A PETROGRAPHIC STUDY OF THE METAMORPHIC ROCKS OF LITTLE MANICOUAGAN LAKE AREA

by

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PREFACE

During the summer of 1957 a reconnaissance survey was conducted between Shelter Bay, Quebec - a village on the St. Lawrence River's north shore, some 36 road miles west of Seven Islands - and the northern end of Little Manicouagan lake. This involved a strip one hundred and eighty miles in length and three to five miles wide along available wood-roads and navigable rivers and lakes. The purpose of this survey was to provide data on the surface geology and the lithology that would be encountered along the access road of the Quebec Cartier Mining Company Ltd.

In the course of the investigation it was discovered that the rocks within the boundaries of the section fitted the descriptions, in part at least, of the types found within many of the St. Lawrence North Shore map-areas described in the Preliminary Reports and the Geologic Reports of the Quebec Department of Mines. Reports by Faessler (1942), W. Emo (1955), M.A. Klugman (1954, 55 & 56), and J. Jenkins (1956) all contain superficial descriptions of the lithologic units. They have been variously described as orthogneiss and paragneiss with related gabbroic, granitic and dioritic intrusives. It was found, however, that the descriptions of some of the granitic and dioritic "intrusives" were not specific enough to warrant correlation of these with any similar types found within the reconna issance area. It was felt, therefore, that during the course of the survey there would be a decided advantage in allotting extra time to areas containing good exposures of these "intrusive rocks", thus adding valuable data to the literature. Since this time a paper by M.A. Klugman (1956) has provided excellent descriptions of many of the rock-types in a similar region to the east.

The Little Manicouagan Lake map-area was underlain by a series of granulites and related rock-types. The granulites, of dioritic appearance, made up the major rock-type. Excellent exposure of both vertical and horizontal outcrop-sections provided optimum conditions for a detailed investigation. In addition, the textural and structural peculiarities of the rocks suggested tectonism; and since deformation has been described in a metasedimentary series to the north, it occurred to the writer that the local rocks may hold the key to the forces involved in the northern sector. Thus it appeared that a detailed consideration of the lithology of the Little Manicouagan Lake area would provide valuable data on one of the "Grenville-type" rocks and would probably shed some light on tectonism involved in the fringe zone of the "Grenville Province".

Definition of "Grenville" and related terms:

The term "Grenville-type" has been used by many writers in connection with crystalline limestones and amphibolites whic h show similarities to those of the type-area described by Logan, W.E. (1858) in Grenville Township, Quebec. A more modern usage has stretched the term somewhat to include a series of orthogneisses and paragneisses with related gabbroic and granitic intrusives; the only apparent requisites being a high degree of metamorphism and/or the presence of anorthosites and related intrusives. Presently it appears that the term may be legitimately used to include all rocks south of an hypothetical line from Georgian Bay through Chibougamou, Mistassini and Seal Lake districts to the eastern coast of Labrador and, in general, north of the St. Lawrence River. (R.M. Farquhar and R.D. Russell 1957- p. 31). This embraces a broad lithologic province within whose boundaries the rocks have been dated between 800-1100 million years. While there seems to be little justification in using the term in areas remote to and of obviously different lithology from the type-area, this procedure has become firmly entrenched in the literature, and it seems only logical that it be continued until sufficient ages are available to set up a complete and accurate calendar.

For the purposes of this thesis the region set aside by Farquhar and Russell (1957), and termed "Grenville", shall hereinafter be referred to as the "Grenville province" and the rocks therein as "Grenville-type rocks."

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INTRODUCTION

Location and Accessibility

The Little Manicouagan Lake map-area lies within the co-ordinated: 51°30' N. and 51°55' N., and 67°20' W. and 67°53' W. The actual boundaries of the mapped area are not coincident with these co-ordinates since no attempt has been made at mapping a geographic unit; rather, the limits are provided by the outcrop areas investigated and therefore are largely confined to a narrow strip of readily available outcrops along the shores of the lake and the walls of the pass to the south.

In summer, Little Manicouagan lake can be reached by hydroplane from Lac des Rapides lake, ten air miles northwest of Seven Islands; or by amphibious aircraft directly from Seven Islands airport. In addition, the area may be reached by following the new access road which runs north from Shelter Bay along the site of an old woodroad belonging to the Quebec North Shore Pulp and Paper Company.

This road is being constructed presently by the Perini-O'Connell-Quemont Construction Co. Ltd. for the Quebec Cartier Mining Co. Ltd. The purpose for opening this route is to facilitate construction of a railroad which will eventually link Lake Jeannine - the location of the Quebec Cartier Mining Company iron ore project - with a river port site near Shelter Bay, Quebec. Ninety-three miles of the two hundred mile long roadway had been completed by the end of the summer season. In order to travel beyond the road-end, to Little Manicouagan lake, it was necessary to employ the canoe-portage methods used by early trappers. Once Little Manicouagan lake was reached, travel to any point on its twenty-six mile long shoreline could be made by canoe.

The southern end of the lake is bounded by high rock walls, many of which form near-vertical cliffs that rise precipitiously from the water's edge; others are abutted by steep talus slopes composed of huge angular blocks. Though these provide readily available rock exposures, they also effect an almost insurmountable barrier to land-travel beyond the lake shore. However, a number of small streams entering the southern end of the lake have developed clefts in the rock walls which provide slopes that can be scaled more readily. In the northern sector a drastic reduction in the relief greatly facilitates inland travel; unfortunately, however, there are very few rock exposures in this portion of the map area.

Drainage of Little Manicouagan lake is by way of the Hart-Jaune river which has its source in the northern end of the western arm of the lake. This river flows some twenty to twenty-five miles to the southwest where it discharges into Manicouagan lake. To complete the picture it should be pointed out that Manicouagan lake is, in turn, drained to the south through the Manicouagan river and into the River St. Lawrence, near the town of Baie Comeau, Quebec.

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Previous Work

Little trace of habitation or previous work was evident in the Little Manicouagan lake region. However, several old campsites, known to have been occupied by crews carrying out topographic surveys, were found near the wouthern end of the lake. Aside from these campsites the only other evidence of early visitors to the area is an old Indian-type trapper's cabin located on the southeastern shore.

As far as it is known only two earlier geologists have visited the area. These were Dr. E.H. Kranck, who made a short stop-over visit in 1954, and Dr. D. Bradley who, along with members of his four-man party, carried out a reconnaissance survey during the summer of 1956. Neither of these men have published any data compiled during their visits. However, a report, and a considerable number of specimens have been made available to the writer by Dr. Bradley.

Field Work

A campsite was chosen on Little Manicouagan lake (see map) on the eighteenth of August. The party consisted of two geologists, two junior assistants and a cook. Dr. Henry Lepp of the University of Minnesota (Duluth Branch) was party leader until he left the field in late August, after which the writer held this responsibility. Two weeks later the two assistants returned to university and the writer continued to collect data until heavy snows, in late September, brought the field season to a close.

From time to time the party had the use of a "Bell" helicopter chartered from Spartan Airways Ltd. by Quebec Cartier Mining Co. Ltd. When this aircraft was available it "airlifted" one or more of the group to the summits of the nearby Manicouagan mountains, or to Roselea lake, a small lake which lies ten miles west of Little Manicouagan. However, the larger part of the survey was carried out by outboard motor-driven canoes of the "prospector" or"freighter" types. These crafts made it possible to reach all parts of the lake within two hours. Consequently, the "shore geology" became the most important part of the survey.

From the shores of Little Manicouagan lake several loop-type foot-traverses were made in areas which looked most promising for rock exposure; unfortunately, this method of covering ground proved highly inefficient in the more rugged terrain.

Mapping of both canoe and helicopter traverses was implemented by spot-identification on aerial photographs; the foot-traverses were mapped by pace-and-compass orientation with the aid of aerial photograph s. In all three types of surveys outcrops were plotted directly on aerial photograph "acetone-overlays." The data were then transferred to a base-map drafted on the scale of the photographs (i.e. 1 in. = 3333 ft.) Since the field work was completed a more acc urate base-map has been made from the preliminary topographic series issued by the Canadian Topographic and Technical Surveys.

