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GEOLOGY OF THE MEMPHREMAGOG MAP AREA

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~~Dr. Collins.~~

Geology of the Memphremagog map-area
~~complete~~

F. A. Kerr.

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CHAPTER I

Introduction.

Purpose.

The part of southern Quebec area lying southeast of the upper St. Lawrence River has occupied the attention of geologists since the inception of the Geological Survey and has presented problems so complex as to have afforded grounds for bitter controversy for over sixty years. Though much work has been done throughout the area it has been for the most part promiscuous or in the nature of large area reconnaissance. Consequently satisfactory knowledge of the general geology or solution of many of the major problems has never been gained. For some time a detailed revision of the geology of southern Quebec has been contemplated and it was with a view to beginning this that the present work in the Memphremagog area was undertaken. This area was selected because it was thought to afford the best opportunities for obtaining a comprehensive knowledge of the stratigraphy and because of the presence of granite masses of considerable economic importance.

Location and Size of Map Area.

The Memphremagog area as herein defined comprises that part of the 15 by 30 minute Memphremagog sheet which lies east of Lake Memphremagog. It is situated in southeastern Quebec on the international boundary in that was the county of Stanstead, and includes the township of Stanstead, parts of Magog and Hatley and Coaticook (Figure 1). It is an area 12 miles wide and 17 miles long, approximately 200 square miles. Physiographically it represents the transition from the relatively flat country of southern Quebec to the more rugged mountainous areas of northern Vermont and New Hampshire.

Field Work.

The geological field work upon which the report is based was done during the summer of 1923. The base map used is that of the Department of Militia and Defence published on a scale of one mile to the inch with 25-foot contours. Locations on this were made mainly by pace and compass traverses and compass triangulation.

directions. Lake Massawippi, a long narrow lake occupying a crook in the valley, has an elevation of 523 feet. The depth of the lake was not ascertained but appearances would lead one to believe that it easily exceeds 50 feet - ~~the difference between these two elevations~~ - and may be considerably more. South west of Lake Massawippi there is a fairly abrupt slope upward to an elevation of 775 feet, then a long gradual descent to an elevation of 683 feet at Fitch Bay. This part of the valley is probably filled to a considerable depth with superficial material. Near lake Massawippi wells drilled to a depth of 60 feet are entirely in so-called gravel. Fitch bay near Magoon point is reported to be from 40 to 60 feet deep. The narrowness of the valley here clearly indicates that its rock floor is considerably higher than at lake Massawippi. In general the rock floor, the present bottom and the land and water surface show an increase in elevation from north east to south west within the map area. The valley is unsymmetrical, with a high ridge of abrupt slope on its western side and on the eastern a ridge several hundred feet lower with a gradual slope.

The northwestern of the two sections into which the map area is divided by the great valley just described is almost a peninsula. It is bounded on the west by lake Memphremagog and on the east by Fitch bay swamps, and lake Massawippi. In general it constitutes an asymmetrical ridge with a gradual slope to the west and an abrupt one to the east. The axis lies within a mile or two of the southeast edge boundary valley. Along the shore of Lake Memphremagog is a well-defined low ridge of Siluro-Devonian and Silurian limestones. Between this and the top of the main ridge there are many minor undulations not arranged according to any plan which have no very definite form. The hill north of Magoon point assumes such prominence as to dwarf the main ridge which in this section falls away rather rapidly. Farther north Lovering lake sprawls out in a large, irregular, though probably shallow, north-south depression on the western slope. Its outlet-stream flowing south takes advantage of a break in the ridge and enters Fitch bay. Northwest of lake Massawippi a broad depression with a northwest-southeast trend and another further to the south with an east-west trend destroy ~~its~~ the continuity of the ridge in this section of the area.

In the southeastern section of the map area there is in gen-

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Previous Work.

To outline completely the previous work done in southern Quebec would require more space and time than the benefits accruing from such a resume would warrant. The proximity of this section of the country to the original headquarters of the Canadian Survey at Montreal led the early workers to turn their attention to it. Some of the problems found there soon became subjects of controversy, and the "Taconic Question" developed into a storm center in the geological literature of the period. The country around Lake Champlain and other sections along the international boundary became important hunting grounds for palaeontologists and geologists from across the border. Many articles appeared dealing with the fauna, stratigraphy, igneous rocks, and to a lesser degree the structure.

In the latter part of the nineteenth century R.W.Elis revised and completed the mapping of the entire southern part of the province - a task which had been begun by Sir William Logan and carried on by his colleagues. Since that time much work has been done on small scattered areas, faunas, intrusives, mineral deposits, and so on, but very little of it took the form of systematic areal mapping.

Of all this work and the literature resulting from it the most outstanding feature is the achievement of Logan. Though he did not complete the mapping of the southern part of Quebec it is quite apparent that he was able to perceive to a remarkable degree the character of the geology. In many respects the knowledge he gained has never been improved upon; in fact in some instances there has been a retrogression where his deductions, though more nearly correct than later ones, have been discarded.

Though much excellent work has been done on many isolated areas it is clear that as regards the general character of the geology no very great advance has been made nor does it seem likely that it will be until the systematic mapping of the area is well under way. This is 3
a task which would seem to require concentrated effort over a period of years, for there is no doubt that the problems to be solved are extremely difficult.

Much of the general literature on this section includes references to the geology of the Memphremagog area and there are many short articles on different specific phases. The more important of these will be mentioned when the subjects with which they deal are discussed.

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CHAPTER II

General Character of the District.

Topography.

Regional Relationships of the Memphremagog Area.

4 The Memphremagog area lies between two great physiographic provinces. To the north is the relatively flat and low country, with its few isolated prominent peaks and ridges, which includes the greater part of southeastern Quebec. To the south lies the rugged mountainous area of northern Vermont and New Hampshire. The Memphremagog area belongs mainly to the northern province but a general increase in elevations toward the south, which continues beyond the area, represents the beginning of the change to the topography of the southern province.

North and northeast of the area the country is low and there is little relief except for one ridge. This lies west of and parallels the Massawippi and St. Francis Rivers (Figure 1) and is a continuation northward of the prominent ridge west of Lake Massawippi. The greater 5 part of this area as of the whole physiographic province to which it belongs is underlain by Palaeozoic sediments. Features such as the ridge mentioned above and isolated peaks owe their prominence to the presence of very early Palaeozoic or ~~pre-Cambrian~~ Precambrian sediments, or to igneous rocks.

West of Lake Memphremagog, which constitutes the western boundary of the map area, is a very rugged section with a relief of 2000 5/6 feet. It might be considered an extension of the southern province into Canada but geologically it is somewhat similar to the northern province. Its ruggedness and relief are due to increased areas of the types of rock which are responsible for the prominent elevations in the northern province. To the south and southeast of the map area the ruggedness and relief are similar to that found west of the lake. Not much is known about the geology of this country but is seems certain that it is different in general aspect from that of the northern province. Just north of the boundary in southern Quebec there are many masses of granodiorite which are largely responsible for the increase of elevations and ruggedness. They extend into the United States and there too probably have an important influence on the topography.

Relief.

Within the Memphremagog area there are, with a few exceptions, only gradual slopes. The south eastern slope of ~~the~~ one prominent ridge extending northeasterly across ~~through the center of~~ the map-area is unusually abrupt and west of Blueberry point on lake Massawippi shows a relief of nearly 900 feet. Otherwise no single slope shows more than a few hundred feet relief and the maximum for the whole area is less than 1000 feet.

Lake Memphremagog forms a distinct physiographic boundary on the west side of the map area - the other boundaries are merely map lines. It is long and narrow with a curved north-south trend. Its width exceeds two miles in only a few places and is generally nearer one. Beyond the map-area to the north it extends one mile and to the south six, being in all about 24 miles long. It has two long arms, one on the west side - Sargents bay - and the other on the east - Fitch bay. The depth of the lake was ascertained only indefinitely*1. From Magoon point south it is fairly shallow, probably ~~never~~ nowhere exceeding 75 feet. North of this it deepens rapidly to a point opposite Owl Head mountain where it is reported to be 600 feet. This is thought to be greatly exaggerated as such a depth would necessitate slopes on both sides as precipitous as those of Owl Head mountain, extending down to a sharp V ~~shape~~ at the bottom. Depths of several hundred feet are reported for points nearby so that to assume a depth of something near 400 feet seems reasonable. Farther north the lake becomes shallower and for the greater part of its length is said to average between 100 and 150 feet. Thus the total relief of the land surface including the 400 feet below the surface of lake Memphremagog is about 1250 feet.

The map-area is divided into two distinct parts by the ~~great~~ marked prominent valley which is occupied by Fitch bay, B~~l~~unker brook and lake Massawippi within the area and beyond by the Massawippi and St.Francis rivers. It parallels the ridge previously described, extending northeastward for 40 miles or more beyond the map-area. At Lennoxville about ~~twenty~~ 10 miles northeast of The north edge of the map-area, ~~Ayers Cliff~~ the bottom of the valley has an elevation of 475 feet. From that ~~this~~ point there is a gradual slope upward ~~in both~~ to the northeast and southwest

*1. For information about the depth of Lake Memphremagog the writer is indebted to Mr.Eryou of Fitch Bay who gained his knowledge from a variety of sources.

eral a gradual slope upward from the boundary valley. The maximum elevations, between fourteen and fifteen hundred feet, are found in a broken ridge which roughly parallels the valley, cutting diagonally across the map area about three miles from ~~its~~ the southeastern corner of the map-area. Toward this corner there is a slight decrease in elevations. The broad ridge-like area of the westward and eastward slopes southeast and northwest of the map-area is broken by a series of long valleys trending northeast which are roughly parallel to the ridge itself. Chief among these is that of the Tomifobia river which is almost as prominent as the Fitch bay-Massawippi lake valley. The southeast ridges section is thus divided into two parts which are subdivided by the parallel valleys into a series of long narrow ridges. These in turn are cut transversely by many valleys which are tributary to the main longitudinal ones. The ridges, though actually ~~while still~~ present are not readily apparent and there seems to be mainly a topography of irregular low hills with no very definite arrangement. In the southwest there are many prominent well-rounded knolls of white granodiorite which give to this area a somewhat different topographic character. 9/10

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Drainage.

The rivers and lakes of the area belong to one drainage system which by way of the St.Francis is tributary to the St.Lawrence. The main trend of water movement is northeast both within the area and as far as Sherbrooke 10 miles beyond (Figure 1). From there it is northwest to the St.Lawrence.

The lakes already described constitute ~~important~~ prominent drainage features. Lovering lake receives its water from only a small basin on the western slope of Bunker hill. It drains south to lake Memphremagog. 10/11 The streams which enter ~~this~~ Memphremagog lake are small and drain a bordering zone which seldom exceeds three miles in width. The outlet of the lake is to the north into the Magog river, which northwest of Katevale ~~this~~ broadens and becomes Little Magog lake into which drain the two streams west of that village. From ~~this~~ there Magog river flows northeast to the St.Francis.

The greater part of the area is in the Lake Massawippi water shed. In this ~~the~~ Tomifobia river constitutes the chief drainage channel. Two important branches of this stream enter the map-area in the southeastern corner, unite to form the main stream and flow west for about six miles. At this point the river makes an abrupt turn and flows northeast to Lake Massawippi. The character of the stream is variable. In the first five miles after entering the map area the main stream (northern branch) has a fall of 200 feet. Stearns Brook (southern branch) in the mile above the junction, and the Tomifobia River for the five miles below the junction, are sluggish with a gradient of only 12 feet to the mile. In the three miles from Stanstead to Beebe the water falls 300 feet. A third of this occurs in a series of rapids and falls at Rock Island, within a few hundred feet. Below this though the current is swift the valley is wide. 11/12 For three miles below Beebe the river meanders in a fairly wide valley bottom with low gradient. Within the next mile it falls 50 feet, developing several rapids. In the last ten miles to the lake it has a gradient of five feet to the mile, and a character similar to that of the section just below Beebe. The Nigger River which joins the Tomifobia near its mouth is the only other large stream in the area. The tributaries of these which flow in a northeast or southwest direction are the longest. They have ~~a~~ fairly low gradients and wide valleys. Other tributaries are short with steep gradients and narrow valleys. Two fairly important large streams which present a crude dendritic pattern enter the southwestern corner of Lake Massawippi. They occupy large valleys and drain a fairly large area. The outlet of Lake Massawippi is to the north into the river of the same name, which enters the St.Francis 10 miles to the northeast. 12/13

The Tomifobia River and Lovering Brook are dammed at a number of points to develop water power for small grist and saw mills.

Industries.

Farming is the most important industry, supporting by far the greatest number of the inhabitants. Quarrying is important in the granodiorite area west of Beebe. There is a little lumbering throughout the area. In Beebe there are a few small factories and one large and several small stone mills. At Rock Island there ~~is~~ are a large machine shop and several small factories. Graniteville is located in the center of the quarrying industry. Georgeville is chiefly a summer resort. In Stanstead is located the college of that name. All these to some extent and the other villages almost entirely owe their existence to the trade from neighboring farms.

Farming.

Nearly all the farms in this district are situated on the crests or slopes of hills. The valleys and low lands are for the most part wooded or swampy. Presumably it is because of the poor drainage in these areas that they have been neglected. Much of the high land also because of its rocky character or abrupt slope is not suitable for cultivation. The surface soil over a great part of the area is a fine clayey sand which seems to be very productive. In most places this is only a few feet thick. Where it is absent glacial drift constitutes the soil.

A large part of the district is wooded with sugar maples, which constitute one of the greatest assets of the farmer. It is said that the annual revenue from the "sugar bush" of many farmers exceeds that from all other sources combined.

The farming might be called mixed though it is really dairying. The farmer's time seems to be divided largely between caring for his cows and growing feed for them. There are small creameries in several towns. These make butter and pasteurize the milk and cream. Their products are shipped mainly to the United States. Also much cream and milk is collected by large motor trucks or along the railway and transported direct across the border. This trade is carried on at a disadvantage to the Canadian farmer as there is a duty on dairy products which he must pay in order to compete with his neighbors in Vermont.

Lumbering.

Lumbering is not very extensive. There are a few small mills throughout the area which cut lumber mainly for local use. Small quantities of pulp wood are cut every year for shipment by rail. The Christmas tree industry has developed to amazingly large proportions. Thousands of small trees are cut during the fall months, bundled together, transported to the railway stations and then sent to the cities of the eastern United States.

Water Supply.

Because most of the streams traverse inhabited areas their water is not potable. The larger towns obtain their water supply from a considerable distance. Springs are numerous in many parts of the area.

They are found in both high and low ground. They have no definite arrangement and are not confined to any particular type of rock. Some, notably those west of the village of Stanstead, appear to be the result of an accumulation of water above a Pleistocene clay bed. The majority however probably owe their origin to faults or fractures. Along the Massawippi fault northeast of the map area springs are very numerous. Browns Hill and the area just east of Fitch Bay seem to be the driest. This is probably due to the nature of the underlying rock - a clacareous sandstone which affords a poor reservoir.

Throughout the area as a rule wells afford a good supply of water. Owing to the nature of the structure the selection of a site for a well must necessarily be random. However a well of reasonable depth ought to yield a good supply of water almost any place in the district except in the areas of granodiorite or of high gravel and morainal deposits.

General Geology.

The Memphremagog area though it has a relief of 1000 feet and some rugged topographical features presents in general only gradual slopes. It has been subjected to intense glaciation which has left the surface of the rock well rounded and smooth, and in practically the whole area heavily covered with drift. Submergences of many parts have contributed much sand and gravel to the superficial material. These accumulations have caused damming and large parts of the area are now covered with lakes. In the valleys streams meander in gravel and sand, rarely cutting through to bedrock. The greater part of the area is heavily wooded with both evergreen and desiduous trees. As a consequence of these features the amount of exposed rock is relatively small and many of the outcrops are obscure. Clearing and cultivation of land and the building of roads with the resultant increased removal of superficial materials have added considerably to the number of outcrops.

The majority of outcrops are small; many constitute only a few square feet of rock exposed in cultivated fields, in ditches or in other places where the soil has been washed away. Such outcrops generally present merely a flat or rounded polished surface. Exceedingly few afford an opportunity to view a vertical section of the rock. Really good outcrops are found only along the shores of Lakes Memphremagog and Massawippi and in cuttings made by a few streams which have been diverted into new channels by the effects of glaciation. On the higher ridges west of the great Bunker valley ~~and~~ at Magoon Point and in the granite area exposures of rock are abundant and extensive but as elsewhere are flat or rounded. 13/14

The Memphremagog area lies in a section of North America which ~~throughout~~ during Paleozoic times was involved in much diastrophism. Hence it is not surprising that the geology, both stratigraphic and structural, is extremely complicated. This feature coupled with the inadequacy of outcrops has made the solving of problems extremely difficult. A more or less uniform northeast-southwest strike and westerly dip indicative of isoclinal folding together with intense metamorphism of all sediments added materially to the difficulty. The age of only the youngest formations was definitely fixed by fossil evidence.

The area is divided by the Fitch Bay -Bunker Brook -Lake Massawippi valley into two distinct parts which so far as geological correlation is concerned might be separated by many miles rather than one narrow valley. It was therefore necessary to treat the two areas as separate units. Only after a complete study of each has it been possible to make a reasonable conjecture about their relationship to one another. 14/15

The geology is so complicated that it was found impossible to correlate sections made across the strike. Such sections, though only a short distance apart, at first seemed to show no apparent reasonable relationship. As a consequence of this it was found necessary to restrict study to one formation at a time. Each was completely mapped, the data concerning it assembled and an exhaustive study made. This principle has been maintained in compiling the report so that each section is restricted so far as possible to a discussion of information gained from one formation. As a consequence there is some repetition especially in the description of the structure. This serves very effectively to emphasize the reasonableness of the deductions in that it is a means of showing that the same conclusions have been reached by separate study of different lots of data.

Many of the igneous masses have been intruded since the last great deformation and were therefore fairly readily mapped. These include Stanstead granodiorite, serpentine, sodium diorite and several groups of dikes, all of which are thought to be of late Devonian age. 15/16

Throughout the area southeast of the Fitch Bay-Bunker Brook valley there is a marked uniformity of material, thus greatly adding to the perplexities already mentioned. A dominance of limestone in one part of the area suggested that a subdivision might be made on this basis but owing to the abundance of similar limestone elsewhere it was not found entirely feasible. All the rocks of this area were therefore grouped in the Tomifobia series. Beyond the general nature of the folding and the character of the material not a great deal of information about the structure or the stratigraphy was gained from this series.

Northeast of the valley several distinct formations are readily recognized. Of these only a limestone series along the shore of Lake Memphremagog was easily outlined and separated from the other formations on a lithological basis. Although of fairly uniform character throughout was found to contain fossils of middle Silurian and middle Devonian age. As two formations were not apparent in the field the separation had to be made on fossil evidence alone. The other formations in this area are older and have been subjected to much more metamorphism and deformation and therefore the outlining of them was very difficult. 16/17

For a long time it seemed impossible to make an adequate subdivision of this complex though it was quite apparent that one should be made. There was much black slate which could be fairly readily differentiated on lithological characteristics but in many places it was so intricately involved with other rock that there seemed to be several slate members. Ells*1 divided the slate into Siluro-Cambrian and Cambrian. Although at the outset this seemed logical no satisfactory solution of the difficulties could be made on such a basis. The slate showed marked differences in character, probably due largely to metamorphism, but very distinct resemblances were also apparent throughout. It was not until all the areas of black slate were outlined that the geology of the area began to become apparent. The inclusion of all the slate in one series - the Memphremagog - then seemed to be a logical conclusion. It is from the study of this series and its relationship to the older rocks that most of the pre-Silurian history and structure of the area was obtained. One poor collection of graptolites had previously established the age of this formation as middle Ordovician.

Having gained some definite idea of the structure it was possible to establish a series of metamorphosed coarse sediments (McConnell) stratigraphically below the Memphremagog series. Its lower contact was outlined by the presence of a coarse basal conglomerate and a general lithologic change. It appears to be a basal member for the Memphremagog series and was therefore thought to be of Ordovician age. The information gained from this series bore out to a remarkable degree the conclusions made from the study of the slate series. On lithologic basis and structural relationships there seem to be some grounds for correlating the Tomifobia series in part with the McConnell and ascribing Ordovician age to it also. 17/18

*1. R.W.Ells. Report on the Geology of a Portion of the Eastern Townships, Part J, Annual Report 1886. Geol. Surv., Can.

Report on a Portion of the Province of Quebec, Part J, Annual Report 1896, Vol.VII. Geol. Surv., Can.

After all these formations were mapped both highly metamorphosed sediments and igneous rocks remained. Masses of the latter though widely scattered were thought to belong to the same intrusive period because of a pronounced similarity in composition. These have been designated as diorite but they probably include both intrusives and extrusives. They are equivalent in age to the lower McConnell series. Owing to their similarity to some of the sediments it has been impossible to separate them out entirely. The metamorphosed sediments therefore include much altered igneous rock. While there are rather distinct differences in the character of the sediments there was nothing to warrant subdividing them. They are called the Bunker series and their age is assumed to be Cambrian. 19

The information about structure and history as gained from each formation is included in the individual sections. Separate chapters on the structure and history as a whole constitute in a general way a summary of these.

The following is a table of the formations:

Table of Formations.

Recent				Gravel, sand and silt, chiefly delta deposits.
Pleistocene				Glacial drift, sand and clay.
		Unconformity		
Devonian	Upper	Basaltic dikes		Hornblende basaltic dikes.
		Dikes		Picrite porphyry. Massawippi dikes - acid diabase & vogesite.
		Serpentine		Chiefly green serpentine, some magnesite-serpentine rock.
		Stanstead Granodiorite		Chiefly granodiorite.
		Sodium Diorite		Intrusives, alaskite to sodium diorite
	Upper	Porphyry		Altered feldspar porphyry
	Middle	Limestone		Metamorphosed limestone, generally arenaceous or argillaceous.
		Unconformity		
Silurian	Middle	Limestone		Metamorphosed limestone, generally arenaceous or argillaceous.
		Unconformity		
Ordovician		Memphremagog Series	Oliver Sandstone	Chiefly sandstone.
			Oliver Slate	Conglomerate, slate and sandstone.
			Slight unconformity	
	Upper Middle } Trenton		Lovering Slate	Black and dark gray slates.
		Slight unconformity		
Ordovician?	?	Tomifobia Series		Black arenaceous limestone and interbedded black slates, argillites and limestone.
	?	McConnell Series		Coarse basal conglomerate, quartzites, grits, quartzitic argillites and slates, and some argillites and slates.
		Diorite		Altered intrusives and extrusives, chiefly diorite.
		Unconformity		
Cambrian?		Bunker series		Quartzites, grits, quartzitic argillites and slates.

Bunker Series.

The Bunker series is the oldest in the Memphremagog area. It includes rocks which have previously been designated as pre-Cambrian and to a lesser extent Siluro-Cambrian and Cambrian. It represents what was left after all the other formations were mapped.

~~Location~~ and Distribution.

The Bunker series is confined in distribution to a narrow strip between Magoon Point Lake Memphremagog and Back Point on Lake Massawippi. It is not continuous throughout this area but is represented mainly by disconnected patches. With the exception of the large area east of Lovering Lake these are all small. In shape they are very irregular but generally elongate in the direction of their distribution.

As all the boundaries represent contacts with overlying formations a detailed description of them will be left to the chapters dealing with the younger series. Suffice it to say here that they are very indefinite known ~~owing~~ to the scarcity of outcrops and their great irregularity, which is the result of several unconformities and of very complicated structure.

Physiography.

The Bunker series is very largely responsible for the prominent ridge which extends from Magoon Point to the northeast, paralleling the great Fitch Bay -Bunker Brook -Lake Massawippi depression. Both these features can be observed to extend for miles beyond the Memphremagog area in approximately the same direction as maintained within it. The series thus occupies nearly all the most prominent hills in the western part of the map area. It is found in very few low places and even then it generally stands up prominently above the younger rocks.

Description.

The Bunker series is mainly sedimentary though there are certain areas now indicated as of this formation which are known to contain much undifferentiated igneous rock. For descriptive purposes the Bunker series may be subdivided into two members. One consists of the very coarse quartzites which are found throughout the greater part of the area and the other of quartzitic slates and argillites which occupy a band west of the quartzite extending from the southern end of Lake Massawippi to ~~within a few miles of Magoon Point.~~ The ~~latter~~ slates seem to be the ~~upper~~ younger of the two members.

The coarse quartzite member is made up almost entirely of rocks very high in quartz. Most of ~~these~~ them are coarse-grained, some so much so as to warrant the name conglomerate. They are either gray or green. 22/23 Some of the coarser phases show a mottling due to the presence of grains of quartz, feldspar and other minerals. Quartz grains in a more or less schistose groundmass give to most of them an augen-like texture. In places there are beds which consist almost entirely of cemented quartz pebbles. These are sometimes well sorted and rounded but generally are unsorted. Many of the quartzites might well be called grits - rocks with large rounded grains of quartz in a fine-grained groundmass. Under the microscope most of these are observed to be made up of rounded grains of quartz in a schistose and brecciated mass of quartz, chlorite, mica and iron oxide. Other minerals found are calcite, magnetite, zircon, apatite, hornblende, epidote, zoisite, feldspar, siderite and pyrite. The quartzites are generally massive but occasionally show poor bedding. They are very resistant to weathering and have a rough surface due to the prominence of the quartz grains. Interbedded in this quartzite series there are also found green chloritic and dark blue-gray slates of various types and other softer and finer-grained rocks.

The ~~series of~~ quartzose slates and argillites, which lie to the west of the quartzites, differ from them mainly in having finer textures. ~~It~~ The series contains a great variety of materials. Most of the beds are hard, com- 23/24 pact and highly quartzose but some are soft and talcose. All appear to be largely crystalline. The color is variable though mainly gray. They often have a pearly, greasy or adamantine luster due to mica, talc or quartz. They are made up of the same minerals as the coarser rocks. They are well bedded and often schistose. Though quite resistant to weathering they are much less so than the quartzite series.

In the northeastern part of the area west of Lake Massawippi the rocks classified as Bunker series, though not exactly similar to either group to the south, in parts bear many resemblances to both. They are mainly hard gray and green quartzose rocks: massive light gray quartzites, bedded quartzites, quartz schists, quartzose argillites and some slates.

At many places in the Bunker series there are very peculiar rocks, particularly adjacent to the main igneous mass south of the Ayers Cliff-Magog road. Here all the rocks appear to have been altered somewhat by the action of the intrusion. There are so many different types of rock that it would be impossible to describe all. Some are massive, green and brown, and rather soft, and appear to be igneous or to grade to igneous. There are many which are very light gray or white and appear 24/25
to have been baked and leached. These are crystalline and show an abundance of calcite, mica and iron minerals which appear to have replaced the dark constituents of the original rock. Much of this in the field appears to be like acid tuffs but under the microscope nothing of this nature was discovered.

Just west of the igneous mass mentioned above there is found a peculiar breccia in which the fragments are white as of a baked and leached quartzite or quartz schist cemented by siderite. Some distance east of the mass is found a dark dense gray rock with lenticular lighter gray inclusions. The differnece in colour appears to be due to the presence in one case of opacite or magnetite and lack of it in the other. The light gray inclusions are probably pebbles of quartz ground to clastic masses and drawn out into lenses.

At many places ~~in this series~~ there is an abundance of iron oxide which is due to the decomposition of siderite and other iron minerals. These are generally found close to igneous masses and it seems probable that they are largely the result of contact metamorphism.

Rocks of this series are all extremely metamorphosed. Megascopically it is impossible to tell whether many are igneous or sediment- 25/26
ary. In the field a larger number appeared to be igneous - intrusive, extrusive and tuffaceous - than was confirmed by microscopic work. Because of this and a similarity of many of these phases to the altered diorite it has been impossible to differentiate accurately between the two. Consequently much igneous rock is included in the Bunker areas.

In practically all the rocks an entirely new suite of minerals is developed except for the fact that quartz, though sometimes r[illegible] recrystallized, remains largely as it was originally deposited. This is particularly true where the quartz is found in a schistose groundmass. The presence of rounded grains of quartz was the one fairly sound criterion of the sedimentary origin of a rock.

Owing to the fact that the Bunker series is a metamorphic complex with innumerable types of rock it has been impossible to describe adequately all phases. An attempt has been made only to give some general idea of the character of the rocks, of the variations, the metamorphism and the complex problems involved in any detailed study.

26/27

Age and Correlation.

Nothing is known of the age of the Bunker series except that it lies below and is separated from the McConnell series by a great unconformity. The McConnell series is assumed to be Ordovician. Because of this and the fact that to the west and southwest there are sediments definitely determined as of Cambrian age it seems reasonable to assign the Bunker series to this age. It has previously been assigned in part to the pre-Cambrian*1. If this is correct it would seem that the Cambrian is absent here. That these rocks are all of the same age has not been definitely determined but no evidence to the contrary was discovered. No attempt was made to correlate them with rocks beyond the area.

Structure.

Because of the massiveness of the greater part of the Bunker series, its limited extent and the inadequacy of outcrops little information about the general structure has been obtained from it. From the age of these rocks it follows that their surface distribution is an indication mainly of the location of anticlines. In this way there is brought out by the distribution along the west side of the great Fitch Bay - Bunker Brook depression the presence of a great anticlinorium (the Bunker) with a northeast-southwest trend. By the distribution north of Magoon Point another (the Magoon) is indicated, extending for only a short distance to the north. The smaller masses are generally indicative of the location of minor anticlines. Their shape gives some suggestion of the trend and nature of these. The discontinuity of these areas is suggestive of cross folds and structure developed previous to that represented

27/28

*1. Ells' reports.

by the main northeast-southwest trends.

The strike of these strata is mainly nearly parallel to the general axial trend of the main Bunker anticlinorium. The dip is steep, to the west. As is clearly shown in the upper formations ~~but~~ and only vaguely here, this uniformity of strike and dip is indicative of isoclinally folded strata rather than of one continuous section. Though there is no place in the Bunker series where this type of structure is well exposed there is sufficient evidence to show that it is present. The information gained by studying the relationship of the series to younger formations confirms this. Though the Bunker rocks are the most resistant in the area they seem to have undergone the same intense isoclinal folding as the less resistant.

The majority of drag folds found here like those in younger formations indicate that the beds are overturned. Cleavage and schistosity are present, even in some of the more resistant quartzites. They generally show a dip and strike approximately the same as that of the bedding. Owing to their uniformity the cleavage and drag folds are of little value in working out detailed structure, for they are clearly not indicative of a continuous overturned section. This feature will be more fully discussed later.

28/29

The two members of the Bunker series previously described suggest by their distribution that these rocks had been deformed prior to the deposition of the McConnell series, as the latter rests in part on both members. The presence of a great unconformity between these two series as indicated by other features supports this suggestion. If the quartzite member is the older as seems to be likely, the strata in the Bunker hill area dipped northwest during the deposition of the McConnell series.

