fragments are pink syenite and gray gabbro. These are about equidimensional and the gabbro fragments are subrounded. The anorthositic fragments are two inches to a foot in larger diameter and one to two inches in width, with rare blocks up to two feet in diameter.
The camptonite of the border facies consists of augite and sparse olivine as idiomorphic phenocrysts in a fine-grained groundmass consisting of a felt of plagioclase, intergranular augite, and idiomorphic biotite with some interstitial alkali feldspar and much carbonate. The alkali feldspar also forms borders to the plagioclase, and terminated crystals projecting into the calcite fillings. Magnetite is a common accessory. The augite is partly altered to chlorite and the feldspar is flecked with sericite. To a slight degree the augite is altered to biotite. The rock is similar to that described as augite camptonite by Cushing (Hudson and Cushing, 1931, p. 101).

The gabbro fragments have a fine-grained (0.5 mm–0.8 mm) granular subdoleritic (Krokström, 1933) texture. They consist of plagioclase, augite and enstatite. There are peculiar strings of enstatite surrounding some of the plagioclase. There are abundant small (0.5 mm–0.8 mm) spheroids of brown to black material of unknown nature.

The syenite fragments are a fine-grained (1 mm) rock composed of potash feldspar and plagioclase with an orthophyric texture. Magnetite, zircon and apatite are present in slight amount. No other mafic material than the magnetite was noted.

The Whiteface gabbroic anorthosite fragments are similar in every way to the rocks exposed in the Precambrian area to the west. They must have been brought up for 4000 feet or so corresponding to the estimated thickness of the Paleozoic sedimentary strata below the horizon in which they now occur. The gabbro and syenite are what might reasonably be expected from the crystallization of small hypabyssal bodies of magma comparable to that which formed the camptonite and trachyte porphyry respectively of the post-Canajoharie intrusives. The magma to form the dike must have come up along a shattered zone which traversed the old basement anorthosite and slightly earlier consolidated masses of syenite and gabbro belonging to the same epoch as the camptonite itself. Similar breccia dikes have been described from the area to the north (Hudson and Cushing, 1931, p. 108).

**Biotitic-Augite Camptonite or Diabase**

On the right bank of the north branch of the Bouquet river by the westernmost outcrops of the Beekmantown limestone there is a ten-foot dike of a fine-grained mafic rock. In thin section it is found to consist of a felt of plagioclase with alkali feldspar as borders or interstitial fillings, idiomorphic biotite with subordinate granular augite and brown hornblende as the predominant mafic minerals,
and accessory disseminated minute iron oxides, and apatite needles. There is much carbonate and subordinate chlorite filling triangular spaces between the feldspars. The major minerals all belong to the same generation, though the rock appears to be related to biotite-augite camptonite of the lamprophyre group.

Age of the Intrusions

The age of the intrusions which cut the Paleozoic rocks is a question that has never been satisfactorily settled. That they must be younger than the Canajoharie, as they intrude these rocks, has long been known, but there has been considerable difference of opinion as to how much younger they are. Kemp and Marsters (1893, p. 36–37) were of the opinion that the dikes were formed at the end of the Ordovician, saying:

It will at once occur to one familiar with the Green Mountains that they were elevated at the close of the Lower Silurian (Ordovician) and were formed in one of the great upheavals of New England. We think it probable that the intrusion of the dikes was occasioned by this great disturbance. Outpourings or intrusions of igneous rock almost always attend mountain-making action, and it is reasonable to suppose that the Green mountains have been no exception. Aside from this line of inference we have no direct evidence of the age of the dikes except that they followed the Utica slate or shale, for this is the latest formation pierced by them.

In the tabular statement of them it will be seen at once that they are almost all vertical where found in the sedimentary rocks. Dikes which have suffered no subsequent movements would naturally take this course in coming to the surface. It is reasonable to conclude that the uniform verticality indicates that the wall rocks have not been much, if at all, disturbed since their intrusion, or else that they and their walls have moved en masse over a great territorial extent.

White in 1894 (p. 229) simply states that they are younger than the Utica (Canajoharie). In 1905 Cushing (p. 287, 397) suggested a Carboniferous age for the dikes. In 1931 Hudson and Cushing said (p. 96–97):

We will hold, subject to revision, that of the Post-Cambrian dikes the monchiquites and bostonites are the earlier and were injected some 200 million years ago or during the development of the Taconic mountains. The camptonites and fourchites we shall, for the present, refer to a date as late as 150 million years ago. That the camptonites fall into a class by themselves is indicated by the large territory they occupy, their small number in any limited area in this territory, their great variation in strike, their penetration of the margin of the Pre cambrics, and their practical freedom from crushed and ground inclusions of older rocks.
As a result of the field work done in the summer of 1938 certain conclusions may be drawn.

One mile southwest of Essex village there is a sill of bostonite in the Chazy limestone. The outcrop of this sill may be followed south-eastward from the road for a distance of some two thousand yards to the line of the fault C-C beyond which point no trace of the bostonite could be found. This would indicate that the sill was intruded before the faulting took place.

An additional bit of information is given by Hudson and Cushing (1931, p. 99), who state, "The fact that certain faults cut the dikes show that in these instances the dike invasion preceded the faulting . . ."

As has been previously shown, Hudson and Cushing believed that there were at least two periods of dike invasion. In the recent study nothing was found to contradict this conclusion and at one place evidence was found that would substantiate it. Along fault H-H a few hundred feet north of its intersection with fault A-A, a ten-foot dike of keratophyre was found cutting directly across the fault and the dike could be followed into the anorthosite to the west and eastward across the Willsboro-Reber road in the Beekmantown. This would indicate that this intrusion took place after the faulting.

The other dikes of the region were so located that they gave no information of their age as compared to the folding or faulting.

**STRUCTURE**

The Willsboro quadrangle lies about midway on the west shore of Lake Champlain and the Paleozoic rocks of the region are the largest and most northerly of several isolated local patches between the lake and the Precambrians of the Adirondacks. From Port Kent, a few miles north of the area, to the Canadian line there is a continuous belt of Paleozoics of increasing width which lie between the lake and the Precambrian. From Port Kent southward the Precambrian makes up the west shore of the lake except for the isolated areas of Paleozoics as at Port Douglas, Willsboro-Essex, Westport, Port Henry, Crown Point, Ticonderoga and some patches along South bay.

These local areas of Paleozoic rocks represent fragmental remnants of a once continuous belt which overlapped the edges of the Precambrian and which is now more fully represented by the rocks of the Vermont shore of the lake.

In studying the structure of the Willsboro quadrangle it must be remembered that it is only a small portion of a much larger area and that at some future date when the structure of all of the Paleozoic
rocks of the Champlain valley have been worked out in detail the interpretation of the structure of the Willsboro quadrangle, here presented, may have to be modified to fit into the general scheme. Considerable work has been done on the faults of the Champlain valley and some work has been done dealing with the folds and other structural problems, but there is still a lot of detailed work that will have to be completed before the entire picture can be painted.

In discussing the faults of this limited area, particular care has been exercised in order not to do violence to any general principle that applies to the Champlain valley as a whole. The discussion on folds is, however, a more local problem and not so dependent upon other areas. It is possible that some of the ideas brought out by the discussion of the folding in this area may eventually be tied in to the north or south or across the lake in Vermont.

**Folds**

The Paleozoic rocks that lie within the boundaries of Essex and Willsboro townships must have originally been deposited as nearly horizontal beds in the "Chazy basin" or trough during part of the Cambrian and Ordovician periods. At some time after the deposition of the youngest rocks, Canajoharie, the horizontally bedded sediments were subjected to pressure coming from a little south of east. As a result of this pressure the strata were folded into an anticline or upward fold on the west and a syncline or down warp to the east with the axes of the folds trending approximately N. 25° E. and plunging to the north.

This folding of the rocks is believed to be the first evidence of the application of pressure from the southeast and to have preceded the development of the normal faults.