Acknowledgements

The writer is deeply indebted to members of the staff of the Quebec Cartier Mining Co. Ltd. who have made possible the survey covered in this thesis. Special thanks is due to Dr. R. Marsden, Mr. D. Ferreira and Mr. W. Grosz who provided the vital aid and encouragement required to make this study a success. To Dr. D. Bradley sincere appreciation is due for the valuable assistance and encouragement, and especially for permission to use his unpublished data to supplement material collected by the writer.

The writer wishes to acknowledge the assistance, the encouragement, and the innumerable valuable suggestions provided by Dr. E.H. Kranck and Dr. J.S. Stevenson.

Thanks is due to Dr. Henry Lepp, who first pointed out the critical nature of the area, and from whom great assistance was received through valuable discussions in the field.

T. Miller and R. Klang, junior assistants, and A. Ringette, cook, provided able assistance during the field work. The author is also grateful to Mrs. F. Vann and Miss B. Bartley who's excellent stenographic work made possible the completion of the manuscript.

Climate

Data on climatic conditions for the St.Lawrence North Shore region are rare. It is only within the past ten to fifteen years that this area has become critical and a great deal of attention has been paid to climatic characteristic. Two weather stations have been in operation on the North Shore for a number of years. At Seven Islands a navigational weather office has been functioning for over thirty years, and a modern weather station operated by the Canadian Government Department of Transport has yielded information during the past nine years. At Schefferville (formerly Knob Lake) the weather bureau has been in operation for five years. Supplementation of the records from Seven Islands and Schefferville can be made by temperatures and precipitation recorded at Blough lake. Observations from the three stations mentioned appear in table (1).

Table (1)

Weather Bureau	Average Daily Temp. in F°			Precipitation in Inches			Remarks
	July	Aug.	Sept.	July	Aug.	Annual	
Seven Islands[1]	60	58	-	4	4	43.3	1949-57incl.
Schefferville[2]	55	52	-	-	-	27.5	1953-57incl.
Blough Lake[3]	48.7	50.4	45.9	4.4	3.4	-	1956

[1]Seven Islands - Canadian Government Department of Transport Weather Bureau - personal communication.

[2]Schefferville - Canadian Government Department of Transport Weather Bureau - personal communication.

[3]Blough Lake - Quebec Cartier Mining Co. Ltd. - Weather records.

It is obvious from table (1) that relatively low temperatures and high precipitation prevail over most of the St. Lawrence North Shore, and that these conditions extend as far north as the map-area covered in this thesis.

High winds were experienced during the period spent at the Little Manicouagan campsite. It may be suggested that these high wind velocities are due to the venturi effect produced on the "northwesterlies" by the funnel-shaped character of the south end of Little Manicouagan lake and the narrow canyon through the high Manicouagan range. This mechanism, coupled with the approximate parallelism between the long axis of the lake and the trade wind direction (northwest-southeast), could well account for high speed winds. Winds of gale force presented a hazard to canoe-travel and considerable caution had to be exercised when there was a threat of squalls.

In general the westerly and northwesterly winds were accompanied by cooler temperatures and clear skies, southerly and easterly winds by warmer air and heavy rains.

Physiography

The major surface feature of the Little Manicouagan Lake map-area is a high northeast-southwest trending plateau which begins opposite the larger island in the southern end of the lake and continues south to Blouin lake; thus,providing an overall width of ten miles. The lateral extent of this highland is not fully known; but, topographic maps indicate that it may hold as far east as the Marguerite river, and west as far as Manicouagan lake. This would mean a length of seventy miles and a total area of seven hundred square miles. The average elevation, calculated from the known high points, is 3100 feet above sea-level. Inasmuch as only a small portion of the highland appears within the map-area this figure cannot be considered representative for the local sector. Among the bush pilots and geologists working in this part of the Province of Quebec this high plateau has become known as the Manicouagan mountains, or Manicouagan mountain range. Since the range is bounded on either end by lakes of a similar name the title seems entirely appropriate.

The lower elevations of Manicouagan lake (altitude 1640 ft.) and the floor of the Manicouagan pass to the south forms a striking contrast to the high surrounding plateau. The southern end of the lake and the pass, together form a wind gap that transects the highland and emerges on the upper part of the Toulnustouc river. The bottom of the gorge-like pass rises from lake-level to a maximum elevation of 1990 feet at a point four miles south of the lake and falls off to 1700 feet at Blouin lake. Obviously, the small streams which form the drainage system of the gorge flow in opposite directions from the highest point on the canyon floor; the north flowing stream entering Little Manicouagan lake, the southern complement forming the source for the northern branch of the Toulnustouc river. Accordingly, the greatest relief is in the vicinity of the canyon near the southern end of Little Manicouagan lake. Here a maximum local relief of seventeen hundred feet is provided in little over one-half mile.

North and westward from a point opposite the largest island of the lake, the elevation of the terrain drops off rapidly to less than 250 feet above the lake-level, forming a deeply embayed lowland upon whose floor flow the tributaries and main-stream of Game Creek. Beyond, to the north, there is a rapid increase in surface-level to an average altitude of 3250 feet. This high region is developed by the Tyler range, an easterly extending arm-like apophysis of the main highland, which carries the high plateau level back to within one-half mile of the western shoreline. In effect, then, Game creek winds its way along the floor of a roughly hemi-elliptical basin that is surrounded by the Manicouagan plateau to the south and west, and the Tyler range to the north and northwest.

North of the Tyler range the land surface returns to a lower level producing an average altitude of 1800 feet along the Hart-Jaune river.

On the eastern shore the slope, at first relatively steep, becomes concave below the treeline and then mildly convex towards the lake. With the exception of a single low hill east of the lake the entire land-area north of the Manicouagan range resembles a broad low basin.

Coincident with the acute change in relief between the southern and northern sections of the map-area there is an equally marked difference in stream patterns. In the southern postion, streams entering the lake from the high plateau are still in a youthful stage. Many of them cascade down the steep slopes, forming only shallow channels in the bedrock. In general, the upper reaches of these streams have developed V-shaped valleys; whereas the lower portions, near the lake, appear to have had little time to produce proper stream channels. Many of them merely drop from one rock ledge to the next without having any continuous confining trough in which they might flow. This observation can be held as proof for either a drastic drop in the local base level - Little Manicouagan lake - or a truncation of the pre-glacial streams by rapid down-cutting of a valley glacier. In the former case this condition necessitates a drop in the lake-level; in the latter it requires that the southern portion of Little Manicouagan lake and the pass must have been, at one time, occupied by a valley glacier. The straightness of the streams suggests that these stream channels were developed along joints or other lineaments in the bedrock.

In the "lowlands" to the north the streams entering Little Manicouagan lake from the surrounding slopes wind their way through a glacial debris cover. Consequently they have varied patterns, from dendritic to deranged. On the eastern shore, beyond the northern island, the stream frequency is high and their abundance and relatively parallel distribution typifies a newly exposed, gently tilted surface. These streams can therefore be considered as "consequent."

To the northeast, where drainage is largely northward off the Manicouagan plateau, there is a notable change in the character of the streams when they reach the "break in slope." At an elevation of 2000 to 2050 feet an old erosion surface is found. This surface, now somewhat dissected by lakes and streams, is composed largely of a bedrock undersurface covered by a mantle of glacial till. The glacial till, largely boulder debris with a sandy matrix, has the "drumlinized" and grooved surface expression characteristic to reworked morainic material. On this glacial plain the streams have reached a more mature state as a result of their ability to rapidly erode the unconsolidated material. Consequently, the lower portions of the streams have broader valleys and show a considerable tendency to meander; whereas the upper portions, flowing over barren bedrock, cascade down steep slopes in relatively straight and narrow channels. It appears, therefore, that the present nature of the old glacial plain is the result of recent exposure of this surface to erosion. This could well have been brought about by a drop in the local base level - or by a relative uplift of the land surface.

In addition to the drumlins there are other surfacial litters such as eskers and various lacustrian deposits.