The information gained from the Bunker series alone is very vague. However there is sufficient to show that it has been affected to the same extent as other formations by post-McConnell deformations and was probably also involved in pre-McConnell folding. Many suggestions about the structure are forthcoming from a study of the Bunker series but none takes very definite shape without supplementary information from other formations. Therefore most of these suggestions will be dealt with later.

29/30

Thickness.

No very definite idea of the thickness of the Bunker series was obtained. There is no indication of its base and the structure is too vague to permit of an accurate estimate. A rough guess would place the thickness of the strata exposed between 3000 and 5000 feet.

History.

The oldest rocks in the area are probably the coarse quartzites and fine conglomerates of the Bunker series. These represent near-shore conditions. No indication of the source of this material was observed. During the early stages of deposition of the Bunker series fairly rapid erosion must have been taking place near at hand to supply the great thicknesses of coarse material. This was followed by a period during which finer materials were laid down - the result either of deepening seas or decreased erosion nearby. Sedimentation then ceased and was followed by a period of deformation, uplift and great erosion, as is indicated by the presence of a great unconformity between the Bunker and overlying series.

McConnell Series.

The McConnell series is a new subdivision of the strata in the Memphremagog area. It includes parts of what was previously designated pre-Cambrian, Cambrian and Siluro-Cambrian. The name "McConnell" was chosen because the formation is well developed near the locality of that name. The series is made up almost entirely of metamorphosed conglomerates and sandstones and coarse argillites. It lies above the Bunker series and below the Memphremagog.

Location and Distribution.

In general the McConnell series lies in an irregular somewhat discontinuous narrow band which stretches from the road east of Belmere Point to the bend in Lake Massawippi. In the northern part of the area there are many inclusions in the younger Memphremagog series. These have a linear arrangement with a trend approximately at right angles to the general strike of the formation. Northeast of Magoon Point there is another series of masses which assume a nearly north-south trend. Besides these there are many small outliers and inclusions, a few of the larger and more important of which are shown on the map.

The upper contact is mainly a lithological division. It is extremely irregular, and as a consequence of this and of poor facilities for observation it is very indefinitely located (for a full description see <u>Memphremagog Series</u>). The lower contact is marked by a pronounced unconformity as well as a lithologic change. In many places its position is indicated by a very coarse basal conglomerate. However owing to the complex structure, great metamorphism and the poor exposures of the strata both above and below the contact its location is seldom definite and its trend is never apparent for more than a few feet. Accordingly the boundary everywhere is indicated as assumed.

31/32

Physiography.

The rocks of the McConnell series are found largely on the western side of the Magoon-Bunker ridge. They occur on the slopes of the larger hills and on the crests of the majority of small hills to the west. Throughout the area to the north and west lines drawn around the base of the hills would represent in a rough way the boundary between the McConnell and Memphremagog series. The former is made up of more resistant rocks than the latter, but of less resistant than the Bunker series. Consequently where the two younger formations alone are present the rocks of the McConnell series assume a prominence which is considerably dwarfed in the presence of the Bunker series.

Description.

32/33

The McConnell series is made up almost entirely of coarse clastics - in fact it is separated from the Memphremagog series largely on this basis. The rocks vary from coarse basal conglomerates with bowlders up to three feet in diameter to quartzitic argillites and even fine-grained slates.

The basal conglomerate is well exposed just south of McConnell. It can be traced for several miles to the southwest; is observed again just east of the southern end of Lovering Lake, and traced more or less intermittently to Magoon Point. It outcrops at many places, most of which are indicated on the map. It is variable, depending largely on the character of the underlying rock. The matrix is generally metamorphosed arenaceous material of the type found in the overlying beds. In some places it is slaty, more particularly so where it is overlain directly by the Memphremagog slate. In such places the conglomerate is more truly the basal member of the Memphremagog series.

The bowlders in the conglomerate are largely of the underlying rock, apparently having been transported no very great distance. South of McConnell there is a predominance of quartzite similar to that found in the Bunker series nearby. Also with these there are bowlders of various kinds of slates and quartzitic and cherty argillites. In one place bowlders of limestone were observed and in another a few of granite-like igneous rock. All except the last two bore some resemblance to rocks of the Bunker series. The limestone was somewhat similar to that east of Bunker Creek. Nothing similar to the igneous rock was found. While at no place bowlders definitely from the igneous masses to the east were found, one specimen examined microscopically showed clastic sediment on igneous rock.

33/34

North of the village of Fitch Bay the bowlders are of quartz, quartzite and other materials similar to those in the lower series.

Just north of the town there are conglomerate-like rocks which contain an abundance of bowlders of igneous rock similar to that found nearby. These are closely associated with rock which appears to have typical bolster structure. On microscopic examination the material between the bolsters was found to be sedimentary in character. While this does not necessarily preclude the igneous origin of these rocks it seems to suggest, together with other characteristics, that there are present both pillow lavas and conglomerates derived from them.

In the southern section greenstone or igneous rock is abundant in the conglomerate as are quartzites and other coarse metamorphics of the series below. Also there are bowlders of fine blue-gray slate and lighter gray quartzitic and cherty argillites. At one place there was observed a fine-grained granitic rock and a bowlder which had weathered entirely to quartz and iron oxide.

The conglomerate is highly metamorphosed. Bowlders are greatly squeezed, rendered schistose and even drawn out into drag folds. The rock is often so highly altered that its original character is not apparent and bowlders cannot be assigned to a definite source. The mineralogical change in these rocks is similar to that in the finer-grained materials overlying and underlying them.

Above the conglomerate in most localities there is a rather thick series of impure quartzites, metamorphosed sandstones and grits. These vary greatly in all characteristics. They are generally of a light brown to gray color mottled with white, brown, black and purple. The mottling is rather a distinctive feature of this series. The size, sorting and shape of the grains are extremely variable. The texture varies with these and also with the type of materials present. There are dense quartzites, almost entirely quartz (these are rare), and schistose grits where the quartz is in isolated grains among other minerals. In such the grains seem to have been protected by the softer minerals surrounding them and often retain their original rounded or angular shape. From beds originally with a large percentage of argillaceous material there have been developed grit slates peculiarly blotched dark and light gray. The hardness varies largely with the quartz content: the more abundant the quartz the harder the rock. However a uniformity of composition and sorting seems to be important in the development of resistant rocks.

The unsorted admixture of quartz and argillaceous material in many cases developed a more or less friable rock.

These metamorphosed grits and sandstones occur throughout the series, in general decreasing in importance upward. Interbedded with them is a great variety of quartzites, argillites and slates. These show all variations and gradations, from the coarse materials previously described to the dense black slates of the Memphremagog series. Their color is gray, green, brown or yellow, generally light. They are both compact and granular, generally hard and resistant. Some of them, due to the development of mica or the fracturing and recrystallization of quartz, show many bright sparkling surfaces. Others present a cherty, amorphous appearance. 36/37

The rocks of the McConnell series are as variable in composition as in other characteristics. Quartz is the only mineral which can be recognized megascopically. In many of the coarser beds the quartz grains, angular and rounded, stand out prominently in a schistose groundmass. In the main the beds are not calcareous but a few are, some abundantly so. Just west of the southern end of lake Massawippi and near the headwaters of McConnell creek (southeast of the lake Massawippi - Bunker Brook valley) there are found arenaceous limestones somewhat similar to those in the Tomifobia series. Microscopically the rocks of the series are seen to be ~~made up of~~ a schistose brecciated mass, largely quartz, with mica, chlorite, hornblende, magnetite and other iron oxides. Other minerals present in small quantities are calcite, leucoxene, zircon, apatite, rutile, epidote, zoisite, feldspar and siderite. The quartz is generally either clastic or recrystallized, though frequently it retains its original character as rounded or angular grains. The other minerals constitute a badly sheared and schistose matrix.

The rocks are all intensely metamorphosed. With, in general, the exception of quartz, an entirely new suite of minerals has been developed. Iron oxides are abundant. Minute spotting in red, brown and yellow is very common. Often large brown spots as of decomposed siderite, common in the Memphremagog series, are found here. In the northern part of the area there are found many very rusty beds which appear to be in contact with dikes. They probably have been altered as a consequence of this and because of the resultant increase in iron content weather very rusty. 37/38

In the coarser basal rocks bedding is seldom noted but in the higher beds it is quite pronounced due to the numerous color and textural changes. Cleavage is rarely noted but the lower beds are generally quite schistose.

The rocks of this series throughout are generally fairly resistant to weathering. Some of the coarser materials however exfoliate or break fairly readily into nodule-like masses. The finer-grained materials as a rule are less resistant than the coarse.

Much of this series, including slates, argillites, quartzites and altered sandstones, does not differ greatly from some of the Bunker rocks. Both have been so highly metamorphosed that it is often difficult to differentiate between them.

38/39

Age and Correlation.

So far as it is known no fossils have ever been found in the McConnell series nor is it likely that any will be. The type of material is largely unsuitable for their preservation and the rock too highly metamorphosed. The McConnell lies below the Memphremagog series which has been established as of middle and upper Trenton age. These two may be separated by an unconformity but this probably does not represent a major division. It is thought that the McConnell series belongs to the same period - Ordovician - as the Memphremagog. It is younger than the Bunker series and is separated from it by a great unconformity. The series has been correlated only with the Tomifobia (cf.id.). No other correlations were attempted.

Structure.

In general the structure of the McConnell series is monoclinal due to the limitation of its distribution to the west side of the main Bunker anticlinorium. West of the southern part of Lake Massawippi the series passes over and occurs on both sides of the anticlinal axis. Northeast of Magoon Point a small mass occupies the trough of a syncline between two important anticlines. In the southern section there are many isolated outliers and inclusions while to the northwest the latter are very abundant. On the east side of the anticline there are only a few small isolated masses which may belong to the McConnell series.

The strike of the strata as observed is generally between N 20° E and N 50° E, and the dip is steep westerly. Though this is maintained throughout the area it does not indicate simple structure. As in the Bunker series and in younger formations the structure is very complicated and the strata are isoclinally folded. Hence the strike and dip while indicating some structural features tend to conceal many others.

In certain localities there are features which show the type of structure. At the top of the western slope of the hill between the village of Fitch Bay and Georgeville the McConnell -Bunker series contact is fairly easily followed in many places. Just south of the group of three houses on the road long narrow bands of conglomerate can be seen. Clearly they do not extend to the south but are cut off abruptly in that direction. They are not thick here but plunge to the north and appear like huge bowlders protruding out of the drift. Between these there are many sharp minor anticlines in the Bunker formation which plunge north at about 30 degrees. West of this the irregular nature of the contact as mapped due to similar folds plunging in either direction can be observed. These features clearly show that the strata are involved in a series of isoclinal folds which are variable in size and plunge. The structure observed in a fairly good cross section of the strata exposed on the creek to the south and that deduced from a study of drag folds and repetition of strata on the Georgeville-Fitch Bay road confirm these conclusions.

At many other localities the same type of structure was observed. The strata are everywhere isoclinally folded as in the Bunker series. The folds are of all sizes from those of a few feet to the major structures. They plunge and pinch out in a most erratic manner. Owing to this extreme complexity very little of the detailed structure could be worked out. The inferences drawn from drag folds are not very valuable as no idea of the extent of strata to which they are applicable could be obtained. That is to say that if the attitude of the beds is known in one place it will give little indication of the attitude in other places only a few feet away. By far the greater majority of drag folds indicate that the strata are overturned. Along the Ayers Cliff-Magog road this relationship is indiacted fairly continuously as far as the cross road about three miles west of the lake.

Cleavage appears to be fairly uniform throughout the area and is mainly nearly parallel to the bedding. It is probably regional and is of little value other than to indicate general axial trends.

The distribution of the formation and the conglomerate at its base form the most reliable clues to the structure. There is the general distribution in a northeast-southwest strip which indicates the monoclinal structure with westerly dip previously mentioned. The linear arrangement of the isolated masses in the northern part of the sheet indicates the crests of a number of ancient anticlines - structures which are described more fully under the Memphremagog Series. Also the irregular distribution of the formation and its basal conglomerate confirm to a remarkable degree the structure worked out from the features observed in the Memphremagog series and described under that heading.

In the southern part of the area the inconsistent distribution of both the formation and its basal conglomerate with reference to the Memphremagog series gives some intimation of an erosional period between the two series. Also there seems to be some slight indication in the features observed that the erosion was preceded by folding.

The turning of the strike, contortions, drag folds and other features at the north end of the main Bunker Hill igneous mass seem to indicate that this series was involved in doming due to the intrusion.

Thickness.

The thickness of the McConnell series is extremely variable. Its greatest development seems to be near McConnell where it probably does not exceed 2000 or 3000 feet. In most places it is represented by only a few hundred feet.

Relationship to Older Formations.

The McConnell clearly overlies the Bunker series unconformably. The base of the former is represented everywhere by a very coarse conglomerate made up of materials from the lower formation. The boulders contained vary greatly from place to place as the conglomerate is found overlying different parts of the Bunker series. This latter feature would seem to indicate that the unconformity is angular and very great.

The surface on which the McConnell series was laid down was extremely irregular as indicated by the spotty distribution and the great and abrupt variations in the thickness of the series. On the Fitch Bay-Georgeville road at one place basal conglomerate can be observed within a few feet of the Memphremagog series while at another not far away there is clearly quite a thickness of strata intervening. The series is by no means continuous under the Memphremagog slate. While these features may in part be the result of erosion between the two series they are undoubtedly also the result of an original irregular distribution which left great areas uncovered.

History.

Deposition of the McConnell series was preceded by a period of deformation and much erosion. This left an extremely irregular land surface. Submergence began northwest of the southern end of Lake Massawippi. Deposition of coarse conglomerates and sandstones took place in this part of the area and slowly progressed to the southwest while the area to the south between Bunker hill and Whetstone island remained as land and possibly was the source of much of the material which went to make up the McConnell series.

During this progressive overlap of the land and before it had encompassed those areas south of Fitch Bay village there was a period of igneous activity. Throughout the north there were intrusions, the major of which caused a doming of the strata. Dykes are known to cut the lower beds of the McConnell series as far south as Lovering Lake. Beyond this it is possible that the igneous activity assumed the form of extrusives. At least the igneous masses were so near the surface as to permit erosion to remove the overlying material and expose them, so that boulders of this material were included in the basal conglomerate of the southern area.

Overlapping proceeded until sediments were continuous along the north side of the ridge. Apparently extensive bays penetrated farther south at several points and the distribution of water was quite irregular. Following this there seems to have been a slight deformation with increased erosion. This may not have been very extensive and probably was not very important.

Diorite.

Under this name are grouped a large number of areas of highly metamorphosed igneous rock. The majority of these are similar in composition and appear to be largely altered diorite. They are confined to the area immediately west of the Fitch Bay-Bunker Brook valley in which they are scattered promiscuously from McConnell to Magoon Point. To the south the strip within which they are found widens to include almost the whole width of the peninsula between Fitch Bay and the lake.

Because of the similarity of the highly metamorphosed igneous and sedimentary rock in the field, the gradation between these, the intricate structure and complex boundaries it has been impossible to map at all accurately the areas of diorite. Only masses which were more or less definitely recognized as igneous and the extent of which was somewhat accurately known have been outlined. In many parts where information is inadequate the igneous rock has not been mapped, notably in the 45/46 areas of the Bunker series east and southeast of Belmere Point and northeast of the village of Fitch Bay, and in the McConnell series lying to the east of McConnell. Also in some areas designated igneous there is much undifferentiated sedimentary rock, especially near Fitch Bay village and immediately west of Fitch Bay.

As these rocks are associated with the older more resistant rocks they do not in themselves stand out prominently. Where observed in contact with rocks of the Bunker or McConnell series their presence is not indicated by pronounced topographic features. However where associated with the overlying Memphremagog slate, as in the case of the other older rocks, the diorite is generally found in prominent hills. Thus the masses in the southeast which are surrounded by slate constitute a series of ridges extending to the limit of Whetstone Island, and the exposure north of Fitch Bay village occupies a prominent hill.

Description.

A complete description of the rocks included in this group would involve very many separate descriptions, for the rock is so extremely variable that two specimens are seldom alike. It is probable that the masses are not all of the same age nor of the same character; some being extrusives while others are intrusives. Besides the difference in origin there are wide differences in nearly every phase. The greater majority of the specimens examined fall within approximately the same mineralogical classification and under the microscope appear to be about equally metamorphosed. These are the most important similarities and largely form the basis for the present grouping.

Most of the rocks of this group have the appearance of metamorphosed igneous rocks. However this is also a common feature of the adjacent sediments. Green is the predominant color though there are variations from the light gray or brown of the mass north of McConnell to the black found west of Fitch Bay. The rock on Bunker Hill shows many peculiar mottlings of green and white. Striping parallel to the schistosity is not uncommon. In the north there are found very soft shale-like phases. Some of the green schists are talcose while non-schistose phases are quite hard. The texture is extremely variable. Many outcrops particularly in the north show a dense shale-like rock. Porphyritic texture with large white phenocrysts in a green groundmass is found in many places. Some of the rocks, particularly the black phases, look like typical medium to coarse-grained diorites or even more basic rocks. The rocks in the north are commonly medium to coarse-grained while in the south they are fine-grained, only one specimen (163 -Figure 2) showing a texture comparable in coarseness to those in the north. Schistosity is generally quite pronounced and gneissic structure is sometimes observed. In a few places the rock appears quite fresh. Many peculiar textures were noted. In the main Bunker mass there is much material which shows an augen texture with lenses about one inch long and half an inch wide. South of this the rock shows peculiar rounded segregations of white feldspar in a green schistose groundmass. The segregations are as much as two or three inches in diameter and appear to be partly the result of metamorphism.

Under the microscope all specimens were observed to be much sheared, cataclastic and greatly metamorphosed. There is a more marked resemblance when they are examined thus than is apparent megascopically. The great alterations make it difficult to determine their original texture or composition. The majority appear to have been fine to coarse hypautomorphic granular - some still retain a little of this texture. Many are porphyritic, some tracytoid or bostonitic. One was slightly suggestive of a tuff. The composition of these rocks is largely secondary. Chlorite, calcite and other less abundant minerals as iron oxides make determination of the original constituents very difficult. These, while definitely detemined in some slides, were only deduced in many. Of the twentyseven specimens examined one (164) is a biotite quartz porphyry (porphyritic); one (218) was a bostonite; two (262,268) are soda tonalites, and the rest are diorites or diorite porphyries. The plagioclase feldspar is albite-oligoclase in one specimen (218), oligoclase-albite in three(262,268,286), oligoclase in one (252), and andesine in all the rest except a few in which no definite determinations could be made. Orthoclase feldspar was recognized in four specimens and thought to occur in a few others. Quartz in small quantities occurs in about half the specimens. In the quartz porphyry (164) there is 37% quartz. Hornblende probably occurs in all specimens, varying in quantity from less than 1% to 40%. In many it is now entirely altered. No new ¶ Accessory minerals are apatite, magnetite up to 10%, zircon, ilmenite, titaniferous magnetite, muscovite(rare), pyrrhotite and rutile(each in one). Alteration of the original constituents is almost complete: the feldspars have gone over to calcite, kaolin, white mica, epidote and zoisite, and the hornblende to chlorite. Siderite, leucoxene, pyrite and iron oxides are quite common. Other secondary minerals are actinolite(important in some specimens), quartz and biotite.

The texture and composition of most of the specimens seems to indicate that the rocks are plutonic. Some (145 and others) were as much sedimentary in appearance as igneous. A few though very similar to others definitely determined as igneous were clearly sedimentary and one (258) was part sedimentary and part igneous. Two (212, 155) showed some slight resemblance to tuffs. There was nothing which indicated definitely that any of the rock was of extrusive origin.

On the hill north of Fitch Bay village and south of this at several points there are surfaces which appear to show typical bolster structure. Pillow-shaped masses ranging in size from a few inches to three and four feet long are packed in the usual way with each one fitting a space between others. They are separated only by a thin film generally about one inch thick and of a somewhat different color. A specimen taken from this when examined under the microscope showed rounded grains of quartz in a schistose groundmass, like clastic sediment. The bolsters would seem to indicate an extrusive origin. However the presence of similar rock which is definitely conglomerate and the sedimentary film throw some slight doubt on this interpretation.

The main mass on Bunker Hill is cut by veins of quartz and green chlorite. The latter occurs sometimes irregularly through the quartz or igneous rock itself, in masses which appear to be largely flaky chlorite. In places the igneous rock is cut by veins of hard light green material.

Associated Dikes.

In the northern part of the area there are a large number of dikes which cut the lower part of the McConnell and the Bunker series. These resemble very much phases of the diorite, particularly the most northern mass. They are usually accompanied by very rusty rock which is probably an altered contact phase such as is often found near the main masses. The dike material is dense, light gray to brown, but generally so rusty that its original character is completely obscured. One specimen (232) from a dike was examined microscopically. It seems to be a metamorphosed porphyry with phenocrysts of feldspar now entirely altered to white mica, in a cryptocrystalline groundmass. No primary minerals were determined except quartz. Secondary minerals are mica, calcite, chlorite, brown iron oxide, zoisite and leucoxene. These dikes so closely resemble and are so closely associated with the diorite masses that there is little doubt that they are the result of the same intrusion. No similar dikes were observed south of Lovering Lake.

Contact Relationships.

The contact of the diorite with the sedimentary rock is seldom very clearly defined. Both rocks are very badly sheared, metamorphosed and often intermixed. In the south the igneous rock is found largely in contact with slate. Here as a rule there seems to be a gradation from one to the other: the sedimentary rests on and is derived largely from the igneous. In many places the rock at the contact is quite rusty. A coarse conglomerate which contains bowlders of the diorite is sometimes found at the base of the slate. This relationship is also found 51 at the base of the McConnell series in the southern part of the area 52 only.

On Bunker Hill the contact in a few places is sharp. The igneous rock is found in direct contact with a white slate. The former shows a gradation from coarse to fine texture toward the contact. The slate is white and appears to have assumed this color through alteration. However in most places the contact is not clear and it is difficult to tell where igneous rock ends and sedimentary begins.

Contact Metamorphism.

Throughout the northern part of the area sedimentaries found in contact with the diorite appear to be much metamorphosed. The most outstanding alteration seems to be a whitening of the rocks. Near the contact they are mainly light gray or white, presenting a baked or leached appearance. On microscopic examination these are found to be mainly quartz. Some show a development of calcite and pyrite. The rock appears to be more highly rust-spotted or ochre-spotted near the intrusives. Adjacent slates contain masses of green chlorite and quartz as found in the igneous rock. Metamorphism seems to have been effective for some distance. However owing to the great amount of dynamic metamorphism which all these rocks have undergone it is difficult to evaluate fully the effect of contact metamorphism. 52 53

Native Character of the Rock.

On Bunker Hill the nature of the material, its texture, the general relationships at the contact, the apparent contact metamorphism and the presence of dikes seem to indicate clearly an intrusive origin. South of Fitch Bay village the bolster structure, the fine-grained texture, the absence of dikes, the distribution of the rock and its inclusion as bowlders in the basal McConnell suggest an extrusive origin. Microscopic examination did not definitely confirm this, but tended rather to indicate that the specimens examined were intrusive. It seems probable that while in the north the rock was intrusive in the lower McConnell and Bunker series, in the south it was both extrusive and intrusive. No place where the rock is exposed now was far below the surface at the time of intrusion, which helps to explain the great variation in the character and composition of the rock.

Age.

While there is no definite proof that all these diorite masses belong to the same intrusive period this nevertheless seems to be a reasonable conclusion. However the variations in plagioclase feldspar ~~probably~~ may indicate that there was more than one intrusion.

In the north the intrusions seem to cut and dome the McConnell series. In the south bowlders of diorite are included in the basal conglomerate of the same series. As the McConnell series represents a progressive overlap from the north to the south this relationship would indicate that while material was being deposited in the north and before deposition began in the south the diorite was intruded. It cut the McConnell series rocks already deposited but farther to the south cut only rocks of the Bunker series and there also appears to have flowed out over the surface. These features would indicate an age equivalent to that of the lower or middle McConnell. Everywhere the Memphremagog series appears to overlie the diorite unconformably. Clearly the diorite masses have been involved in much folding and show somewhat the same structural features as the Bunker and McConnell series.

Tomifobia Series.

The southeastern half of the map area, except for the granodiorite and dikes, is underlain entirely by rocks of the Tomifobia*1 series. This section of the map area is cut off from that to the northwest by the great drift and water-filled Fitch Bay -Bunker Brook -Lake Massawippi valley. At no place along this depression do outcrops on either side occur closer to one another than 1500 feet. So far as correlation of geological features across this line is concerned the two areas might be separated by many miles instead of one narrow valley. Except for the general type of structure there is little in common between the two areas. For this reason the southeastern section is here treated as a separate unit.

Boundaries and Extent of the Series.

One boundary, the Fitch Bay -Bunker Brook -Lake Massawippi depression, has already been mentioned. To the south the formation extends beyond the map area into Vermont. No information about its extent in that direction was available. To the east and northeast it extends for at least some considerable distance beyond the map area with a continuation of the same features as are found within. Ells*2 shows this formation as very extensive throughout southeastern Quebec.

Physiography.

In general the topography of the area is that of well-rounded hills. There is a gradual rise of the whole from the Fitch Bay -Bunker Brook depression to the southeast, where a maximum elevation of 1000 feet above Lake Massawippi is reached. The area is crossed by a series of prominent physiographic features parallel to the northwestern boundary of this section. They include the great valleys of Fitch Bay -Bunker Brook and the Tomifobia River; the less pronounced valleys of tributaries such as that which extends from Harvey Bay almost to Ayers Cliff 55/56

*1. Tomifobia is a local name used to designate what was previously included under the general heading "Siluro-Cambrian."

*2. Map of a Portion of the Province of Quebec, 1887, and Province of Quebec (Montreal Sheet), 1896.

and that from west of Judge Mills to the Nigger River, and two other valleys in the southeast corner marked by tributaries of the Tomifobia. Also several ridges indicated by the position of some of the more important highways and other roads constitute part of this system of parallels.

The exposures of rock are very poor - as a rule in patches of only a few square feet. On Lake Massawippi and Lake Memphremagog and at a few other places scattered through the area there are short sections of the strata exposed.

Subdivision.

Owing to the similarity of the character of the material, the absence of definite horizons and fossils, and the complicated structure of the area it was impossible to make any definite map subdivisions of the series. However on lithological characteristics of the strata the 56/57 area may be divided vaguely into two sections. The boundary between these would be a very irregular serrate line (similar to those farther west) from Bullis Point to Burrows Falls (at the main highway crossing of the Nigger River). Northwest of such a boundary the rocks are almost entirely limestone while to the southeast there are calcareous strata of the same type interbedded with non-calcareous. Whether this boundary represents a geological contact or is due to a lateral variation it was not possible to discover. However the structure, as will be shown later, seems to favor the former. Such a boundary could never be very definitely located and outliers could not be easily identified as such.

Description of Rocks of the Two Sections.

The rock throughout the northeastern section is essentially a limestone. It is at no place very pure though some of it was previously used to make lime. Most of it is arenaceous and the rest argillaceous. In color it is light brownish gray to dark gray. Sometimes it is banded black and white but generally the color is fairly uniform. In texture the arenaceous limestone due to the quartz is granular - medium to fine - while a very little can be considered coarse. Much of this material shows innumerable small sparkling surfaces due to the presence of quartz grains. Crystalline calcite also adds to the brilliance while mica sometimes gives the rock a silvery surface.

Megascopic examination shows the composition to be mainly calcite and quartz. Pyrite in small cubes is sometimes found. The specimens examined microscopically contained from 50 to 75% calcite, 25 to 50% quartz and very small quantities of carbonaceous material, magnetite, white mica, biotite, red and brown iron oxides and pyrite.

Under the microscope all specimens showed a linear arrangement of the constituents. The minerals are entirely recrystallized. White bands are made up of recrystallized quartz with some calcite, and darker bands of calcite, carbonaceous material and other minerals. Some specimens from which the calcite has been dissolved by weathering are entirely an ochrous quartz. This mineral was in minute angular pieces, 90% of which passed through 100 mesh and the remainder through 80 mesh. This indicates the cataclastic nature of the quartz content. Clearly the rock has suffered great dynamic metamorphism which developed new minerals and a somewhat gneissic texture and ground the quartz very fine.

On weathering the calcite is dissolved out leaving a rotten arenaceous mass. This varies in color from black to yellow according to the relative proportions of carbonaceous material and iron oxides. In one place the decomposition powder is such that it has been used for yellow paint, the iron oxide providing the coloring and finely ground quartz acting as a filler.

Wherever the rocks are well exposed they are seen to be bedded. The beds vary considerably in thickness from a few inches to several feet. Very fine banding of the constituents as described above is prevalent but whether this is due to original deposition or metamorphism could not be determined.

In the southeastern section the rocks vary much more in character than those to the northwest. Limestone of the type found in the latter is very abundant. From this there are variations to a quite pure limestone, to slates, schists and quartzites. As a rule calcareous and non-calcareous rocks are found interbedded. The latter are seldom found alone but the former often are.

The slates are generally black, rarely brown or gray. They are compact and fine-grained, and both hard and soft. They generally have a dull earthy appearance; some however have a luster like that of graphite;

others like bright silvery mica. Some have a well-developed cleavage; others have none and are truly argillites. Pyrite is usually present, sometimes as drawn-out slivers but commonly as cubes with a maximum thickness of one inch. An abundance of biotite flakes is found in some of the hard argillites. Many of the rocks are minutely ochre-spotted similar to those in the McConnell series. - Start here. 59 60

Microscopically they are largely mica (white and biotite) with chlorite (hornblende), carbonaceous material, quartz, calcite, zoisite, magnetite and pyrite. These comprise a new suite of minerals developed by metamorphism. Some specimens show a rough linear arrangement of the constituents.

None of the quartzites in the Tomifobia series are pure. All contain a percentage of argillaceous or calcareous material or both. All are fine to medium-grained. In only very few specimens were grains of one-eighth inch in diameter observed. The texture is as a rule very uniform though in a few specimens large grains of quartz were found in a finer-grained groundmass. In these the larger grains sometimes retain their original form, though quartz is usually recrystallized. In most respects the impure quartzites resemble the arenaceous limestones or slates.

The schists though not very abundant show a great variation in constituents and characteristics. They represent rocks intermediate in composition between the three main types. They include quartz, mica, chlorite and graphite schists.

This series is much better bedded than that to the northwest-at least the beds, being of different materials, stand out more prominently. Schistosity varies with the quartz and calcite content: the higher this is the less schistose the rock, except that in the slates cleavage is developed. No new ¶. 60 61

The rocks of ~~the Tomifobia series~~ have undergone intense metamorphism. This seems to be largely dynamic though some may be due to contact with intrusives. No new ¶.