The structure of the plunging anticline is well shown by the outcrops on Willsboro point. The northern end of the point is made up of Canajoharie shales with strikes ranging from N. 72° E. to N. 62° E. and with dips of 10° or less to the northwest. On the Four Brothers islands the strike is N. 83° W. with a 15° dip to the northeast. South of the Canajoharie shale belt is a zone which supposedly represents the area of Glens Falls limestone although no exposures were found due to the glacial cover and the character of the shore line. The Chazy limestone is well shown in numerous quarries and in shore exposures at the base of Willsboro point and at the head of Willsboro bay. On the southeastern shore of Willsboro bay there are good outcrops along the lake with many specimens of the characteristic fossil *Maclurites magnus*. A quarter of a mile
south of the head of the bay, on the east side of the main stream entering from the south, is an old abandoned quarry in the *Mac-
 lurites* beds of the Chazy where the strike is N. 37° E. and the dip 8° to the northwest. At the Rowley (old Frisbie) quarry on the west shore of Willsboro point and along the shore for one-half mile south, Chazy is exposed almost continuously with the strike varying between N. 32° E. and N. 17° E. On the east shore at Ligonier point (old spelling Lagoneer) there are the most extensive quarries in the whole region with the strike approximately N. 75° E. At the southeast corner of Buena Vista, a summer colony on Willsboro point, or the northern point making Rowley bay, one mile south of Ligonier point, the Chazy is again exposed with a strike of N. 57° E. and a dip of 8° to the northwest. These various Chazy exposures with their varying strikes represent the western limb of the plunging anticline. South of Rowley bay the Beekmantown limestone is found along the shore dipping under the Chazy and these beds are the oldest ones shown in this part of the anticline.

The slaty cleavage developed in the Canajoharie beds at the north end of Willsboro point strikes approximately N. 25° E. Slaty cleavage is developed parallel to the axis of the fold; therefore the axis of this plunging anticline should trend about 25 degrees East of north.

In Essex township there is evidence that points to the presence of a plunging syncline. The youngest sedimentary rocks, the Canajoharie, are present along the shore between Whallon bay and the southern limits of the village of Essex. Actual measurement of dip and strike at frequent intervals along the shore will show the presence of minor folds and wrinkles, but the prevailing or average strike is around N. 75° W. dipping some 5° to the northeast. On the north shore of Split Rock point the Glens Falls limestone is present (figure 23). Throughout the length of the exposure the beds are contorted and offset by a series of step faults so that actual readings of dip and strike hold good for only a few feet. The general aspect of the outcrop would give a strike of somewhere near N. 50° E. and a dip of about 25° to the northwest.

At Whallonsburg, by the old mill dam, the Beekmantown limestone in the bed of the Bouquet river strikes N. 25° W. dipping some 6° to the northeast.

In the southern part of the village of Essex and to the southwest for about one mile numerous Chazy outcrops are to be found in quarries and throughout the woods and fields. This area is separated from the three previously mentioned by a fault but seems to
fit into the picture helping to prove the existence of the plunging syncline. The strike of the Chazy is not constant throughout the area and no generalized strike can be given due to the low angle of dip.

At Bouquet, by the old mill dam, the Potsdam sandstone is visible for several hundred yards along the river. Here the Potsdam strikes N. 7° E. and dips to the southeast in varying amounts, depending upon the nearness of the exposure to the Potsdam-Precambrian fault.

Considering the five areas discussed and remembering that the Chazy and Potsdam outcrops are on a different fault block than the first three outcrops, the synclinal structure becomes more apparent.

The area in the southeastern corner of Willsboro township is not so easily fitted into the folded structure, as faulting has complicated the situation, but when the faulting is considered the beds will fall into the right position to agree with the folds as mentioned. In the rest of the area mapped the distribution of the various rock types and the attitude of the beds fall into this general anticlinal, synclinal structure so that there seems to be ample justification for assuming that this folding represents the preliminary stage in the structural deformation of the region.

Faults

Much work has been done on the faults of the Paleozoic sediments of the Champlain valley. Cushing (1895) has shown that in Chazy township there is a network of faults which he grouped together into three classes based upon his idea of their importance. It is to be noted that they fall into three other groups if classified upon their direction, namely, north-south, northeast-southwest and northwest-southeast. In concluding he states (Cushing, 1895, p. 296):

It has just been shown that a large proportion of the contacts between rocks of different age in Chazy township are fault-contacts, and the same may be shown with equal readiness in most other townships on either side of Lake Champlain. It is believed that this will be found to be true also in the Adirondacks themselves, but their discrimination from ordinary deposition-contacts will be extremely difficult. As an illustration: Wherever in Clinton County the writer has found demonstrable deposition-contacts between the Potsdam and the older rocks a basal conglomerate or an arkose or both are shown. Where these are absent the relations are often such as to strongly suggest contact by faulting. At other times no indications whatever of the character of the contact are
afforded. That the crystalline rocks of the Adirondacks are also faulted can be shown by means of the numerous dikes and of the beds of iron ore. The topography is often such as to strongly suggest faulting. Certainly the possible presence of faults must be constantly kept in mind when endeavoring to interpret the stratigraphy of that region, and the main purpose of this paper is to emphasize this fact, in view of the work now being prosecuted there.

The value of these statements is immediately evident to anyone working in this area.

Hudson (1931) in a paper entitled The Fault Systems of the Northern Champlain Valley, New York, carried the study of the faults into a larger area, to wit, that of the Plattsburg and Rouses Point sheets of the United States Geological Survey, and by so doing developed some very important hypotheses. Hudson showed that there was a series of roughly parallel meridional faults often accompanied by parallel minor step faults with the downthrow side predominantly on the east. These meridional faults or fault zones, which constitute his first system, have been lines of weakness and have delimited the shores of many of the islands, headlands and bays of the lake.

Of his second system of east-northeast faults he says (Hudson, 1931, p. 22):

This system appears to have had its origin at a date later than that of the meridional system. Its faults do not attain such length, parallelism, uniformity of spacing, regularity in direction of downthrow, or on the whole so great a displacement as those of the older system. Their effect on topography is much less pronounced and glacial erosion and deposit, because of their direction across the glacial path, has served only still further to obscure the evidences of their presence.

The northeast and southwest auxiliary faults make up Hudson's third system which are well represented on Valcour island.

Quinn (1933) has taken a still larger area than Hudson and has published a significant paper on the faults of the whole Champlain valley. He not only studied the Paleozoic areas but on the basis of previously published work carried his faults over into the Precambrian rocks of the Adirondacks. He shows two main systems of faults, one north-south, another northeast-southwest, with less important groups trending northwest-southeast and east-west. There were a few faults which would not fall into any of these classifications.

Whereas Hudson believed that his system of east-northeast faults was developed after his meridional system, Quinn is of the opinion
that the point is not proved. To quote from his paper (Quinn, 1933, p. 120–122):

The question arises as to whether these sets of faults represent different episodes of faulting. If they do, there is some reason for thinking that the north-south set was formed first. A glance at Figure 5¹ will show that several of the north-south faults appear to be cut off by those of the northeast-southwest system. This can be seen especially well along the boundary of the Adirondack Precambrian rocks southwest of Willsboro. At no place, however, is a fault of one system seen to be actually offset by one of another system, and the relations are not considered to be definite enough to prove that one system of faults is older than another. On the contrary, there is a situation which suggests that the different systems were developed at the same time. In this case a fault of one system intersects one of another without there being a continuation of either beyond the point of intersection (see the Precambrian boundary north of Ticonderoga and Figure 6). The relations at the points indicated show that the mass outlined by the faults moved as a unit. In Figure 6 it is plain that faults with north-south, northeast-southwest, east-west, and northwest-southeast strikes moved simultaneously.

He goes on to conclude that the evidence is in favor of the idea that the faulting along the various systems was contemporaneous and not in series, one set after another.

Balk (1931, p. 421) in his Structural Geology of the Adirondack Anorthosite, says:

Faulting in the northeasterly direction must have continued until after the Ordovician, as appears from the fact that along the eastern border of the anorthosite both the Cambrian Potsdam sandstone and the Ordovician limestones are faulted along these fractures. In the western embankment of the Bouquet River, north of the main highway to Essex Station (Willsboro quadr.), massive anorthosite is in visible contact with Potsdam sandstone. The fault strikes N. 48° E., dipping at 70° to the southeast.—One mile and a half west-southwest of Willsboro, Ordovician limestone and foliated anorthosite approach each other up to 60 feet on the east side of the low elevation 400. The fault is not exposed but seems to run north-south and is probably identical with the main fault which cuts off the Precambrian rocks of the Adirondacks against the Paleozoic strata of the Champlain Valley. South of this hill, however, there must be another fault in northeast-southwest, and additional faults in the same direction can be inferred from the wedge-shaped patches of Paleozoic sediments shown on the geologic map of the State and from the striking topography between East Bouquet Mountain (Willsboro quadr.) and Split Rock Mountain (Port Henry quadr.).