The eskers shown on the geological map, plate I have a note-worthy distribution. It can be readily pointed out that they follow, approximately, the courses of the present major streams. One exception to this is the high esker remnants mapped on the east side of the lake. It would appear, therefore, that streams flowing within the glacier must have followed similar courses to those which are present today. This would suggest that the depression in which Little Manicouagan lake now lies was in existance during, if not before, the latest glaciation.

Lacustrine deposits have been identified in the region of the southern postion of the lake. Several such deposits appear on the map at points south of the campsite. Inasmuch as a number of these reach one hundred feet above the present lake-level, it seems logical to conclude that the lake was, at one time, one hundred or more feet above its present level.

GEOLOGY

General Statement

The consolidated rocks of the Little Manicouagan lake map-area fall into two general classes - igneous rocks, and metamorphic rocks. The former class includes the rock-types found within discordant "bodies" whose mineral assemblages and textural properties suggest a primary origin, and those of concordant bodies that generally show sharp contact relationships with their hosts. The metamorphic class includes heterogeneous rocks that, regardless of origin, show considerable change in composition and/or structure. This group does not, however, contain any igneous or sedimentary rocks that have merely undergone alteration as a result of surface weathering.

The consolidated rocks of the area are all of Precambrian age. The most abundant variety is the hypersthene-granulite and related garnet-pyroxene-plagioclase gneiss. Of less extent are the anorthosite and related gabbroic rocks and the interbedded granitic and amphibolitic gneisses, both of which are in approximately equal abundance.

Age relationships of these rocks and their intrusive bodies have been resolved as far as possible by contact characteristics. In cases where contacts were vague relative ages were resolved by comparison of the degrees of metamorphism and deformation reached in the different lithologic components.

The rocks of the map-area belong to a lithologic group commonly ascribed to the Grenville province. The area itself lies in a transitional zone between Archean and Proterozoic rocks of low grade metamorphism and the highly metamorphosed gneissic complex of the Grenville province. Hewitt (Gill 1957) has accepted this transitional zone as the Grenville front. Bradley (1957), Sterling (1957), Tyler (1954), and others have described rocks in the Lake Jeannine-Mount Reed area that resemble the Proterozoic "Trough" rocks described by Harrison (1952). Bradley (1957) has pointed out that this series, containing gneisses, carbonates and iron formations, extends as far south as the Hart-Jaune river and the end of Little Manicouagan lake. Further, he describes a conglomerate that outcrops south of the Hart-Jaune river and suggests that it could represent the "base of the Cartier series". By so doing he is also suggesting that the "Cartier series" is lying unconformably on a "red granite gneiss" and therefore is younger than the latter. In proof of this he points to "small subrounded fragments of granite and minerals derived from the weathering of granite" in the conglomerate.

Assuming this age relationship to be correct then it would appear that the rocks south of the "Cartier series", that is, those of the present map-area, are older than the Cartier rocks. If this assumption were valid then it would be reasonable to assume also that the rocks of the present map-area represent pre-Cartier sediments that have subsequently been "rejuvinated" as a result of regional metamorphism. It is worthy of note that this theory is in keeping with the general concept that the "Grenville orogeny" involved rocks of Proterozoic age (Hewitt; see Gill, 1957). However, the theory goes beyond this to suggest that the rocks involved in this orogeny were older than the Proterozoic rocks identified north of the Grenville front.

Table (2)

Table of Formations

Cenozoic	Recent	Lake and stream deposits - sands, gravels, and clays.
	Pleistocene	Glacial deposits - tills, sorted gravels, and clays.
Late Precambrian	Keweenawan	Recent intrusions - basaltic and diabase dikes. Late intrusion - anorthosite, gabbroic-anorthosite and anorthositic-gabbro. Early intrusion - pegmatites and quartz dikes. Late deformation - shearing accompanied by siliceous intrusion Thin-banded felsic rock. Post regional metamorphism metasomatism - development of joint stringers. Early deformation -regional metamorphism - hypersthene-granulites and granitic-amphibolite gneiss complex.

Lithology

Igneous Rocks:

In general, igneous rocks are considered to have formed directly by the solidification of a lava,or crystallization of a magma; or, indirectly, through the precipitation of magmatic emanations. It follows, therefore, that any rock which can be shown to have had an intrusive or extrusive origin may justifiably be classified as "igneous". Though this seems straight forward, some difficulty is encountered in classifying minor discordant bodies such as pegmatites and joint stringers. These are generally presumed to have formed by the solidification of magmatic effusives. However, Ramberg (1952), has shown how pegmatites can develop from joint stringers through the action of diffusion and replacement during regional metamorphism. Although this writer has cast doubt on their igneous origin, convention should hold until his conclusions have become generally accepted. It seems advisable therefore to perpetuate the original classification of Turner and Verhoogen (1951), in which pegmatites appear under "igneous rocks".

In accordance with the foregoing classification the igneous rocks of the map-area are found as joint stringers, dikes, pegmatites, and sills.

Joint Stringers: Joint Stringers are abundant throughout the region where they cut all the major rock-types with the exception of the Roselea Lake group. It was also found that they do not cut any pegmatites and are therefore considered to be older than these course-grained bodies. In addition to cutting many of the regional lithologic units they also transect one another at various angles of strike and dip. From this it is apparent that these stringers represent "fillings" along the planes of a complex joint system.

Two major joint sets have been resolved within the complex system of stringers. These two sets form oblique angles with one another; one having an average strike of N. 20° W., and a mean dip of 80° to the north-east; the other averages an east-west directional tendency, with a dip angle of 40° N. The space distribution of these two systems of planes causes them to converge with increasing depth, forming a line-of-intersection that dips 39° along an azimuth of 357°. From their altitudes it is apparent that neither of the joint sets come at all close to paralleling the regional structure - average strike N. 40° E.; dip 50°- 70° S.E. - and, therefore, they cannot be considered as having originated along either flow or fracture cleavage openings.

According to Billings (1955) parallel parting surfaces which have developed at oblique angles to the strike and dip directions of the associated rocks should be classified as "oblique" or "diagonal" joints. The surfaces along which the joint stringers have formed most likely originated as such; however, the original gneissosity is found to be vague, and some difficulty in resolving their inter-relationships is encountered.

Wherever foliation is prominent it truncates the joint stringers. Obviously, then, the major schistose structure of the rocks must have been associated with some metamorphic stage that tooke place after the "oblique" joints had been filled.

Several thin sections have been taken showing joint stringers. Their composition, texture, and relationship to the surrounding host rock have been given prime consideration.

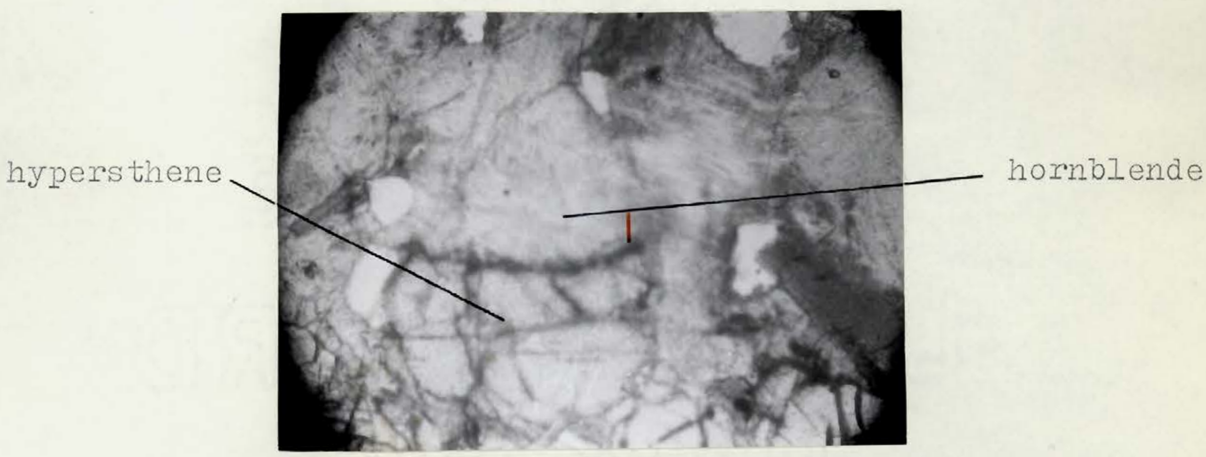
In general they are found to have a broad range in thickness from approximately one thirty-second of an inch up to one inch. These widths, which megascopically appear delineated, are quite diffuse in thin section. Microscopically they are vein-like, showing a marked tendency to "pinch," "swell," and occasionally branch.