~~The rocks of this series~~ They weather less readily than those to the northwest for with the increase of argillaceous and arenaceous content they become more resistant. The large iron content gives many a rusty appearance.

Age and Correlation.

At several places along the shore of Lake Memphremagog the limestone contains nodules. These were thought to be fossiliferous but none could be definitely determined as such. Ells*1 designated these beds as of Siluro-Cambrian age from their relationship to the Silurian at North Hatley*2 and their fossil content (collections made near that village were studied microscopically and then compared with determinable collections made elsewhere). However this cannot be considered as fixing the age very definitely.

Within the map area there are a few features which give some clue to the age and stratigraphic position of this formation. Certainly it bears no resemblance to the Bunker series and seems to be fairly deinitely younger than that formation. Also its metamorphism, lithology and structure seem to indicate clearly that it is older than the Silurian. Deductions on this basis seem to be in agreement with the conclu- 61/62 sions made by Ells, that the formation lies between the Cambrian and Silurian and is therefore of Ordovician age. Further it is to the formations which represent this interval that it bears some resemblance lithologically, structurally and in extent of metamorphism.

In the McConnell series, as previously stated, there are a few limestone beds which resemble very closely those found in the northwestern section of the Tomifobia area. Northwest of the southern end of Lake Massawippi in the same series there are bedded slates and limestones which are similar to those found in the southeastern section. The pyrite-bearing slates (Memphremagog series) of MacPherson Bay Brook are of the same type as those found in Rock Island canyon. These are the most out-outstanding lithological similarities that the Tomifobia series bears, first, to the McConnell, and second to the Memphremagog series. The detailed structure of these three series seems to indicate that all have suffered about the same amount of deformation. The one suggested geological boundary in the Tomifobia series, that between the bedded slates and limestone and the limestone, shows about the same trend as a series of ancient structures on the west side of Bunker valley (see Structure-Memphremagog series). The metamorphism of the strata of these series 62/63

*1. Ells, R.W. Report on the Geology of a Portion of the Eastern Townships. Annual Report, 1886. P. 211J.

*2. At the northern end of Lake Massawippi.

including the development of ochre and rust spots - a feature not noted in the Silurian and Devonian rocks - seems to be of about the same degree of intensity. All these features tend to indicate that the Tomifobia series correlates with the Memphremagog and McConnell and therefore confirm the conclusion previously made that its age is Ordovician.

A more definite correlation can be deduced. However in order to understand why it is possible to suggest the following relationships for formations which, though very close geographically, are so different in thickness and lithology, it is necessary to assume that a thrust fault of considerable displacement separates them. The two upper members of the Memphremagog series (Oliver slate and sandstone) are of a character which suggests little resemblance to the Tomifobia series. The lower member (Lovering slate), in the absence of calcareous and scarcity of arenaceous materials, does not seem to correlate well with a series which everywhere shows much arenaceous limestone. Further, at the base of the slate in ~~many~~ several places the conglomerate contains limestone which, though not exactly similar is somewhat suggestive of that in the Tomifobia series. These features would indicate that a correlation with the Memphremagog series is not very feasible.

The coarse-textured materials of the McConnell series together with the presence of carbonates throughout strongly suggest the possibility of its correlation with the Tomifobia series. The former represents near-shore conditions while the latter is the result of deeper-water deposition - the two having been separated originally by a much greater distance than at present. However it is thought that the Tomifobia series represents a greater expanse of time, and corresponds in part to the McConnell series and is in part older.

Structure.

The description of the structure in the southeastern part of the map area can best be accomplished in two sections, one to deal with those areas in which the rocks have not been affected by the intrusion of the granodiorite and another to include those in which they have. The former will be taken up first and the general statements made will refer only to the areas unaffected by intrusion.

In general the structure of the Tomifobia series is very similar to that found in the older rocks west of the Bunker Brook -Fitch Bay valley. Strikes throughout the whole area, excepting, as previously stated, that part affected by intrusion of the granodiorite, average between N 30° E and N 40° E. In the southern two or three miles the strike swings to nearly due north at the southern limit. To the northeast around the southern end of Lake Massawippi the strike swings more easterly to N 60° -70° E and near the limit of the map swings back again to N 30° - 40° E. The dip throughout the greater part of the area is between 40° and 60° west. In the southeastern part of the area the dip is lowest, probably in places averaging less than 45°. Northwest across the strike it increases until at Bunker Brook it is about 70°. Along the international boundary it is generally nearly vertical and in the northeast it is almost as steep. There are extremely few easterly dips, and few westerly dips that fall below 30°.

64/65

There were very few outcrops which gave more information about the structure than the dip and strike of the strata. Drag folds and cleavage were seldom observed. The rare occurrences noted almost invariably indicated an overturning of the strata to the east. In a section across the strike from the southern end of Lake Massawippi to the eastern edge of the map area this attitude was indicated wherever there was any evidence. Drag folds are relatively numerous here especially in the exposures along the southern shore of the lake and the Nigger River, and in many outcrops near Boynton. Such evidence taken in conjunction with the uniform dip would seem to indicate a continuous overturned stratigraphic section, but here as in the west this is a delusion.

65/66

Many outcrops in this area show contortions of the strata. These generally yield no more information than the fact that the beds have been intensely folded. A few however show the structure - a great series of isoclinal folds. The folds observed are small, but this may be a limitation due to lack of facilities for proper observation rather than an indication of the absence of larger folds. Their trend is in general parallel to the strike and they were most frequently observed to have a northerly plunge. Though somewhat vague the evidence here is sufficient to show that the detailed structure resembles that found to the west and best exemplified in the Memphremagog series.

The scarcity of evidence indicating a normal attitude of the strata in some places is perplexing. However it seems probable that this is due to an actual scarcity rather than a lack of observation. It is reasonable to assume that the overturned parts, having suffered the more intense deformation, should show the greater number of drag folds.

Greatly contorted strata seem to be confined to relatively narrow zones which parallel the general strike-trends. One of these zones extends from Crystal Lake north to a point about one mile southwest of Fairfax, paralleling the main highway for a considerable distance. Others can be traced: from two or three miles south of the village of Tomifobia to Boynton, from west of Cedarville to a point about two miles north of Marlington, in the area of dikes west of the Stan- 66 67
stead highway and less definitely in other sections. It is probable that these zones indicate the location of axes of major structural features.

West of the Bunker ~~fault~~ valley, due to the more rapid erosion of the younger sedimentary rocks, valleys occur in synclines, and hills generally indicate the location of anticlines. Though the younger formations are now largely absent east of the fault, it seems reasonable to assume that prior to their removal they established the location of the major topographical features.

The valley of the Tomifobia River indicates the location of a syncline, though its present shape is probably the result of erosion in the Tomifobia series rather than an indication of the shape of the overlying Siluro-Devonian. Also the valley from Harvey Bay to within a few miles of Ayers Cliff, that east of the Crystal Lake zone of contorted strata, and three others southeast of this probably mark the position of synclines. Intervening ridges would thus represent anticlines. Of these features the Tomifobia is the most important syncline and the ridge east of Crystal Lake the most important anticline. There is evidence which suggests that these anticlines and synclines pinch out and show the same irregularities of plunge as those west of the Bunker fault. 67 68

~~West of the Bunker fault~~ There it was possible to work out two systems of ancient structures. In the area of the Tomifobia series, though this has not been entirely feasible, some evidence of one of these systems at least is apparent. The conjectured geological boundary between the bedded slate and limestone and the limestone has a general trend of N 50° E. This corresponds roughly to the trends in one of the systems found to the west (Figure 10). After plotting the locations of outcrops and grouping those in which the same types of material were observed it was found that the resulting areas were similar in pattern to those of formational masses just west of the Bunker fault. This would suggest that the structure of these rocks had been developed by the same periods of deformation as that in the older formations to the west.

The plunge of minor folds wherever observed was to the north at angles varying from 20° to 30°. Also in the northwestern part of the area there is a pronounced slickenside lining on bedding planes which dips north 20° to 45°. While these features may suggest a plunge of the strata developed by the last deformation they more probably indicate the dip of the formation prior to it. By computation from the direction of the supposed geological boundaries and the plunge of adjacent folds it is figured that the formation has a dip to the northwest of something over 30°. Thus the limestone lies in a syncline while the bedded limestone and slate occupy an anticline. This is only relatively, for the structure is not simple and such relationships should probably be spoken of in terms of synclinoria and anticlinoria. 68-69

As previously stated the structure of the Tomifobia series in the areas adjacent to the main mass of the Stanstead granodiorite is different from that found elsewhere. Apparently the force of intrusion has had considerable effect on the attitude of the strata.

From Beebe around the northeast side of the mass and to the north there is a general curving of the strike, with dips such as to indicate a dome in the granodiorite area. Near Beebe there is a steep dip east which flattens to the north so that at Marlington it is about 30° northeast. Beyond this to the west the northeasterly dip continues, becoming more northerly. This dome-like structure occupies quite a large area to the north and east of the mass. To the north it appears to plunge out along a series of axes which radiate somewhat but also tend to parallel the main structural trends. Within the area of granite outcrops the strikes and dips vary greatly except in the west where they conform fairly well to the general structural trend.

Clearly the intrusion has caused doming with great and irregular distortion of the beds directly overlying it but whether this took place before or after the period of general deformation is difficult to determine. The regularity of the doming to the northeast of the main mass and a general tendency for structural trends to curve around the granodiorite suggest that the intrusion took place first. The irregularity of the deformation of the sedimentary rocks within certain sections of the igneous area tends to confirm this. However it is possible to conceive of the development of these features by doming after intense isoclinal folding - indeed a summation of all evidence seems to favor strongly ~~favor~~ this conclusion. The granodiorite shows little indication of having been subjected to the intense deformation which developed the isoclinal folding. A bend in the structural trends, the axis of which passes through the granodiorite area, may account for many of the features which appear to be due to the presence of an intrusive buffer during folding. Within the granodiorite mass near the lake several small inclusions of sedimentary rock have a strike and dip paralleling those observed beyond the mass. This suggests that they were isoclinally folded prior to the intrusion. Granodiorite dikes throughout the area do not appear to be folded with the strata. They are seldom much deformed and frequently tend to parallel the structural trends. Thus intrusion with a general doming and in places intense local deformation seems to have followed the development of the isoclinal folding. To the east of the intrusive area there are indications of the presence of a syncline. The axis extends from Beebe to a point about a mile west of the ~~valley~~ village of Tomifobia. To the north springs, valleys, and a disagreement of dip and strike suggest a fault extending from Harvey Bay toward Tomifobia to a point about a mile east of Griffin. The strata on the south side appear to be uplifted relative to those on the north. Both these features are probably the result of doming and uplift of the strata by intrusion.

South of Massawippi station a sudden change in the strike and dip of the strata is suggestive of a fault. To the southeast beyond the map area the evidence for this is fairly conclusive. The line of fault passes just east of Kingscroft, following the stream that flows toward Lake Massawippi. To the southeast it follows a series of depressions with the same trend. For a mile north and two miles south of the village the fault is marked by a series of depressions and many springs. On either side the strata are badly contorted and there is little agreement in strike and dip. Much quartz is present. Farther northeast the area is heavily drift-covered and as a consequence nothing could be learned of the fault. The line projected would pass through the depression one-half mile south of Massawippi station. This is where the evidence of strike and dip would place it. The general trend is approximately N 48°W. Nothing more of a definite nature could be ascertained. It is probably a normal fault of post-Devonian age. Elsewhere there is some evidence of post-intrusion deformation, but the nature of this was not ascertained. There are probably other small faults as indicated by lines of springs and other features but it is unlikely that any of these are important.

Thickness.

From the foregoing description of the structure it can clearly be seen that no very accurate estimate of the thickness of the Tomifobia series can be made. The formation occurs throughout a large area which has a relief of 1000 feet. The beds have a very steep dip and the plunge of minor folds is considerable. In the area there are no outcrops of other sedimentary formations either overlying or underlying. These features suggest that the thickness of the formation must be great. Computations for a simple synclinal structure of the limestone on the basis of a 30° northwesterly dip give a maximum thickness for this member of 6500 feet. On the same basis with somewhat less definite limits 10,000 feet of bedded slate and limestone may be estimated. This makes a total of 16,500 feet. However as the structure is by no means as simple as that used for the purpose of computation this figure is probably too high - indeed half of it would seem more reasonable and would be adequate to explain all the features observed.

Relationship to Other Formations.

As previously stated the area in which the Tomifobia series occurs is isolated from the rest by the Bunker fault. The series extends far beyond the limits of the map. At no place was its relationship to older formations observed. Ells reports that Silurian strata overlie it unconformably at North Hatley*1. Otherwise no information is available.

History.

Deposition of the series as now exposed seems to have been continuous. In the earlier stages there were changing conditions during which arenaceous calcareous materials were alternated with non-calcareous argillaceous. Later there was continuous deposition of the former type only.

Prior to the middle Devonian these beds were probably subjected to several periods of deformation, during one of which folds with an axial trend of about N 50° E were developed. They were also involved in the late Devonian folding which developed largely the present stnucture. A little later they were intruded and deformed by the Stanstead granodiorite. This was followed by slight deformation, the age and nature of which is unknown. Since the Devonian, erosion has removed all the younger formations and a large part of the Tomifobia itself.

*1. See section on <u>Silurian</u>.

Memphremagog Series.

Rocks referred to under this title have previously been included in the Farnham slates*1. This name was first applied to the slate formation found near the town of Farnham and later was used to include much of the black slate throughout southeastern Quebec. As the correlation of the slates in various parts of the country has never been definitely established it was deemed best to apply some local name to those found in the Memphremagog area. They have often been referred to as the "black and gray graptolitic slates of Lake Memphremagog*2." As their connection with that name is well fixed it seemed advisable to retain it, and designate them as the Memphremagog series. The term includes, besides the so-called Farnham slates, much that was previously described as Cambrian slate, since sufficient evidence for such a division was not found.

Location and Distribution.

The rocks of the Memphremagog series occupy the greater part of the area between the Fitch Bay-Bunker ~~Hill~~ Brook valley and the boundary of the Siluro-Devonian limestone about a mile east of Lake Memphremagog. In general there are two distinct areas. One is triangular in shape, bounded by the Siluro-Devonian contact, a line between Belmere Point and Lake Massawippi, and the northern limit of the map area, and the other a narrow strip on the east side of the Fitch Bay-Bunker Brook valley. The continuity within these is broken by numerous inclusions of older rocks and many outliers are scattered through the remainder of the area. The distribution is even more irregular than it seemed advisable or even possible to show. Many small masses of slate and older rocks have been purposely omitted and many more unavoidably so. 75

The contact with the Siluro-Devonian series is very well defined (see Siluro-Devonian). That with the lower formations is extremely difficult to trace, though generally marked by a distinct difference in lithological characteristics. The Memphremagog series was separated out as a slate member and consequently the limit of the slate represents

*1. Ells' and Harvie's Reports.
*2. Op.Cit.

the boundary. However owing to the scarcity of outcrops in the slate area and the extremely complicated structure of these strata the tracing of the boundary for any considerable distance was impossible. While its location was perhaps accurate at some points its trend beyond was generally not clear. Besides this vagueness there is always the hazard of placing a contact on lithological basis only for it is impossible to be sure that a variation is stratigraphical and not lateral. In order to show ~~indicate~~ this vagueness the boundary is everywhere indicated as assumed.

Owing to the extremely complicated structure the boundary is very irregular. At a few places it was found possible to discover its true nature. Elsewhere it has been assumed after a careful study of structural, lithologic and physiographic features. Where evidence was entirely lacking a boundary consistent with the type found elsewhere was drawn. Thus while the extent of each area may be incorrect its location (at least for the outcrops studied) is correct and its shape as outlined approaches that which actually exists. Any direct linking of known locations would give results entirely incongruous with what is known to exist and would therefore produce a map of extremely little value. The boundaries are even more irregular than it has been deemed wise to show. Each serration is in itself serrate and the contact between beds in many places resembles the edge of a large mill saw. Thus it has been possible to show boundaries and formation areas only in a very general way.

Physiography.

The Memphremagog series in general occupies the great lowland area to the west of Bunker Ridge. The slate almost invariably is found in the valleys. Streams and lakes are confined mainly to areas of rock of this series. The older rocks are so much more resistant that in many places their surface represents approximately the base of the slate. North of Magoon Point at many places there has been developed a peculiar washboard topography. Narrow bands of hard quartzite stand up in parallel ridges while slate occupies the intervening valleys. Along the slopes northeast of Long Island and elsewhere the same realtionship has produced a series of terraces. The shore along the west side of Lake Massawippi and Fitch Bay shows series of indentations which are largely the result of the removal of slate from between more resistant rocks.

Outcrops are generally well rounded, smooth and often polished. Good sections are very rare even in the stream valleys. At only one place was it possible to observe a cross section of the folds which are so numerous.

Subdivision.

The Memphremagog series is subdivided into three members: an upper, Oliver sandstone; a middle, Oliver slate; and a lower, Lovering slate. The subdivision is made on the basis of a difference in lithological characteristics and a slight unconformity between the two slates. The upper boundary is marked by a change from slate to sandstone and the lower one by a thick conglomerate series. These boundaries owing to the scarcity of outcrops are at best very indefinite. The latter where no outcrops occur was made to conform in direction more or less with the former.

The Oliver sandstone lies to the east of the Siluro-Devonian in a narrow band northeast of Oliver. The Oliver slate is farther east in a similar though more extensive narrow band. The Lovering slate east of this again is by far the most extensive of these three series.

Description.

The Memphremagog series overlies rocks of many kinds. As a result the basal members are extremely variable, for their character is greatly influenced by that of the underlying rock. Where they directly overlie the Bunker series or igneous rock there is rarely a coarse basal conglomerate. In most places gray slate, frequently containing small pebbles of quartz, argillite and slate, is found in contact with the older rocks. If these however are green, as is the case in many parts to the south, the overlying slate is usually also green, though sometimes brown or light gray. Thus a perfect gradation between the two series is often found, even igneous rock grading imperceptibly into sedimentary. They are similar in composition, containing the same feldspars, mica and other minerals. The sedimentary rock can be differentiated only microscopically by its clastic texture.

Where the slate overlies the basal conglomerate of the McConnell series it assumes the same characteristics, differing only in the type of matrix. Elsewhere the basal slate resembles other underlying members of this series. That is, besides the typical dark gray slate which frequently contains quartz pebbles there are other kinds of slates, argillites and metamorphosed sandstones which resemble those in the McConnell series. In some places overlying this and the Bunker formations there are coarse conglomerates and slates which contain hard light gray non-calcareous nodules.

The Lovering slates, which make up by far the greater part of the Memphremagog series, as implied by the name are almost entirely slate. They are in the main black to dark bluish gray. Occasionally there are lighter gray, brown or yellow beds. In many places, especially in the upper part of the series, there is a fine striping of white or light gray. The lustre is generally dull though in some of the slates high in flake mica or graphite it is quite bright. Near Magog the slate resembles and has been mistaken for cannel coal.

The texture in by far the largest part of the series is dense. There is a variation from a coarse, hard and brittle argillite to a relatively smooth, soft and flexible schist. Occasionally there are bands of hard granular material. These are usually lighter in color. The lighter gray and white stripes are generally of this type. In a few places there are very soft greasy graphitic schists. Rarely these slates contain quartz grains and slate pebbles.

The composition of the slate series is fairly uniform. The light-colored hard materials, however, which are found more abundantly at the base and more rarely higher up, show considerable variation. They include cherty and quartzitic argillites, quartz schists, quartzites and calcareous quartzites and slates, all similar to those found in the series below. Otherwise the beds are of metamorphosed argillaceous rock. The quartz content is usually low, but there are gradations to the highly quartzose rocks previously mentioned. The flake mica and graphite content is variable from insignificant to abundant. The basal green slates are high in chlorite. Under the microscope they are seen to be largely mica (biotite), chlorite and quartz with some magnetite and calcite.

Bedding is quite pronounced in those slates which are striped. Otherwise it is difficult to distinguish. Variations in color often bring out a very fine thread-like bedding. Cleavage is usually present though it is often so nearly parallel to the bedding that it is not prominent. Schistosity is developed in some beds which are softer or of less uniform texture. No new ¶

Everywhere the rock is metamorphosed. It is now generally a well developed slate. Quartz is the only mineral which is not altered 80/81
and in many cases it has been recrystallized. Pyrite is abundant. It is usually in the form of cubes which are sometimes as much as one inch through. In some places it is considerably deformed.

Much of the slate, especially that near the base, carries an abundance of altered crystals of siderite or some highly ferruginous carbonate. The crystals are distinct rhombs and range in size from very small to almost a quarter inch through. The mineral is almost entirely altered to brown limonite but some of the original cleavage planes still remain distinct. Some crystals show no deformation though frequently they are quite rounded. Many of the coarse beds have iron oxide spots similar to those found in the rocks of the McConnell series.

The slate is fairly resistant to weathering- more so than the overlying calcareous rocks but less than the more quartziferous beds underlying it. In many places the outcrops consist of well polished, glaciated surfaces which show little change since their development. Owing to the abundance of pyrite the slate usually becomes rusty on exposure. Otherwise it changes little in color. In places the bedding is brought out by a ridging due to weathering.

The Oliver slate consists of slates, argillites, metamorphosed sandstones and conglomerates. At the base there are fifty feet of coarse 81/82
conglomerates, some of which rest on uneven surfaces. The pebbles and bowlders are almost entirely of coarse, hard materials such as are occasionally found in the Lovering slate. The matrix is made up mainly of the same materials with a considerable quantity of quartz. The pebbles are generally well rounded and the matrix well washed, for little of the finer slaty material remains. Above the conglomerate the series is similar to the Lovering slate except that there is a much greater abundance of the coarser argillites and sandstones.

The Oliver sandstone is a ~~series~~ formation of green sandstones. They resemble somewhat the metamorphosed sandstone found in the lower ~~series~~ formations.

The rocks of these two upper members of the Memphremagog series appear to be less metamorphosed than those of the lower member. Though similarly folded they do not appear to be so highly altered. The pebbles in the conglomerate are not greatly deformed as are those at the base of the Lovering slate and the sandstone to a large extent seems to have retained its original character.

Age and Correlation.

The age of the Memphremagog series was not definitely re-established. Throughout the area the slates are generally so highly metamorphosed as to be unfit for the preservation of fossils. None were collected though one locality where collections had been made was examined carefully.

Ells reports having obtained two collections of highly graptolitic shales, one from near Magog on the west side of the lake and the other from "a cutting on the main road, about 100 yards north of the entrance to the grounds and residence of the late Sir Hugh Allan"[*1] (Belmere Point). Prof. Lapworth places the first collection at "about the horizon of the Trenton or Utica rocks of the western area[*2]." Of the collection made near Belmere Point he says: " The state of preservation of these fossils is so poor that it is impossible to identify any of them with absolute certainty. They are all clearly of the same general facies as those of Magog, but better specimens should be obtained before the matter can be satisfactorily determined[*3]."

Ruedemann[*4] describes a large collection made by Gurley near Magog in the "Magog shale," which he places between the Normanskill and Utica, that is in a position equivalent to the middle and upper Trenton. This collection was probably obtained from the well known locality on the west side of the lake. However Prof. Lapworth's correlation of this with that on the east side on fossil evidence and a fairly definite correlation on field evidence is sufficient to warrant ascribing the same age to both.

*1. R.W. Ells. Report on the Geology of a Portion of the Eastern Townships, Part J. Annual Report, 1886, Geol. Sur. Can. P. 16J.
*2. Ibid. P. 17J.
*3. Ibid.
*4. R. Ruedemann. Graptolites of New York, State Museum, New York, Memoir 11, Part 2.

As the fossil horizon is about the middle of the Lovering slate the Oliver slate and sandstone above this may represent Utica or even later Ordovician age. 81A 82A

The Memphremagog slate may correlate in part with the Tomifobia series (cf. id.). Beyond the area it probably correlates with the slate which lies to the north and to the west of the Siluro-Devonian limestone.

Structure.

As in the lower formations the structure of the Memphremagog series is extremely complicated. In general the slate outcrops on the east and west limbs of the main (Bunker) anticlinorium. As this is asymmetrical with the axial plane dipping west the areas of slate are far more extensive in that direction than to the east. The Bunker fault also may abbreviate somewhat the eastern area.

Throughout, except for the narrow bands which are continuous on either side of the Bunker anticlinorium, the slate series is preserved in minor synclines. These assume all manner of irregularities in shape and size, though they show fairly definite axial trends and a similarity of type.

The strike of the slate is fairly uniform throughout the area, mainly between N 20°E and N 50°E, though in some places there are notable divergences. The dip also is fairly uniform, generally exceeding 60° to the west. Near the base of the slate series where it comes into contact with the older more resistant rocks the strike and dip are more variable and the beds are frequently very much contorted. 82A 83

The uniform dip and strike is clearly not indicative of one continuous stratigraphic section. The strata like those in the lower formations are isoclinally folded. Throughout the area the trend and dip of the axial plane and the nature of the folds are approximately the same. The structure is clearly shown at ~~a few places:~~ McPherson Bay brook, the lake shore near Magoon Point, and at several places on McConnell Creek. At many other outcrops which are relatively extensive the type of structure is clear but generally the exact details are vague.

The folds are very sharp and V-shaped at the apex. The beds have been so pressed together and squeezed that the dips show only slight convergence near the axes of folds. The same lack of variation is observed in the strikes of the strata on plunging folds. Near more resistant rocks however the trend of the strike and dip is more variable. The type of structure developed in the slate is somewhat different from that in both the overlying and underlying series, for under the great pressure the slate beds were more readily deformed. Hence folds were developed which due to the thinning and thickening of beds were hardly recognizable as such.

The folds vary greatly in size from those of a few inches to the major structures. It is seldom possible however to gain any definite conception of their size. The dip of their plunge is extremely variable and irregular. In places it is very abrupt and shows sudden changes. No new ¶

Drag folds in some places are very numerous, but they are of little value in working out the detailed structure. While a drag fold may indicate the relationship of the strata at one point it is never possible to tell for what distance this relationship is correct. Likewise the plunge of such folds changes so frequently and abruptly that information obtained from its observation is applicable to an undeterminable extent. No new ¶

The majority of the drag folds observed indicate that the adjacent strata lie on the eastern limb of an anticline recumbent to the east. This is probably due to a greater development of drag folds on the under limb of overturned anticlines - a part which has suffered more intense deformation - rather than to the actual presence of a greater amount of strata with this attitude.

Cleavage is of little value in locating folds. Generally it parallels the main structural trends and dips steeply west. It seems to be the result of the intense squeezing and is a regional development rather than that of a number of individual folds. It did not show any consistent variations in dip across either minor or major folds nor in strike around the ends of plunging folds. These were the deductions from a very great number of registered strikes and dips and actual observation of sections. However some folds the beds of which vary slightly in hardness, showed a very peculiar individual development of cleavage illustrated by Figure of a cross section of a small fold on McConnell Creek about a mile west of the lake. The cleavage on the south side appears to be a result of the development of the fold while that to the north is later and is a product of the squeezing. Regional cleavage has not entirely obliterated that of the folds. Uniform systems of joints were not noted. In many places, however, there are joints, minor faults and fractures, both regular and irregular. These were of no value in working out the structure.

Though all these features, which are usually sufficient to work out structure, are inadequate to solve the major problems they are of value when considered in conjunction with other data and in some places have their usual significance. At Magoon Point the strike of the slate beds shows a distinct convergence toward the south indicating the nose of a south-plunging anticline. East of Belmere Point and farther south the strike of the beds and the lower contact of the slate indicates the angularity of the unconformity which exists below the Siluro-Devonian limestone. In the northeastern part of the map area the general curving of the strike around the hill west of Lake Massawippi suggests that some resistant mass or new structural feature has prevented the continuation of the trends found to the south. Within this area the strikes and dips are found to indicate an entirely different structure from that found in the rest of the area. Elsewhere changes in the trend of strikes are suggestive of structural features but are generally of value only in supplementing other data.

The structure is brought out best by the distribution and shape of the slate areas. In conjunction with this the information gained from the features just described, from underlying and overlying formations, and from physiography are important assets. The ~~latter~~ last is of great value because the underlying rocks are so much more resistant than the slate that in many places their present surface represents a horizon not far below the original base of the slate.

The most outstanding structural feature is the great Bunker anticlinorium. This is asymmetrical, as is clearly brought out by the unequal extent of the slate outcrops on either limb. Its axis extends from the hill northwest of Lake Massawippi to Whetstone Island. However in the south there is another axis of about equal importance to the west. The ridge marking its position is a prominent physiographic feature and can be traced within the area and beyond for miles to the northeast with the same general trend. It dies out at no great distance beyond Whetstone Island where it appears to be plunging steeply to the south. This anticlinorium represents one of the the main features of the latest and most important deformation in the area. It is a simultaneous development with the isoclinal folding previously described. The dip of the axis of the anticlinorium probably corresponds to the dip of the axes of minor folds, of the bedding and cleavage, all of which are more or less parallel : that is, with a dip to the west between 60° and 80°.

In the southern part of the area there are two important anticlinoria rather than one (Figure 10). That just west of Fitch Bay which is the continuation of the Bunker anticlinorium appears to narrow considerably toward the south. Immediately west of it is the Magoon syncline described under Siluro-Devonian. West of this again is the Magoon anticline, then the Lake Memphremagog syncline. These four major structural features clearly converge, plunge steeply and appear to pinch out rapidly to the south. All this is more fully described under Siluro-Devonian.

To the north the Magoon Point anticline appears to broaden out, plunge slightly and break up into several smaller ones. The Magoon syncline seems to disappear in much the same way though with a rise instead of a plunge. Beyond to the north less important folds which replace these can be outlined. Imposed upon all are numerous smaller anticlines and synclines of various sizes. These have the same general trend and dip of the axial plane but they show all manner of variations in plunge. Folds suddenly pinch out and are replaced by others with no definite system apparent.

The development of the intricate structure in the southern part of the slate area is due in part to various factors which are brought out more clearly when the features of the whole area are considered. These will be discussed later. Though in part due to such factors this development is largely the result of a bend in the main structural trends. At the limit of the map area in the south the trends are nearly due north. Near Magoon Point they begin to swing eastward and continue to do so until at a point not far north of this they have reached a direction between N 30° E and N 50° E. The axis of this arc thus passes somewhere south of Magoon Point. Such a bend involved intense squeezing with un-

unequal stresses in various parts. This caused the development of unusual features: the lateral pinching out of structures, the overlapping of folds and other irregularities - all necessary to make the adjustments in such a bend. This development of folds by its irregularity makes it difficult to observe in the south structural features which are very clear in the north. Though much in the south seems to be in accord with observations made in the north it does not seem advisable to conjecture more about the structure from this intricate series of folds.