¹ All references to figures are to those in Quinn’s paper.
Rodgers (1937, p. 1583) in a study of the south end of Lake Champlain groups his high angle faults into four sets, as follows:

Longitudinal faults: Strikes ranging from N-S to N 40° E, averaging N 10° E.
Transverse faults: Strikes ranging from N 85° W to N 75° E, averaging N 80° E.
Northwest minor faults: Strikes approximately N 45° W.
Northeast minor faults: Strikes approximately N'45° E.

It will be seen from the work of these five geologists that there is a definite system to the faults of the Champlain valley from its northern to southern end. The work of Balk and others (See Quinn's footnote 14) carried the faults into the Precambrian mass of the Adirondacks and showed that the fault system does not stop at the Paleozoic-Precambrian border.

The faults of the Willsboro quadrangle seem to fit into this well-established pattern. It must be pointed out, however, that the placing of inferred fault lines has at times been influenced by the work of the former authors. As actual fault contacts are rarely seen in the area it has been necessary to utilize topographic breaks, changes in the attitude of the beds in adjacent outcrops, and the stratigraphic sequence in drawing the faults. The faults as drawn fall into two categories, one where evidence is sufficiently strong to assure the presence of the fault (drawn in solid lines) and the other where the fault is placed by inference with less evidence and consequent doubt as to the absolute validity of the line (drawn in broken lines).

In discussing the faults each one will be taken up separately with a statement of the evidence upon which it is based.

A-A The first two and a half miles on the southwestern end of the fault are based upon the abrupt change in strike of the foliation and the offsetting of Precambrian structures, as shown by the work of Buddington. The next three miles are drawn on the grounds of the topographic break and on the contact of the glacial and plain with the first Precambrian exposures. In the village of Willsboro the Beekmantown limestone exposed in the river upstream from the bridge and along the main street strikes approximately north-south. At the dam and below, the Beekmantown strikes N. 70° E. to N. 75° E. As this noticeable change in strike falls on the trace of the southwestern end of the fault it seems certain that the fault is extended through Willsboro to the bay north of Jones point.

B-B Three-quarters of a mile south of Jones point along the shore a fault is visible between the Potsdam and the Beekmantown. The beds of Potsdam to the north are deflected downward and the Beek-
Figure 23 Glens Falls limestone on north side of Split Rock point near major fault, showing local contortion and faulting of the strata.
mantown beds are turned up, showing that the southern side was the downthrow side. The strike of the fault was measured as N. 52° E. The trace of the fault can be followed inland along a depression to the road and by the proximity of Potsdam and Beekmantown ledges. Just west of the Delaware and Hudson Railroad track the northern end of a north-south Beekmantown ridge stands above the surrounding glacial sand plane as a pronounced topographic feature and it is suggestive of a fault. West of the Bouquet river the fault is drawn along the topographic break between the Precambrian and the sand plain toward the intersection with fault P-P. From this point to the western edge of the map the fault may or may not be present.

C-C On the shore at the south edge of the village of Essex a fault is visible between the Chazy limestone and Canajoharie shale (figure 24). This fault was mentioned and illustrated by Emmons (1842, p. 273–75, fig. 69) and has been referred to by other authors (Kemp & Marsters, 1893, p. 44; White, 1894, p. 224; Quinn, 1933, p. 123). The upturned ends of the beds of Canajoharie shale on the downthrow side is noticeable and there is considerable crushed material along the fault plane which strikes N. 44° E. This fault can be traced inland to the southwest for over a mile by the abundance of Chazy outcrops to the north and absence of outcrops of any type to the south. About a mile from the shore the fault cuts off a sill which can be traced for about 2000 yards to the northwest, but which shows no continuation south of the line of the fault. For the next two and a half miles there is no evidence of the fault, but after crossing the Bouquet river north of Whallonsburg the topographic break between known Precambrian and the sand plain falls along the extension of this line for the last mile.

D-D On the north side of Split Rock point the Glens Falls limestone is in fault contact with the Precambrian (figure 25). Along the fault, which strikes N. 60° E., there is considerable gouge and the beds of the Glens Falls have been contorted and shattered. This fault can be traced for a mile and a half along this line of strike to the southwest on the basis of Precambrian outcrops on one side and none on the other and on the topography. A mile and a half from the shore the fault by the same criteria turns more to the south and continues to the edge of the map.

There is a possibility that this fault does not really turn to the south but rather that it is continuous to the southwest intersecting with the continuation of fault E-E on the north side of Coon mountain in Westport township (Port Henry quadrangle), that the east
side of Coon mountain is a north-south fault that would line up with fault R-R and that the southern end of fault D-D is really another northeast-southwest fault roughly parallel with fault C-C. If this is the case, the area between Coon mountain and Split Rock mountain mapped as anorthosite by Kemp and Ruedemann (1910) in the Geology of the Elizabethtown and Port Henry Quadrangles is not underlain by anorthosite but really by an area of Paleozoic rocks. As there is no evidence available of actual outcrops within this area, it is impossible to make a positive statement regarding the bedrock present.

Since this interpretation is based solely upon the study of maps having been made by Whitcomb after he left the field, and as it deals primarily with the Port Henry quadrangle, the fault D-D is drawn as turning to the south rather than as two intersecting faults.

E-E This fault starts at the southern edge of the map and runs a little east of north with Precambrian on the west and river deposits at a lower level on the east for the first half mile. In the next mile as it cuts across a Precambrian spur it is shown by structures in the rocks. From the point where it intersects fault S-S to near the intersection of G-G it is drawn on topography and the presence of Precambrian on one side and its absence on the other. An excellent spring, that has been used for seventy odd years without ever running dry,¹ located along the fault line on the first road north of S-S is a good indication of the trace of the fault. Just below the old mill on the left bank of the river at Bouquet the Potsdam and Precambrian are seen in contact along the fault.

Balk (1931, p. 421) and Quinn (1933, p. 123) both refer to this particular outcrop and it is significant as it is the only point on the western border of the Paleozoics where an actual fault contact can be seen (figure 26). From the river the fault is continued northward on less definite grounds. The long hill (320') on the east bank of the river at Bouquet is evidently held up by Potsdam sandstone which can be traced along its base for one-quarter mile downstream from the bridge, the fault is assumed to run along the northwestern edge of the hill and continue to the intersection of fault M-M in order to delimit the block L-L, M-M, N-N and E-E. From the intersection with M-M it presumably continues to fault K-K. A difference in strike of 20° between the Beekmantown on the two sides of this extension would be possible evidence of its existence.

¹ Personal communication, Dr J. M. Stafford.
Figure 24  Fault along lake at south end of village of Essex. Canajoharie on left, Chazy on right. Depression cut in shattered Canajoharie.

Figure 25  Fault on north shore of Split Rock point. Precambrian on left, Glens Falls in depression under overhanging bank. Hammer lies upon fault plane.
Figure 26. Looking downstream from old mill at Bouquet. First outcrop Precambrian along fault, second outcrop Potsdam in fault contact with Precambrian.

Figure 27. Looking south from Willsboro-Keeseville road along Precambrian-Paleozoic fault. Fields at low level on left on Paleozoic; bench at right on Precambrian.
At the south end of Willsboro bay, Glens Falls and Chazy limestones are adjacent to each other with marked differences in strike. Whereas the strike of the Glens Falls varies along the shore from N. 48° W. to N. 71° W., the Chazy varies between N. 3° W. to N. 8° W. and in an abandoned quarry up the stream the Chazy strikes N. 37° E. It therefore seems essential to place a fault along this contact and if it be assumed that the main stream entering from the south at the end of the bay lies along the fault zone it will be found that the northern extension of this line lies just west of the two promontories on the west shore of Willsboro point and delimits the east side of the down-dropped block that now forms Willsboro bay.

Fault G-G is one of the north-south faults separating the Precambrian and Paleozoic rocks and is drawn entirely on the basis of topography plus the easternmost exposures of Precambrian rocks. The river for some distance follows closely along the fault as drawn.

There is a new road, not shown on the map, running from the Willsboro railroad station to the regular Willsboro-Reber road which it joins near the intersection of A-A and H-H. Two hundred feet southwest of the intersection in the western drainage ditch there is a small exposure of fault breccia. In the fields to the north Precambrian and Beekmantown are exposed within 20 feet of each other. Three-quarters of a mile north of this point a quarry has been opened in the eastward dipping Beekmantown and other quarries west of the line are in Precambrian. Where the fault intersects K-K along the road from Willsboro to Keeseville a well-defined break in the topography is visible (figure 27).

On the southwest shore of Willsboro bay the Beekmantown dipping east with a strike of N. 11° E. is found close to the Precambrian and along the road to the south there is a definite bench on which the railroad runs. This fault looks like the continuation of H-H.