The join "fillings" are composed almost entirely

Fig. (1)

Photomicrograph showing hornblende hypersthene relationship. Hornblende replacing hypersthene. Ordinary light. Field width 4.8 mm.

Fig. (2)



Photomicrograph showing hornblende hypersthene relationship. Hornblende replacing hypersthene. Ordinary light. Field width 1.54 mm.

of coarse grained hornblende which had the following optical properties:-

> Z C - 16^{o}; X - pale green,
> Y - green, Z - blue-green pleochroic;
> negative 2V of 40^{o} - 60^{o}; n_x, n_y & n_z
> all greater than 1.62 (minimum n_y & n_z
> of biotite).

Other minerals associated with hornblende are biotite, hypersthene, and quartz. It is found that the biotite and pyroxene are distributed along the margins of the amphibolitic stringers where partial replacement of these two, by the hornblende, produce widening. The quartz appears only in areas where the hornblende has developed from the replacement of the hypersthene. Wahlstrom (1955) has referred to common hornblende psuedomorphic after pyroxene as "uralite".

Ramberg (1952) has shown how aluminous rich hornblende will convert to enstatite and anorthite at high temperatures. The reaction appears as follows:-

Low temperatures	High temperatures
$Ca_2(Mg,Fe)_3Al_2Si_6Al_2O_{22}(OH)_2 + SiO_2$	$2CaAl_2Si_2O_8 + H_2O$
	$+ 3\ (Mg,Fe)\ SiO_3$

It seems logical from the foregoing that calcium-rich plagioclase, hypersthene, and aluminous-hornblende could also exist in equilibrium with one another, and that the hornblende would predominate at the lower temperatures. The reaction would appear thus:-

High temperature — Low temperature

$$2(Ca,Na)Al_2Si_2O_2 + 3MgFe(SiO_3)_2 + H_2O \qquad 4SiO_2 + (Ca,Na)_2(Mg,Fe)_3Al_2Si_6Al_2O_{22}(OH)_2$$

A reaction such as this would account for the alteration of hypersthene over to hornblende with quartz as a byproduct. Since the rocks in which this alteration is observed contain an abundance of andesine (calcic-rich plagioclase), there could be little doubt that such a reaction would take place.

It is noteworthy, however, that water vapour would be necessary to complete the change-over of hypersthene plus andesine to hornblende. This fluid is known to occupy rock pore spaces near the surface, and joints and other fractures to a much greater depth. One may conclude, therefore, that all the necessary ingredients and conditions are present in the system to warrant development of the observed mineralogical changes.

The foregoing discussion has virtually eliminated an igneous genesis for the amphibolized joint sets; rather, it has shown almost conclusively that these minor lithologic units are the products of retrograde metamorphic processes initiated along joint surfaces.

Dikes: Dikes are few in number in the map-area. Commonly, they form narrow concordant transecting bodies varying from four inches to one foot in width. Geographically, they appear to be restricted to the major medium and high grade metamorphic rocks in the central and southern portions of the region.

Although no speciemns of these dikes have been examined in "thin section", hand specimens were collected and studied megascopically.

In general, the dikes appear to have a basaltic composition; however, their fine- to medium - grain size give them a distinct diabasic texture and a tough "baked" consistency. They have a dark grey to black colour with considerable limonitic staining on the weathered surface. This dark internal colouring is due to the deep-blue feldspars and black ferro-magnesians which made up the bulk of the essential minerals. Characteristic of fresh basaltic dikes, one body displays an excellent set of transverse tension fractures which divide it into polygonal columns lying normal to the contact surfaces (i.e. dike walls).

The transecting nature of these basaltic dikes and the presence of vague contact aureoles attests to their igneous origin. This intrusive characteristic makes them ideal for studying relative ages. Accordingly, when it was discovered that they were not cut by amphibolitic joint stringers, they were automatically classed as post jointing. However, the rarity of their occurrence renders difficult any study of their age relationship with respect to other monir intrusive type bodies. On an island-outcrop, in the south-eastern part of Little Manicouagan lake, one of these is seen cutting across a small mass of anorthositic-gabbro. The latter rock is generically related to the anorthosite of the Tyler Range - a lithologic unit which is younger than the adjacent metamorphic series.

Thus far, then, it can be established that the joint stringers are associated with regional metamorphism; the anorthositic intrusive is post-regional metamorphism (to be shown); and the basaltic dikes are post-anorthositic intrusion.

Pegmatites: The pegmatites of the Little Manicouagan Lake area include a group of discordant, transecting, intrusive-like bodies. They are generally medium to coarse grained (grains up to one inch in diameter) crystalline aggregates of quartz and feldspar, with subordinate amounts of biotite - or muscovite - and/or hornblende. Accessory minerals such as sphene and garnet are not infrequently present.

No thin section studies have been made of the pegmatites because, for the most part, their mineralogical components could be identified megascopically. Furthermore, in accordance with the degree of importance which they hold as a rock unit, sufficient data could be extracted by visual examination.

Although their distribution is somewhat erratic the pegmatitic bodies are entirely restricted to the zone of metamorphic rocks. Neither Bradley (1957) nor the writer could find any pegmatites in the anorthosites of the Tyler Range.

Three major species of pegmatites have been discovered, each of which can be distinguished on the basis of mineralogic differences.

The most frequently occurring type is a massive, mottled pink-to-white, medium- to coarse-grained variety. Generally it is made up of potash feldspar and quartz in the proportions of 60 per cent to 35 per cent - the other 5 per cent being biotite. This variety has been uncovered in the rocks of the central section of the lake, where a number of these pegmatites cut indiscriminately across the foliated metamorphics. For the most part, they are discordant and transecting; but, occasionally, they deviate and follow the planes of foliation in a sill-like fashion. Generally speaking, their sharp contact relationships plus the presence of a number of wall-rock inclusions provide sufficient evidence to attest to the intrusive nature of these discordant bodies.

Farther south, in the vicinity of the large island, mineralogically dissimilar pegmatites are found. This group, also medium- to coarse-grained are white in colour; the color being due to quartz and sodic-rich plagioclase. Another major compositional difference is the presence of a yellowish variety of muscovite rather than the usual biotite mica. In this sector the pegmatites transect and are apparently foreign to the rocks in which they are found.

On a talus slope, east of the lake, approximately one mile south of the campsite, a dark grey, medium-grained pegmatite is found cutting some of the larger slide-blocks. The cliff-like nature of the outcrop made it impossible to examine this rock-type in place. This unit is composed of large crystals of hornblende in a greyish-blue feldspar (plagioclase) matrix. In effect, the composition is close to that of the host rock. This similarity in composition indicates that pegmatites of this type are not intrusive but are formed "in situ" as a result of metamorphism.

Other pegmatitic bodies observed farther south along the shore outcrops are quite similar to the first variety described. In a few instances, however, the enveloping host rocks show a marked increase in mafics, and occasionally became noticeably amphibolitic. These pegmatites are assumed to be, in part at least, accretionary, growing at the expense of the felsite content of the adjacent rocks. Such a mechanism has been outlined by Ramberg (1952, p.p. 248-258) and briefly discussed in an earlier section.

In conclusion, it may be pointed out that the pegmatites are for the most part intrusive and are therefore related to late igneous activity, or high grade metamorphism (sufficiently high grade to support some localized anatexis). Only an arbitrary age can be affixed to these bodies - between the jointing, which provided openings for the joint stringers, and the emplacement of anorthositic intrusives.