Toward the north the folds seem to open out and axes radiate in a manner more or less fan-like. The main Lake Memphremagog synclinal axis diverges from the main Bunker anticlinal axis at quite a pronounced angle. In a like manner many minor axes diverge and as they do so the folds become more open and others appear between them. These features are clearly indicated by the divergence of the trends of various masses and of groups of strikes. However the minor folds are still largely isoclinal though toward the northern limit of the map area there is a marked tendency for these also to open out.

The general dip of formations on the limbs of major folds - that is, whether the folds are open or close - is difficult to ascertain. It can be estimated only after careful study of the relationship of the various masses, of the physiography, especially of exposed resistant formations, of the nature of boundaries, the plunge and nature of minor folds and to a lesser extent of other features. The methods employed will be dealt with more fully in considering the structure of younger formations. Computed as for a formation which had been involved only in the last deformation the dips probably would not exceed 60° in the south and 30° in the north. Dips on the base of the Memphremagog series in places probably exceed these figures due to an inclined position of the strata previous to the last deformation. On the east side of the main axis and possibly of some of the minor axes the dips are very steep or overturned.

In the northwestern part of the area the dip is to the east instead of the west as elsewhere. No adequate interpretation of this has been conceived.

In the northeastern section there appear two major structural features which extend beyond the map area. In the valley of Turnertown is an important syncline which has its beginning a few miles to the southwest. To the west of this is an anticline as indicated by a rather pronounced broad ridge. The axial trend of these is in accord with the fan-like divergence previously described. The form of the anticline seems to be similar to that of the main anticline at Bunker Hill. Minor folds are imposed upon these as elsewhere.

On the main Bunker anticline west of Lake Massawippi there is ~~some~~ some unusual structure. An area of several square miles including the southern part of the ridge is not isoclinally folded and is the only section which does not show the northeast-southwest strike. Here the strata strike mainly northwest and southeast and dip north at relatively low angles. Structural trends bend around the area just as schistosity often does around hard inclusions such as pebbles or pyrite. The area ~~It~~ appears to represent the surface of a mass which was sufficiently resistant to to withstand to a large degree the deformative forces which so intensely folded the rock of the rest of the area. In the exposed rock there is nothing to explain the isolation of this mass from the rest nor is there evidence other than the features described to indicate the presence of a resistant igneous core.

The structure so far described is all a result of post middle Devonian folding. Much evidence of structures previously developed is clearly forthcoming. The features observed would seem to indicate that the Memphremagog series had been involved in at least two distinct and separate periods of deformation previous to the deposition of the Devonian.

The lower contact of the main mass of the Memphremagog series has a general northeasterly trend (Figure 10). It can be traced more or less continuously from the boundary of the Siluro-Devonian rocks east of Belmere Point to a point on the Bunker valley road about two miles south of Lake Massawippi. The trend of the lower contact of the McConnell series roughly approximates this, which seems to represent in a general way the strike of these formations. In a few other places boundaries trend in about the same direction. These features seem to indicate a series of folds with an approximate axial trend of N 55°E. South of the village of Fitch Bay there is an anticlinal axis while well to the north there is a synclinal axis. In the vicinity of Magoon Point is another synclinal axis. The folds were probably parallel, broad and open with dips not exceeding 30°.

Another distinct and separate series of ancient folds is apparent. They are indicated in many places by the linear arrangement of isolated masses and boundary indentations, the plunge of both major and minor folds, and the physiography, and to a limited degree in some localities by the strike of the strata and the direction of the boundaries. These have a general trend between N 30°W and N 50°W and cross the Devonian folds almost at right angles. An important anticline in the series is just south of and almost parallel with the most direct Ayers Cliff-Magog road. North of this road is another anticline. North of this again is a pronounced syncline now occupied by the valley of McConnell Creek. Still farther north a series of small folds rises up to an important anticline which crosses the ridge west of Lake Massawippi. Here a very interesting feature is noted. For some distance along the top of this hill, as previously stated, Devonian deformation was not as effective as elsewhere. Hence pre-Devonian structure has not been greatly changed. The strikes recorded though variable are mainly N 50°W and the dips northeast. Though the information is very inadequate it seems to be in accord with the postulations of the structure. Southwesterly dips may not actually be absent or a general uplift with tilting - which appears to have taken place - may have reversed them.

In the southern part of the area evidences of this deformation are not so apparent. At the village of Fitch Bay there is a pronounced syncline and north of this the Oliver road appears to follow an anticlinal axis. At other points there is evidence of similar cross folds but as a rule it is not very definite. Owing to the very intense Devonian folding in the extreme south all previous folds have been so distorted as to be unrecognizable now.

In this series of structures there appear to have been many folds, probably synclinori~~ums~~a and anticlinori~~ums~~a. They seem to have been fairly close with dips which probably reached fifty and sixty degrees.

The relative age of the two periods of deformation is not readily apparent. In fact all that can be definitely stated is that they are pre-Devonian and post-Ordovician. One probably took place at the end of the Ordovician during the Taconic revolution and the other between middle Silurian and middle Devonian.

Thickness.

No accurate estimate of the thickness of the Memphremagog formation can be made. Its greatest thickness now is probably represented in a section from the Siluro-Devonian contact north of Oliver to one of the small masses between the Magog roads. The dip of the formation in this direction is probably less than 30° so that the thickness calculated accordingly is less than 5000 feet. This seems to be quite sufficient to explain all features observed, yet it may be very far from correct.

Relationship to Other Formations.

As the slate series has been determined largely on a lithological basis the boundary is generally placed where slate is in contact with other rocks. Therefore it is doubtful that the base of the series as shown represents throughout exactly the same horizon. However it probably does so sufficiently to give results commensurate with the accuracy obtained in other respects.

The slate at its base is found in contact with a great variety of rocks. In the northwest part of the area it overlies at different points all the many phases of the McConnell series. At the southern limit of this formation it is found directly overlying the coarse basal conglomerate which here really constitutes a basal conglomerate for both series. In the southeastern part of the area in many places it overlies rocks of greater age than the McConnell series. The slates rest directly on the altered diorite, often assuming a distinct green color, and in places have a composition so similar to that of the igneous rock that they can be differentiated from it only by their clastic texture. They are also found overlying the quartzites, grits and schists of the Bunker series.

At the base of the Memphremagog series a gradation from slate to the underlying rock is generally found though there is often merely an abrupt change. In many places the basal slate contains small pebbles of quartz and other materials. In a few places besides those where it directly overlies the McConnell conglomerate there is found a fairly coarse basal member. The greater number of these occurrences was found west of McConnell though some were at the contact with the rocks of the Bunker series. The rocks below the slate, especially the igneous rocks and those near them, are very often rusty. From these features it is concluded that the Memphremagog series overlies the McConnell series with a slight or partial unconformity and that beyond it overlaps the older rocks of the Bunker series and the altered diorite.

The amount of slate lying beneath the Siluro-Devonian limestone is extremely variable. In the southwest for a short distance along the contact with the main mass and around some of the smaller masses it is entirely absent. The variations in thickness of the Memphremagog series are apparently great. This is due to an original unequal deposition and to a greater extent to post-Ordovician erosion. The great amount of erosion is clearly indicative of the unconformity which exists above the Ordovician.

History.

The conditions under which deposition of the Memphremagog slate began are by no means clear. It seems likely that part of the area was already under water and that deposition of the coarser material of the McConnell series was in progress. At the beginning of the Memphremagog period there was probably a rapid submergence of the remainder of the area, and deposition of argillaceous material started over an area far greater than that covered by the McConnell series.

During the deposition of the Lovering slates there was not much variation in conditions. At the end of this time there were several emergences during which erosion took place and between which conglomerates were deposited. After this conditions continued to be variable - near-shore coarse sediments and fine clays were alternately deposited. During the final stages of this period a considerable thickness of sandstone was laid down.

Between the time of the deposition of the Oliver sandstone and the Devonian limestone these rocks were subjected to two periods of folding. Erosion was active and in places removed entirely the rocks of the Memphremagog formation.

Silurian.

Only two small outcrops in the area were definitely recognized as Silurian. However it is not unlikely that some of the isolated patches or part of the main mass now designated as Devonian belong to the previous period. A similarity in lithologic character and a scarcity and very poor state of preservation of fossils in both formations make it difficult to differentiate between the two. As the rock overlying the older formations for considerable distance along the boundary is known definitely to be Devonian any parts incorrectly designated must be small and unimportant.

The similarity in most respects of the Silurian and Devonian makes a complete separate description of the former superfluous. Features common to both will be fully described under the heading Siluro-Devonian.

Location and Description of Outcrops.

One of the two outcrops mentioned above occurs about two miles south of Oliver and about one half mile east of the Lake road. Here the material exposed is a massive limestone with a somewhat polished surface. It has a marble-like appearance with calcite segregated into streaks and blotches in a pale bluish-gray matrix. Silicified fossils stand out prominently on the weathered surface. Some of these appeared to be complete crinoids but owing to their poor state of preservation none of the few specimens which were successfully extracted was recognized as such. The smoothness of the surface and the massiveness of the limestone made it impossible to obtain any information about the structure.

To the north no fossils were found for three miles. At this distance an outcrop occurring very close to Ordovician rocks contains fossils which are probably Devonian. Also toward the north there is a convergence of the strike of the Devonian beds and the direction of the boundary between the limestone and slates. From these two features it is assumed that the Silurian gradually thins out and disappears in this direction. Toward the south it probably does the same thing as the Devonian appears to overlie directly the Ordovician at the Georgeville-Fitch Bay road. Judging from the curve in its lower boundary this small mass of Silurian rocks represents a basin deposit either originally discontinuous or isolated by pre-Devonian erosion.

South of the Georgeville-Fitch Bay road as far as the little pond on the main tributary of the stream flowing into MacPherson Bay the rock overlying the Ordovician is fairly definitely Devonian. Beyond this no indicative fossils were found near the slate until Belmere Point was reached. Just north of the large crook in ~~this~~ the road to this point there is an extensive outcrop which is definitely Silurian. This must be the basal 99/100 member of the formation in this locality as it is separated only by a very narrow valley from the older rocks.

The rock here consists of irregularly lenticular masses of hard calcareous material in a slaty, somewhat calcareous matrix. The latter weathers and crumbles very readily to earthy dust, leaving the nodular masses free. The slaty material appears to be a decomposition product of the underlying slates. The hard nodules vary in size from that of a fist to several feet in length and appear in the main to be fossils, partially silicified, in an accumulation of calcite. Scattered throughout are many fairly large quartz grains. The whole mass resembles a conglomerate. It has been subjected to great pressure and is highly sheared. The matrix is quite schistose and the nodules have been drawn out into lenses. A more detailed description of this type of material will be given under the Devonian.

South of this outcrop there is exposed in the stream bed a continuous section from the Ordovician rocks to those definitely determined as Devonian - approximately 1000 feet lower down along the stream. At the base the older slates appear to grade to a nodular material like 100/101 that found to the north. The slates immediately east of this gradation or below it stratigraphically are slightly calcareous. Whether the calcite has been derived from overlying beds or is a result of original deposition was not determined. If the latter is the case these beds may belong to the younger formations but it seems more probable that the base is represented by the nodular beds. No unconformity could be discerned but it is quite evident from the structural relationship that one does exist at or not far below the point where nodular material was first noted.

This basal material is very similar to that described above.

and appears to contain the same fossils. The series in the creek bed continues much the same to a point six hundred feet down stream, becoming more slaty and containing fewer nodules. At this point a bed is found which is somewhat similar in lithologic character and fossil content to strata which outcrop below the bridge on the stream south of Georgeville. There Devonian fossils were collected. Both of these horizons appear like coral reefs and are made up largely of favosites and a stromatoporoid coral. At 854 feet there is another nodular bed and at 1000 Devonian fossils occur. Fossils were collected at various points from the base up to this but none were identified definitely enough to be of value. From the foregoing evidence and the fact that material determined as Devonian overlies directly the older slates at the corner in the road to the south it seems best to place the base of the Devonian somewhere in the first six 101 hundred feet of nodular material. It is evident that the Silurian mass 102 which outcrops on the Belmere Point road is similar in nature and extent to that farther north. It is improbable that there is any more Silurian to the south of the Belmere Point outcrop as what was there definitely determined as Devonian is found in contact with much older rock in two places. Beyond these ~~the Siluro-~~ early Devonian erosion appears to have been ~~greater~~ effective longer than elsewhere. Consequently the beds found here are younger than at most places along the contact and therefore are definitely of Devonian age.

It is possible that small masses of the Silurian brought to the surface on the crests of minor anticlines may be present within the Devonian. Some of the small outliers may also be Silurian. However in each case it seemed preferable to assign them to Devonian as the lower formation is absent in those parts of the main mass to which they are nearest.

Ells' map and report*1 indicate an outcrop of Silurian from which fossils were collected at the northern end of Lake Massawippi four miles north of the northeastern corner of the map area. A careful search on 102 two separate occasions disclosed no outcrop - only great thicknesses of 103 drift, so that no further information about this could be obtained.

*1. R.W.Ells- Report on the Geology of a Portion of the Eastern Townships- Part J - Annual Report- 1886. Geological Survey of Canada.

Of this formation west of the lake Robert Harvie writes[*1]: "The Silurian system is of relatively small extent in the district. . . . . . The northern half of Lake Memphremagog lies in a synclinal trough of Silurian measures whose age as previously determined has been chiefly based on a few species of not very characteristic corals. However the discovery of a new fossil locality at Knowlton Landing containing a much wider range of species has given an opportunity for a much more decisive determination." This statement is in part incorrect as some of the rock referred to as Silurian is Devonian. However it seems to indicate that the older formation is more extensive and thicker on the west side of the lake than on the east.

Age. ~~and Correlation.~~

Extensive collections of material were made at both the outcrops described above but very little proved to be of any value. Dr.E.M. Kindle reports as follows on the collection from these two outcrops:

"Lot No.100- Favosites cf. favosus
102- Conchidium?
- Conchidium sp. undet.

10$\frac{3}{4}$

Lot no. 102 (southern outcrop) represents the next younger horizon ~~(Ordovician)~~ represented in this collection so far as can be ascertained from the evidence of the poorly preserved fossils. A Conchidium badly crushed and distorted but showing the spondilium and coarse plications of this genus indicate for this lot a middle Silurian horizon. Other lots from 100 to 109 (collections made at various other outcrops in the area) may belong to the same horizon as 102 as understood by Mr. Kerr, but the fossils are too few and poor either to confirm or confute this opinion conclusively. The coral in lot 100 (northern outcrop), however, appears to represent the Silurian species Favosites favosus."

"Lot 102 may correspond to the Silurian horizon at Littleton, N.H., but the evidence is too imperfect to furnish more than a suggestion. (See Bull. Geol. Soc. Amer., vol.XV, p.480, 1904; and F.H.Lahee- A New Fossiliferous Horizon on Blueberry Mt. in Littleton, N.H.: Science, N.S., vol.XXXVI, pp.275, 276, 1912.)" This lot probably also corresponds to the Silurian horizon found at Knowlton Landing[*2].

*1. Robert Harvie- Geology of Orford Map Area, Que. Summary Report-1911, Geol. Survey of Canada. P. 289.
*2. Id. P. 286.

Structure, Thickness and Relationship to Other Formations.

The Silurian beds strike a little east of north and dip very steeply to the west. The outcrops represent the truncation of the eastern limb of a syncline. The apparent thickness may be an exaggeration, due to isoclinal folding, of the actual thickness as is found in the other formations. Without assuming such duplication it may be postulated as not more than six or seven hundred feet- indeed less than this would be more reasonable. 104/105

A distinct angular unconformity separates the Silurian from the underlying formations. No accurate estimate of its greatness can be ascertained. Certainly to the south it was pronounced as the strike of the older formations is inclined at an angle of 15° and over to that of the younger. Toward the north however the slates have been so intensely squeezed that minor folds have developed parallel to the general structural trend, which is approximately parallel to the base of the Siluro-Devonian. Therefore any strikes taken register these minor isoclinal folds and give no indication of the true trend of the formation. So far as it has been possible to ascertain, the plunge of these minor folds throughout the region is to the north at a fairly steep angle. This would indicate that the strata here angle into the upper formation as they do to the south. Taking all the available information into account it seems that the unconformity is very great and that at all places along the contact there is a distinct differance in the strike of the two formations; that is, a pronounced angular unconformity exists between the Ordovician and Silurian.

History.

According to fossil evidence the lower Silurian is entirely missing here and probably was never laid down. The amount of erosion during transition and early Silurian times must have been tremendous to produce the truncation of the older formations now observed. The area was very probably land during that time. The indications which point to this are the enormous truncation and the evidences of deep weathering in the underlying strata: the part adjacent to the contact is almost invariably softer and decays more readily causing the development of valleys. 105/106

Also there are many features which suggest peneplanation followed by fairly rapid submergence. There is the deep disintegration mentioned above, the evenness of the boundary, the earthy type of matrix found at the base and the lack of well-washed basal conglomerates, sandstone or coarse sediments. Also there is the fact that the lower Silurian sediments are of a type such as to intimate the slow introduction of a small amount of clastic material. Thus it appears that the Silurian was deposited on a more or less peneplaned surface covered with mud.

Judging by the fineness of texture and the large percentage of calcareous material erosion was very slow or the source of the sediments was at some distance. The direction from which they came is difficult to postulate. However during early Silurian times the structure was such that the more resistant strata occurred to the south. Also the boundary relationships of the Siluro-Devonian rocks to the older formations seem to indicate a progressive overlap in the same direction. These two features with the general distribution of the limestone suggest the existence of land to the south which was the source of the clastic material.

The nature of the distribution or the cause of its apparent irregularity can be conjectured only vaguely with the very scanty evidence available. To the north and south the Silurian is absent and even before the present truncation was probably largely so to the east. It increased in thickness to the west. Whether all this is the result of an original irregular distribution or of Silurian warping with erosion of part of the formation deposited is difficult to postulate, but the latter seems a somewhat more satisfactory explanation.

To the north the Silurian is absent-whether due to a warping before the Silurian, leaving this as a land area, or warping after with complete removal of the Silurian it is impossible to say definitely, but the latter seems more acceptable.

It is probable that the middle Silurian was much more widespread than at present. No evidences of the upper Silurian were found. This may be due to one of the two causes mentioned above. Its absence as well as that of the lower Devonian seems to confirm the suggestion of an erosional period between the middle Silurian and middle Devonian.

Siluro-Devonian.

The Silurian has been separated from the Devonian on the basis of fossil evidence only. The two formations are otherwise indistinguishable. Because of this, as previously stated, and to avoid repetition and facilitate description they are here treated as one. Many features of the Silurian have already been described in the previous chapter and those peculiar to the Devonian will be dealt with in this chapter.

Location and Distribution.

The main body of Siluro-Devonian rocks of the area occupies a narrow strip along the northeastern shore of Lake Memphremagog extending to the south nearly as far as Long Island and to the north beyond the limit of the sheet. They are reported to occur on the west side of the lake extending as far south as Owl ~~s~~ Head*1 (Figure 4) The same formations are found on Lords Island and Molson Island. Of Round Island Ells writes*2: "South of the Owl's Head Mountain wharf, on Round Island, the same dolomitic slates, in places changed almost to a talcose mica-schist, contain characteristic fossils of Silurian age." (Ells referred to all these rocks as of Silurian age). Thus the Siluro-Devonian rocks here occupy a long narrow basin. They are largely obscured by Lake Memphremagog and are ~~now~~ observed merely as a narrow border around the northern half of the lake.

There are four smaller masses, fairly definitely outliers of the main body. One is at Magoon Point, one north of this near the cross-road and two southeast of Georgeville. One of these is not far from the Georgeville-Narrows road on the main branch of the MacPherson Bay stream and the other farther south. There are also two small outcrops of limestone, one on the crest of Bunker Hill near the little stream a mile and a half southwest of Lake Massawippi, and the other about one mile west of the lake at a point just north of the most direct Magog-Ayers Cliff road. They overlie slate which has been included in the Memphremagog series and are entirely isolated from anything with which they can be definitely correlated. For these reasons and because of greater resemblance to Siluro-Devonian rocks than to any others they have been included here.

*1. Ells' and Harvie's Reports.

*2. Ells- Report on a Portion of the Province of Quebec-Part J, Vol.VII. Annual Report-1896.

Physiography.

The main mass of Siluro-Devonian rocks is found in a somewhat ellipsoidal basin, the lowest part of which is occupied by the northern end of Lake Memphremagog. To the west of the lake these rocks form a low, gently undulating and relatively flat ridge. The Lake road runs along the crest as far as the creek south of Georgeville. Beyond this the ridge continues but it is broken up by two large bays (MacPherson and Quinn) which cut almost completely across it. The Siluro-Devonian probably extended to the south prior to the development of the lake. The boundary may be represented by a line passing west of Long and east of Round Island, then back to the northeast so as to loop around the Magoon Point mass (Figure 4). The latter also lies in a basin, rather as if in the tip of a spoon pointing north, the bowl of which is the lake. While the Siluro-Devonian rocks at this point are relatively flat the older rocks rise up somewhat abruptly from them. The other smaller masses are merely perched on top of the older formations.

The base of the Siluro-Devonian is for the most part very easily traced by physiographic features. It is generally marked by a distinct valley. North of Long Island this is occupied by a stream, from the head of which to the point where the road crosses the contact there is a well-defined depression. To the north the development of glacial topography has obliterated this feature as far as Belmere Point. Here again it is pronounced and can be traced to Quinn Bay, thence across the road to the little pond (a result of this feature), to the northern tributary, up it and beyond for half a mile. Then for four miles the area is heavily drift-covered. Southeast of Oliver the contact can again be recognized by a gully and a crook in the stream. North of this on both of the eastern byroads and elsewhere there are pronounced gullies along the boundary. The Magoon Point mass is also bounded by a fairly deep depression.

Along the shore of the lake the limestone is well exposed. It forms precipitous cliffs as a result of the nearly vertical dip of the bedding. Near the northern end of the lake the shore is drift-covered but from Lafrenave Point south the drift shore decreases in extent and the rocky cliffs increase. These also increase in height to the Georgeville-Jewett Point stretch where they are forty to fifty feet sheer.

South of this except on Molson Island the cliffs are less pronounced. At many places the two systems of joint planes are so nearly horizontal and vertical as to give this cliff the aspect of an artificial sea wall made up of rectangular blocks.

Description.

The Devonian rocks are essentially limestone though in places they become so argillaceous or arenaceous as to be called either shales or slates, or sandstones. Ells refers to these rocks as dolomitic which they may in part be. However they show vigorous effervescence when treated with hydrochloric acid. No mineralogical nor chemical analyses were made.

At one place only was basal conglomerate found. East of the second small point south of Quinn Bay there is a conglomerate with pebbles of hard light gray and dark gray slate and of quartz in a calcareous arenaceous matrix. These range in size up to one half inch in diameter. Otherwise the basal beds are of the same type as found in the Silurian, very shaly limestones with nodules or concretions of calcite. The matrix of this material seems to be a product of decomposition of the underlying slates. This would indicate a muddy bottom at the time of deposition. The nodules appear to be a later development- concretionary in origin with fossils as nuclei. The presence of corals among these fossils might seem to be incongruous with the idea of a muddy bottom but it has been shown that corals of the type found here apparently thrived in mud.*1. Rarely this material shows definite bedding planes. In some places as at Magoon Point and east of Georgeville beds near the base are made up almost entirely of crinoid stems and other fossil remains. These two types of material, though found mainly near the base, sometimes occur higher in the formation. In some places these beds appear to be quite thick. The creek section south of Belmere Point and that along the shore of MacPherson Bay show over 500 feet.

The rocks of these two formations are in the main calcareous. At Georgeville and Magoon Point the limestone is fairly pure- so much so at the latter point that great quantities were burnt for lime.

*1. Collections made in the MacKenzie River valley show large corals derived from shale beds.

Most of them, however, range between limestone and shale or sandstone. They vary in color from the pink, blue-gray and black of the more nearly pure limestone to the brown, gray and even yellow of the sandstones and shales. With the exception of the nodular and a little massive material these rocks are well bedded. The arenaceous limestone is found in thicker beds than the shaly limestones and shales. The former range in thickness from one inch to a foot while the latter are generally less than an inch.

Everywhere these series are highly metamorphosed: the limestone and quartz are re-crystallized, mica is developed and the rock is frequently schistose. The matrix of the nodular material is quite schistose and the nodules have been drawn out into lenticular masses. Some of the shaly beds have developed a slaty cleavage and might more properly be described as slate. Also cleavage is well developed in some of the more brittle arenaceous limestones. Pyrite cubes up to one quarter inch are found in much of this slaty material. Fossils wherever present have been badly distorted and crushed. Jointing is prominent. Around the metamorphosed porphyry north of Oliver there is considerable contact metamorphism which is described in the ~~chapter~~ section on dikes under the sub-heading for this intrusive.

The basal nodular material generally carries an abundance fossils. Above it are the crinoid stem beds and strata which seem to represent ancient reefs of corals similar to favosites or dyphyphyllum. The upper beds show very few fossil remains. Some of the lower limestones show peculiar concentrically banded forms which range in size from a few inches to a foot in diameter.

On weathering the calcite is dissolved out and the rock becomes brown on the surface. Where the carbonate is a minor constituent a rotten sandy or shaly mass remains. The nodular material weathers to nodules and fine dust.

Age and Correlation of the Devonian.

A large amount of fossil material was collected from a number of points in the area of Siluro-Devonian rocks. Very little of this was of value in making accurate determinations. Places from which fossils of indicative value were obtained are marked on the map with a large F, those from which the fossils were of no value with a small **F**. Collections determined as of Silurian age have already been described in the chapter dealing with that formation. From the others Dr.E.M.Kindle makes the following determinations:

Crinoid stems (abundant in some horizons)
Favosites cf. basaltica (abundant)
Syringopora?
Cladopora roemeri?
Favosites sp. Tubes small as in F. placenta
Favosites cf. emmonsi
Stromatopora sp.
Orthoceras ? sp.
Zaphrentis?
Favosites other species

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"Most of them (referring to 21 collections made at various points) contain specimens of one or more species of favosite corals. One of these is near, if not identical with, F.basaltica. These lots are believed to represent a Middle Devonian horizon. This is probably the same horizon as the Devonian horizon near Knowltons Landing, Lake Memphremagog. (Can.Geol.Surv.,Summ.Rept.for 1913, p.215)"

Ells reports as follows on various collections:*1

"Georgeville," Que.; A.Webster, 1879 :-

Zoophyta:

1. Halysites catenularia, Linnæus.
2. Favosites Gothlandicus, Lamarck. A tolerably well preserved specimen, showing the mural pores, &c.; resembles the form occurring near Tuck's Landing, Sargent's Bay, on the west side of the lake.
3. Favosites, sp., cf. F.favosus, Goldfuss. With exceptionally large corallites.
4. Zaphrentis, sp.

Echinodermata:

5. Fragments of crinoidal columns.

Capt. Gully's point, opposite Owl's Head, Lake Memphremagog, Que.; Ells, 1890.

Hydroida:

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*1 Report on a Portion of the Province of Quebec - Ann Report - Part J. Vol VII. P.154.

1. Stromatoporoid (undetermined).

<u>Zoophyta</u>:

2. Favosites Gothlandicus, Lamarck.

3. " with smaller corallites, and resembling F.Helderbergiæ, Hall.

Round Island, Lake Memphremagog, Que.; Ells, July, 1890 (in a dark gray glossy pyritiferous calc-schist; obscure fossils).

1. Stromatopora, sp.

2. Heliolites, sp. Very imperfectly shown.

3. Favosites, sp.indt.

The fossils in these collections would indicate Silurian age for the rocks of thesthree localities where they were obtained. However no determinable fossils were found in extensive collections recently made near Georgeville and Capt. Gully's point. As no other reference to the collections described by Ells was found their exact location and therefore their true significance could not be ascertained.

The folding of the Siluro-Devonian beds is isoclinal and consequently the structure is not clear. The Silurian may occur at the surface almost anywhere in the area of these rocks on the crests of undiscovered anticlines. The presence of Silurian at Capt. Gully's point or on Round Island (both points near the base of the Siluro-Devonian rocks) might even be expected. Such masses could easily be explained as similar to those already described. However if the collection marked "Georgeville" was made near the town the postulated extent and structure of these series are incorrect. This point would not be on the axis of the main syncline but rather of an anticline. The general principles however would remain the same. Without further verification and more accurate locations it seems best to disregard these collections.

The final summation of definite knowledge concerning the age of these rocks gives two outcrops of the main mass as Silurian and the rest of it as Devonian. The outliers were not definitely placed by fossil evidence. The Magoon Point mass and that north of it were correlated with the Devonian on the bases of similarity of lithlogic character (more particularly with the rocks of Molson Island), of metamorphism, structure and certain beds of crinoid stems. The two outliers south of Georgeville were correlated on lithologic character alone. The two small masses of limestone near Lake Massawippi have been included here because of their isolation, relationship to the Memphremagog slate and a slight similarity to other outliers. On the west side of Lake Memphremagog there are the areas described above which probably belong in this group. It has already been mentioned that Ells reported the discovery of a Silurian outcrop at the northern end of Lake Massawippi. Besides these no others are known nearby. 117/118

Structure.

The Siluro-Devonian strata are situated in two synclinoria, one of which includes the Memphremagog strip and the other that at Magoon Point. The smaller masses which are definitely outliers are associated with these in the same structural features. The two masses near Lake Massawippi would occupy minor synclines on the crest of the main anticlinorium. The Memphremagog strip is part of a mass which extends beyond the map area to the north and west (Figure 4). Farther west there is another large area of Siluro-Devonian rocks which may be included in another synclinorium. Rocks of the same age are found to the south on Round Island.

The boundaries of the Siluro-Devonian masses within the area have already been delineated but there remain some important features to be mentioned. At several places the boundary is very irregular, probably more generally so than it has been possible to discover. At two points within the limestone area there are slates which resemble closely those found below. They appear to be inclusions of older rock. One of these is situated about a mile and a half northeast of Georgeville and the other three quarters of a mile southwest of Oliver. There is one quite definite inclusion near the southern extremity of the Lake Memphremagog mass. These features are important aids in working out the nature of the structure. 118/119

In an effort to bring out more clearly the probable shape of these Siluro-Devonian masses before they were cut into by the lake the boundaries have been projected (Figure 4). The western contact of the

Magoon Point mass has been bent around the Point to link up with the eastern contact of the other mass. The structure of the older rocks which here indicates a steeply and abruptly plunging anticline seems to justify this. The other projected contact skirts the lake shore from west of Knowlton Landing to Round Island, then swings north again. The absence of Siluro-Devonian south of the island suggested this interpretation. The Magoon Point mass has been linked with the little one north of it, as many limestone blocks still remain scattered between them.