The Beekmantown-Glens Falls contact at the south end of Willsboro bay is not visible but as there is a marked discordance in strike, as in the case of the Glens Falls-Chazy boundary (fault F-F) a fault is needed. Running this fault parallel to I-I it falls along the topographic break between the known Precambrian and the supposed Paleozoics, which lie at a lower level, for the last half mile before intersecting K-K. It is this little offset of Precambrian on the north side of K-K that prevents one from connecting H-H with I-I. Beyond the intersection with fault K-K there is less evidence but it seems as if J-J continues to the intersection with A-A for the
Beekmantown adjacent to the Precambrian has a strike approaching north-south while to the east of the road intersection near the junction of J-J and A-A the Beekmantown strikes N. 83° W. This association of faults H-H and I-I with J-J would be a case of parallel faults producing a steplike break which is known to be common in the region.

K-K The fault from one mile west of Long pond to its intersection with the fault H-H is based upon Precambrian structures discovered by Buddington. The section between H-H and J-J is shown by the topographic break and the offset of the Precambrian-Paleozoic border at this place. Beyond the junction with F-F the fault accounts for the sudden change in the direction of the Bouquet river. Along the lake shore north of the mouth of the Bouquet river no outcrops are found until one goes out on the south side of the first point, where Beekmantown limestone appears; from there on outcrops are continuous up to the Potsdam-Beekmantown fault B-B. It is believed that this point is bounded on the south side by the fault.

L-L At Essex, in the bay between Begg point (old Nail Factory point) and Bluff point in the southern half of the village, the Glens Falls and Chazy have been reported to be in fault contact. At the present time no place was found where the beds were visibly adjacent but Emmons (1842, p. 273–74) described it as follows:

The immediate vicinity of Essex furnishes an instance in the arrangement of the rock, well calculated to deceive when only a cursory examination is made. Near the central part of the village, where the church stands, we find the trenton limestone very distinctly revealed, bearing its most common fossils, the Orthis testudinaria, Claymene senaria, and several others, in a shaly mass. Proceeding less than forty rods south, we pass on to this dark-colored limestone, elevated at least fifty feet above the trenton; which limestone being of a dark color, and resembling lithologically some varieties of the trenton, might thus be considered, only we frequently find in it the maclurea, which never appears in the trenton. On looking about, however, we shall find, that in going south from the church, we pass a slight depression; and upon a close examination, this will be found to mark the line of separation between the trenton and chazy limestone. This depression is directed towards the northwest, and may be traced some distance: on the right is the trenton, and upon the left the chazy. This depression extends down to the lake shore, and both masses being elevated somewhat above the water, the contact of the two rocks is seen, when it appears that the former rock has been elevated and pushed through the latter, which was without doubt borne upwards.

White in 1894 said (p. 225):

At the south end of Essex village, near an old limekiln, the Trenton is faulted against the Chazy. The exact fault is obscured by
drift, but the adjacent layers of shaly limestone are much crumbled and crumpled. The fault passes northwestward in all probability through the village, along the depression of the surface noted by Emmons.

The dips and strikes obtained along the shore from Bluff point to Begg point do not require a fault to explain the position of the beds but if one goes inland one finds that the measurements taken on near-by Glens Falls and Chazy outcrops are at variance with each other. In view of the evidence given by Emmons (1842) it becomes necessary to place a fault at this point; it is believed, however, that his northwest direction for the fault is not correct but that it should run due east and west. If the municipal water system discussed in another portion of this paper becomes a reality the excavation on the two north-south streets will probably clear up this point if somebody happens to see them at the right time. From the village of Essex to the Bouquet river there is no indication of the fault. On the east bank of the Bouquet about one-fourth of a mile downstream from the bridge several large boulders of Potsdam fault breccia were found. As all of the fragments were Potsdam recemented by silica and as it was found north of the junction of faults E-E and G-G it is not believed to belong to the Precambrian-Paleozoic fault but rather to this cross fault from Essex. This evidence may be rather inconclusive but as it was the only place that such breccia was found and as it fits into the picture of an east-west fault, it becomes more important. The northwest direction given by Emmons does not satisfy the known distribution of Chazy-Glens Falls outcrops.

M-M This east-west fault is based upon less conclusive evidence than most of the other faults. Going north along the shore from Essex the Glens Falls is exposed for a mile and a half after which Canajoharie outcrops are followed for slightly over a half mile to the mouth of a small brook which crosses the Willsboro-Essex shore road by a red brick schoolhouse. North of this creek there are no more outcrops along the shore, but inland the Beekmantown is found and it presumably extends to the shore. One-quarter of a mile west of the brick schoolhouse Chazy limestone outcrops in some old quarries, but on going north the Chazy stops and the next outcrops are Beekmantown. It therefore seems necessary to put in this east-west fault to connect with the northern extension of E-E.

N-N In the northern portion of the area between faults L-L, E-E and M-M there is a distribution of outcrops of various formations that necessitate fault N-N. West of the northern end of N-N the Beek-
mantown and Chazy are in normal sequence striking roughly N. 30° W. and dipping to the northeast. The Canajoharie along the shore and up the creek past the shore road is striking east of north. The exact dip and strike can not be obtained as there are many minor folds in the Canajoharie at this point, but the general strike would approximate N. 30° E. and the Canajoharie is underlain by Glens Falls with the same general dip and strike. This set of conditions require that fault N-N be inserted and it is drawn as a north-south fault to best conform to the situation.

\(O-O\) Fault \(O-O\) is necessitated in order to terminate the block of Beekmantown that lies between faults \(I-I\) and \(J-J\).

\(P-P\) This fault, which is needed to complete the boundaries of the down-dropped block or graben between faults \(A-A\) and \(B-B\), is drawn as a north-south fault following the general principle that the westernmost faults are in general north-south. As the area is covered by sand plain deposits it could lie in some other direction. Balk (1931, pl. xi) has drawn this fault as north-south.

\(R-R\) The Precambrian northwest of Whallonsburg is, on the basis of topography and the distribution of Precambrian outcrops, bounded on the east by a fault that runs a little east of north.

\(S-S\) This is another fault like \(R-R\) drawn on topography and distribution of Precambrian outcrops.

\(T-T\) Along the railroad north of Port Douglas by the milepost, “Rouses Point 40 miles, Albany 151 miles,” there is an interesting exposure. On the northwest side of the track is the Precambrian anorthosite and on the other side 15 feet away is the Potsdam sandstone. The Potsdam strikes N. 55° E. and dips to the southeast at a high angle. This place might be used as evidence for either a fault or for a normal depositional contact but in the light of what has been seen in other parts of the area it seems most likely to be a fault contact. The fault is extended to the southwest along the topographic break and just south of the first visible Precambrian outcrops until it meets fault \(V-V\).

\(U-U\) Fault \(U-U\) is drawn roughly parallel to \(T-T\) just to the northwest of the last Precambrian outcrops on this side of the Potsdam area, its southwestern end terminating at the southeastern end of a very pronounced hogback.

\(V-V\) The southeastern half mile of this fault is drawn along the back side of a pronounced hogback. Anorthosite outcrops in the stream behind this hogback and the topography is so striking when seen from the eastern slopes of Mount Bigelow that there is little doubt about the validity of this fault.
General discussion. So far as is known, all of the faults are of the normal, or gravity, type. All of the north-south faults have their downthrow side to the east but there does not seem to be any special agreement among the faults of the other groups. This coincides with the results that Quinn (1933, p. 119) obtained, although it should be pointed out that his westward dip of the downthrow block does not seem to hold. This is probably due to the anticlinal-synclinal structure of the region.

The angle of dip of the fault planes can be observed only in three or four places and where observed it is always a high angle. As it is impossible to determine the dip of the faults in the rest of the Paleozoic area, the geology has been mapped on the assumption of vertical faults. In several cases what appears to be the same fault on the map has the downthrow side reversed at the opposite ends of the fault, such as along A-A, B-B and E-E. It should be noted that this indicates only the relative movement between adjacent blocks and should not be taken as interpreting the dip of the fault planes. The inability of determining exact data regarding the attitude of the faults and of their relative age makes it possible that there may be some slight offset where certain faults intersect others.

If one considers the work of Hudson (1931), the question immediately arises as to why more of his meridional faults do not show on the map. In order to carry out such a system it is necessary to investigate larger areas than this study allowed. The absence of the faults does not deny their existence but is simply due to lack of evidence. Some faults of this type could be drawn by inference but it is not deemed wise to place faults upon the map without better foundation. As an example, a fault parallel to and about a mile and a half east of F-F would delimit the eastern side of Willsboro point and would fall along the stream just east of the hill (260') east of Willsboro. The topography on the east side of the hill would seemingly substantiate a fault at this place, but from there on south there is no indication of one. Such a fault does not facilitate the interpretation of structure; in fact, as it causes difficulties, it is not drawn. If work in adjacent quadrangles indicates, however, that faults carry over into the Willsboro quadrangle, they will have to be inserted on the strength of such new evidence.