Sills: One of the major lithologic units - the anorthosite - has been described by Bradley (1957) as a "sill". As evidence for this he has pointed out that "flow stratification and orientation of platy phenocrysts within the anorthosite" are generally concordant with attitudes in the bordering gneisses to the north. He does not, however, show the contact relationships of the southern exposure, but merely states that "parallelism of attitudes north in the igneous rocks (anorthosite*) and south in the "Roselea Lake series" indicates also that the body is a sill."

Although the writer did not have the opportunity of examining the northern contact, work carried out along the southern exposure, and in areas east of the range, indicates that the anorthositic mass represents but a poorly defined sill-like intrusive. It has been found that the east-west trending anorthositic intrusive of the Tyler range ends abruptly approximately one half mile west of Little Manicouagan lake. East of this point anorthosite and related rock-types have been identified in small isolated outcrops where they are associated with amphibolitic gneiss **.

There is a general tendency for the structural trend in the thin banded gneisses north of the anorthosite massif to converge upon that of the southern group (Bradley 1957). This indicates a "pinching-out" of the mass towards its eastern end. From this obvious narrowing of the massif, it can be concluded that the anorthosite is found within what may properly be described as a sill-like body, which because of its disjunctive character,

* Author's note.

** amphibolitic gneiss - the description of this rock-type has been reserved for a later section and can be found under the subtitle "Metamorphic Rocks" - "Amphibole Facies".

cannot be referred to as a <u>sill</u> proper.

Proof of the intrusive nature of this concordant mass lies in its relationship with the country rocks. The tough baked appearance of the flanking thin-banded gneisses is indicative of thermal metamorphism - an alteration characteristically produced by the influence of a hot magma. A lack of transecting branches diverging from the main mass into the country rock need not contradict the "intrusive theory". The coarse grained character of the anorthosite proves conclusively that crystallization took place at considerable depth; under such conditions the bordering gneisses would have been too mobile and incompetant to provide fractures, or other openings as magmatic receptacles.

Anorthosite:

In previous discussions the rocks of the Tyler range have been designated as "anorthosites" without qualification. In order to place these rocks within their proper categorie, data on compositional and textural properties have been used to compare them with "characteristic anorthosites" described by Turner and Verhoogen (1951).

Turner and Verhoogen have classified anorthosites as follows:-

"1. Bytownite anorthosites occurring as layers within stratified basic sheets and lopoliths.....
2. Andesine or labradorite anorthosites occurring in large independent intrusions in pre-Cambrian terranes......." *

The anorthosites of the Little Manicouagan Lake area belong to the second categorie and the discussion that follows will refer only to this particular type. Turner and Verhoogen, after Buddington (1939), have outlined the vital properties of the second class in the following manner:-

"1. The anorthosite bodies are limited to pre-Cambrian terranes.
2. They take the form of large intrusions with domed roofs and batholithic proportions......
3. The principal constituent mineral is plagioclase approximating to andesine-labradorite but ranging from An_{35} to An_{60}. Hypersthene and augite, less commonly accompanied by olivine, make up less than 10 per cent of the composition in anorthosite proper, 10 to 22½ per cent in gabbroic anorthosite, and 22½ to 35 per cent in anorthositic gabbro.
4. Many anorthosites are very coarse grained. Cataclastic and locally mylonitic fabrics are common.
5. Complete transition from anorthosite to norite gabbro has been traced in most large bodies of

* Page 252

> anorthosite. There can be no doubt that these rocks have a common origin. Pyroxene-bearing granites (charnockites), syenites, and monzonites (mangerites) are also associated with anorthosites, but whether these have been derived from the same magmatic source as the anorthosites or whether their presence is due rather to a particular environment of intrusion is by no means clear.
> 6. Lavas of anorthositic composition are unknown. But there are rare instances of dike rocks exactly equivalent in composition to gabbroic anorthosite......"*

The average composition of specimens taken from the Tyler Range outcrops are as follows:-

plagioclase - 90%
olivine + hypersthene (?) corona - 8%
opaques + iddingsite (?) corona - 2%

It is obvious from number 2 above that the present "anorthosite" belongs to the group which contains 90 per cent plagioclase and less than 10 per cent olivine and/or hypersthene; that is, it is "anorthosite proper".

This anorthosite has a distinct blue-grey colour on the fresh faces and a muttled green-blue on the weathered surface. The grain-size is fairly constant and remains within the range of $\frac{1}{4}$ to 1 inch in diameter. Actually the feldspar crystals, largest of the grains, are considerably

* Page 253

elongated in one direction with a width-to-length ratio of 1:4. A good pan-idiomorphic granoblastic texture prevails in this coarse grained homogeneous rock.

The plagioclase, by far the most abundant constituent, has a composition of An_{30} - An_{35}. This mineral has been identified by the following optical properties:-

biaxial negative; 2V - 90°;
maximum extinction angle * - 16°;
bifringence .007, in section .03 mm. thick.

In general, the euhedral to subhedral plagioclase grains show very little saussuritization. Almost all of the grains have albite twinning; a few show carlsbad, and more rarely, pericline twinning. They are for the most part colourless in thin section, but the presence of "dusty" inclusions tends to cloud most of the grains.

The presence of "dusty" inclusions in plagioclase has been discussed at length by Adams (1895), Barth (1930), Poldervaart and Gilkey (1954), and Klugman (1956). Barth has observed that the "rod-like" inclusions are largely pyroxenes. Poldervaart and Gilkey, on the other hand, found them to be mostly iron oxides. Klugman supports the conclusions of the latter authors and suggests that

* extinction angle - measured from the trace of the (010) plane in sections showing albite twinning.

they are iron oxides "probably magnetite and hematite". Although the writer has not studied the opaque inclusions in detail it is felt that ilmenite would be a more likely constituent than hematite. This suggestion is based on the well-known association of titanium oxides and anorthositic rocks. The writer has found, as did Klugman, that the "dusty" inclusions have an even distribution and therefore develop a texture characteristic of exsolution.

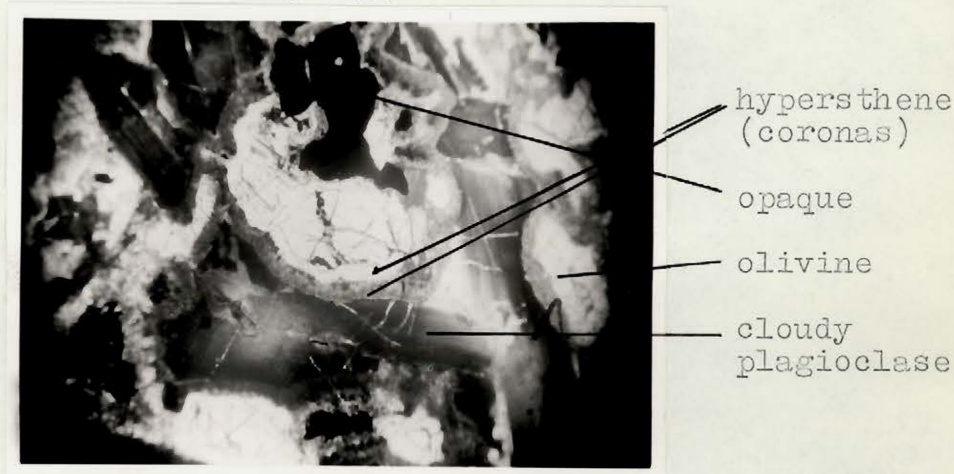
Olivine, the most abundant semi-opaque mineral, is invariably surrounded by coronas (see figs. 3 - 4). These reaction rims are composed of a radiating pyroxene which has optical properties similar to those of hypersthene - i.e. slightly pleochroic, biaxial negative, and length fast. The outer surface of these coronas is usually convex towards the bordering plagioclase; apparently replacing the latter. In many cases two distinct reaction rims are present, the innermost composed of clear pyroxene, the outermost containing a cloudiness similar to the plagioclase.

The optical properties by which the olivine is identified are as follows:-

> biaxial negative; 2V - 80° - 90°;
> birefringence - .040; high
> positive relief.