At their northern ends both synclin~~es~~oria clearly plunge south. The depression to the east of Magoon Point appears to be the result to a large extent of the removal of the limestone from the eastern synclinorium. Throughout the area there is a tendency for structural trends to swing to a north-south direction, toward the south. This arching seems to have caused the abrupt termination of anticlines and synclines in its axis. In other words there was a squeezing and pinching out of folds. The structure of the older rocks seems to indicate a sudden pinching out of the anticlin~~e~~orium between these two synclin~~es~~oria leaving just one synclin~~e~~orium to the south. 119/120 This too appears to be pinched out farther south. Thus there are two doubly plunging synclin~~es~~oria which join toward the south. To the north the structure is not unusual but to the south owing to the arching it is somewhat intricate. The mass to the west of the lake appears to be pinched out at about the same place- that is in the axis of the arch.

The strike of the strata is generally nearly parallel to the trend of the north-south boundary of the Memphremagog mass. The dip in the main is nearly vertical. From Oliver south it is generally to the west while north of this it is to the east. The detailed structure of the strata, though difficult to interpret due to the uniform strike and dip, is clearly indicated by a number of features observed. The cross sections of the Magoon Point mass and of parts of the main mass near Georgeville exposed along the lake shore show series of very close folds. North of Oliver doming due to intrusion (see Metamorphosed Porphyry) with subsequent erosion has developed a deep jog in the boundary. The depth of such jogs is indicative of the dip of the contact. This one is very deep which would indicate a low dip rather than the nearly

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vertical one registered on the strata. General east-west boundary trends such as that at the northern end of the Magoon Point mass are nearly at right angles to the strikes. At several places there are inclusions of older rock within the series though the dip of the strata between them and the contact is nearly vertical. These features together with the general relationship of the various outliers clearly indicate that the strata are isoclinally folded and that the general dip of the contact is low. Probably it did not exceed 30°and in some places nearly conformed with the present slope of the land. 120 121

The detailed structure of these strata beyond the fact of isoclinal folding is difficult to interpret. The exposures generally show little more than beds with a nearly vertical dip. The outcrops east of the metamorphosed porphyry reveal something of the nature of the minor folds. One outcrop representing the surface of a resistant bed has the appearance of a pointed rifle bullet half buried in the ground- in other words a very closely folded anticline which plunges abruptly. This latter feature however is unusual for the folds seldom show more than a 15°plunge and are generally nearly horizontal. The Magoon Point mass shows a series of crumples which vary in size. They are small and seldom seem to involve strata for as much as a hundred feet in the shore section. However it is probable that those observed are merely parts of larger folds.

Just south of Georgeville and north for several miles drag folds are abundant and can be clearly seen. From these it has been possible to work out the structure of an important synclinal axis. A few hundred feet north of the wharf the syncline can be observed and traced for 500 feet. To the east of this the strata are badly contorted with many drag folds which clearly indicate the presence of a synclinal axis to the west. For some distance along the shore to the north the contortions continue and east of the axis as projected there are drag folds similar to those near Georgeville but west of it nothing of a definite nature could be discerned. However on the north shore of the second bay beyond the village there are drag folds which indicate a synclinal axis to the east. North of this along the shore outcrops are abundant but they show very little contortion. It would seem that the 122 axis must continue to the north, east of the shore line. Indeed this is somewhat substantiated by greater contortion of the strata at the heads of the bays than on the points.

It cannot be definitely stated that this is the major synclinal axis for the basin but the evidence seems to indicate that it is. At Georgeville it is situated approximately in the center of the Siluro-Devonian mass. The absence of contortion in much of the rock west of it suggests that there is no other important axis nearby. 122/123
From Georgeville north the axis parallels the strike of the rocks, the axes of the minor folds and the Siluro-Devonian boundary. Drag folds on the point south of Georgeville probably indicate that the axis is not far to the west. Farther south it would seem reasonable to suppose that the axis curved to continue its parallelism with strike and boundary. Near Georgeville the axis is practically horizontal. To the north it seems to assume a slight northerly plunge which at greater distance must change. To the south from Georgeville to the limit of these rocks at least it would seem to rise.

The axis of the syncline east of Magoon Point may be assumed to pass through the center of the two Siluro-Devonian masses and continue to the south more or less parallel to the strikes on the shore. These two axes thus converge rather rapidly toward the south, substantiating the assumption of the boundaries as projected.

The parallelism of the major and minor axes and the strikes and main boundaries of these strata would seem to indicate that all had been developed at the same time. This would also indicate an absence of any important folding since that time. The swing in the structural trends to the south and the rather abrupt pinching out of synclines and anticlines might indicate later deformation, but there is nothing to substantiate this. Except for the doming near Oliver and other very 123/124
slight deformations the Devonian strata seem to have been involved in only the one period of folding.

The age of the folding which developed the structure in the Devonian cannot be definitely fixed. It is post middle Devonian for strata of that age were involved in the last deformation. Probably it is for the most part previous to the intrusion of the Stanstead granodiorite. It is definitely older than the basaltic dikes which cut folded strata.

It is known that in the upper Devonian the Schickshockian revolution affected a great part of eastern Canada. In Gaspé and New Brunswick nearly horizontal beds of Carboniferous age overlie unconformably older formations. As these areas lie to the northeast in line with the structural trends of the Memphremagog area it is probable that the same relationships exist in both places. Granite definitely determined as of upper Devonian or of Carboniferous age is found in Gaspé, New Brunswick and Nova Scotia. None of younger age is known. In view of these facts it seems reasonable to consider the granodiorite of southeastern Quebec as of the same age. The basic intrusives and extrusives of this area have long been regarded as of late Devonian age. From the foregoing the logical conclusion seems to be that the last great deformation to affect the Memphremagog area is of late Devonian or Schickshockian age.

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History of the Siluro-Devonian Formations. (This sub section should come at end of this section).

Prior to the beginning of the middle Silurian there was a period of very great erosion during which thousands of feet of the older formations were removed. In some places important series were entirely eroded away and the land was at least in part peneplained. Drainage was very sluggish and little clastic material was carried to the sea.

Submergence of the land began in the middle Silurian and deposition started in the vicinity of Georgeville. The extent of the sediments of this age is not known but it seems to have been somewhat limited. Between the middle Silurian and ~~the~~ middle Devonian the history is obscure. There may have been deposition in the upper Silurian. It seems probable that there was a slight warping of the land surface at the end of ~~the~~ this period. Subsequent erosion of the elevated parts left isolated patches of the Silurian and again more or less levelled the surface.

The history of the Devonian to the middle of the period seems to be much the same as that of the Silurian, though sediments of the younger period were probably more extensive. No definite record of the early upper Devonian was discovered. It is probable that the intrusion of the porphyry with consequent doming north of Oliver took place during this time. Later the Schickshockian revolution affected this area. The strata were not only thrown into a series of great anticlinoria and synclinoria but were also intensely squeezed into intricate isoclinal folds. Following this they were cut by basaltic dikes.

A short distance south of Georgeville there are several huge blocks of conglomerate. These are made up largely of the underlying limestone. They may represent the base of some younger formation. Otherwise strata of middle Devonian age are the youngest consolidated sediments in the area. History as revealed by other features is discussed elsewhere.

Thickness.

The intricate structure of the Siluro-Devonian strata makes it difficult to estimate their thickness. The lowest beds in the series are probably found at the contact east of Georgeville and the highest in the axis of the syncline just west of that village. The distance between these two points is over ~~five thousand~~ 5000 feet across the strike. The estimated dip of the contact is less than 30°. Calculations from these figures give a thickness of less than 2500 feet. Other features seem to indicate that this is a reasonable estimate.

Relationship to Older Formations.

The contact between the Siluro-Devonian and older formations is usually marked by a depression. This is caused by more rapid weathering and erosion of the beds just below the contact- a feature which is consistent in spite of variations in the material involved. It would seem to be the result of conditions prevalent prior to the deposition of the Siluro-Devonian rocks. At that time the nature of the surface material was such as to permit the penetration of calcareous solutions to considerable depth, which probably disseminated the small amount of calcite now found in these rocks. The solution of this mineral may be in part the cause of their more rapid disintegration. This feature together with the earthy character of the matrix in the basal Siluro-Devonian would indicate that these formations were laid down on an old land surface. The small amount of clastic material, the absence of sorting and evidences of pre-Silurian deep weathering suggest that this surface was partially peneplained. All these features clearly indicate at least an erosional unconformity.

Toward the south the boundary between the Siluro-Devonian and the older rocks is very irregular. At one place about a mile south of Molson Island on the mainland there is an inclusion of the older rocks within the limestone. While these features may in part be due to the nature of the folding they probably also indicate that there was a more irregular land surface here than to the north.

The Siluro-Devonian rocks overlie formations of different ages which clearly show as much as a 15° difference in strike. This indicates that there is a distinct angular as well as an erosional unconformity at the base of the limestone series. Deposition probably began in the area adjacent to the Georgeville-Fitch Bay road and gradually overlapped to the south and north.

The relationship of the Devonian to the Silurian is not very clear. Certainly the Devonian lies on a base which includes the older formations as well as the Silurian. This suggests two interpretations; one that the Silurian was never continuous and the other that its continuity was destroyed by erosion. The absence of the upper Silurian and the lower Devonian and the boundary relationships seem to favor the latter. This would indicate the presence of an erosional and probably an angular unconformity between the two formations.

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Sodium Diorite.

On the high hill west of Lake Massawippi in the northeastern part of the map area there occur several outcrops of acid igneous rock. The exposures though small are fairly conspicuous because of their light, almost white color and because of their location on the face of an abrupt escarpment.

The rock is quite variable, from a massive compact material resembling gray quartzite to a granular green rock which has a distinct igneous appearance. Owing to the similarity of some phases to a massive quartzite it is impossible to be sure that the extent of the igneous rock is properly indicated. The rock in the main is quite fresh in appearance though at one place it seems to be sheared.

Under the microscope the rock is seen to be hypautomorphic granular and shows very little if any sheared or clastic material. In composition it is variable from alaskite to sodium diorite: orthoclase content ranges from 60% in the former to none in the latter. Quartz is never more than 5% of the total; hornblende is 50% in one specimen, 30% in another, less than 5% in others and absent in the alaskite; oligoclase albite makes up more than 35% of the total of each specimen. Accessory minerals are apatite, magnetite, zircon and titanite, and secondary minerals are white mica, quartz, zoisite, iron oxide, chlorite (from biotite), kaolin, leucoxene and epidote.

Here there are found masses of flake chlorite in quartz similar to those associated with the intrusives on Bunker Hill. On weathering the green rock shows irregular cuts and rounded masses, while the massive gray rock becomes chalky white and powders readily.

In composition these rocks are similar to some of those found on Bunker Hill, but are far less metamorphosed. The fresh character of the rock observed both megascopically and microscopically would seem to indicate that it was intruded to its present position after the intense folding of the late Devonian. As lack of time prevented the making of a very careful study of this area the relative age of this mass and the serpentine was not established though there is a suggestion in the presence of quartz in the magnesite-serpentine rock that the sodium diorite is younger - supposing the quartz to have been a result of contact metamorphism. Also it seems that the hornblende content is largest where the rock is near the serpentine and insignificant when in contact with slate. There is a suggestion here that assimilation or differentiation due to contact with the basic rock may have been the cause. This would concur with the previous suggestion but neither is of sufficient value to warrant serious consideration. There is really nothing which gives a clue to the relationship of the sodium diorite to other igneous rocks.

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The Stanstead Granodiorite.

Name and General Relationships.

Stanstead*1 Granodiorite is a term used to designate a group of intrusives which are parts of or are associated with the granodiorite mass northwest of Beebe. These, according to previous workers*2, belong to a greater group of which the individuals are widely scattered from Lake Memphremagog east to Lake Megantic, north to Lake St. Francis, and south beyond the boundary between Canada and the United States. They have been described as Devonian granite.

The exposed portions are merely apophyses or the highest points of the irregular surface of an extensive batholith. Though the granodiorite is the surface rock in only a small part of the map area it probably underlies at no great depth at least the southern third of it. Thus it is possible that such masses as the Beebe and Barnston*3 intrusives and even those at greater distances are parts of one great underlying mass.

Topographic Features.

The topographic features due to the presence of this igneous body are quite pronounced, especially in the west , and to the east in the Coaticook area. There is a gradual increase in elevation toward the south from points which might readily be conceived of as representing the northern limit of influence of the intrusive on what is now the surface rock - an influence which is the result of uplift or induration of the sedimentary rocks or of injected apophyses. Granodiorite, having greater resistance to erosion than the adjacent material, is responsible for many of the prominent hills near the boundary, especially those to the west of Tomifobia.

*1. Stanstead was selected because it is the name of the county in which the granodiorite is found and the trade name used by one of the most important and oldest quarrying companies at Beebe.

*2. Ells' Report on the Geology of a Portion of the Eastern Townships- 1887 - p.36. Logan, Geology of Canada - 1863 - pp.430-434.

*3. Just east of the map area.

Description.

The igneous rock where it is exposed is well rounded by the action of ice and weathering and in most places it shows a very clean and at times a highly polished surface. In general appearance it is similar to the so-called gray granite used for building purposes. Natural outcrops are fairly abundant, and the presence of many quarries and prospect pits affords excellent exposures of the rock.

The outcrops of the area fall into two groups: those which are parts of the main intrusive northwest of Beebe (represented in Figures 5 and 6 by 9, 10, 11, 12, 14, 15, 16, 18, 19, 20, 21, 22, 24, 25, 26, 28 and 29), and those which are apophyses associated with this. In order to bring out certain petrographic relationships the two groups will be dealt with separately. ← Insert Figures here.

The material of the main mass is gray, varying from almost white with a few black specks to fairly dark gray in which the mottling with black is so pronounced as to give at a short distance the appearance of a uniform color. It has a medium-grained granitic texture which throughout varies only slightly and it shows practically no deformation. Microscopically the rock is hypautomorphic-granular. In a few specimens the quartz is strained, showing undulatory or patchy extinction, and in some the zonal growth of the feldspar crystals is distorted.

The mineralogical composition of the rock is shown by Figure 6. The majority of the specimens studied fall into the granodiorite group. The potassium feldspar is microcline or orthoclase or both. The ferro-magnesian minerals are biotite and muscovite, the latter being much less abundant and sometimes absent. Accessory minerals are apatite (found in practically all specimens examined); zircon, titanite, magnetite, and rutile (found in many); and tourmaline and pyrrhotite (in one adjacent to a pegmatite vein).

Border phases (2, 8, 17, and 23) are porphyritic in a few places: phenocrysts of oligoclase occur in a fine-grained dark gray groundmass with those of orthoclase, biotite, or quartz. Dikes (32 and 50), cutting the granodiorite, and fine-grained phases (27 and 28) are aplitic in texture. Though different in color and texture from the main mass they are quite similar in composition.

The apophyses which constitute the second group under discussion are scattered through the southern part of the area. Some of these are clearly offshoots of the granodiorite mass; others are conjectured to be so because of their position. Some show a similarity to various phases of the main mass; others are unusually schistose and show a resemblance to metamorphosed grits but owing to the development of new minerals are not determinable microscopically and are therefore rather doubtfully assigned to this group.

Although all these rocks bear some similarity to the main mass ~~they show~~ great variations from it and among themselves. The color of the material varies from light to very dark gray, with shades and mottlings of green and brown. The texture in most places is fine granular, but occasionally is equal in coarseness to that of the main intrusive. Some dikes have an appearance resembling tapioca pudding, due to an irregular blotching of white feldspar in a darker gray or brown groundmass. The dike north of Cedarville has a great abundance of large nearly parallel biotite flakes in a groundmass which appears to be somewhat cataclastic. The dikes on Providence Island are quite schistose, with the biotite chloritized and drawn out as green lenses. Besides granular rocks there are others which are aphanitic. Several of the large dikes north of the Sherbrooke Highway show a hard, dense, cloudy gray phase. Closely associated with this, and elsewhere, is found a highly altered, frequently quite schistose and pyritiferous light gray material, which in some places is spotted brown with iron oxide or siderite. This aphanitic material is a contact phase and grades downward into rock of granitic texture.

Microscopically the dike material is mainly hypautomorphic granular, though in many cases porphyritic. Some specimens show a linear arrangement of the constituents, due to schistosity. In composition most of these specimens fall in the granodiorite group (Figure 7). They are very similar to the rock of the main mass both in essential and accessory minerals. Some however have andesine instead of oligoclase, and many are very low in ferro-magnesian minerals.

To the northwest and northeast of the Beebe mass there are coarse-grained porphyritic phases which bear a slight resemblance to pegmatitic material but which are probably parts of the main mass.

These are light gray, with very little if any biotite. One specimen (5, Figure 6) examined under the microscope has a micropegmatitic texture. Part of this section shows muscovite instead of quartz intercrystallized with microcline. A relatively high percentage of muscovite, and miarolitic cavities are unusual features noted in this rock.

Differentiation in the Granodiorite.

From a careful comparison of the mineralogical composition of all phases no definite differentiation zones can be outlined. On the basis of megascopic examination alone a somewhat indefinite band of very light granodiorite may be distinguished extending from House Hill*1 and the La Crosse quarry*2 to Eagle Point. That this is due to a consistent change in composition is not evident, for specimens from within the zone show the same composition and the same type of variation as those found outside. However in many places there is distinct evidence of differentiation both in situ and at depth in the magma.

Several distinct periods of intrusion with pronounced differences in mineralogical composition are manifest. At Derosier's quarry (16, 17, and 18, Figures 5 and 6) three such periods may be present: two at least are clearly shown where a 10%/65% (plagioclase to orthoclase relationship) granite intrudes an older 38%/30% granodiorite. In the old quarry (13 and 14, Figures 5 and 6) on the Graniteville Electric Railway a 15%/60% granite dike cuts a 60%/12% granodiorite. Northwest of Stanstead (36 and 37, Figures 5 and 7) a 40%/30% cuts a 48%/15% granodiorite. In other localities similar variations are shown where dikes and veins cut older intrusives. That such variations in composition are the result of differentiation at very great depth is not necessarily the case. They more probably represent periods of upwelling during which there were uplift, shattering, stoping, and possibly absorption of parts of the igneous and sedimentary rock, with injections of the magma in the fractures created. Between these periods of activity

*1. Prominence about one mile northwest of Beebe.

*2. Half mile north of Beebe Station.

crystallization took place, probably for the most part along the contact. Meanwhile the magma was undergoing a continual change in composition due to differentiation and possibly to the addition of material, hence each injection introduced a different rock phase. The change in all cases studied involved an increase in the percentage of orthoclase and generally a decrease in plagioclase. The presence of andesine in the border phases of some of the dikes may be indicative of the composition of the earliest injections. The magma seems to have become progressively more alkaline.

Many local variations due to differentiation in situ are found. Variations of this type are generally greater near contacts. As the granodiorite is at no place exposed to more than a very shallow depth below its original surface, they are here very great and may be observed in many of the quarries. They assume no definite form, and probably indicate nothing unusual in an intrusive of this sort.

Segregations of Biotite.

Segregations of biotite are another type of variation in the granodiorite. They generally assume the form of streaks and as such 137 occur in practically all the quarries, although only to a slight degree 138 in those at Graniteville. These streaks are distinctly discernible in the fresh rock because of their darker coloring which appears to be due to the great abundance of biotite, and on weathered surfaces by a grooving which is the result of their more rapid disintegration. They are as a rule irregular in shape, size, and extent, but at one point in an old quarry to the east of House Hill (28, Figure 5) they show a wonderful parallelism both on a horizontal and vertical plane. They strike north 40° east, and dip about 70° west. They vary in width from one quarter to one and a half inches, but the thickness of each is fairly uniform for the distance exposed, which may be several feet. In composition and texture they do not appear to differ much from the adjacent rock except in a greater abundance of biotite, which is arranged more or less parallel to the streak, and in the presence of cataclastic feldspar. They seem to be the result of the formation of shear planes during the later stages of crystallization. Along these planes there developed a parallelism of biotite flakes and cataclastic feldspar, and possibly a circulation of fresh solutions increased the supply of biotite. Their direction is nearly parallel with the general trend of structural lines, suggesting that they were developed by the same forces which caused the regional folding. This is substantiated by observation in the quarries of the fact that with increase of depth and toward the center of the mass the streaks are less numerous.

Segregation knots of biotite occur scattered promiscuously in the granodiorite along the west side of the small mass just northwest of Beebe, mainly north of the La Crosse quarry (29, Figure 5). These are very dark gray, almost black, ellipsoidal or spherical masses which vary from a few inches to six feet in diameter. They consist ~~largely~~ of concentrically arranged biotite flakes with some feldspar and quartz. The biotite is much more abundant here than in the surrounding rock. In most cases there seems to be a gradation from the knots outward, but in some cases there is a fairly sharp boundary. Crystallization of the magma seems to have been a more or less continuous process beginning with the segregation of the knots. It is said that these portions rich in biotite decrease in abundance and that the rock becomes more uniform with depth.

The Influence of Contact on the Granodiorite.

The influence of the contact on the texture and mineralogical composition of the granodiorite in the larger masses is as a rule not pronounced. This would seem to indicate that the adjacent sediments were highly heated, and that the process of intrusion and crystallization was a lengthy one. In the dikes however, as is evident from the petrographic description, the variations to fine-grained or dense, even schistose or metamorphosed rock, is more common and in some places quite pronounced. In many cases dikes intruded at the same time vary much in texture according to their width: the narrow ones as a rule are more finely crystalline. Toward the contact in each dike the material generally increases in fineness. Where gradations are noted they are generally abrupt - in ~~some~~ places so much so that the two extremes appear like separate intrusives, as if indicating the sudden formation of a fine-grained crust at the border which acted as an insulator while the interior crystallized slowly. In some of the dikes there are slight mineralogical variations toward the contact, including the addition of ferruginous calcite, siderite, and pyrite, minerals which are now mainly represented by iron oxide. At Magoon Point to the west of the mass - the one place where quartzite was observed in contact with igneous rock - there was noted what appears to be a complete and gradual gradation from a medium-grained granite to a gritty quartzite. In the field it is not possible to place a definite boundary between the igneous and sedimentary rock. The former grades to a darker porphyritic material, with feldspar phenocrysts in a groundmass too fine for determination, and this to metamorphosed quartzite which contains feldspar and other minerals from the magma. Beyond the feldspar quartzite the unaffected rock is largely quartz with hornblende, white mica, magnetite, epidote, zoisite, rutile, and iron oxide - a typical dynamically metamorphosed grit. Contacts with other types of material are generally quite sharp.

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Pegmatite Veins.

Pegmatite veins (straps) cut most of the exposures of the granodiorite. The best development of these is found in an old quarry east of House Hill (28, Figure 5) where the igneous rock is cut by many parallel veins. They are spaced at irregular intervals of from six inches to fifteen feet and vary in width from that of a thread to a foot, but are remarkably straight and uniform in thickness. They strike north 20° east, dip 52° west and are approximately parallel to the biotite streaks. Probably they were deposited in fractures which were developed by the same forces that produced the biotite-rich shear planes. Similar veins elsewhere are much less regular. Some of these pegmatite veins show no sharp boundaries: they grade more or less into the wall rock as if they had been injected before crystallization was complete. Some are banded, probably indicating deposition from changing solutions at different periods. Mineralogically they are composed of quartz, feldspar, muscovite, tourmaline, garnet, and a light yellow-green mineral pistacite (pisacite).

Quartz Veins.

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Quartz veins associated with the granodiorite are found abundantly throughout the intruded area. Some are contorted; others cut the main mass, the dikes, or even the pegmatite veins. Apparently they were formed both during and after intrusion of the magma. In composition they are mainly silica.

Alteration of the Granodiorite.

Microscopically the granodiorite is observed to be considerably altered. The changes do not appear to be entirely the result of weathering; as the extent of alteration is not dependent on the proximity either to the present surface or to fissures. The metamorphosing forces seem to have been more intense near the pegmatite veins and other points where ~~the~~ thermal solutions could have had ready access. It is likely that the development of secondary minerals is due largely to this factor - an early post-intrusion metamorphism rather than a late one. Feldspars are altered to white mica, kaolin, epidote, zoisite, and calcite. Biotite is bleached or changed to chlorite, rutile, titanite, and iron oxide. Magnetite is replaced by hematite, leucoxene and limonite.

In weathering, the feldspars bleach and become chalky white, while the biotite darkens and becomes rusty. The coarse-grained material crumbles readily into a granular state, but the finer-grained and dense material does not disintegrate rapidly, apparently weathering only at the immediate surface. Some of the schistose rock becomes abundantly rust spotted from the decomposition of a metamorphic mineral which was not determined. Large stains are caused by the presence of pyrite, magnetite, and pyrrhotite, but with the exception of pyrite in some contact phases these are very rare. Under the microscope the products of weathering cannot be separated from those of previous metamorphism.

Jointing.

The granodiorite throughout the area is jointed, but there is very little agreement in the direction of the joint planes in the various outcrops or between their direction and that of the pressures causing their development. In some joints there is a flaky gouge-like material between slicken-sided surfaces - the result of movement along these planes. These features show that the forces were neither great enough nor sufficiently concentrated in one direction to produce uniformity, and that there were two periods of deformation affecting the granodiorite- one represented by the jointing, and another by the movement along the fractures thus formed. From this it may be deduced that crystallization did not take place until deformation was practically complete, and that after this the pressure did not continue or was too weak to develop uniform systems. The later movement was probably a result of settling, an after effect of intense folding, or of contraction on cooling of the igneous mass.

Sheeting.

Sheeting is quite pronounced in all the quarries. In some places it is parallel to the present weathering surface but in many it is not. In practically all it seems to conform in general outline to what may have been the surface when the granodiorite was first exposed and prior to the beginning of unequal erosion due to the difference in resistance of the igneous and sedimentary rock. It appears that the sheeting started to develop parallel to the surface when there was still considerable covering over the rock affected and that as erosion progressed new cracks formed parallel to new surfaces, thus giving thinner and lenticular laminae near the exposed part.

The General Effects of Intrusion.

The general relationships throughout the area northwest of Beebe clearly indicate that any sedimentary rock overlying the granodiorite is thin. A study of the structure here reveals the fact that intrusion was accompanied by some deformation of the strata. Near Beebe the sediments have been very irregularly folded, apparently in such a way as to make them conform more or less to the upper surface of the igneous mass, but farther northwest the arching was more general and does not show the same intimate conformity. Small inclusions of sedimentary rock rarely have a dip which conforms with the slope of the granodiorite surface.

Though there has been this general arching and in places a detailed folding, the igneous rock gained its present position largely by cutting across the stratification. Though some of the space it occupies may be attributed to upbowing and possibly general uplift, there still remains a tremendous amount to be accounted for in some other way. In places the older sedimentary formations must have been completely removed as they do not now outcrop at any point around the border of the granodiorite.

On the map it may be noted that outcrops of parts of the main intrusive show great variations in size and shape. This irregularity is not merely the truncation of an uneven surface like that of a hilly region. Besides the knoblike protuberances, there are many which are not vertical in the direction of their protrusion, and which pinch and swell in a very erratic manner. If horizontal sections were to be made at different stages in the erosion of such a mass they would not necessarily show a progressive increase in size or a similarity of shape of the various parts. The map represents such a section. If others had been taken above this illustrating conditions that have existed they would on the whole, though not necessarily in each part, probably show less granodiorite. Sections below would show more. In other words between the sedimentary rocks, with few penetrating dikes, and the granodiorite, free from inclusions, there is a zone probably hundreds of feet thick in which the igneous rock is intimately and irregularly interfingered and interlocked with the slate. Toward the top the intruded rock remains firmly united, while lower down near the base many parts are very nearly isolated. Had the process of intrusion continued they would probably have been completely severed, and there is little doubt that many blocks actually were separated during the period of activity. In this way - by stoping - much material must have been removed, thus making way for the advance of the magma.

The larger sedimentary blocks which now appear as inclusions in the granodiorite have almost certainly been isolated by erosion of the connecting masses. That such is the case is shown fairly conclusively by their orientation, with strike and dip corresponding to the general structural trend of the area. They cannot well be stoped blocks which floated on top of the magma, for such activity as was necessary to do the stoping must surely have been great enough to revolve and

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move them. There is no evidence nor has it ever been shown that stoped blocks might be found within or at the base of an igneous mass. Hence it is assumed that these no longer exist, unless certain small fragments, apparently fused, represent remnants thereof.

On the Beebe road to the lake, near the latter, and on Long Island there were found in the granodiorite a few small inclusions which had rounded corners and the aspect of fused material. The presence of these and an apparent re-absorption of the granodiorite at Derosier's quarry seem to show that the temperature attained in places was sufficient to cause assimilation of solid material. That this condition prevailed along a very great extent of the upper surface is not likely, but that it existed at all probably indicates that not far below such conditions were more nearly general. Thus detached blocks of sediment would have been placed in a position which seemingly should be postulated as being suitable for absorption by the magma.

From the foregoing statements on the effect of intrusion, and the conclusions drawn therefrom, it follows that the igneous rock reached those positions where it is now exposed partly by causing an arching and uplift of the overlying strata but largely by stoping and assimilation. During this process the magma became progressively more acid, possibly due in part to the absorption of rocks high in quartz and low in calcite such as are found underlying the calcareous beds which now outcrop around the granodiorite.

The Age of the Granodiorite.

The age of the granodiorite can be fixed more accurately by reference to the late Devonian de formation than to the intruded strata, as these are so much older that they are of little value in making a definite determination. The relationship to the structure and the slight deformation of the igneous rock as shown by the development of schistosity, biotite shear streaks, pegmatite vein fractures, joints, contorted quartz veins and slightly cataclastic minerals indicate that crystallization of those parts now exposed took place during the final stages of folding. This would denote very late Devonian as the age of this intrusive.

The Development of the Intrusives.

Deformation of the strata in the map area has been very intense as indicated by the multitude of small isoclinal folds. That this type of folding involves a very thick crust seems unlikely. Yet with such great adjustments near the surface there must have been some lower down, and these probably were effected by plasticity with consequent mobility and change of shape by flow. Thus below the zone of intense folding there existed a magma from which the igneous rock now exposed ascended, or by which it was developed.

Hypothetically, as it is by no means apparent at the surface, the section in which igneous activity occurred corresponded roughly to 143/144 that of Devonian deformation, the former development being somewhat a result and concomitant of the latter. In shape it was wedge-like, the area of folded crust representing approximately the thick end of the wedge, and the limit of deformation within the earth the thin end, with orientation of the long direction parallel to the main structural lines. During the period of activity that part deepest within the earth was subjected to the greatest, though least differential, pressure while nearer the surface the opposite was true. Temperature probably increased with depth.