The relative movement of the various fault blocks is shown by the symbols giving the downthrow side and in most cases needs no further comment, but there are a few places that must be discussed in particular.
The maximum throw found in the area, and according to Quinn (1933, p. 123) the maximum throw for any fault of the Champlain valley is found on fault D-D at Split Rock point where the Glens Falls limestone has been down-faulted against the Precambrian, is a displacement of some 4000 feet. Other faults which have the Beekmantown on both sides of the fault plane may have a throw of only a few hundred feet.

The block along the shore north of Essex delimited by faults L-L, M-M and N-N is one that needs further consideration. It is believed that the northwestern corner of this block was dropped farther than the southeastern corner, giving a reversal of the direction of dip and a change in the direction of strike. This accounts for the discrepancy between the strike and dip of the Canajoharie and Glens Falls east of the fault.

The block lying between faults A-A, B-B and P-P has been dropped downward and on the bases of Precambrian structures moved slightly to the southwest to form a graben. The Beekmantown flooring the graben at its western end dips to the northwest and is part of the western limb of the plunging anticline seen on Willsboro point. As the axis of this anticlinal fold strikes N. 25° E. the horizontal movement is not so great as it would seem at first glance, the apparent large horizontal displacement being due to the preservation of Beekmantown beds in this graben while the same beds at a higher level have been removed by erosion.

As the folded structure has been cut by the faulting and portions of the once continuous folds are shown on different fault blocks the faulting must have come after the folding. Cushing and Ruedemann (1914, p. 144-45) and Rodgers (1937, p. 1585) have pointed out that the Taconic thrust sheets do not show the effect of the high angle normal faulting and that therefore the faulting such as is found in the Willsboro region was probably completed before the later period of Taconic movement when the great thrust sheets were forced westward on the Vermont side of the lake.

PLEISTOCENE AND RECENT GEOLOGY OF THE PRECAMBRIAN AREA

In the Champlain lowlands the glacial striae indicate that the last advance of the ice was in a generally uniform southerly direction. In the highlands, however, the direction of the striae varies somewhat as a result of deflection of the flowage lines of the ice by the more marked irregularities of the topography. This is especially marked along the valley of the North Branch of the Bouquet river
Figure 28. Road on natural pavement of glaciated Potsdam sandstone, Flat Rock camp, Jones point.
Figure 29 Glacial striations on Potsdam sandstone, Flat Rock camp, Jones point.

Figure 30 Glacial chattermarks on Potsdam sandstone, Flat Rock camp, Jones point. Movement of ice is in direction of horns of crescent.
where the striae are oriented southwest, indicating a deflection of at least the basal ice layers up the river valley.

During the period of deglaciation, northward drainage was locally dammed by the ice with the consequent formation of temporary local lakes into which deltas were built. (See Fairchild, 1918.) The sand plains at altitudes of about 460 feet along Sprucemill brook, at 540 feet north of Reber, 480 feet southwest of Whipple mountain and 500 feet south of Keeseville, represent the effects of such local ponding. Irregular deposition of material carried in the ice resulted in local dams to the drainage and the consequent formation of ponds.

**PALEOZOIC AREA**

When the great mass of ice of the Wisconsin glacial advance pushed its way through the Champlain valley it gouged, scoured and polished the bedrock on which it rested. Evidence of the direction taken by the ice is preserved in the form of glacial striae which may be seen on the rock surfaces (figure 29). Although well shown in many localities there are a few outstanding areas for the study of this phenomenon. By far the largest continuous area is to be found at Flat Rock camp on Jones point, where the flat-lying Potsdam sandstone has preserved a remarkable record of glacial action. At the present time a considerable area may be seen on the north shore and also in the interior where the flat surface of the Potsdam, from which the camp takes its name, has been used as a roadway (figure 28). It is only in the case of a few bad joints or depressions that concrete has been added. The rest of the roadway is made up of the smoothed and striated Potsdam surface.

In several places on Jones point may be seen a series of crescentic cracks or chatter marks (figure 30), presumably made as some rock, frozen in the foot of the glacial ice, was pushed over the Potsdam surface.

Another excellent place to see the glacial striae is along the shore at the point south of Buena Vista, where the surface of the Chazy limestone not only preserves the striations but also shows a very interesting undulatory surface produced by the glacier (figures 31 and 32).

At many other places in the area, particularly along the shore, the striations are well preserved. At all places where measurements were made the direction of the striations was within three or four degrees of true south. It therefore seems certain that in the area now occupied by the lake and along the low-lying Paleozoic rocks the direction of movement of the ice was remarkably uniform. There
was not the deviation in course as found by Buddington in the Pre-
cambrian portion of the quadrangle, where the greater differences
in relief diverted at least the lower portion of the ice, producing basal
eddies or cross currents.

The advance of the ice smoothed out the topography and produced
approximately the present rock floor on which the Pleistocene sedi-
ments were deposited.

During the period of deglaciation till was deposited unevenly over
the area. Of the cobbles in this till the great preponderance are of
resistant Potsdam sandstone brought down from the large areas to
the north where this formation is exposed.

As the ice left the Champlain region, temporary lakes were formed
along the ice front and then there was a submergence of the land and
a long arm of the sea invaded the lower portions of the region. J. B.
Woodworth (1905) in an excellent paper did much to delimit the
shore lines of this marine transgression, and Winifred Goldring
(1920) showed by means of the paucity of the fauna and its dwarfin
t that the waters in the vicinity of Willsboro were not of the salinity
of the open sea but rather of the brackish water type, that is probably
two or three parts of salt in a thousand of water.

Shells of the marine gastropod *Macoma groenlandica* Beck were
found in large quantities in a small excavation one-half of a mile
south of the end of Willsboro point (figure 33) at an approximate
elevation of 140 feet above tide and in the W. P. A. sand pit north
of Willsboro at an elevation of about 240 feet. They were also found
in two pits south of the village of Willsboro, one by the northern
intersection of the 300-foot contour and the middle road, two miles
due south of the village, and the other at an elevation of approximately
270 feet one-half of a mile to the northeast of the middle road pit.
Other locations at which Pleistocene shells have been found in the
past are cited by White (1894, p. 228) and Woodworth (1905, p. 213).
Goldring lists five genera as having been found in the
region, to wit:

*Saxicava rugosa* Lam. (= artica L.)  *Mytilus edulis* Linn.
*Macoma groenlandica* Beck (= balth-
ica L.)  *Yoldia arctica* Gray.
*Balanus crenatus* Brug.

Only one of these genera, *Macoma*, as mentioned above, was found in
1938. Pleistocene clays from the bulge in the river caused by the
1937 landslide were washed and examined in the hopes of finding
Foraminifera or macroscopic forms, but not even a fragment of a
shell was recovered.
Figure 31  Striations on glaciated surface of Chazy limestone on point southeast of Buena Vista. Sand collected in depressions shows undulatory nature of the glaciated surface.

Figure 32  Glacial striations and fossil gastropods on Chazy limestone. Same location as figure 31.
Figure 33 Shells of Pleistocene Macoma groenlandica in sand pit one-half mile south of north end of Willsboro point.

Figure 34 Cross-bedded Pleistocene sands along road on west bank of Bouquet river three-quarters of a mile north of Whallonsburg.
The discovery of *Macoma groenlandica* at an elevation of 300 feet shows that the marine invasion must have covered the land to at least that point. Woodworth (1905, p. 170) states, "It is probable, as I have attempted to show in chapter 10, that the upper marine limit at Port Kent is found at about 340 feet." As Port Kent is but a matter of two or three miles north of the northern edge of the Willsboro quadrangle, the elevation here given may be assumed to be reasonably accurate for the Willsboro area.

In the vicinity of Keeseville there is a delta plain built by the Ausable river at an elevation of 500 feet. There is no evidence of a delta at this elevation in that part of the drainage basin of the Bouquet river that lies within the Paleozoic area.

On the North Branch of the Bouquet there is a delta plain built to an elevation of about 260 feet. This sand plain has buried all but three exposures of Paleozoic rocks in this valley. Along the east bank of the Bouquet river between Whallonsburg and Willsboro there is a well-developed sand plain at an elevation of approximately 260 feet which was evidently deposited while the delta of the North Branch was being formed and is probably, in part at least, the delta of the Bouquet river (figure 34).