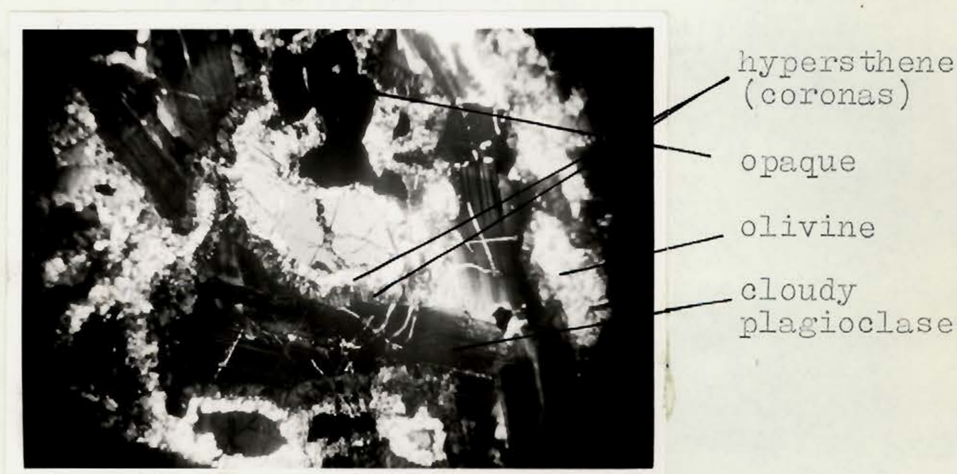
Subordinate quantities of opaque minerals are

Fig. (3)



Photomicrograph showing olivine partially replaced by opaques and surrounded by a double-corona.
Ordinary light.
Length of field 4.8 mm.

Fig. (4)



Photomicrograph showing olivine partially replaced by opaques and surrounded by a double-corona.
Polarized light.
Length of field 4.8 mm.

found scattered throughout the sections. These opaques, largely magnetite-ilmenite intergrowths, show replacement relationships to the olivine grains. These, like the olivine grains they replace, are also surrounded by a double corona. The reaction rim immediately adjacent to the opaque mineral is brownish in colour and is thought to be iddingsite - an alteration of plagioclase. The outer reaction rim is apparently composed of unaltered pyroxene.

Table (3)*

Thin Section No.	314	315	366
Plagioclase	47.2	51.1	40.0
Olivine	12.0	29.3	6.2
Hypersthene	---	6.6	7.5
Opaques	2.7	Trace	4.0
Corona (alteration)	24.0	11.4	28.7
Scapolite	4.0	---	10.0
Amphibole	5.0	1.2	1.2
Biotite	1.4	---	1.2
Carbonate	Trace	---	Trace
Spinel (Green)	Trace	---	---
Apatite	---	---	Trace
Sphene	---	Trace	0.5

* Percentages of minerals estimated by the use of a grid ocular.

Table (3) compares the mineral content of three specimens taken at widely distributed points east of the main anorthositic body. Specimen number 315 comes from an outcrop at the east end of the range, number 366 from the western shore of Little Manicouagan lake, and number 314 from the eastern shoreline of the lake. According to the classification of anorthosites outlined on pp. 35 - 36, the rocks from which specimens numbers 314 and 366 have been taken can be catalogued as gabbroic-anorthosites; whereas specimen number 315, which contains more than 22 per cent olivine, represents an anorthositic-gabbro.

The most notable difference between these specimens and those of the main body is the presence of scapolite. No scapolite has been identified in specimen number 315; in this respect, it is similar to the Tyler Range anorthosite.

Scapolite grains examined in thin sections numbers 314 and 366 have the following optical properties:-

> uniaxial negative; low positive relief;
> medium birefringence - first order yellow.

This mineral has been found in these thin sections as an alteration product of plagioclase - a phenomenon known as scapolitization.

In a discussion on scapolitization, Ramberg (1952) has pointed out that "a metosomatic origin of scapolite is common in some regionally altered rocks". In order for scapolitization to proceed, he shows the necessity of having "fugitive" ions such as $CO_3^{=}$, Cl^{-} or $SO_4^{=}$ about, to combine with the plagioclase. Water is also necessary in the lattice.

Whereas, regional metamorphism is not apparent among the rocks in which scapolitization has been observed, some degree of local metamorphism is found. This is seen in the form of an alteration of pyroxene grain boundaries over to amphiboles. It should be pointed out that both thin sections which showed scapolitization also contain traces of carbonate (see Table (3)). Accordingly, the proper ingredients - CO_3 ions, moisture, and plagioclase- and ideal metamorphic conditions prevail in this rock-type. Obviously, then, the scapolitization observed therein has taken place through metasomatism.

Metamorphic Rock:

Metamorphism has been described by Turner & Verhoogen (1951) in the following manner:-

> "........it (metamorphism*) refers to the mineralogical and structural adjustments of solid rock to physical or chemical conditions which have been imposed at depths below the surface zones of weathering and cementation and which differ from the conditions under which the rocks in question originated."

According to this definition 80 - 90 per cent of the rocks of the Little Manicouagan Lake area have undergone metamorphism and can therefore be classified as metamorphic rocks.

Many of the metamorphic rocks have experienced a high degree of recrystallization, and can be recognized as metamorphics by the presence of relic structures and compositional differenciations. Most of the rocks which show retrograde metamorphism contain vestiges of the original mineralogic assemblages.

A few of these retrograde metamorphic rocks have been derived from rocks which themselves were metamorphic derivatives of an earlier paragenesis. Thus more than one stage of metamorphism is often evident in the present lithology.

* Author's note.

Generally speaking, the metamorphic rocks of the Little Manicouagan Lake map-area can be divided into two main groups; those of high grade metamorphism - Granulite Facies; and those of intermediate grade - Amphibolite Facies. The former group underlies the entire southern area, forming the core of the Manicouagan plateau. The latter group is restricted to the boundary zones on the north and south sides of the north-easterly trending plateau.

On the north side of the Manicouagan range the rocks which have been classified as the "Amphibolite Fac ies" cover the area between the end of the granulites and the Tyler Range intrusive. Beyond this range a narrow band of similar rocks continues north until the biotite-quartz-feldspar gneisses of the "Cartier series" are met (Bradley, 1957).

The thin-banded gneisses of the Roselea Lake series are presumed to represent the hornfelsized equivalents of the "Amphibolite Facies" rocks on Little Manicouagan lake.

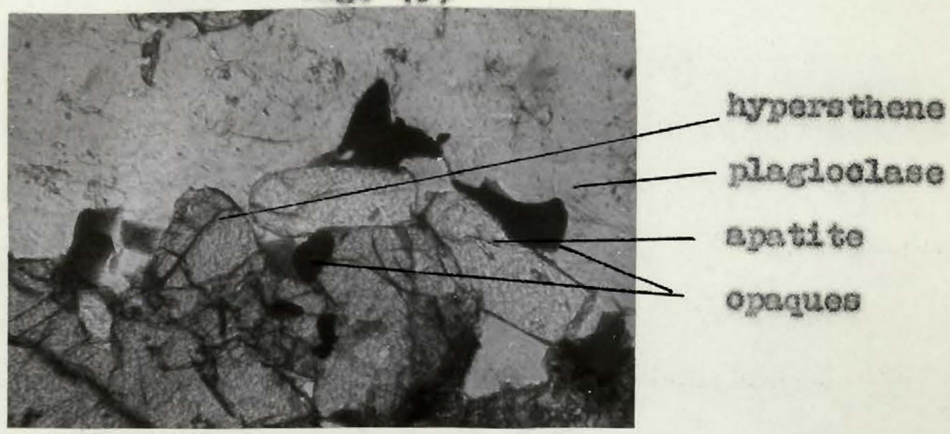
South of the Manicouagan plateau the "Amphibolitic Facies" rocks are found as a transition between the granulites and a series of biotite-quartz-feldspar gneisses and biotite-feldspar augen gneisses. The latter are typical of the vast region that stretches south as far as the North Shore "gabbroic intrusive belt".

Granulite Facies:- This group involves a broad belt of rocks stretching from a point approximately one half mile north of the campsite to a marginal zone several miles north of Blouin lake. The length of the belt is not known. However, from as far west as Roselea lake to two miles east of Little Manicouagan lake, similar rocks have been identified.