This section was divided, according to the state of the material within it, into a zone of flow and one of no flow. The former (more properly a zone of potential magma) was that part in which magma could be originated under the influence of pressure and temperature, and might correspond to that in which an actual flowage of the solid rock was possible. This zone included all from the base, which is most susceptible to flowage, to an upper boundary marked by an imperceptible gradation from this state to that of no flow. This boundary was extremely irregular and indefinite, and variable with changes of conditions. During the period of deformation, throughout this zone there was probably some adjustment by rock flow. At the base this was probably the only type of movement. Here and for some distance above, it 149/150 was quite uniform. Upward to the boundary marking the limit of its effectiveness it decreased in uniformity and regularity of distribution. With an increase upward of differential pressure deformation became more active. Due to this and a decrease in susceptibility to flow adjustment was localized. This primarily caused but was later the result of the development of plasticity and even liquidity - in other words the creation of magmas. These, once formed, increased readily in size, and tending upward in the direction of least resistance probably united in some places. In other places they died out, due to the development of new magmas elsewhere, or during a period of quiet became solid again. Toward the surface a decrease in susceptibility to flowage (developed by pressure and temperature) as a factor in hindering the formation of magma was probably counteracted by an increase in differential pressure. Therefore the proportion of magma to solid material at different levels might have varied greatly, except for a short distance above the zone of adjustment by rock flow only, where it increased upward.

Above this zone in that of no flow magmas could not be originated, but were induced by the processes previously described. At the base of this part, magma conditions were probably nearly general. Toward the surface they became less comprehensive though not necessarily progressively so. Here magmas were apophyses of others in the zone of flow. All parts of the intrusive were undoubtedly not in the magma state at the same time.

Movement of magmas was mainly toward the surface, though some was lateral, parallel to the structural trend, and therefore at right angles to the direction of greatest pressure. Often this movement was effected under great differential pressure which caused arching or even general uplift of the overlying strata. As a result of the variations of conditions and of irregularities in the formation and movement of magmas there was formed, both in the upper part of the zone of flow and above it, a great variety of igneous rock forms: laccoliths, batholiths, dikes, sills, etc~~etera~~.

The nature and regularity of adjustment throughout the section varied greatly. Near the top, as is indicated by numerous small isoclinal folds, it seems to have been fairly uniform except for some thrust faulting in places where strains developed too rapidly or became too great for compensation by folding. Lower down where irregular plastic or liquid masses existed adjustment undoubtedly took place largely within these masses, and therefore was not consistent throughout. Near the base of the section there was another zone of uniform adjustment due to movement by flow.

Metamorphism of the Sedimentary Rocks by the Granodiorite Intrusion.

The sedimentary rocks throughout the southeastern half of the area are highly metamorphosed. There is no apparent increase in extent of alteration toward the granodiorite. According to Ells and Logan (op. cit.) the effect of intrusion, presumably noted mainly in other areas, is distinct, mica, staurolite, and andalusite having been developed in the schists. Though many specimens were examined both megascopically and microscopically the last two minerals were not observed. Mica is abundant everywhere, but its presence and that of metamorphic features in general seem to be more properly assigned to dynamic forces.

The effect of intrusion on the immediately adjacent rocks varies with the nature of the material intruded. The gradational contact between the granite of Magoon Point and the quartzite has already been described. Contacts with other types of material are sharp. Limestone and calcareous sandstone show an addition of iron bearing minerals, probably carbonate, which have been altered by weathering to iron oxide. Slates also show an increase in iron bearing minerals and are generally indurated. Probably other changes in mineralogical composition took place as a result of intrusion, but it was not possible to separate these from those caused by dynamic metamorphism, as features found within the presumably affected zone were also found beyond it.

Serpentine.

Serpentine occurs in the northeastern corner of the map area. The largest exposure, which constitutes the egg-shaped area on the map, is a very prominent topographic feature. It stands out as one of the highest hills in this area, a peculiarly shaped knob. To the north it has a very abrupt, in places almost perpendicular, slope while to the south the slope is more gentle. It is a rather typical roche moutonnée, having assumed its present shape as a result of ice erosion. None of the other exposures is prominent. All are relatively low, flat and obscure.

The rock found in the large exposure is somewhat different from that found elsewhere. In general it appears to be the typical greasy green serpentine. However on careful examination it is found to vary greatly in character, from a hard greenish black or light green massive rock to a soft light green schistose serpentine. The former appears to show traces of the original texture of the rock: in places large black phenocryst-like masses are apparent. The other outcrops show even greater variations. While at a few places the rock is similar to the main mass, in most it is a peculiar blue material, spotted light gray. This is very soft, spongy, and quite talcose to the touch. It is found grading to or closely associated with a mottled light and dark gray crystalline material. Some specimens, particularly from the large exposure, show fibrous serpentine which appears to be mainly the result of slickensiding.

Under the microscope the material is seen to be largely serpentine with magnesite, magnetite and chromite. In a few places there is sufficient evidence to indicate that the serpentine is derived from olivine, and in one from pyroxene. In several specimens the serpentine was observed to be fibrous. The mottled light and dark gray rock is made up of quartz, magnesite and magnetite. All specimens show an almost complete alteration from the original composition.

The rock of the main exposure has the peculiar texture frequently found in serpentine. Hard, irregularly shaped masses are surrounded by softer fibrous and slickensided material. Apparently the rock has been irregularly sheared as a result of the increase in volume due to serpentinization. The smaller outcrops are in places cut by yellowish-green veins of talc.

The rock of the main mass weathers irregularly. Apparently the softer slickensided material is more susceptible and is removed first. Thus the rock is left peculiarly cut and crevassed.

The blue serpentine on the surface shows numerous pits which appear to be the result of more rapid weathering of the magnesite. This mineral seems to be more or less segregated into knots. In some places a ridging is developed, probably due to the same cause. All the smaller outcrops are soft and weather more readily than the main mass due to the presence of magnesite. The phase which is devoid of serpentine weathers to a very rusty granular mass. Many weathered surfaces show a pearly luster as of mica.

The original character of the material and the significance of its variations are somewhat difficult to fathom. The main mass was probably a peridotite, now represented by the green serpentine. The peculiar magnesite phases are thought to be the result of alteration of the original rock and to represent the upper or outer limits of the mass. Magnesite as shown by its ready removal on weathering is more susceptible to solution than the serpentine, and was probably largely removed from the body of the mass and concentrated at the contact both in the sedimentary and igneous rock.

The main mass is stock-like in character and probably extended much higher than at present. Practically all the other exposures are flat and show the magnesite phase. They are probably not far below the original surface of the intrusive.

As the work in this area was very hastily done the relationship of the serpentine to the other rocks was not definitely ascertained. No direct contact with slate was observed. It seems certain however that the serpentine is intrusive into the Memphremagog slate. There is nothing in the structure of the slates nor in the shape of the masses nor the texture of the igneous rock which suggests that the intrusives were involved in the intense folding of the late Devonian. It is probable that the serpentine followed this folding closely and is of very late Devonian or Carboniferous age. There was nothing of a very definite nature which might suggest the age relationship of the serpentine to other late Devonian igneous rocks.

Dikes.

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Besides those dikes which are definitely associated with major intrusives there are some scattered throughout the area for which no such association is apparent.

Metamorphosed Dikes.

West of McConnell in the McConnell series there are found several dikes which resemble closely some of the sediments but their relationship seems to indicate their igneous character. They are very light gray, medium-grained and ochre-spotted like the sediments nearby. No microscopic examination was made. The dikes cut the McConnell series but were not observed to cut the slate. They are folded with the sediments and are probably equivalent in age to the upper McConnell series.

Serpentine Dikes.

At several places west of the southern end of Lake Massawippi there are found very peculiar dikes. Two outcrops occur on the hill south of McConnell and two more on the brook southwest of this. The dike-material does not stand out prominently at any of these points. It is mainly a dark blue-gray and green serpentine-like rock with much crystalline calcite. In some places it is blotched and irregularly streaked with malachite green. It contains considerable quantities of quartz which on weathering stands up in irregular masses or veins. Talc-like material is also found associated with these dikes. 156
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Microscopically one specimen was found to be mainly calcite with quartz, mica, serpentine, magnetite and hematite. Parts however appear to be more largely serpentine.

The dikes are all narrow. They bear some resemblance to serpentine and may be associated with it. Outcrops are so poor that no very definite idea of the relationship to the sediments was obtained.

Metamorphosed Porphyry.

One mile north of Oliver between the lake and the road is a peculiar band of material which outcrops close to the road for nearly two miles. Figure 8 Near the southern limit it stands up prominently in irregular roches moutonnées. Toward the north these become continuous in one ridge which dies out with the thinning of the band. In most places the surface is well rounded and polished, occasionally showing striae.

This band of material is made up of dikes and the adjacent or interlaminated metamorphosed strata. Both types of rock are very similar megascopically. In the southern part there is one large dike which toward the north is divided into several smaller ones. The igneous rock is very hard, bluish gray, and in texture mainly fine-grained to dense. In most places it appears very much like chert or impure quartzite. The weathered product is light gray and yields a chalky white powder. The center of the large dike is quite massive but its border phase and the smaller dikes seem to be somewhat laminated. Only slight schistosity is apparent on the fresh surfaces.

The adjacent and interlaminated sediments have been so highly metamorphosed that they are very similar in appearance to the igneous rock. At only a few places was a sharp contact noted. Generally it was gradational, or, as there was so little difference between the two kinds of rock, the change was not perceptible. The chief alteration of the sediments seems to have been a loss of calcite and an addition of silica and other minerals from the magma. In some places a gradual decrease of calcite toward the dikes is quite apparent. Near and in them the mineral is present only in fractures.

Under the microscope the dike rock is seen to be highly metamorphosed. Originally it was probably a porphyry with large phenocrysts of feldspar in a very finely crystalline groundmass of feldspar, quartz, biotite and muscovite. Only outlines of the ~~former~~ phenocrysts now remain; the feldspar has been completely altered to white mica and other minerals. The groundmass is now a fine-grained aggregate of quartz (a large part apparently secondary), biotite (in part or even wholly hornblende), white mica (both primary and secondary), and a little chlorite, magnetite and iron oxide.

The outlines of some phenocrysts appear to be intact but others seem to have been broken. The groundmass may be partially cataclastic but the development of new minerals has proceeded so far as to make any definite determination impossible. Judging from the tendency to cataclastic texture and schistosity the intrusion took place some time before the Devonian deformation was complete. Further evidence, in the intruded sedimentary rocks, seems to confirm this. They were apparently domed by the intrusion. The cleavage in the adjacent sediments is clearly parallel to the main structural trends while the bedding is not. This feature is peculiar to the area near the intrusive and would seem to indicate that the main structure was developed after the doming. Thus the age would be early upper or late middle Devonian, somewhat earlier than the other Devonian intrusives.

The structure developed in the area of the intrusive is peculiar. That intrusion caused doming is apparent from the jog in the boundary of the Devonian and local structural features. Its linear arrangement would suggest that Devonian folding was well under way before intrusion took place. However it had not been carried through to ~~to~~ completion as the cleavage was not yet developed. The partially folded dome was more completely folded during the final stages of deformation. The resulting structure might be represented by a piece of paper folded fan-like, held tightly at either end and bulged out in the center. It would seem from the developed structure that this dike is merely an apophysis of a closely underlying larger mass.

Picrite Porphyry.

One small exposure of picrite porphyry was found in the southeastern part of the area mapped. The outcrop is less than two hundred feet long but is quite well defined. Owing to its greater resistance to weathering and ice action than that of the adjacent rock it stands up prominently as a roche moutonnée. Only an approximate estimate of the surface extent of this intrusive (probably a dike) could be made as it occurs in an area well covered with drift.

The rock is porphyritic: large (one-quarter inch) phenocrysts of black augite are fairly abundant, and less numerous but larger ones of glassy green olivine stand out prominently in a greenish black groundmass which has somewhat the appearance of serpentine. Microscopically hornblende is also observed among the phenocrysts. These occur in a tinguitic groundmass of titaniferous augite, olivine and andesine. The first of these constitutes 75% of the rock, the second 15%, and the last 5%. Accessory minerals include 5% magnetite, pyrite, biotite and hypersthene with titaniferous augite rims. Secondary minerals are chlorite, serpentine, hornblende, calcite, titanite and iron oxides. 160/161

Hornblende, hypersthene and feldspar apparently crystallized first, and were later partially resorbed. These were followed by olivine and augite - the latter surrounding the former.

The rock weathers dark rusty brown. It breaks with an irregular fracture, presenting a pisolite-like appearance. It shows very little evidence of having been subjected to much pressure: neither jointing nor schistosity was apparent. It is probably younger than the granodiorite and therefore late or post-Devonian. Judging by the location it is an apophysis of some igneous mass to the southeast.

([redacted] ~~N.B. This is followed immediately by Page~~)

Massawippi Dikes.

Around the southern end of Lake Massawippi there are several dikes which may be associated with the same intrusion. Though similar in many respects, their differences are sufficiently great to warrant separation into two groups. The large dioritic (acid diabase) dike southeast of Ayers Cliff constitutes one, and the vogesites south and west of the lake make up the other.

The single large dike mentioned above outcrops in two places: in the creek bed where a fresh surface is exposed, and north of this near the road where a well-weathered phase may be observed. It is a medium-grained dark green porphyry: megascopically, light green or white ~~with quite distinct~~ and black phenocrysts in a greenish-black finely crystalline groundmass. Microscopically it is ophitic, with biotite and augite as large xenomorphic individuals instead of augite alone. Mineralogically it is 60% andesine, 20% biotite, 15% augite, 5% titaniferous magnetite, hornblende (chlorite present appears to be partly a result of decomposition of hornblende) and apatite. Toward the edges of the dikes the rock grades to a light brown dense porphyry which under the microscope is seen to be much altered, and is now largely kaolin and calcite, with small amounts of quartz, white mica, feldspar and magnetite. On weathering the center phase becomes dark greenish brown while the border shows little change.

The contact of the igneous material with the sediments is quite sharp. Jointing, schistosity, or other evidences of movement since intrusion are not apparent. Stringers from the dike have penetrated and contorted the adjacent strata. Veins of calcite are continuous through the dike and beyond. Except a little induration there seems to be no contact metamorphism of the sediments.

The other dikes are grouped together on the basis of a similarity of appearance, for only one, that directly south of Ayers Cliff, has been examined microscopically. All are porphyritic: phenocrysts of black hornblende and white feldspar occur in a finely crystalline black groundmass. The specimen examined under the microscope is subtrachytic, microlitic and porphyritic. Mineralogically it is 50% hornblende, 30% orthoclase and 20% andesine. These dikes show the same type of border phase as the dioritic dike. Their effect on similar adjacent sediments is the same. One of them, however, cuts limestone, and has caused a complete re-crystallization.

They show the same structural features and relationships as the dioritic dike except ~~that~~ one directly south of Ayers Cliff which follows a joint plane. Both groups appear to be of approximately the same age. They seem to have been intruded after the strata had been folded into their present position and therefore are late or post-Devonian.

Hornblende Basaltic Dikes.

On the eastern shore of Lake Memphremagog several basaltic dikes, from one to ten feet wide, cut the Devonian limestone. They are greenish black porphyry with phenocrysts of a white glassy mineral in ~~a crypt~~ocrystalline groundmass. This material on weathering becomes rusty brown. Microscopically it is trachytic with a trachytoid groundmass. Mineralogically it is 25% augite, 25% brown hornblende, 5% andesine and 5% olivine in a glassy groundmass with microlites of plagioclase feldspar. Alteration products are calcite, quartz, chlorite, leucoxene, serpentine and brown iron oxide.

The dikes show only a slight variation from the center to the edges. Between them and the country rock on both sides there are one-inch veins of calcite. These veins are coarsely crystalline and show scalenohedral crystal forms on the dike side. Apparently after the crystallization of the intrusive cracks were developed between it and the sedimentary rocks. Hot solutions rich in calcite from the intruded rock circulated along these and deposited a layer of the mineral on the limestone walls. The igneous rock also contains much calcite as vein material and as a replacement throughout. The adjacent limestone is slightly altered and appears to have lost some of its carbonate content.

These dikes cut across the bedding and trend approximately east and west. From this and their location it is concluded that they are closely related to some of the igneous masses[*1] to the west. They show no effects of dynamic metamorphism. They were certainly intruded

*1. Ells' Report on the Geology of a Portion of the Eastern Townships - Pp. 39, 40.

after the folding and are therefore late or post-Devonian.

Although the last four groups (Picrite Porphyry, two Massawippi Dikes and Hornblende Basaltic Dikes) are widely separated and different in many respects, they show some resemblances. Andesine is found in all; augite in all except the vogesite; olivine in the picrite porphyry and hornblende basalt; hornblende in all, though that in the basalt is brown and in the others green. Each shows about the same freshness and lack of metamorphism, and has been determined as late or post-Devonian. These similarities suggest that all came from the same magma though probably not at the same time, while their basic character suggests the possibility of some relationship to the serpentine.

Quartz Veins.

Throughout the area quartz veins are numerous. Some are clearly as early as pre-Memphremagog slate as they cut underlying diorite without penetrating the slate and many are undoubtedly associated with the granite. It is probable that there were other periods in which quartz veins were developed as there are great variations in the extent of their metamorphism.

Devonian to Pleistocene.

There are no formations recognized as representing any part of this interval but there is some evidence that deformation took place. This probably was in the nature of an uplift, tilting or gentle doming and did not greatly change the structure already developed. In the northeastern part of the area there was some normal faulting. It is not unreasonable to suppose that formations younger than the middle Devonian were laid down and entirely eroded, for the amount of erosion which is now apparent is not commensurate with the time interval unless the area was at near-peneplain conditions for the greater part of it. Either much of the history is missing, owing to complete removal of evidence, or the history of the area is one of monotonous stability.

Pleistocene.

During the Pleistocene the Memphremagog area was subjected to glaciation. Everywhere there are glacial deposits which reach considerable thickness over the greater part of the area. Though not studied in great detail it is evident that the Pleistocene period should be divided into at least five different stages. Each of these is represented by deposits.

Table of Pleistocene Deposits.

Stage	Type of deposit.		Character.
Marine invasion	Marine, fluviatile	deltas, terraces, etc.	Gravel, sand.
Lake stages during retreat of ice sheet	Lacustrine, fluviatile	terraces, deltas, etc.	Sand, gravel
Cassville glacial	Morainal	terminal recessional ground	Glacial drift
Beebe interglacial	Lacustrine		Bedded clays and sand
Beebe glacial	Morainal	Mainly terminal	Glacial drift.

Beebe Glacial Deposits.

The deposits of the Beebe glacial stage are represented mainly in the large terminal moraine which occupies the area along the international boundary (southern deposits indicated in Figure 9). They are best exposed northeast of Beebe and west of Rock Island. They consist largely of unsorted glacial drift in which there are bowlders up to five feet in diameter. These are mainly of local material but there is also much which has come from beyond the area: granite gneiss, diorites, quartzites and other types of rocks, many of which resemble those of the Laurentian Highlands. With the unsorted material there are beds and lenses of gravel and sand. The thickness of the deposits in places probably exceeds 200 feet.

Other deposits within the map area may belong to this stage but no attempt has been made to differentiate them. The northern group of deposits (shown in Figure 89) represents approximately the southern limit of the Cassville glacial drift. Probably the greater percentage of the drift south of this is of Beebe age.

Beebe Interglacial Deposits.

Lake deposits overlie and occupy approximately the same area as the Beebe moraine. Similar and therefore correlated deposits occur in two places farther north. One is on Fairfax Brook two or three miles north of Fairfax and the other about two miles up the stream that joins the Tomifobia River on the east, northeast of Ticehurst Corner. Other small deposits in the southern part of the area not indicated in Figure 7 probably are of the same age but these are for the most part very thin.

The deposits of this age are best exposed just northeast of Beebe where the clay was previously used in making brick. There is much finely laminated blue-gray clay which is remarkably pure. It is interbedded with brown sand which in some beds is clayey and in others is cemented into a sandstone. Some pure clay beds are as much as ten feet thick but generally they are measured in inches. Laterally they seem to vary considerably in short distances. Toward the top sand predominates. The surface material over the larger part of the high land between Stanstead and Beebe is this brown sand. In the sand there are found scattered pebbles and bowlders. The maximum thickness of these deposits exceeds 50 feet and may reach 100.

Cassville Deposits.

West of Beebe and on Stanstead plain the lake deposits are overlain by more or less sorted gravels while the small deposits to the north are overlain by glacial drift. This has been referred to the Cassville stage with all the glacial drift north of and including the northern group of deposits shown in Figure 7. Those shown are only the most southerly of the thicker Cassville deposits. The Cassville deposits as a whole are of the same general character as those of the Beebe stage. There are included terminal, recessional and ground moraines, drumlins, eskers, and much outwash gravel and sand.

The thickness in places is considerable but it probably does not anywhere equal that of the Beebe moraine. South, southwest and west of Cassville there are quite thick deposits with an irregular topography. East of Lovering Lake is another area of very thick drift which has the general appearance of a terminal moraine and in one place of an esker. West and southwest of Katevale the whole hillside is covered with more than 30 feet of drift in which there is a great abundance of 6 to 8 foot bowlders. Southwest of Lake Massawippi and north of the Nigger River the deposits are again very thick - having considerable influence on the topography in the development of sharp V-shaped gullies.

Deposits of Lake Stages and Marine Invasion.

Overlying the Cassville deposits in many parts of the area are fine sands. Southeast of Lake Massawippi along the Nigger and Tomifobia Rivers is a series of terraces and deltas. Some of the deposits probably belong to the late Pleistocene marine invasion while others, especially those beyond the probable limits of that stage, were laid down in lakes developed during the retreat of the ice. As no fossils have been found it is impossible to make any definite ~~determin~~ differentiation.

The deposits on the Nigger and Tomifobia are largely of bedded sand and gravel. Some of the sand has a fairly uniform, nearly horizontal bedding, as if deposited in a lake a short distance from the shore. Other deposits show a typical delta structure. None of these deposits are extensive or very thick.

Bedded sand which appears to make up the hill in the valley north of Turnertown must be of considerable thickness - probably more than 50 feet. Throughout this valley there is much bedded sand and gravel. South of Turnertown there are two hills which are very similar to drumlins in shape but are made up largely of bedded gravels. 170/171

History - Pre-Pleistocene Topography.

Between the Devonian and the Pleistocene much erosion took place and a drainage system somewhat similar to that now in existence was developed. At the end of the Pliocene the topography was probably not greatly different from that of today. There was a great open Memphremagog valley which was occupied by a fairly large river. The trend of the tributary valleys and the increased width to the south suggest that the direction of flow then was opposite to what it is at present. However no outlet in that direction is apparent, nor is an ancient valley of sufficient size and suitable gradient indicated anywhere. Present topography as shown on the maps would seem to indicate that the assumption of an outlet to the northeast by the present route is the most plausible. Fitch Bay valley was occupied by a tributary stream which probably drained a smaller area than Bunker Brook does now. In the Lovering Brook valley there was a tributary to this which also drained less than the present stream.

The water of the Tomifobia River system above Tomifobia village flowed west from Beebe to the Memphremagog River (Figure 9). At Rock Island its channel was somewhat farther north and may have been in the Crystal Lake valley. Below Tomifobia there was a stream somewhat similar to the present Tomifobia River though much smaller. The Nigger River occupied a valley corresponding somewhat to that of the small stream now east of it. The Massawippi system was similar to the present except that there was a river where the lake is now. Thus about half of the area drained north to the Massawippi system and the other half west to the Memphremagog.

The detailed drainage was similar in general aspect to that of today but there were many minor differences. The small streams were well entrenched - many probably more deeply so than now. The topography was mature and the rock surface deeply weathered.

Ice Advance.

Over the mature topography of the Pliocene the Pleistocene ice sheet advanced and subjected the Memphremagog area to much the same rigorous treatment as the rest of eastern Canada. In some of the older reports it was suggested that the ice moved from the south to the north - probably because it was thought that it could not move up toward the high land in the south. However there is much evidence to show that the movement was almost due south.

Glacial striae are found on many outcrops. These clearly indicate a north-south trend (Figure 9). A few by the nature of the grooving indicate a southward movement. Chatter marks, plucking, and gouging developed around pebbles in conglomerate and quartz masses in slate as found in many places confirm this conclusion. To the south of every granite knoll there is found an abundance of granite bowlders while to the north they are very rare. Northern slopes are generally gradual while those to the south are often abrupt and indicate plucking. Along lake shores the points are generally of hard rock to the north and soft to the south. Diorite of the type occurring on the Whetstone-Bunker ridge is found fairly abundantly on the east side of Fitch Bay. Conglomerate, sandstone and other kinds of rock present in the McConnell series were observed around Ayers Cliff. Glacial lakes must have been dammed to the north by the retreating ice sheet. All of this indicates a southward movement of the ice and a retreat to the north.

Thickness of Ice Sheet.

In the Memphremagog area the ice sheet covered everything. The thickness thus registered is represented by the present land relief of only 1200 feet. However it is stated on fairly good authority that glaciated pebbles have been found on the top of Orford Mountain at an elevation of over 2700 feet. This would indicate at this point a thickness of more than 2000 feet. As this mountain is situated only a few miles northwest of Lake Memphremagog it is not unreasonable to assume the same thickness for the ice within the area. 172 174

Beebe Stage.

The last ice sheet which entirely covered the map area halted with its front close to what is now the international boundary. The details of events prior to this are not clear but it is evident that all the glacial erosion in the southern part of the area and probably most of that in the rest of it had already taken place. It is very probable that the greater part of the period of glaciation had passed before the Beebe stage began.

During the halt of the ice sheet a great terminal moraine was deposited in the southern part of the map area and beyond. It completely filled the old valley of the Tomifobia and upon this filling built hills, which surpassed in elevation those nearby of granodiorite or sedimentary rocks. Remnants of these still exist between Beebe and Stanstead, and elsewhere as indicated in Figure 9.

Beebe Interglacial Stage.

Later the ice sheet retreated. During this retreat a great lake was developed south of the ice. The surface of this lake reached an elevation nearly equivalent to that represented by the present 1100 foot contour. This would indicate that the ice must have halted not many miles to the north developing a dam between the Sutton range about ten miles west of the lake and the high land to the east. In this way alone could such a water level be maintained and then it would be limited by the lowest summit of the passes to the south - probably that of the Black River*1. This would then constitute the outlet of the lake (a study of available maps suggests this as the most plausible interpretation). The lake must have been maintained for some time to permit of the laying down of thick deposits. The materials for these were probably supplied largely by streams occupying the valley of the upper Tomifobia and entering the lake west of Stanstead. Floating ice was probably the transporter of the pebbles and bowlders found in the sand.

Cassville Stage - Lakes and Marine Invasion.

The ice advanced again over part of the lake basin to a point a few miles north of the Beebe moraine. The lake was again developed or still maintained but in a smaller area. The ice did not pause long at the limit of its advance as evidenced by the small terminal moraine. As it retreated the lake increased in size until other outlets lower than the one by Black River were uncovered. Then the Tomifobia River began to develop - seeking first a channel across Stanstead and Beebe plains to the valley of Lake Memphremagog. Later as the route to the north became accessible the river turned and assumed its present course. Greater Lake Memphremagog, Turnertown Lake and Greater Massawippi Lake developed as the ice retreated. Terraces and delta deposits on the Nigger River at 730, and 690 feet were probably the result of lake stages. Lower terraces at 610, 600, and 575 feet may be due either to lake or marine stages. The history of the two cannot be separated. The direction of lake drainage must have been to the north and the lowering of the levels must have been due first to the ice retreat and later to the removal of glacial deposit dams.

*1. The Black River flowing north enters Lake Memphremagog at its southern end.

The marine submergence at Montreal reached points now 630 feet above sea level*1. At Ascot ten miles north of the map area marine clay deposits are found at an elevation of 630 feet*1. Probably the submergence in the Memphremagog area was as great, thus affecting only the Lake Massawippi basin.

Topography Developed.

The Pleistocene both as a period of erosion and of deposition has had a very marked influence on the topography. While the general features of the rock surface have not been greatly altered the details have suffered considerably. Glaciation was not sufficiently effective to obliterate entirely all minor topographic features. Many valleys occupied by small tributaries persisted and are again occupied. It does not seem that glacial erosion removed more than a few hundred feet of rock anywhere.

The main effects of glacial erosion seem to have been a general rounding of slopes, the obliteration of small east-west valleys and the deepening of north-south ones. The slate and younger formations were gouged out more deeply than the more resistant older rocks, thus bringing out the structure somewhat more clearly by topographic expression. The total effect produced is a rock surface which has about as much relief and ruggedness as it did before glaciation. The valleys now occupied by Lakes Memphremagog and Massawippi must have been considerably deepened, especially if the reported depth of 400 feet in the former is correct. The excessive deepening opposite Owl Head Mountain may have been due to the constriction of the ice between that mountain and Magoon Point hill with a consequent increased erosive power.

To a large extent the relief produced by glacial gouging and consequent deepening of valleys has been decreased by drift and water filling. Tremendous quantities of glacial drift and lake deposits have softened the ruggedness of the glaciated surface and altogether, because of these, a new topography was superimposed on that carved by the ice. Moraines, by reason of their original shape, and thick deposits, because of the rapid development of deep gullies, have locally given a youthful

*1. J. Keele. Preliminary Report on the Clay and Shale Deposits of the Province of Quebec. Memoir 64, Geol. Surv., Can.

aspect to the topography. Along the Nigger and Tomifobia Rivers terraces have been cut out of gravel and sand deposits.

Lakes Memphremagog and Massawippi seem to owe their origin mainly to a deepening by gouging of the valleys they occupy, though their levels may have been raised somewhat by drift dams. Lovering Lake, while its basin was undoubtedly deepened by the ice, owes its development more to the blocking of an outlet to the west by glacial drift. The Tomifobia River was turned northward at Beebe and its course altered at Stanstead by the huge Beebe moraine. Many minor changes in drainage resulted from glaciation but except for the changes noted the general plan was not greatly altered during the Pleistocene.

Recent.

Recent deposits are not extensive. The most important are the deltas of the Tomifobia River, McConnell and Lovering Brook (Figure 9). Along the Tomifobia and some other streams there are small deposits of silt, sand and clay.

During recent time no very great changes in topography have taken place. Many small valleys and gullies have been cut out, mainly in the superficial deposits. A few rock gorges as that at Rock Island have been made by the larger streams which have had their course diverted by glacial damming. The level of Lake Massawippi and possibly that of the other two lakes has been lowered slightly.

Structural Geology.

This chapter constitutes in part a summary of the structural data in the preceding chapter on general geology. The information gained from each formation is here assembled and correlated and such hypotheses as are necessary to fabricate a reasonable whole are added.