As the study of postglacial shore line phenomena of the Champlain valley has been discussed in general by Woodworth (1905) and as a detailed study requires extensive work in many of the adjacent quadrangles, which is outside of the scope of this work, no attempt has been made to establish successive shore lines that may be present. Before such detailed work for the Willsboro quadrangle can be finally completed it will be necessary to have a more accurate topographic map than is available at the present time.

**LANDSLIDES**

On the 19th or 20th of June 1937, there was an interesting landside on the east bank of the Bouquet river about one-half mile north of the Essex-Willsboro town line. For a distance of about 500 feet, the clay bed of the stream was forced upward, temporarily ponding the flow of water until a new channel was cut in the meadow lands to the west (figures 35 and 36).

At this point the stream is flowing on Pleistocene clays and the east bank made up of sands and clays rises some 50 feet higher than the west bank. At some distance back from the river, on the east bank, a vertical scarp more than 30 feet high was produced by the disturbance. Between this zone of slippage and the river, the land was badly broken and dropped vertically in blocks. Trees were
uprooted, and one tree six inches in diameter was split up the middle of the trunk for several feet as the ground on one side dropped to a lower level.

Dr D. H. Newland, State Geologist, has published a paper (1938) in which he attributes the slide to the uneven distribution of weight on the underlying plastic clay with the resultant sinking of the east bank which caused a horizontal flowage through the clay and a bulging at the point of least pressure, to wit, the river bed. He believes that the movement when once initiated was probably completed within the space of a few seconds and that heavy rain of June 18th and the few days immediately preceding was the factor that "set off" the slide. Newland calls attention to slides of a similar type which he has described (1916a) from the Hudson valley.

At the time of the slide considerable local interest was aroused and the owner of some of the land affected did a brisk business guiding people, both local and tourists, along the river's edge.

The present writer, who was fortunate enough to be in the area a few days after the slide occurred, visited the scene and was struck by a topographic form that resembled a river terrace, but which he believed was due to a former slide of the same type. A preliminary paper was published (Whitcomb, 1938) dealing with this part of the discussion of the slide.

During the field work in the summer of 1938, particular attention was paid to the banks of the Bouquet river with the idea of trying to locate evidence of former slides of this type. As was suspected, it was found that instead of being an unusual feature, the slide of 1937 was normal for the region and had been preceded by many of the same type and by at least one of a slightly different nature.

The characteristic topography that is left after a slide of this balanced type is a clay bulge along the river bank, behind which the ground is uneven and broken into blocks or hummocks, and finally the steep slope of the scarp. Even after great lengths of time the characteristic features may be discovered although, of course, the angularity of the scarp, so prominent in a new slide, has been lost (figures 37 and 38).

About ten places were found which showed indisputable evidence of such former slides, and for one of these there is a definite record. Dr J. M. Stafford, of Essex, took the writer to a place on the left bank of the Bouquet a mile below Whallonsburg where a slide had occurred about 80 years ago. He gave a description of the slide as told to him by his father. The description and the character of
Figure 35 Looking upstream over end of clay bulge produced by landslip of 1937.

Figure 36 Looking downstream along side of clay bulge of 1937, landslip showing new channel.
Figure 37  Scarp produced in woods on east bank of stream by landslip of 1937.

Figure 38  Slumped and overgrown scarp from old landslip, just downstream from slip of 1937.
Figure 39  Bench resembling a terrace produced by subsidence of surface in old landslide. Figure 39 is photograph of area adjacent to figure 38.

Figure 40  Uneven topography produced by slumping. North of cemetery on Whallonsburg-Bouquet road.
the land at the present time leave no doubt as to the similarity of the two slides.

Directly downstream from the slide of 1937 are the remains of an older slide and it was found that the terracelike bench previously discussed (Whitcomb, 1938, figure 39) by the writer was definitely of slide origin. Along the river bank the remains of the clay bulge are visible, behind which the ground is broken and of uneven character. Part of the scarp has weathered into a sandbank that has assumed the angle of repose and joining it to the east is the bench which represents the top of a partially depressed block.

Other places on both the Bouquet river and North Branch of the Bouquet river that show this topography are easily found. Some of the best examples, not readily seen because of the dense woods, are to be found on the south bank of the river between Willboro and the lake.

By the cemetery half way between Whallonsburg and Bouquet there is evidence of a slide beside the Oxbow lake shown on the map. In this case there is no definite bulge of clay along the old stream channel and it is believed that it was a case of surface slumping without any horizontal transferal of material along a plastic substratum (figure 40).

From the facts mentioned above, it becomes evident that the slide of 1937 was not unusual for the region but that as slides occur only after long intervals of time it was not generally realized that the whole valley had been so profoundly modified in the past by this agency.

**ECONOMIC GEOLOGY**

**PRECAMBRIAN AREA**

**Garnet Skarn**

Local bands of the skarn belts consist predominantly of rather massive red garnet rock. This type of material has been prospected at three localities on the quadrangle. A small shipment of such garnet is reported to have been made from a locality known as the Drake mine, one and one-third miles east-northeast of the crest of Mount Bigelow. The garnet rock forms a layer in otherwise dark-colored mafic pyroxenic skarn, and is well exposed in conspicuous cliffs on the west side of the valley. It strikes a little west of north with a gentle west dip. It can be traced for some distance up the hill but dies out toward the crest, and the dark skarn alone carries on for some distance until it in turn dies out in the anortho-
site at the crest of the hill where the strike is nearly westerly. Newland and Hartnagel (1928, p. 35) describes the occurrence as follows:

The garnet, with a small admixture of green pyroxene, constitutes a rock of itself, so that it could be quarried and shipped as lump without special sorting or other preparation. The occurrence, however, is rather limited, and the garnet lacks some of the valuable characteristics of the crystallized mineral. [Isolated crystals such as occur at Gore mountain in the southern Adirondacks. A. F. B.] It has no well-developed fracture planes and breaks down to a granular product in which the individual particles show few smooth surfaces or sharp edges. Its admixture with pyroxene, a mineral of inferior hardness, may also be noted. The country rock of the occurrence is anorthosite, an igneous material consisting practically of the feldspar called labradorite, and the deposit probably represents an inclusion of some foreign rock caught up in the intrusion and converted through pressure and heat into the mixture of garnet and pyroxene. This would account for its purely local development.

Another band of similar garnet skarn, interlayered with pyroxenic skarn and inclosed in anorthosite, outcrops on the point at the northwest end of Butternut pond and strikes north-northwest onto the Ausable quadrangle. Some garnet from this band was carried to a railroad siding one and one-half miles east of Hadley pond, and shipped.

Layers of garnet rock are also found at several localities in the Sugarloaf belts of skarn. Some prospecting has been done on one such layer about 1.9 miles southwest of Willsboro bridge. The rock here consists of interbanded garnet skarn and pyroxene skarn with numerous sills of anorthositic rock. There is one band of white wollastonite several feet thick with some garnet bands. Garnet rock with some streaks of pyroxene skarn occurs in layers three feet and nine feet thick, respectively. Similar garnet rock and associated wollastonite are found along the south side of the skarn belt on each of the three hills to the northwest. Garnet skarn also occurs on the north end of the hill one-half a mile east-southeast of Sugarloaf mountain with a west-northwest strike.

**Wollastonite**

The mineral wollastonite, where found in large bodies, has within the past few years been used locally as a source of material for the manufacture of "rock wool."

Wollastonite forms local white bands within the southern skarn belt south of Sugarloaf mountain. The wollastonite is exposed near the road in a pasture about one and four-fifths miles southwest of Willsboro, where it may have a thickness of nine feet with some
included garnet bands. About a mile to the west northwest, near the south slope of the hill and the south border of the skarn belt, wollastonite rock is interlayered with red garnet and green pyroxene masses. Wollastonite layers with similar relationships are exposed in the next two hills about a mile apart to the west northwest.

Wollastonite in commercial quantities is not exposed in the present outcrops but so much of the skarn belt is covered that the quantity of wollastonite rock present is a problem that could be solved only by prospecting.

**Quarry Materials**

In addition to several quarries which have been worked for road material in the Precambrian rocks, there are two localities where quarries for building and monumental stone have been opened in anorthosite. These are not being worked at present. They have been described in detail by Newland (1916b, p. 98–101), from whose work the following quotations are taken:

**The Keeseville Anorthosite Area**

The anorthosite exposures in the vicinity of Keeseville near Lake Champlain, have been the source of fairly large quantities of building and monumental material. The rock is mostly the light, granulated variety that characterizes the peripheral zone of the great Adirondack mass. The stone has been sold under the name of Ausable granite.