The rocks which have been classified as the "Granulite Facies" are by no means entirely metamorphicly similar throughout. Rather, they show localized changes in metamorphic grade, frequently displaying minor zones of rocks belonging to the amphibolitic and greenschist facies (see "Metamorphic Facies", Eskola P., 1939, p.344).

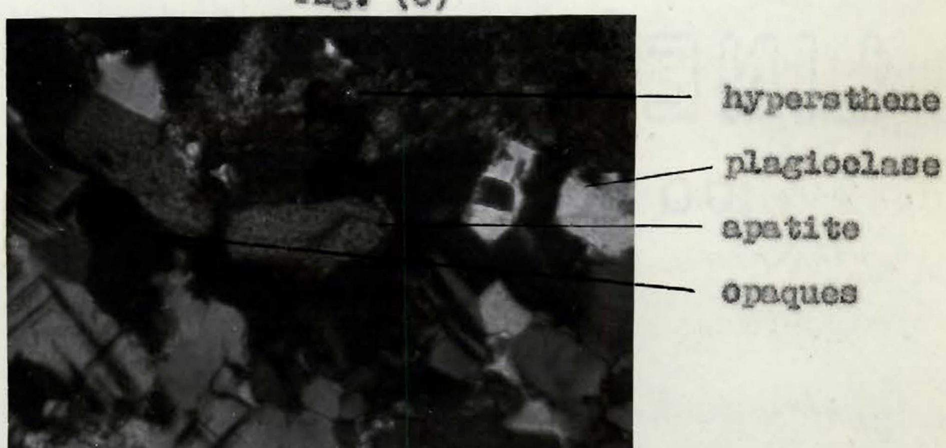
The major rock-type is a hypersthene-granulite (see figs. 5 - 6), composed almost entirely of these two minerals. Subordinate quantities of quartz, biotite and opaques are also present. Apatite, zircon, muscovite, sphere and garnet appear as accessory minerals. Generally, this rock is medium- to coarse-grained and dark grey in color. The weathered surface has a typical "pepper-and-salt" nature due to the dissemination of pyroxene grains in a yellowish-white feldspar background.

Fig. (5)



Photomicrograph of typical
hypersthene-granulite.
Ordinary light.
Length of field 1.54 mm.

Fig. (6)



Photomicrograph of typical
hypersthene-granulite.
Polarized light.
Lenght of field 1.54 mm.

In thin section the rock shows peculiar intergranular relationships. The pyroxenes are generally in clusters scattered throughout the plagioclase matrix. A granoblastic texture is predominant, though a strong lineation is evident in oriented sections. This lineation is due to a parallel orientation of the long axes of plagioclase and pyroxene grains. In many sections there is a fine-grained "crushed" aggregate bounding the plagioclase and pyroxene grains (see fig.7). These granulated boundaries are assumed to have resulted from post-crystallization deformation and are thought to have developed simultaneously with the lineation. Other evidence of late deformation is seen as warped albite twins in plagioclase, and as straining in quartz.

The pyroxene is largely <u>hypersthene</u>. However, s few specimens contain <u>augite</u> in place of hypersthene. Hypersthene has the following optical properties:-

> biaxial negative; parallel extinction; length slow; X-pinkish, Y-yellow-green, Z-green pleochroic; 2V 60° - 90°.

<u>Augite</u> is distinguished from hypersthene on the basis of optical differences. The optical properties of this mineral are as follows:-

> biaxial positive; extinction angle 46°; moderately green color; 2V 60° and 45°.

Fig. (7)

Photomicrograph showing
"crushed" grain boundaries
in hypersthene-granulite.
Polarized light.
Field length 1.54 mm.

The composition of the plagioclase is from An_{28} to An_{62}. However, the average plagioclase is within the limits of An_{38} and An_{56}. This makes up 40 to 50 per cent of the mineralogic composition.

Biotite is rare in this rock. It is generally found as elongated crystals and plates. Typical parallel extinction and "peacock" coloring are evident under doubly polarized light. Under plain light the biotite is brown and buff pleochroic.

Quartz grains are relatively few and are disseminated throughout the plagioclase-pyroxene groundmass. Quartz also appears as inclusions in amphibole grains and biotite plates. The disseminated quartz grains show undulose extinction under crossed nicols. High birefringence in some grains is thought to be due to straining.

The opaques are largely magnetite. However, many specimens from outcrops which showed limonitic surface staining contain disseminated pyrrhotite. Graphite is also present and is particularly noticeable in sheared zones. It is not believed to be a disseminated mineral but is assumed to be restricted to these "sheared" rocks.

Apatite, the most abundant accessory mineral, is widely disseminated throughout the sections. Both euhedral "rod-and-needle" apatite and anhedral granular apatite are found. Apatite rarely exceeds one half of one per cent of the rock.

Table (4)

Spec. No's.	Qtz.	Plagioclase		Pyroxene		Hlbd.	Biot.	Apat.	Opaq$^{\underline{s}}$.	Zirc.
		Olig.	And.	Hyp.	Aug.					
178			47		39	7	4.4	.3	1.7	
180		37		39			Tr.*		4	
188	Tr.		40	58			2	Tr.	Tr.	
193		64.5		29.5		1.5	3.8		0.8	
196			64.5	28.5		Tr.	6.5	Tr.	Tr.	
201	2.2	61		28		7	0.5	Tr.	2	
222	8		17	52				Tr.	5	
224	4.5	57		35		Tr.		.1	3.5	
236	Tr.	61.5		27.5		Tr.	7.5	Tr.	2.5	Tr.
239	Tr.		51	25			11	Tr.	2	Tr.
247			59	33.3		2	0.5	Tr.	3.2	
249	3.5	77.8		11.2			5.7	0.5	Tr.	Tr.

Table (4) outlines the composition of twelve specimens of the hypersthene-granulite, giving percentages of the component minerals.

* Tr. - Trace.

The rocks of the central portion of the granulite belt do not show any pronounced banding; however, those of the transition zones to the north and south have a fairly distinct layering in vertical outcrop sections. Rock exposures which displayed a distinct banding in vertical view do not necessarily show this in the horizontal sections; rather, they appear to be sinuous and, for the most part, discontinuous on the flat surface.

The presently obvious disjunctive banded-nature of the rocks undoubtedly holds the key to their history. Elaborating upon this it may be urged that they were, originally, a sequence of foliated, ptymatically folded rocks that have undergone subsequent deformation. Such conditions exist in the roots of orogenic belts. The disappearance of portions of the original banding could be attributed to metasomatic replacement and recrystallization (Ramberg, 1952).

In a discussion on heat involved in regional metamorphism, Ramberg (1952, pp. 271 - 274) has pointed out that with "adepth of 25 km. and a 'normal' thermal gradient of some 20° C. per km." a temperature of 500° C. would be reached. Since, according to this writer, a temperature of 600° - 700° C. is required to produce granulites, it is necessary to look for other mechanisms by which the "regional rise in crustal temperature" could be augmented. He urges that such an increase could be brought about by; (1) "heat introduced by intruded hot magma.......", (2) ".......intense mechanical shearing.....", (3) "radioactive decay.........", (4) "exothermic chemical reactions.......", (5) "convection current......" action, and (6) "......net effect of complex processes of folded mountain formation........". All or several of these processes could be expected to take place in deeply buried portions of the sial - for example, in the roots of an orogenic belt.

It is interesting to note the similarity between the requirements for regional dynamothermal metamorphism in a granulite facies and the conditions observed in the field. The rocks by virtue of their mineralogic and textural properties are true granulites. The lineation of grains parallel to the relic banding and the presence of "crushed" (mylonitized) grain boundaries provide evidence for preferred directional deformation. The latter could have resulted from "intensive mechanical shearing". Partial obliteration of banding attests to metosomatic replacement, with preferred orientation of the recrystallize minerals. Further, a tendency for the relic banding to become more pronounced in the fringe areas, where stress conditions would be expected to "die out", is characteristic of the rocks in this area.