The topography and drainage system of the Memphremagog area outline in a general way the more important structural features. The Fitch Bay -Bunker Brook -Lake Massawippi valley is cut out along the Bunker fault. Valleys nearly parallel to this, including that of the Tomifobia River and of Lake Memphremagog, and many smaller ones, are located in synclines while the intervening ridges occupy anticlines. Chief of these is that just west of the Bunker fault. Cross valleys such as those at Fitch Bay village and McConnell indicate ancient synclines the trend of which was somewhat similar to that of these valleys. In general and in detail the structure has had a marked influence on the development of the topography which as a result is of great value in locating and ascertaining the nature of structural features.

Throughout the whole area the strata are generally observed to strike northeast and southwest and to dip steeply to the northwest. Only two large areas are notable exceptions to this. Around the main mass of the Stanstead granodiorite the dip is generally away from the intrusive. In the northwestern corner of the map area the dip is as a rule very steep toward the east. Along the southern boundary of the map area the strike is nearly north and south. Toward the north there is a general tendency for it to swing more to the east. This is more pronounced in the east. 179/180

In a section across the strike from the Nigger River to the crossroad three miles west of Lake Massawippi drag folds observed indicate overturned strata. The cleavage throughout the area in general trend parallels the strike and dip. Everywhere the strata are isoclinally folded and these folds are overturned to the east. Beyond this not a great deal is definite about the structure of the area.

The last - upper Devonian - period of great deformation has developed large open synclinoria and anticlinoria and imposed upon them many small isoclinal folds. Lake Memphremagog occupies one of the

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synclinoria (Figure 10). Owing to the presence of Devonian strata here this is the best defined major feature. Elsewhere the structure must be deduced from older strata which have been involved in previous deformations also.

Geologically the area is divided into two distinct and separate sections by the great Fitch Bay -Bunker Brook -Lake Massawippi valley. Northwest of this depression the most important major features are the Lake Memphremagog synclinorium, already mentioned, and the Bunker anticlinorium. The axial plane of the latter probably dips about 70°northwest and that of the former in the same direction though somewhat nearer vertical. In the north the synclinorium plunges to the south and in the south plunges to the north. South of Fitch Bay village the anticlinorium pitches to the south. Besides these two major features there are several other anticlinoria and synclinoria. Toward the south the axes converge just as the strikes of the strata do. The four major features at Magoon Point (Figure 10) converging to the south appear to unite in one syncline. At the northern limit of the map area the Memphremagog synclinorium and the Bunker anticlinorium are many miles apart. Between them new anticlinoria and synclinoria appear as they separate.

In the area southeast of the great dividing depression owing to the uniformity of material no very definite structure could be worked out, as was possible in the other section. However certain zones of unusually contorted strata when considered in conjunction with the topography offer some strong suggestions. The zones conform more or less to the locations of important topographic features with a northeast- southwest trend; for instance, one conforms to the Tomifobia valley, another to the ridge paralleling the Sherbrooke highway. In the northwest it was observed that the youngest rocks are most susceptible to erosion. As a consequence valleys are generally located in synclines. It seems reasonable to assume that in the southeast, prior to the complete removal of the Siluro-Devonian rocks, valleys were likewise located in synclines and since then have persisted in much the same position. Hence it may be conjectured that the Tomifobia valley occupies an important synclinorium, that the Sherbrooke road ridge represents an anticlinorium and other valleys and intervening ridges other synclinoria and anticlinoria.

As has been shown, the structure in these two sections which are so distinctly different lithologically is very similar in general nature. Though there is no direct evidence it seems fairly definite that the valley separating them indicates the location of a great thrust fault - indeed the postulation of this is necessary in order to give an adequate explanation of the features observed. The type of folding found here, apparently an intense squeezing of a thin crust, is generally accompanied by low-angle thrust faults. The Tomifobia series of the southeast seems to correlate with the Ordovician formations of the northwest, most probably with the McConnell series. The vast difference in character and thickness of these seems to indicate that at the time of their deposition the areas observed were separated by a much greater distance than the narrow valley which now separates them. Unless a fault with considerable horizontal displacement is assumed no reasonable correlation can be made across the valley. The topographic features alone strongly suggest the presence of a fault. The great Fitch Bay -Bunker Brook - Lake Massawippi valley can be traced for miles to the northeast with the same general trend (Figure 1). Between Lake Massawippi and Fitch Bay it is probably deeply filled with drift - wells drilled near the lake passed through superficial material only to a depth of sixty feet. The valley and the ridge to the west of it are unique. Most of the valleys are wider and more open, and few of the ridges present as abrupt slopes as that on the eastern side of the Bunker ridge. Most of the northeast-southwest valleys occupy synclines and the parallel ridges anticlines. The Bunker valley by its profile alone is suggestive of a fault and when this is compared with that of the other valleys the suggestion becomes almost an indication. The bends in the axial trends, their divergence to the north in the northwest, their convergence in the same direction toward the Bunker valley in the southeast, the dip of axial planes and many other structural features tend to confirm the fault theory.

Some evidence has already been presented to indicate that the Bunker fault is of the same age as the isoclinal folding and is a thrust. Its parallelism to the strike of the strata and the cleavage and to the main axial trends further tends to confirm these assumptions. Also the presence of the narrow band of slate on the west side of the fault and the relationship of other formations, in their distribution, to the indicated location are additional supports. The Bunker fault is thus clearly of the same age as the isoclinal folding - late Devonian - and was undoubtedly the result of the same deformative forces. It follows from the evidence presented and from the nature of the folding that it is a thrust fault. Many of these features clearly indicate that the dip of the fault plane is to the west but there is nothing which gives a definite clue to the angle of dip. However the nature of the folding strongly suggests that it is low, probably not exceeding 30°.

To the north the Bunker fault probably extends for many miles, its location being indicated by the Massawippi-St.Francis valley (Figure 1). To the south it seems to swing to a more north-south trend, following Lake Memphremagog. In this direction it may not continue far for the axial trends of folds seem to indicate a bend in the structures as if the masses had been hinged to the south. The topography of the Black River valley at the southern end of Lake Memphremagog as mapped is similar to that of the Bunker valley and may indicate the location of the fault there. The displacement of the fault in the map area must be conjectured from the lithological relationship of the Tomifobia and McConnell series. How far apart must the areas of these have been to permit of the differences in lithology and thickness - a few hundred feet being offset by thousands? It seems reasonable to assume a displacement which can be measured in miles - say between two and five.

For the most part the major folds appear to be broad and open. Imposed upon them are smaller folds which also ~~appear to be~~ are fairly open but upon these are many small isoclinal folds. The type of folding seems to indicate great shortening of a thin crust. With a thrust fault of considerable extent and this type of folding the crustal shortening within the map area alone must have been very great.

Such intense deformation at the surface would necessarily involve some adjustments at greater depth. The distribution and age of the granodiorite strongly suggest that a great part of the area affected was underlain by magma during the process of deformation. Therefore it does not seem unreasonable to assume that while folding and faulting were going on at the surface adjustments to compensate for these were being made in the plastic magma, accompanied by a general uplift of the whole area. All these adjustments were probably the result of the same force.

The trend of the direction in which this force acted is presented by lines at right angles to the general structural trends but there is no direct evidence to show whether the thrust was to the northwest or the southeast. Within the map area there is nothing which seems to offer a suggestion for the solution of this problem. Beyond there is found to the north and west at some distance the relatively stable pre-Cambrian shield with its border of slightly deformed Paleozoic sediments. To the east and south are the areas of much deformed Paleozoic sediments bordering the Atlantic Ocean which lie in a supposedly unstable basin. There the folding and faulting almost invariably indicate a thrusting from the southeast. The faults show an overthrusting to the west. The conclusion then would seem to be that within the map area the thrust also came from the southeast and that the Bunker fault is therefore an underthrust. It does not seem reasonable to assume that any great thickness of rock has been thrust bodily toward the stable pre-Cambrian shield-rather that a relatively thin knife-like mass has been thrust in between the solid crust and the underlying magma, and that this crust has been uplifted over a considerable area - probably that underlain by magma. However in view of the lack of definite information it seems best to call it merely a thrust fault in which the western side moved up relative to the eastern.

Besides the features developed by late Devonian deformation there remains in pre-Devonian rocks evidence of two previous periods of deformation (Figure 10). One of these is represented by a series of open folds with a general trend of N 55° E. South of the village of Fitch Bay there is an anticlinal axis while well to the north there is a synclinal axis. West of the Bunker valley the limestone occupies a syncline while the interbedded limestone and slate occur in an anticline. The other period of deformation is represented by a series of ancient folds which had a general trend between N 30° W and N 50° W. Synclinal axes pass through the McConnell Brook valley and the village of Fitch Bay, while anticlinal axes are indicated crossing Bunker Hill and ~~that~~ the hill west of Lake Massawippi. The folding was more intense than that of the deformation just described. There were many small folds as well as the large ones and the dips probably in places reached 50 and 60°. There is nothing to indicate the relative age of these two periods. The rocks of the Bunker series were probably involved in a still older period of deformation about which there is no definite information.

Igneous intrusions have affected the strata considerably. The Ordovician diorite seems to have caused a doming of the strata around the northern end of Bunker Hill. The porphyry which occurs in the northwest part of the map area also uplifted the strata previous to the great Devonian deformation. The main mass of the Stanstead granodiorite and possibly the serpentine had the same affect after the strata had been intensely folded. 187 188

The Massawippi fault is the only normal fault observed though there may be others. It is post Devonian and probably has only a small displacement.

The area has probably been subjected to some deformation since the Devonian and previous to the Pleistocene but there is no direct evidence of such. There is some suggestion in the northerly dip of terraces, clay beds and other Pleistocene deposits of late Pleistocene or recent tilting.

Historical Geology.

In this chapter the information already given about the history as obtained from the study of each formation is summarized. What was found to be absent from lack of observation has been postulated so that here fact and theory are interwoven into one concerted whole.

History as represented in the Memphremagog area probably begins with the Cambrian. In the part which now corresponds to the Magoon-Bunker ridge near-shore conditions prevailed and coarse, poorly
and fine conglomerates (Bunker series) were deposited. After a considerable thickness of these had accumulated conditions changed and finer materials
sorted sandstones were laid down. Sedimentation then ceased and was followed by a period of deformation and uplift.

During the Early Ordovician several miles to the southeast of the Bunker ridge in what is now the southeastern half of the map area arenaceous limestones and slates (Tomifobia series) were being deposited. Later conditions changed slightly and arenaceous limestone alone was laid down. During the early part of this time Bunker Ridge remained as land but later the sea began to encroach upon it. In the north, near what is now McConnell, coarse conglomerates formed the base of a new series (McConnell). With the continued advance of the sea over an irregular land surface this conglomerate became more extensive and was overlain by finer though still coarse materials.

Before the encroachment had entirely covered the land and while the southern part of the ridge was still above the level of the sea there was a period of igneous activity. Throughout the north there were intrusions, the major of which caused a doming of the strata, while in the south the activity assumed the form of extrusives. The sea continued to advance upon the land and the basal conglomerate became more extensive now overlying and including boulders of the extrusives. While some land still remained there was a partial withdrawal of the sea from the area of the newly deposited series and a slight and limited unconformity was developed. This was followed by a rather rapid submergence of the whole area with deposition of very fine argillaceous materials (Memphremagog series). These represent a period of considerable length during which conditions showed only slight changes. The whole Memphremagog area was probably situated at some distance from the shore and the source of material. Toward the end of this period, which probably closely approached the end of the Ordovician, conditions became less stable, slight unconformities were developed and were followed by near-shore conditions, at least in the northwestern part of the area where conglomerate and sandstones were deposited. The period closed with deformation and uplift.

During the early part of the Silurian erosion was very active in the Memphremagog area and it was not until the middle of the period that deposition again took place. At this time limestone was laid down on what seems to have been a very even surface. Between the Middle Silurian and the Middle Devonian another period of deformation occurred. This was again followed by active erosion so that by the Middle Devonian only small remnants of the Silurian limestone remained. This erosive period together with the preceding completely removed in places some of the Ordovician formations.

Early in the Middle Devonian submergence began near Georgeville and gradually progressed toward the south and north. The surface was very regular and must have approached peneplaination, at least in the area just west of Lake Memphremagog. Limestones, mostly arenaceous, were deposited. Toward the end of this time the period of greatest deformation which is apparent in the area began and with it sedimentation ceased.

Toward the close of the Middle Devonian there was developed a great force which exerted a tremendous pressure on the crust of the earth in the Memphremagog area and elsewhere. This was probably exerted from the southeast giving the resultant structures a northeast-southwest trend. At the surface folds were slowly developed while deep below magmas were in the process of formation. As deformation continued folding became more intense and magmas more extensive. These were forced upward and worked their way toward the surface. As a consequence the overlying rocks were uplifted, contorted and shattered, and the broken portions were gathered into the magma and there assimilated. In some places however where there was less violence associated with the igneous activity the overlying rock was slowly eaten into and digested. The tendency of these magmas was generally to move upward though with the gradual increase of pressure, the shortening of the overlying crust and the consequent necessity to move either upward or laterally many of these individual magmas became united. Near the surface where adjustments had to be greater than at depth this tendency to unite was more marked so that it does not seem entirely improbable that the area most intensely affected was underlain by one or a few great magmas.

In the meantime at the surface great transformations were taking place. Large folds were being developed but they had no great depth and were mainly broad and open. Upon these smaller ones were developed which in character were somewhat more indicative of the intense nature of the deformation. However it was in the smallest folds that the intensity was manifest. Isoclinal folds were developed throughout the area, imposed upon the larger more open anticlinoria and synclinoria. The crustal shortening must have been enormous though it seems probable that only a very thin crust was involved. The isoclinal folding represented considerable compensation but it apparently was not sufficient to relieve the strains completely. Throughout a great part of the area these folds were overturned toward the east. A great thrust fault was developed along a line parallel to them. The western part was thrust up and over relative to the eastern and before the strains were completely relieved one of the masses had moved several miles.

Within the map area alone the crust must have been shortened many miles. The nature of the folding and faulting would seem to indicate that they have been effective to no very great depth. Adjustments below this were made within the magma. These must have required the removal of enormous quantities from below the folded and faulted area or must have involved a remarkable change in shape. The latter seems more reasonable as no place to which the material was removed is apparent. The mass affected was probably wedge-shaped with the point toward the center of the earth. The changes probably involved a general uplift of the crust with a consequent lengthening of the wedge. This would give a mass equal in volume though somewhat different in proportions, the thick edge having been shortened by surface deformation and the length increased by uplift.

With the increased intensity of deformation and consequent shortening of the crust conditions suitable for the formation of magma obtained closer and closer to the surface. It is probable that this advance was not continuous. Rather it was spasmodic. Strains were developed and with them the magma masses increased. They were released at intervals and probably at each release the magmas decreased somewhat through crystallization. The strains varied considerably in intensity. As a consequence the magmas developed and existed under a variety of conditions. The porphyry in the northwestern part of the area was probably the first phase of this igneous activity to reach the present surface. It seems to have attained its present position under considerable pressure for there appears to have been a doming of the strata around it. Folding had already begun and was probably still progressing as attested to by the linear shape of the mass parallel to the structure. Its advance upward though facilitated by the doming seems to have been largely by direct assimilation. At the time of the intrusion of the Stanstead granodiorite which appears to have been the next to reach the present surface conditions were somewhat different. Folding was nearly complete. However the magma and the overlying sediments were still under great strain, so much so that not only were the sediments uplifted but they were badly contorted and shattered. By the stoping of huge blocks the great body of the mass was able to rise fairly rapidly while into the many cracks and fissures developed there were shot out great stringers or dikes from the magma. The contacts are sharp and the sediments as a rule not greatly altered. There is not much evidence of direct assimilation except in a few parts of the main mass and at Magoon Point.

About the time that the intrusion of the Stanstead granodiorite was completed most of the deformation seems to have been over. However there followed a period of general adjustment during which fissures were developed in the now completely deformed strata. The upper parts of the magmas had crystallized while ~~but~~ beneath differentiation had taken place. From the differentiated magma because of pressure developed by the new adjustments intrusions filled these fissures. In some instances they reached the surface and there developed extrusives and stock-like masses. These are all basic in character and entirely different from the earlier intrusives.

Since that time the area has been one of relative quiet so far as both deformation and igneous activity are concerned. Small normal faults have been developed as exemplified by that near Massawippi station. Uplifts, subsidences, gentle doming and tilting have probably occurred but none of these have been sufficiently effective to leave marked impression upon the structure of the area. Between the Middle

Devonian and the Pleistocene deposition may have taken place but any evidence of it has since been obliterated. Erosion has removed thousands of feet of rock exposing some of the oldest sedimentary formations as well as many intrusive masses.

Prior to glaciation there had been developed a topography not greatly dissimilar to that of the present day. It was mature. Hills were well rounded and valleys open. The map area was subjected to the same intense glaciation as the rest of southeastern Canada. A great ice sheet moved across the area from north to south. A considerable thickness of material was removed from the surface. The north-south valleys in places were considerably deepened and many of the small east-west valleys were obliterated.

The great ice sheet probably advanced over and retreated from the map area several times just as it did in the areas to the west. The last ice advance to cover completely the whole area paused for a long time with its southern edge near the present international boundary, where great morainal deposits were laid down. During the following retreat of the ice a large lake was developed to the south of it which covered a great part of the map area. In this there were deposited sands and clays. Later the ice advanced over all but the more southerly of these. In its retreat drift was left covering practically the whole area. Lakes, ponded in front of the ice, and a later marine invasion were responsible for terraces, delta deposits, and a thin covering of sand.

Owing to the irregular deepening and the deposition of drift in the north-south valleys great lakes were left after the ice retreated. Since then these have been somewhat lowered by the removal of drift at their outlets but they still maintain about the same aspect as bequeathed to them by the Pleistocene. From the higher ridges and abrupt slopes and in the courses of streams the drift has been removed in patches, exposing the bedrock. Streams have sought mainly their old valleys and are now meandering in a bottom of drift. Where the old valleys were obliterated or so completely filled with Pleistocene deposits as to turn the water aside new valleys have been developed, largely in the drift, though in places cutting through it and into the rock. The large quantities of readily available loose material have permitted of rapid and abundant transportation so that deltas of considerable size have been built up where the larger streams empty into the lakes. While the present topography owes its origin mainly to a pre-Pleistocene development it has been greatly influenced by the erosive and depositional forces of the Pleistocene and slightly by those which have succeeded it.

Granite.

"Granite" quarrying in the vicinity of Beebe in the southwestern part of the map area has been carried on for over forty years. It is one of the most important industries in the area and of its type is the largest and most important producer in the Dominion of Canada. The quarries are situated in the main granodiorite area northwest and west of Beebe. This is commonly known as the Stanstead granite area and the rock produced as Stanstead granite. Graniteville is the center of the industry both geographically and economically for here are situated the three largest quarries. The village is off the main line of the Boston and Maine Railway which traverses this part of the area but is linked to it by a short electric line. Beebe is the headquarters of the industry. Here are situated the offices of many of the quarrying companies, the huge mill of the Stanstead Granite Quarries Company Ltd., several smaller mills and the homes of many of those connected with the industry. It is also the shipping point for the greater part of the stone which leaves the district. Lineboro in Quebec and North Derby in Vermont are also supported largely by the granite industry.

The granite occurs in an area about three miles square. Its Distribution is irregular, in masses of varying size and shape. These are merely protuberances of one great mass or batholith and are separated by only thin shells of sedimentary rock. The geology of the area has already been fully described under Stanstead granodiorite. The distribution of the quarries and prospect pits is shown in Figure 11. 199

Prospecting for suitable quarry sites seems to have been governed largely by a consideration of transportation facilities. Altogether too often this factor has controlled quarrying operations to such an extent as to cause the expenditure of much money or inferior sites. Nearly every igneous mass, no matter how small, in the vicinity of the Boston and Maine Railway has been thoroughly tested. Many test pits have also been located near the best roads within a short haul of Beebe and along the electric railway. In general the tendency seems to have been to find the granite masses and then to locate the test pit or quarry at the point nearest to suitable transportation, with very little regard for the quality of the stone as might be indicated by apparent geological features. This of course has involved much unnecessary expenditure on sites which from the outset might have been observed to have very poor possibilities. However there are notable exceptions to this method of procedure and in most cases these have been productive of the most lucrative quarrying industries in the area. The selection of the Graniteville sites affords the best example of this. Quite apparently ready transportation was a secondary consideration. This disregard however has involved a considerable expenditure for the construction of efficient means of conveyance. The transportation factor of course has militated against the establishment of quarries in the areas of the best stone which as a rule lie at some distance from the main line. For the most part therefore the small quarry operators are content to sacrifice quality for short haulage. While this may have been profitable in a small way to a few, especially to those who confine their activities to cutting paving blocks, it seems certain that on the whole it has been an unprofitable procedure. Another factor however which has also contributed to the exploitation of inferior sections is that of property ownership and rates of rental. 199 200

The quality of the stone should be one of the most important considerations in selecting quarry sites. There are a large number of features which affect the marketability of the granite. The more important among these are the color, hardness and texture, the biotite streaks and knots and the pegmatite veins (straps). These and other features have been fully described in the section on granodiorite. The quality of the stone is governed largely by its position within the igneous mass. In general it varies greatly from the contact to the center. Practically all the important characteristics of the rock itself are more variable near the contact, and segregations, inclusions, veins, and other things which affect the quality of the stone are more prevalent there. Consequently the stone which is most uniform and therefore as a rule best should normally be found at some distance from the contact, 200 201 that is, at those points within the exposures which are farthest from the sedimentary rock. Occasionally this is not the case for the original roof of the batholith may have been flat or concave so that the center of the exposure would not represent the part of the mass farthest from the original contact. The general rule however is well borne out in the

Stanstead ~~granodiorite~~ granite area. The three quarries which produce the best stone are situated at Graniteville in the center of one of the largest masses while the majority of prospect pits or abandoned quarries are found in smaller masses or near the contact in larger ones.

The Graniteville mass has already been proved as of exceptional quality for quarrying. Here there is much less trouble with factors which diminish the value of the stone than elsewhere. The large mass northwest of Beebe produces at the Duncan Quarries a very good quality of granite. However the presence of sedimentary inclusions elsewhere in this mass acts as a warning against the hope of finding as good stone throughout. The mass along the lake shore which seems to have been largely neglected ought to afford some areas of good stone. The southern part has many inclusions but north and west of Graniteville there are sections which seem to have good possibilities. There is no doubt that the area as a whole contains great quantities of high grade stone. 201 202

The working qualities of the stone are factors of the greatest importance in quarrying. As yet it does not seem possible from geological data to outline those zones in which these qualities are likely to be most favorable. In this area the value of the granite in places is greatly enhanced by the excellent sheeting and pronounced grain and rift which render quarrying operations comparatively easy. The quarries near Graniteville seem to be particularly favored in this respect. These characteristics obtain to a somewhat lesser degree in most of the operating quarries. However it seems that the abandonment of some prospect pits and quarries was the result of unfavorable sheeting. Some of the rock instead of having a hard way is said to split equally well in three directions, a characteristic which tends to make the stone take and keep a more uniform polish on all sides. The sheeting appears to have been the result of release of pressure on erosion of the overlying rocks. Because the granite, as a result of its greater resistance to weathering, stands up in somewhat its original shape the sheeting seems to correspond roughly to the old batholith surface. The rift and grain are thought to be the result of the slight deformation that followed the crystallization of the mass.

The physical properties of the stone and the industry as a whole have already been described so fully by Dr. W.A. Parks in his Report on the Building and Ornamental Stones of Canada (Vol.III)[*1] that it seems

*1 Mines Branch, Dept. of Mines, Canada (1914).

unnecessary to deal again with these phases of the subject. In summarizing he writes "The following list of physical properties represents the average of three samples from different quarries and may be regarded as typical of the Stanstead granite in general:-

Specific gravity.	2.687
Weight per cubic foot, lbs.	166.552
Pore space, per cent	0.789
Ratio of absorption, per cent, one hour	0.1913
" " " two hours	0.2059
" " " slow immersion	0.2423
" " " in vacuo	0.2548
" " " under pressure	0.2972
Coefficient of saturation, one hour	.64
" " " two hours	.69
" " " slow immersion	.80
" " " in vacuo	.85
Crushing strength, lbs. per sq. in., dry.	25,250.
" " " " wet	25,116.
" " " " wet after freezing . .	22,133.
Transverse strength, lbs. per sq. in.	1,762.
Shearing strength, lbs. per sq. in.	1,425
Loss on corrosion, grams per sq. in.	0.00091
Drilling factor, mm.	7.

It will be seen from the above list that Stanstead stone is considerably lighter in weight than limestone and that its pore space is rather high for this class of stone. The frost resisting properties as expressed in the coefficient of saturation are satisfactory. The crushing strength is not high for a granite and the transverse and shearing strengths are rather low. The wet specimens seem to suffer little loss in strength but there is an appreciable loss on freezing. The drilling factor is high for a granite and the stone should be capable of being carved with facility."

Of the industry in 1924 Dr.Parks writes *1:" The Stanstead granite masses are excellently sheeted and jointed, rift and grain are well developed, the stone is of even grain and true grey colour, large quarries are possible, and the shipping facilities good. Her is situated the largest granite-quarrying industry in the Dominion with five firms shipping stone at the present time. About 130,000 cubic feet were produced in 1924. Building stone is quoted at $1.00 per cubic foot, f.o.b.,quarries, but monumental stone may cost as much as $3.00 per cubic foot. Freight rates per cubic foot are as follows: to Montreal 30 cents to Halifax 54 cents, to Toronto 47 cents. The stone is used chiefly for building but an increasing amount is finding its way into monumental work. For ordinary buildings Stanstead granite costs about 50 per cent more to finish than soft limestones, but the increased cost is more than justified by the enhanced beauty and durability of the structure."

Altogether ten quarries were in operation during 1924. The stone has been used in a number of important buildings in Montreal, Ottawa, Quebec, Sherbrooke, Regina, Edmonton, Calgary, Chicago and other cities. Large quantities of paving blocks and curbstone are also cut, mainly for Montreal, Sherbrooke and Toronto.

Of the Magoon Point mass Dr.Parks writes: " Inland the granite rises into a considerable hill and presents zones which are much fractured as well as areas in which quarrying might be easily done. A small amount of stone was quarried here in 1878 and was used in the construction of a dam at Magog. .... Other joints cross the formation at S50°E. and this series becomes excessive towards the west side of the property where the stone is much fractured. Towards the south, however, there is little doubt that stone of large size could be easily quarried and loaded into scows on the lake."

So long as there is a sufficient demand for building stone of this type the quarrying industry ought to thrive for the reserves are large, the quality of the stone is excellent, working conditions are almost ideal, and there are a number of well established firms capable

*1 Bull.Can.Inst. of Mining and Metallurgy, April 1925.

of turning out very high grade material.

Lime.

At Magoon Point the limestone was formerly quarried for lime burning. In the center of the mass there is a large quarry about 400 feet long, 25 to 100 feet wide and 30 feet deep. Besides this there are several smaller holes, so that the total quantity of rock removed must have been considerable. Of the material Dr. Parks writes*[1]: "This is a fine grained bluish white glistening marble with a pronounced banded structure. The stone has a strong tendency to split parallel to this banding. Iron-bearing solutions have soaked in along the planes of banding and have stained the stone bright red. Pieces sawn across the bands are very pretty, showing a pure bluish white alternating with bright red bands. This effect is evidently due to surface agencies and could not be relied on to occur throughout the mass of the deposit."

*1 Report on the Building and Ornamental Stones of Canada, Vol. III. Mines Branch, Dept. of Mines, Canada (1914).

Brick.

Previously the Pleistocene clay east of Beebe was used for making brick. Operations have been abandoned for many years. The quality of the clay for this purpose was not ascertained.

Other Deposits.

Mineral deposits of economic value are not known in this area. It is cut by many veins and dikes, some of which are reported to carry gold and other minerals, but it is thought that in the majority of cases these claims have never been substantiated. West of Beebe near the ~~lake~~ there was found one small vein bearing chalcopyrite, pyrite and other sulphides. It is reported to extend to the lake shore where it is visible at low water and it is thought to be continuous with a similar vein on the west side which has been worked to a small extent, unprofitably. The vein has been prospected but is so small as to offer little hope of having ecomomic value. South of Fitch Bay village is found a small galena vein which is reported to carry silver. The vein was covered in a ploughed field so that nothing of a very definite nature was learned. However it is thought to have no economic value.

Southeast of Magog black Ordovician slate has been mistaken for cannel coal which it slightly resembles. A considerable amount of labor and expenditure of money has been wasted on useless exploitation of this.

Dr Young
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*. The diagrams are those used by Johannsen in his Quantitative Mineralogical Classification of Igneous Rocks (Essentials for the Microscopical Determination of Rock-Forming Minerals and Rocks). In this classification rocks are first divided into four classes according to the relative proportion of dark and light constituents. The divisions are as follows: Class 1 - rocks with less than 5 per cent, Class 2 - dark constituents between 5 and 50 per cent, Class 3 - dark constituents between 50 and 95 per cent, and Class 4 - dark constituents more than 95 per cent.

The specimens of rock examined show a variation from 0 - 17 per cent of dark constituents. Accordingly they fall into Classes 1 and 2 and in adhering closely to the system should be shown on two separate diagrams. However they are shown together here in order that the complete relationship of all specimens may be brought out more clearly. The percentage of dark constituents in each specimen is shown by the length of line used for its representation. To differentiate further between the two classes the specimens which belong to Class 1 are indicated by hollow circles and those of Class 2 by filled circles. The family numbers are the same in both cases. The family names for Class 1 are bracketed. In most cases the addition of "leuco" to the family names of Class 2 is the only difference.

Each of the first three classes is subdivided into four orders according to the composition of the plagioclase feldspar. This separation is made on the basis of the Ab An ratio, as before with the 0-5-50-95-100 per cent boundaries. All the specimens examined contain plagioclase with a composition between Ab_5An_{95} and $Ab_{50}An_{50}$ (CaNa feldspar — oligoclase and andesine) and therefore belong to Order 2. Thus Figures 6 and 7 are graphical representations of Class 1 and 2, Order 2.

The order is subdivided into thirteen families according to the proportions of the three remaining important mineral groups: quartz, K feldspar (orthoclase, microcline, microperthite, anorthoclase etc.) and plagioclase feldspar, in this case CaNa feldspar. The boundaries are as before at 0-5-50-95-100 ~~per cent~~ percent. The families are numbered from 0 to 12 and named as indicated in the diagram.* Each specimen can be assigned to a definite class, order and family, or for brevity be given a number. For example the average Stanstead granodiorite specimen A is Class 2, Order 2, Family 7, or 227.

By graphical representation the exact position may be indicated. In the triangular diagram each corner represents one of the three important constituent mineral groups- quartz, K feldspar and CaNa feldspar. The amount of each present in a specimen is computed from the base opposite the corner of that mineral. A corner point indicates a rock that is 100 per cent of one mineral and any point on the opposite base a rock 0 per cent of that mineral. Lines drawn at proportional intervals parallel to the three bases represent the percentage of the three groups in each specimen. The three lines drawn for a specimen with no dark constituents intersect in a point which gives the position of the rock in the classification. The presence of dark constituents causes the development of a triangle. To give the rock position in this case the center point of the triangle is plotted. To represent the percentage of dark constituents a line is drawn from the apex of the triangle to its base in the direction of one of the apeces of the large triangle.