**Prospect Hill Quarries**

The Prospect Hill quarries are situated on the northern and western slopes of that prominence, a rounded knob 300 feet or more high, lying just south of Keeseville. The northerly quarries once belonged to the Ausable Granite Co., and are mentioned by Smock as in active operation at the time of his investigation in the period 1880–90. The company also operated a dressing and monumental works at Keeseville.

The stone of these quarries is medium to coarse in texture, depending on the relative proportion of the granulated and residual uncrushed feldspar, and has a gray color. The rock surfaces show glacial striations and polishing, but are almost unaffected by weathering influences.

Smock describes two quarries as operative, a lower one to the north producing a coarse variety, and an upper quarry about 20 rods south of the former and higher up the hill, each equipped with a single derrick. The quarrying of dimension stone must have been expensive, as the jointing is irregular in regard to direction and spacing. The principal uses of the stone appear to have been in monumental and decorative work. It was employed in the trimmings of the Y. M. C. A. building in Burlington, and also in the interior
The decoration of a Philadelphia church, but had the widest sale for monuments, of which there are many specimens in the cemeteries of that vicinity. A local example of its use in buildings is found in the French Catholic church at Keeseville, which, however, was constructed mainly of the quarry waste. At the time the quarries were worked, the branch railroad from Fort Kent to Keeseville had not been built and all the stone had to be hauled to the lakeside by teams.

G. P. Merrill in his "Stones for Building and Decoration" speaks of the Keeseville stone as "admirably adapted for polished columns, pilasters, and other decorative work." But he also remarks that the material in some places shows minute fractures which may prove detrimental to its weathering qualities.

Physical Tests. The stone is credited by Smock with a crushing strength of 29,000 pounds to the square inch, which is higher than the average. The specific gravity is around 2.75, indicating a weight of 175 pounds to the cubic foot. Ration of absorption, .066 per cent.

Quarry of C. B. White, Augur lake

Along the west side of Augur lake anorthosite outcrops over a large area, forming a broad ridge which breaks off at the lakeside in a line of perpendicular cliffs 100 feet high. It is mostly a light-colored labradorite rock, of medium grain, in general appearance not unlike gray granite. It contains scattered crystals of pyroxene and occasionally some biotite. In places these minerals become sufficiently abundant to give a rather dark tone to the rock surface, but generally they are of subordinate importance. The minor accessory constituents are garnet, ilmenite and a little chlorite and kaolin from decomposition. The anorthosite is undoubtedly a good durable building stone.

The property owned by Mr. White includes a quarry opening which lies on top of the ridge above the lake. The quarry was last worked in 1892; the product was employed in the construction of the Criminal Courts Building in New York City. A large quantity of rough stone, much of it suitable for dimension stone, was left in the quarry. The principal drawback to operations is the long haulage to the railroad, the nearest shipping point being Keeseville, the terminus of a short branch railroad that connects with the Delaware and Hudson line at Port Kent. The quarry is about 5 miles in a direct line from the shore of Lake Champlain.

PALEOZOIC AREA

Quarries

Although the quarry industry is practically nonexistent in the district at the present time, it was at one time a thriving business that supported a large portion of the population. The development of concrete and modern structural materials removed the demand
Figure 41 Abandoned workings of quarry in Chazy limestone, Ligonier point.

Figure 42 Waste blocks of Chazy limestone in abandoned quarry on Ligonier point.
Figure 43  Clark homestead built of Chazy limestone from quarry on Ligonier point.

Figure 44  Old stone wagon used in quarry on Ligonier point. Two similar wagons were purchased for Henry Ford’s museum.
that used to exist for this stone. Nevertheless the old abandoned quarries tell of an important chapter in the economic development of the region and are lasting monuments to the building industry of the past. They also provide some of the finest sections for the study of the rocks.

The largest and most extensive quarry operations were on Ligonier point, where the massive beds of Chazy limestone were easily extracted close to the shore and could be shipped by barge down the lake and thence by canal to the Hudson river.

The earliest date at which rock was quarried on Ligonier point is not a matter of record, but stone was taken from here as early as 1823 for the construction of some of the local houses (Information on Quarries from Clark, C. L., personal communication, 1938, and White, 1894). From 1854 to 1869 S. W. Clark & Company operated extensive quarries and in 1869 the Lake Champlain Blue Stone Company was formed to take over the operation. The last large job was undertaken in 1879. During peak operation more than 300 men were employed in the various jobs about the quarry, and the buildings to accommodate them made a sizable little community. The quarries are now abandoned and trees have grown up throughout the old workings, the buildings have disappeared and the wharf from which the stone was transferred to barges is no longer in existence (figure 41).

The quarry extended for more than 1000 feet along the strike and was worked to a depth of some 25 feet in the gently (6°–8°) dipping beds. One of the great factors in the development of the quarry was the size of the blocks that could be obtained (figure 42). The thickness of the beds varies from one to six feet and they are cut by two sets of joints, one running N. 10° E. and the other approximately east and west. As the joints were not closely spaced, blocks as long as 15 feet could be obtained.

Stone from this quarry was used in the piers of the Brooklyn bridge and in the foundations for the State Capitol in Albany. Stone was also shipped to Albany and Troy for the construction of churches in those cities (figures 43 and 44).

A little over a mile away on the west side of Willsboro point is located the old Frisbie quarry, now owned by the Rowley family. This quarry, also in the Chazy, is the second largest in the region and for years was an important producer. Although considerable building and dimension stone was taken from this quarry, one of its biggest products was lime which was burned in near-by kilns.
The stone for the breakwater at Burlington, Vt., and for some of the fills on the old Central Vermont Railway came from this quarry. The quarry is several hundred feet in length and width and in the back face some 25 feet in height. The dock from which the stone was shipped is no longer in existence, but one can see where it was located by means of the old approaches.

In Essex township to the south and west of the village of Essex there are several quarries in the Chazy limestone. Although none of the quarries in this group can compare in size with those on Willsboro point some of them have produced large amounts of stone, and are still in operation. Many of the local buildings are built of stone from these quarries and they have also produced considerable crushed stone used on the highways. Of these quarries the old Parkhill, now known as Gardiner's quarry, and the old Ross quarry, now used by the town for road material, are the largest. In addition to the two mentioned above there are many small operations from which stone was taken to be burnt for lime, or enough stone was removed to build a house.

About one mile north of the Willsboro-Essex town line there is a Chazy area in which a quarry was operated. The stone was burnt for lime and also used for building purposes. Just east of the quarry along the shore road used to stand the law office of the original owner of the property, a building constructed of stone from the quarry. The building has been torn down and the stone is now part of a dock on the near-by shore.

At the head of Willsboro bay there was another quarry of small size in the Chazy. It might well be noted that in all areas where the Chazy limestone is exposed at the surface, quarries have been in operation at some time in the past.

One-half a mile east of Willsboro village is an old Beekmantown limestone quarry, now used as a backstop for the targets of the Willsboro Gun Club (figure 45). The only other sizable quarry in the Beekmantown is the town quarry for road material located on the new road from Willsboro Station to the Willsboro-Reber road.

Although not of sufficient importance to be spoken of as quarries, there are places on some of the farms where owners have removed small amounts of limestone for their own use.

The old octagonal schoolhouse at Bouquet (figure 8) and the mill buildings along the stream at this locality are built of the Potsdam sandstone removed from the ledges along the river near the old mill dam.
Figure 45 Quarry in Beekmantown limestone behind the targets of the Willsboro Gun Club.

Figure 46 Shifting sand on Pleistocene sand plain, one mile southwest of Essex.
Sand and Gravel

As by far the greatest part of the region is covered by glacial deposits, there has never been any trouble in finding sufficient quantities of sand and gravel for use on roads and in construction (figure 46). There are numerous places along the highways from which this material has been removed. In some cases only a few wagon or truck loads have been used; in others several hundred. The same applies to the farm lands where small pits are often to be found. At the present time (1938) two localities are being used by the W. P. A. to supply road material, one about one mile north of Willsboro to the left of the dirt road running north to Willsboro point and the other on the right side of the road from Essex to Westport behind the Second District schoolhouse. Each of these pits is shallow and of considerable extent and produces a mixture of sand and gravel.

Clay

Although not utilized at the present time there is abundant clay to be found throughout the area. This clay, which was deposited at the close of the glacial period, is a possible source for brickyards or tile works. Whether the economic situation will ever justify the establishment of such an industry is outside the scope of this discussion.