The construction of the triangle and the location of the position of specimen A are illustrated in Figure 6. This is the average of all the specimens plotted on this diagram. <u>abd</u> is the rock triangle. <u>Qv</u>, <u>Kz</u> and <u>Cx</u> scaled off represent the percentage of quartz, K feldspar and CaNa feldspar respectively. Any of the lines within or making up the triangle <u>abd</u> gives the percentage of dark constituents, in this case the line <u>ay</u>. Also it may be noted that the relative proportions of any two, three or four mineral groups may be ascertained readily by reference to the various lines or triangles.

These diagrams show very clearly the mineralogical relationships of all specimens. The rock localities have been systematically numbered (from west to east) and each specimen has been given its locality number. By this method any consistent variation in composition or any general differentiation in the magma would be readily shown by some sort of number grouping on the diagrams. The promiscuous mixing of the numbers in Figure 6 and Figure 7 would seem to indicate nothing but a very irregular variation in composition.

(Omitted- please include)

* The intermediate monzonite families have been shown merely in order to indicate their position in this classification.

Table of Formations.

Recent				Gravel, sand and silt, chiefly delta deposits.
Pleistocene				Glacial drift, sand and clay.
		Unconformity		
		Basaltic dikes		Hornblende basaltic dikes.
		Dikes		Picrite porphyry. Massawippi dikes - acid diabase & vogesite.
	Upper	Serpentine		Chiefly green serpentine, some magnesite-serpentine rock.
Devonian		Stanstead Granodiorite		Chiefly granodiorite.
		Sodium Diorite		~~Intrusives,~~ alaskite to sodium diorite
	Upper	Porphyry		Altered feldspar porphyry
	Middle	Limestone		Metamorphosed limestone, generally arenaceous or argillaceous.
		Unconformity		
Silurian	Middle	Limestone		Metamorphosed limestone, generally arenaceous or argillaceous.
		Unconformity		
			Oliver Sandstone	Chiefly sandstone.
Ordovician		Memphremagog Series	Oliver Slate	Conglomerate, slate and sandstone.
			Slight unconformity	
	Upper Middle } Trenton		Lovering Slate	Black and dark gray slates.
		Slight unconformity		
	?	Tomifobia Series		Black arenaceous limestone and interbedded black slates, argillites and limestone.
Ordovician?	?	McConnell Series		Coarse basal conglomerate, quartzites, grits, quartzitic argillites and slates, and some argillites and slates.
		Diorite		Altered intrusives and extrusives, chiefly diorite.
		Unconformity		
Cambrian?		Bunker series.		Qudrtzites, grits, quartzitic argillites and slates.

The Director

Herewith please find all copy (map and figures) supplied by Dr. Kerr for his thesis.

It consists of

1. Envelope holding 6 drawings intended to be published as figures
1. Bundle of 5 drawings intended to be published as figures
1 Bundle holding copy for the geological map and cross-sections

Attached to this memorandum please find a copy of a letter sent a month ago to Dr. Kerr. No answer has been received.

Please remember that Dr Kerr thought a loan of the map MS would suffice but asked for copies of all figures.

Since the time is approaching when the thesis should be typed, the matter of the figures, map copy etc. requires attention.

I am strongly of the opinion that Dr. Kerr should assemble all materials and should forward them to Chicago. I also believe a final decision should be made in regard to furnishing copies of map and figures.

G A Young
Nov. 30, 1927

Dr. Jan 25. I gave Director all drawings, cross-sections, figures, table of formations. TC

Ottawa, October 31st, 1927.

Dr. F.A. Kerr,
Geological Survey,
510 Winch Building,
Vancouver, B.C.

Dear Dr. Kerr:-

The text of your Memphremagog report has been sent to the Editorial Division with the request that three copies be made. Mr. Clarke has been asked to make three prints of each of the eleven photographic illustrations.

After looking over the drawings for the eleven figures and the manuscript map material, I advised the Director that it would require considerable work to make copies of them. I also called attention to the statement in your letter to the effect that perhaps a loan of the drawings would meet the needs of the University, and that you were writing about the matter to the University. Hoping that a loan of the material would suffice, the Director decided to postpone making a decision as to how the figures and map material would have to be treated. In any case, I think that finally all material should be assembled by you.

Yours very truly,

GAY:EF.

Ottawa, October 31st, 1927.

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Geological Survey,
510 Winch Building,
Vancouver, B.C.

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Yours very truly,

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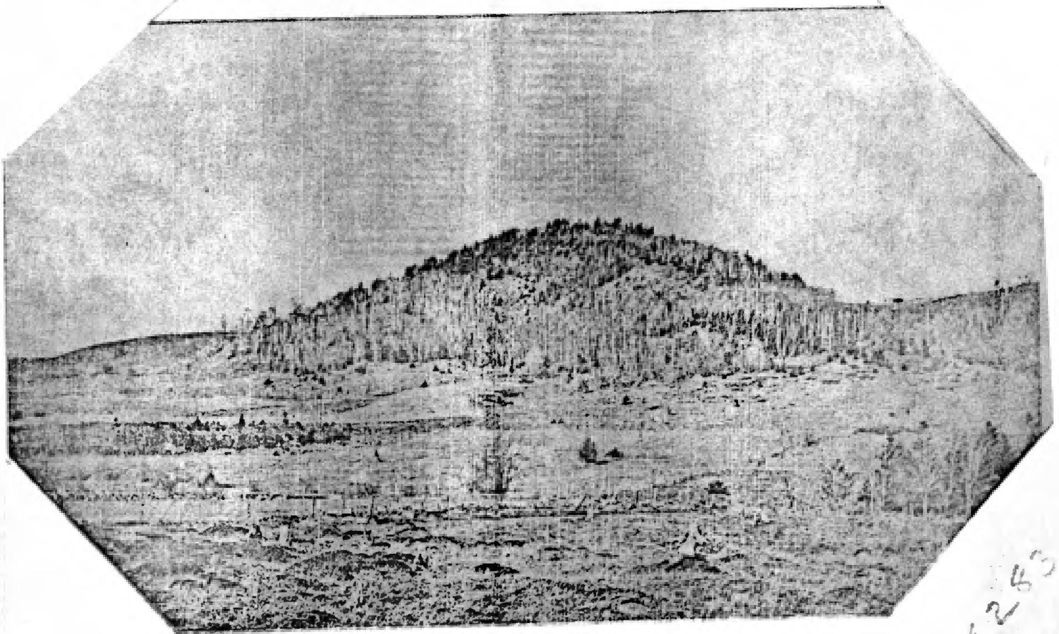
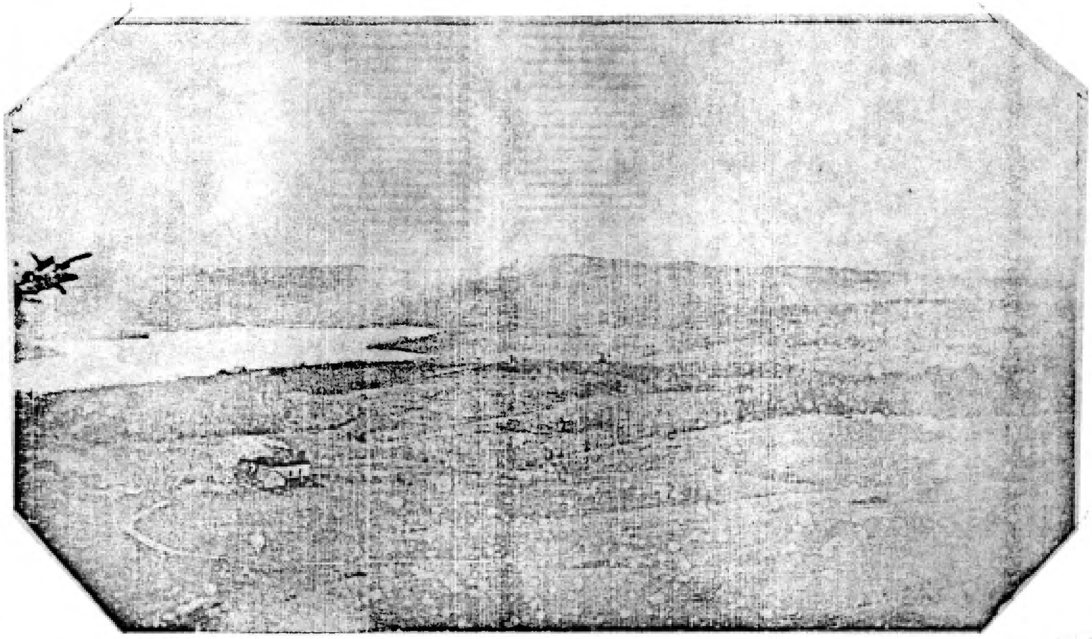


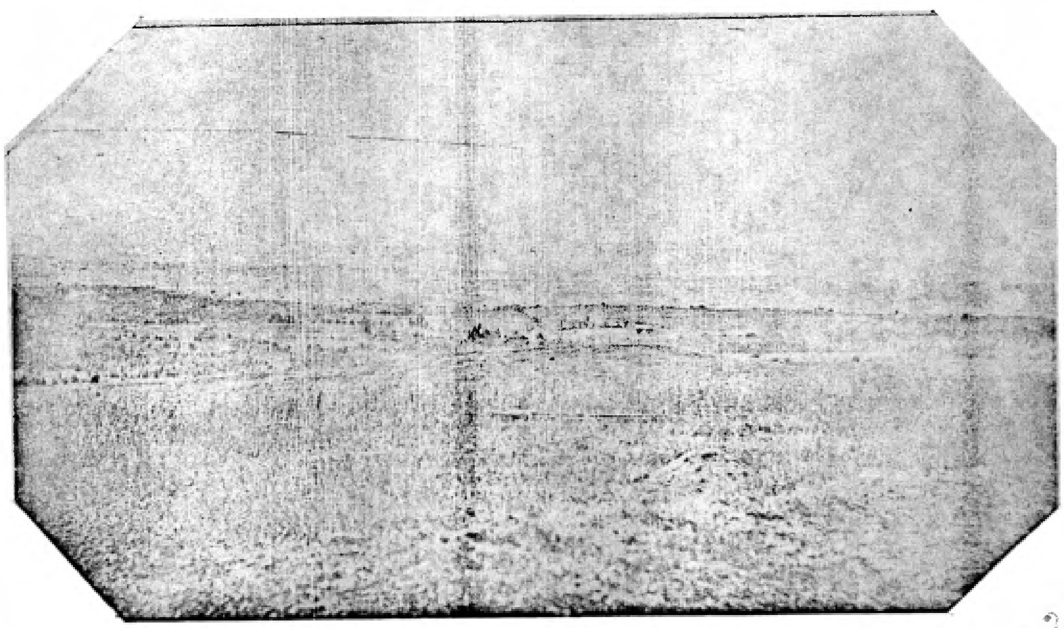
37283

Plate XI - Serpentine hill.



59280

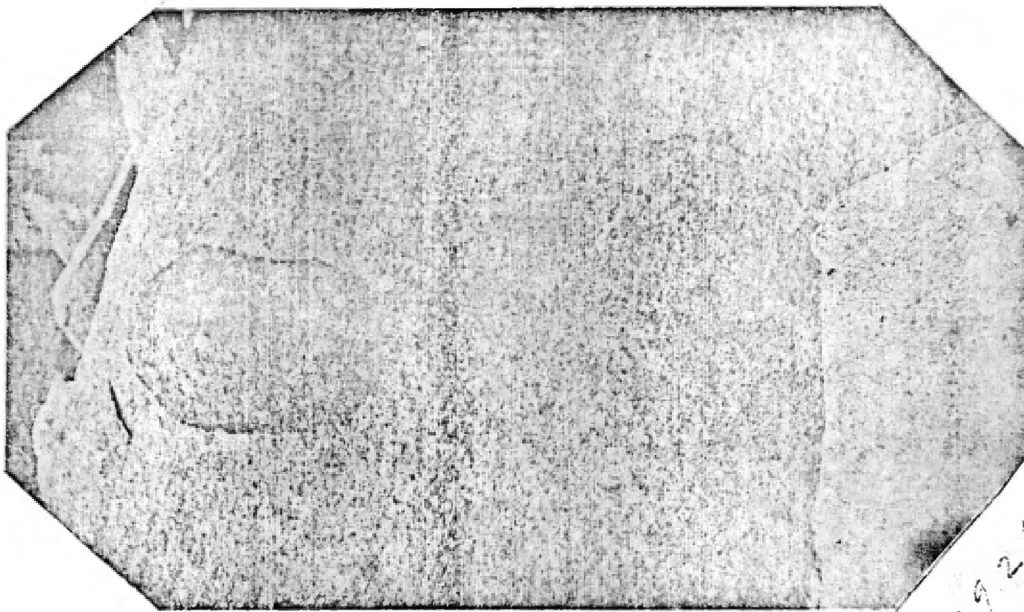
Plate I - L.Massawippi - Bunker Brook - Fitch Bay valley, from the north.



59265

Plate II - Parallel valleys, the second is that of the Tomifobia River and the pronounced valley beyond is that of Bunker Brook.

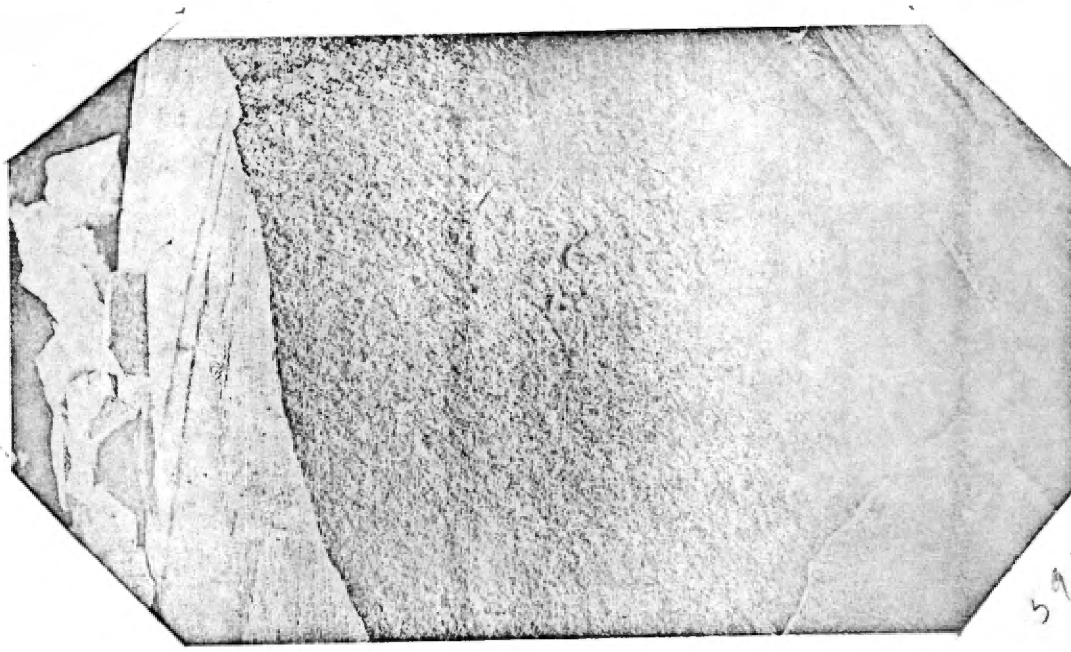
top



59254

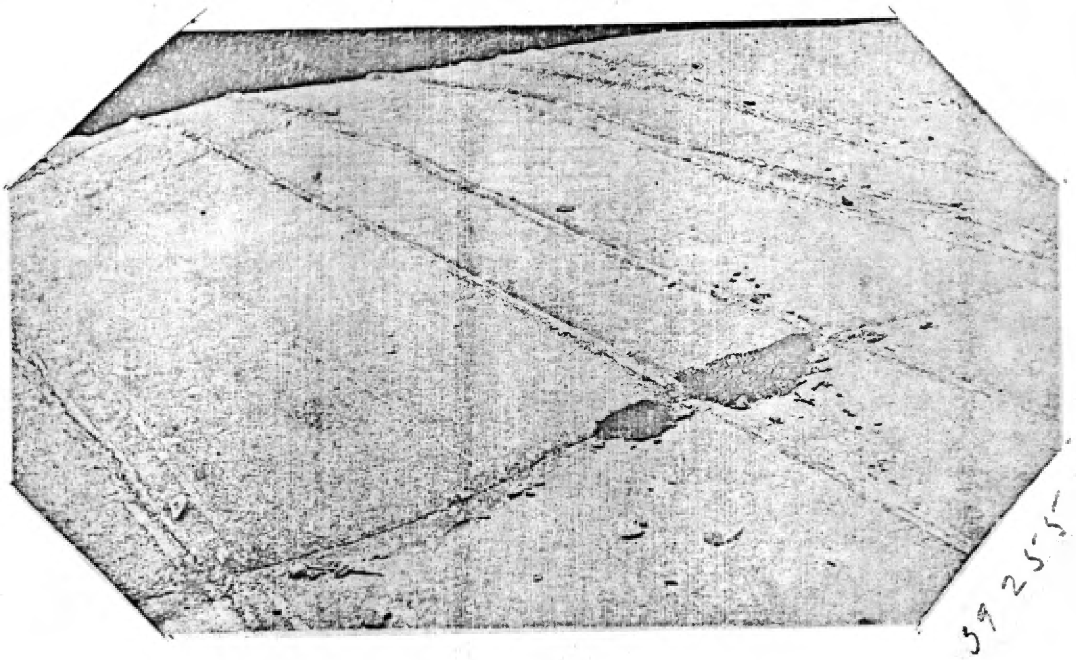
Plate VII - Biotite segregation in Stanstead granodiorite. Size about 3 by 2 feet.

top



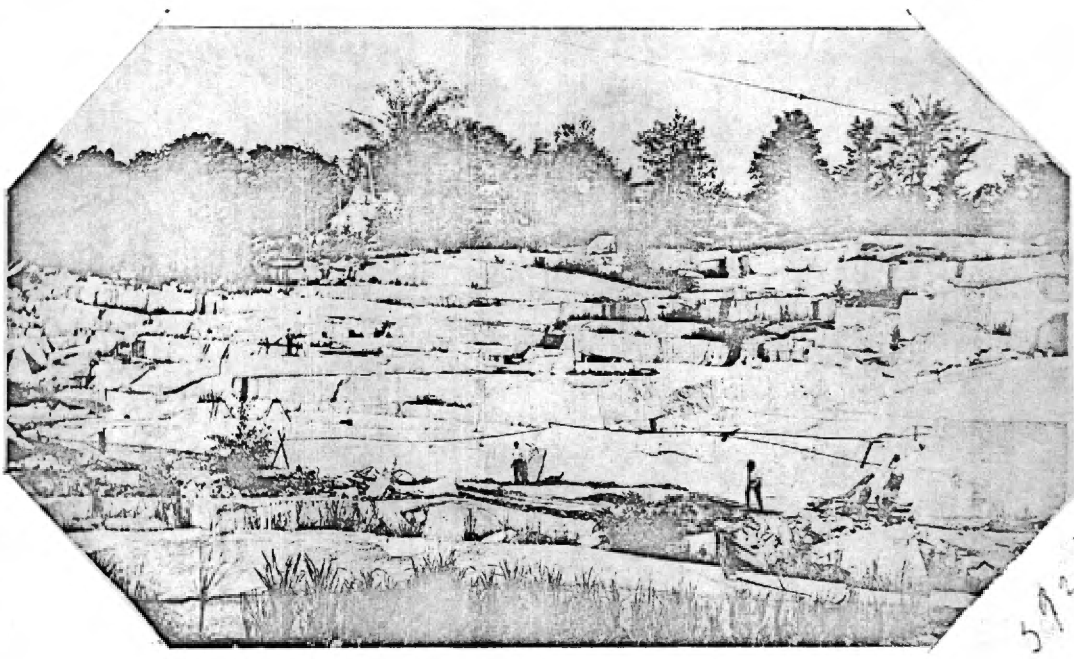
59256

Plate VIII - Biotite streaks in Stanstead granodiorite. The two wide streaks are 5 or 6 inches apart.



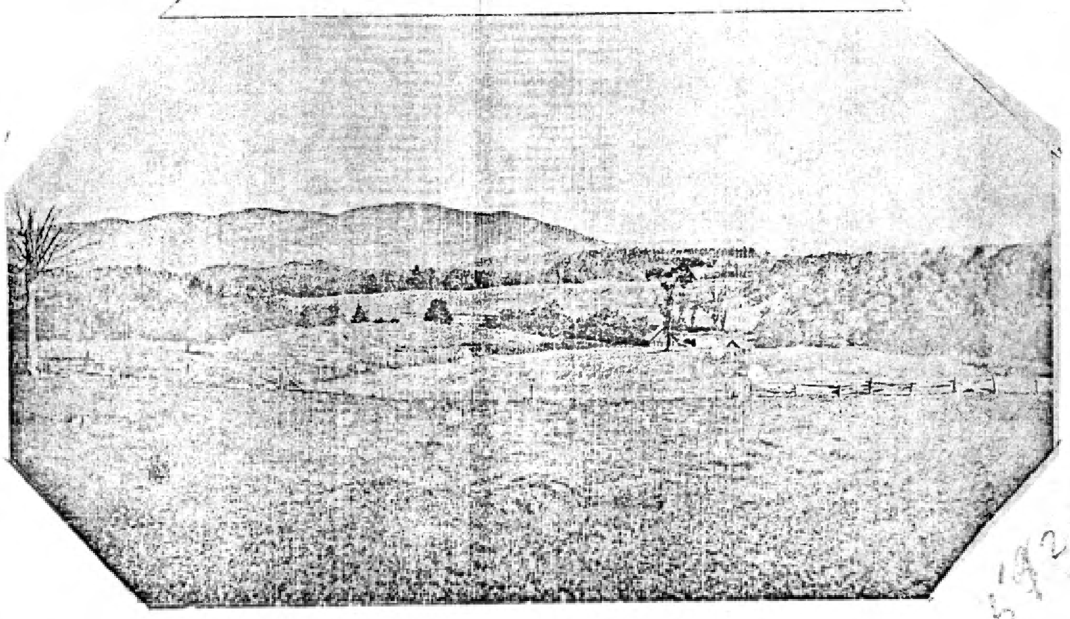
39255

Plate IX - Parallel pegmatite veins in Stanstead grano-
diorite. The width of the veins in the
centre of the picture is about 1 inch and
they are 12 inches apart.



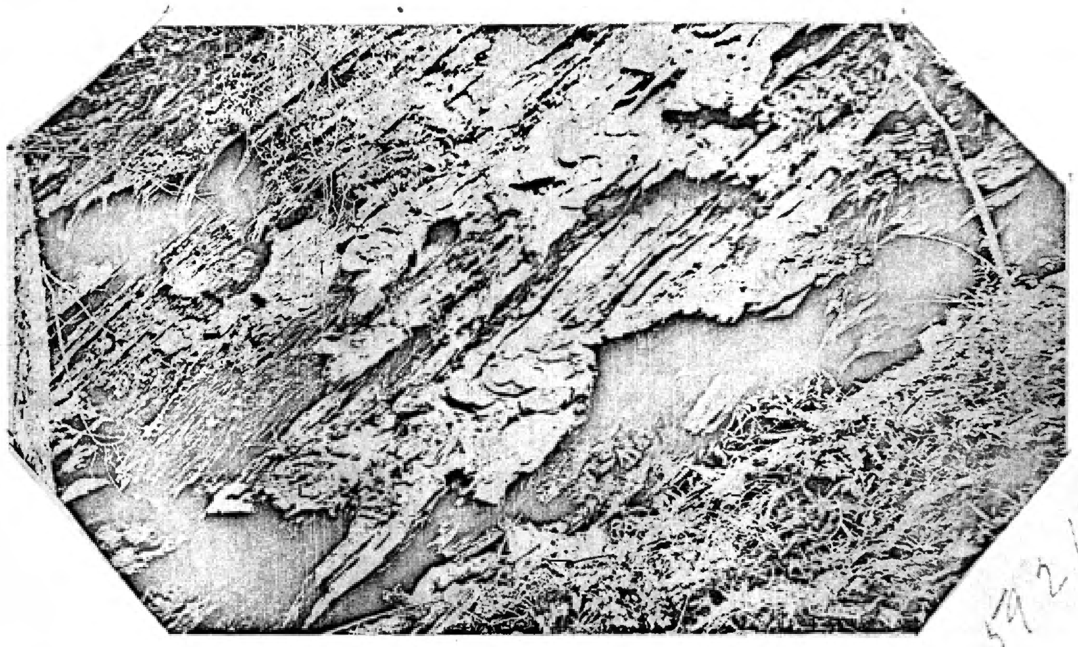
39261

Plate X - Stanstead Granite Company's quarry at Graniteville,
showing the excellent sheeting and ideal working
conditions.



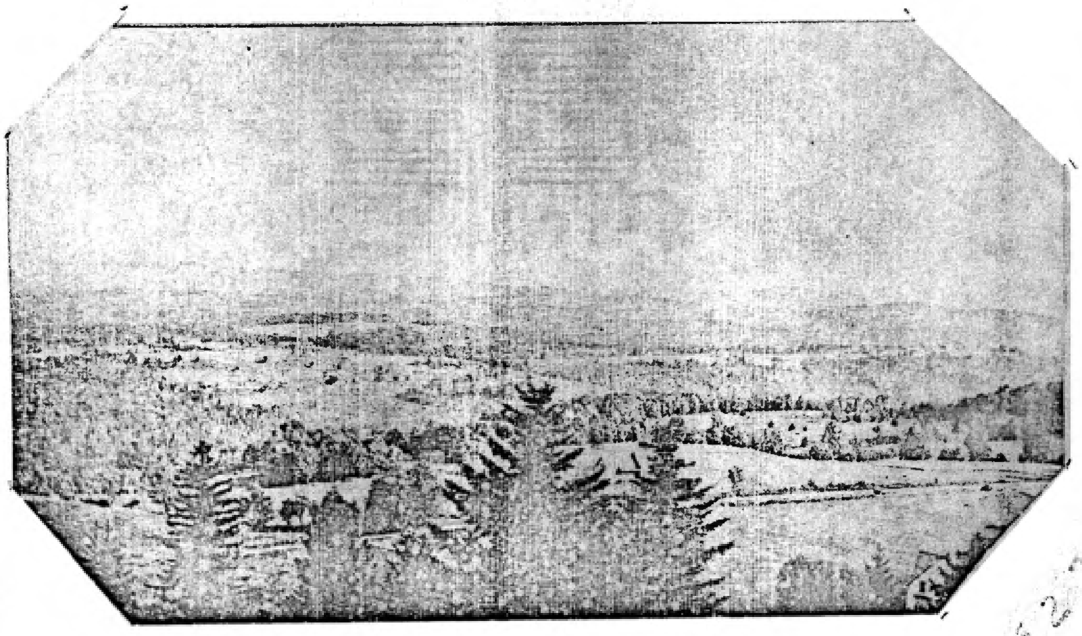
592 69

Plate V - Looking northwest toward Lake Massawippi.
Foreground shows type of topography west of
Bunker fault. In the background the ridge
east of the fault can be traced far to right.



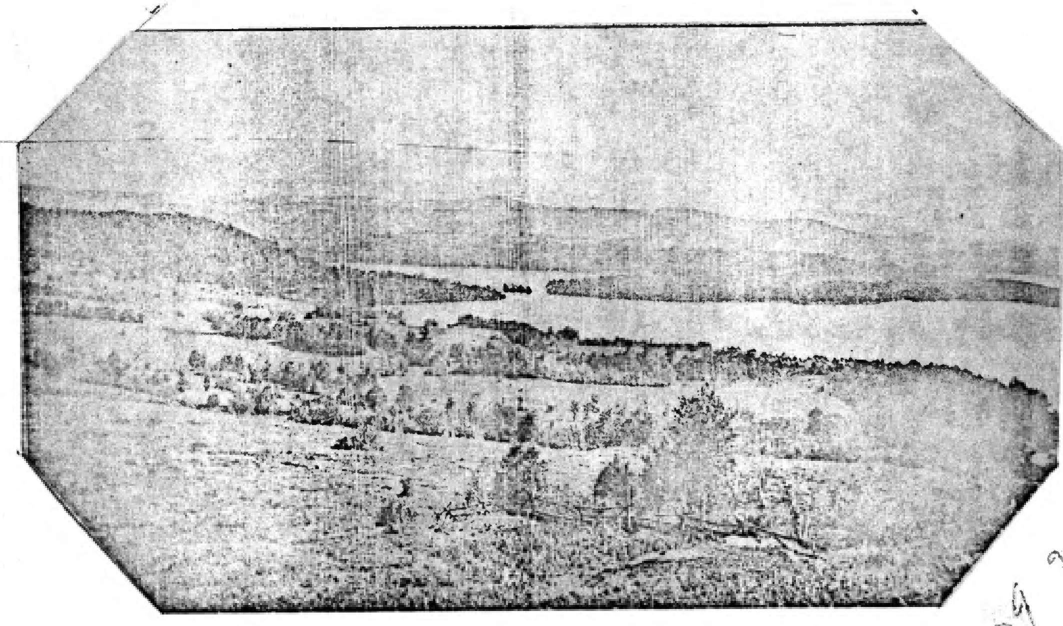
592 66

Plate VI - Drag folds south of Ayer's Cliff in the
Tomifobia interbedded slates and limestone.



59270

Plate III - Looking southeast across Fitch Bay. Hills of Stanstead granodiorite in right background.



59273

Plate IV - Whetstone Island. The low flat area in the foreground is underlain by Devonian limestone. The hills in the background are of Stanstead granodiorite.

Dr Young

The Director

You have returned to me 3 sheets, sent you with the illustrations for Dr. Kerr's MS. These you state are parts of the report. I did not think this to be so when I examined the manuscript, and still do not think so. Copies of them have to be made, and Dr. Kerr will have to decide how they are to be added to his figures or otherwise incorporated in his MSS.

G A Young
Jan 26, 1906

Dr Young:
This is what we spoke about today at noon, I suppose. The [illegible] your [illegible] on [illegible] part of [illegible] MSS.

Dr Young

The Director

Attached are 11 plates designed by Dr Kerr to accompany his thesis

Dr Kerr "thinks" that 3 further sets are necessary to illustrate his thesis

G A Young
Oct 29. 1927

~~Mr~~

Mr Clarke

Will you kindly make 3 sets of prints of each of the prints enclosed herewith

WH

Oct 29/27