Water Supply, Domestic and Farm

The source of water for domestic, farm and human consumption varies greatly in the different portions of the area. Although water in sufficient quantities is everywhere available, the quality of the water and the problems of its procurement are of many types. There are five main sources of water: the lake, river, wells, cisterns and springs.

The village of Essex is served by two private water companies which draw their supply from Lake Champlain at distances of 400 and 1000 feet from shore. Upon the advice of the State Department of Health, chlorination equipment has been provided in both these systems as it has been found that the lake water shows definite traces of contamination and might in the future become a source of trouble. The water is distributed by pipes, which in places are not buried below the frost line with the result that in the winter there is often trouble from frozen or partially frozen pipes. Neither of these systems has a standpipe or reservoir but relies upon air pressure tanks to give the flow throughout the network of pipes.

During the spring of 1938 the local chamber of commerce investigated the possibility of the formation of a water district and the
installation of a modern system aided by a grant from the Public Works Administration. At the end of July 1938, after a preliminary meeting of property owners, the committee was empowered to make application to the P. W. A. for a grant for this purpose. Whether the system will be installed or not can not be said at this time. The plans call for a 200,000-gallon tank at an elevation of about 240 feet, to which water taken from the lake and chlorinated would be pumped. The delivery system with six or eight-inch cast iron pipes in the main streets would have all pipes laid below the frost line. Due to the thinness of the soil this will necessitate blasting throughout a large part of the district. From the point of view of the geologist it would be very interesting if someone could be present to study the bedrock as exposed for there will be at least two places where the pipes will cross one of the faults which has been drawn largely by inference.

South of Essex is located the Crater Club, a group of sixty odd summer cottages surrounding a central community building and dining hall. The Crater Club property runs its own water system, drawing from the lake and chlorinating the water before delivery.

These three systems mentioned above are the largest in the area but there are many more supplying individual houses or groups of three or four properties. Most of these smaller systems use raw lake water without any treatment. This type of supply is very common for the summer cottages along the lake front.

The village of Willsboro, the largest center of population in the area, has no water system and is confronted with a difficult problem. Its location a mile and a half from the nearest point on the lake makes that water unavailable unless some comprehensive system is installed. The water in the Bouquet river flowing through the center of the village is not fit for human consumption. As a result, wells and cisterns are in general use throughout the village although some properties pump from the river for all uses except cooking and drinking.

The only known deep well in the region is at Whallonsburg, for which no record could be obtained. The rest of the area, particularly in the interior, relies largely upon wells dug in the glacial deposits or upon cisterns.

There are a few excellent springs, most of which are located along the Precambrian-Paleozoic contact. On Jones point, A. G. Paine has a spring which seems to be caused by a pocket in the Potsdam sandstone filled with glacial material. This spring supplies 50 to 60 gallons a minute and feeds by gravity to the camp and house.
GLOSSARY OF SOME TECHNICAL TERMS

Aphanitic—A term applied to igneous rocks where the grain is so fine that the individual constituents can not be distinguished by the unaided eye.

Articite Migmatic—A thin-banded “mixed rock” or veined gneiss consisting of layers or thin lenses of igneous rock injected parallel to the foliation of schists, gneisses or skarns.

Corona—A shell constituting the border portion of an earlier mineral and formed from it as a reaction-rim, for example, the zones of radially arranged minerals such as hypersthene, hornblende, garnet etc., that occur around olivine in certain metagabbros.

Doleritic texture—An intergranular texture such as shown by the plagioclase and pyroxene of some mafic rocks where the pyroxene grains are idiomorphic or subidiomorphic with respect to the plagioclase laths.

Euhecdral—A term applied to minerals which have crystal faces peculiar to the particular mineral involved.

Grahen—A block of the earth’s crust relatively depressed between more or less parallel high-angle fault surfaces or fault zones. A fault trough.

Granoblastic—A granular mosaic or granulitic texture of rocks arising from metamorphic crystallization.

Granulite—A granulose metamorphic rock composed of even-sized granular minerals with a mosaic or interlocking texture.

Idiomorphic—See euhecdral. Also used for the texture of a rock containing predominantly euhecdral crystals.

Laccolith—A dome-shaped intrusion with conformity between floor and roof of the intrusion and the bedding planes of the invaded formations, and with the roof arched as a result of the intrusion.

Lamprophyre group—The lamprophyre group includes dark mafic rocks which differ from the normal types with the same essential minerals in having a greater abundance of the mafic minerals, with ferro-magnesian minerals as the sole phenocrysts in an aphanitic or micro-granular groundmass, and in which the mafic minerals of the groundmass show notable crystal form peculiar to them. They are frequently partly altered to calcite and commonly occur as dikes.

Leucocratic—A term applied to facies of igneous rocks, which are exceptionally poor in mafic minerals in comparison with the normal or average rock of the type in question.

Mafic—A mnemonic term for magnesia (ma) and/or iron (fe) rich minerals such as olivine, pyroxene, amphibole, biotite, garnet, magnetite, ilmenite etc. May also include apatite, sphene and sulphides. The term as applied to rocks means those in which mafic minerals are predominant or unusually abundant.

Margarites—Embryonic crystals occurring in glass in the form of minute microspherical bodies called globulites arranged in a line resembling a string of beads.

Metagabbro—A metamorphosed gabbro which has undergone recrystallization and usually reconstitution in part or in whole to a new set of minerals.

Metasomites—Metamorphic rocks which are the product of substantial chemical change of composition of older mineral aggregates through the essentially contemporaneous introduction of material from external sources by thermal solutions and the solution and removal of certain materials previously present. The metasomatism is effected through small openings, usually submicroscopic.

Miarolitic—A structure consisting of small irregular interstitial cavities formed during consolidation of an igneous rock; the cavities are lined with euhecdral crystals of minerals similar to those of the inclosing rock.

Micrographic—An intergrowth of two minerals on a microscopic scale in such a fashion that the resulting texture has the appearance of cuneiform or semitic characters.

Migmatic—Veined rocks in which one part is of magmatic origin and another part is of metamorphosed country rock. The magmatic part may be derived through injection from without or as a product of partial reso-
lution or refusion of those constituents of the country rock constituting the lowest melting aggregate. A migmatite is thus a mixture of elements of two different origins.

*Mylonite*—Rock almost completely microgranulated by differential movement and crushing; a few porphyroclasts remain as relics. Microcrystalline texture. Recognizable flow structure.

*Nebulitic structure*—A structure with nebulous appearance, one in which the structure is indistinct.

*Ophitic texture*—A texture such as characterizes some diabases wherein plagioclase laths are entirely or nearly inclosed within large pyroxene areas.

*Phacoidal*—Lenticular, lens shaped.

*Phantom breccia*—A breccia structure which appears very distinct as viewed in the field occurrence but one in which careful examination shows there is very little difference in composition or texture between fragment and inclosing igneous rock and one shades insensibly into the other.

*Phenocryst*—Visible crystals in an igneous rock which are conspicuously larger than the grains of the groundmass. The latter may be glassy. Phenocrysts characterize porphyritic texture.

*Poikilitic*—A speckled or mottled texture due to inclusions of unoriented grains of a mineral or minerals in another.

*Porphyroblasts*—Crystals or crystal grains in a metamorphic rock which are conspicuously larger than the the groundmass and which are the result of growth and recrystallization during metamorphism; pseudo-porphyritic crystals.

*Porphyroclasts*—Fragments of once much larger crystal grains occurring as relics in a groundmass of smaller grains resulting from granulation of the original coarse grains.

*Saussuritized*—A rock in which the plagioclase has been altered to an aggregate of sodic plagioclase and zoisite or epidote, together with variable amounts of sericite, calcite and possibly other minerals.

*Schlieren*—Relatively short irregular or wavy streaky masses within an igneous rock which differ from it in composition and/or texture but shade insensibly into it.

*Skarn*—Originally a Swedish term for the silicate gangue or country rock of certain iron-ores or sulphide deposits of Archaean age, especially those which have replaced limestone or dolomite. Is now used in a more extended sense for high temperature complex silicate (garnet, pyroxene, amphibole etc.) deposits which are the product of metamorphism, commonly in part or in whole the product of replacement of limestone or dolomite on an extensive scale, and may be of any age.

*Subdoleritic*—A texture exhibited by the plagioclase and pyroxene of some mafic rocks in which the pyroxenes have their outlines determined only by the surrounding plagioclase laths.

*Xenolith*—Fragments of rock which are included within a magma and are foreign to it.
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