Close examination of the component layers of the banded "fringe" rocks (fringe zone of the granulite belt) shows a change in composition between the fractions. Bands, which have the composition of the "normal" hypersthene-granulite, are intertongued with garnet-diopside-feldspar layers. Together these are highly convoluted, and at times banding completely disappears.

The garnet-rich (see figs. 8 - 9) fractions are composed of 15 per cent garnet and 22 per cent diopside in a sutured quartzo-feldspathic grandmass. Optical examination of the garnet found it to be almandite (refractive index, 1.77 - 1.78). The feldspar is largely orthoclase; however, as much as 30 per cent sodic-rich plagioclase (An_{25} - An_{30}) can also occur. The garnet appears to be later than the pyroxene since many of the grains contain inclusions of the latter. Inclusions of magnetite are also found in scattered almandite grains and other larger magnetite grains are found individually in association with the clino-pyroxene.

It is noteworthy that Ramberg (1952; after Eskola, 1921 a; and Wright, 1938) has shown how such a mineral assemblage can exist, as a result of "regional metamorphism".

Fig. (8)

garnet

diopside

orthoclase

Photomicrograph of typical
garnet-diopside-feldspar rock.
Polarized light.
Field length 1.54 mm.

Fig. (9)

garnet

diopside

plagioclase

quartz

Photomicrograph of typical
garnet-diopside-feldspar rock.
Polarized light.
Field diameter 1.54 mm.

The alteration involves a transition of iron-rich biotite, muscovite and quartz to orthoclase and almandite at high temperature and/or high pressure. The reaction is written as follows:-

Low temperature | High temperature

$$KFe_3Si_3AlO_{10}(OH)_2 + KAl_3O_{10}(OH)_2 + 3SiO_2 \qquad 2H_2O + 2KAlSi_3O_8 + Fe_3Al_2Si_3O_{12}$$

Diopside is not provided by the above reaction; however, amphiboles such as tremolite can readily be shown to react with calcite or dolomite to produce diopside (Ramberg, p.63). Beyond, to the north (similarly on the south of the Range) there is an increase in the garnet and feldspar content with a sharp reduction in clino-pyroxene.

Only locally, therefore, is the diopside of any great compositional significance. Ramberg further points out that these products are characteristic to the low granulite facies. Their presence on the border of the granulite belt seems to corroborate the theory of a "dying-out" of metamorphism to the north and south of the Manicouagan range, put forth in an earlier section above.

In addition to the vestigial banding of the "fringe" zone there is a second type of layered complex associated with strong shears. Wherever these slippage surfaces have developed a limonitic graphite-bearing schist has formed. This schist is bounded, on both sides, by a thinnly banded felsir rock which is laterally transitional into normal hypersthene-granulite. Thin sections of these rocks have revealed a feldspar-quartz composition in the ratio of 60:40. The feldspar is largely soda-rich. Only a relatively small number of the grains show albite twinning. Sericitization is prevalent throughout this feldspar.

The quartz forms an intricate grid of semi-parallel branching "streamers". These "streamers" bulge about clots containing feldspar, garnet and minor quantities of pyroxene (see figs. 10 - 11).

The quartz bands are frequently so closely spaced that the rock is composed of many fine, almost parallel, alternating laminae of quartz and garnet-pyroxene-feldspar (see figs. 10 - 11). A small amount of magnetite and, occasionally, pyrrhotite is associated with the quartz. The opaques are generally clustered along the boundaries of the quartz "streamer". Under crossed nicols the quartz appears as bands which are in turn made up of a mosiac of fine grains.

The distribution of alternating quartz and

Fig. (10)

quartz

garnet

feldspar

Photomicrograph showing
"streamers" of quartz and feldspar
bulging about a garnet node.
Polarized light.
Field diameter 4.8 mm.

Fig. (11)

pyroxene

quartz

feldspar

Photomicrograph showing fine
quartz-feldspar laminae
surrounding an elongated hypersthene grain.
Polarized light.
Field diameter 4.8 mm.

mafic-bearing feldspar leminae gives the rock an intricate gneissic banding. A considerable quantity of quartz has been added to these rocks; the addition of which is undoubtedly related to the shearing.

A relatively short distance from the shear surface the rock displays normal textural and compositional characteristics. Specimen number 201 (see table 4), taken five feet from the felsic banded gneiss, is a normal hypersthene-granulite. With regard to relative age, it has been established that these shears are younger than the mafic joint stringers of the regular hypersthene-granulites. This is evident from the fact that the banded felsic gneisses are not cut by these joint stringers.

In the northern portions of the hypersthene granulite belt - Manicouagan plateau - the rocks show a marked degree of lineations and exhibit a diffuse foliation. These structural features are presumed to be due to an expression of metamorphic deformation superimposed on original bedding. The rocks showing this diffuse foliated structure contain a series of amphibolitic joint stringers which cut indiscriminately across the bands of differing composition. On the other hand gneissic rocks associated with shears are not cross-cut by the joint stringers. For this reason it is assumed that these rocks were developed in association with the shearing that, obviously, post-dated the formation of the joint stringers.

Amphibolite Facies:

In the vicinity of the largest island of Little Manicouagan lake the rocks show a remarkable change in character. The interbanded garnet-diopside-feldspar and hypersthene-granulite changes to a series of interbanded granitic (biotite-quartz-feldspar gneiss) and amphibolitic gneisses (biotite-hornblende-plagioclase gneiss). These rocks form a series which the writer has collectively designated as the "Amphibolite Facies".

The normal rocks of the "Granulite Facies" also appear within the fringe of the "Amphibolite Facies" area. The transitional zone contains garnet-amphibole-plagioclase gneiss which is the amphibolitic facies derivative of the garnet-pyroxene-plagioclase granulite, and hornblende-plagioclase gneiss the low-grade equivalent of the hypersthene-granulite.

The rocks of the "Amphibolite Facies" region form a series which is therefore strikingly different from those belonging to the "Granulite Facies" zone. They contain an abundance of hornblende and little or no pyroxene. Moreover, potash feldspars are present in considerable quantity and the plagioclase shows a considerable increase in sodium over calcium content.

Table (5)

Thin Section Numbers		300	303	305
		%	%	%
Essential minerals	Plagioclase	---	47.4	24.0
	Orthoclase	45.0	---	---
	Microcline	---	1.0	43.3
	Quartz	45.0	36.6	31.1
	Biotite	8.0	12.7	1.0
Accessory minerals	Apatite	Trace	0.3	---
	Zircon	Trace	---	---
	Opaques	---	---	Trace
	Anorthite content of plagioclase	---	8-15	10-15
	Average anorthite content of plagioclase		9 - 14	

Biotite-quartz-feldspar gneiss: Table (5) provides compositional data on three specimens taken from separate exposures of the biotite-quartz-feldspar (granitic) gneiss. This gneiss is fine- to medium-grained and only faintly banded. Pink and white colors predominate; however, grey colour is quite common in a variety which has an increased biotite content (e.g. #300 and #303, table (5)).

The granitic gneiss contains plagioclase, orthoclase or microline, quartz, and biotite in widely varying quantities. These form the "essential mineral" group. Apatite, zircon and opaques make up the accessory minerals.

Plagioclase varies widely in abundance, existing in a range of 20 to 50 per cent of the total mineral content. However, in one variety of the granitic gneiss plagioclase is completely lacking. The composition* of the plagioclase is $An_9 - An_{14}$; that is, on the border between albite and obligoclase. It is medium grained granular with a slight elongation parallel to the (001) face. The grains are aligned with their longest axis parallel to the gneissosity. The plagioclase forms a mosaic with intergranular quartz and orthoclase or microline. Considerable sericitization of both the sodic plagioclase and the potash feldspars is evident.

Orthoclase is present in some quantity in a few of the rock exposures. Its low relief, relative to canada balsam (refractive index 1.54), and its typical negative biaxial figure make it readily identifiable. Some of the crystals are twinned according to the Carlsbad Law (Hurlbut, C.S. Jr., 1950). This mineral exists in quantities up to

* Plagioclase compositions have been estimated by the use of extinction angle, 2V, birefringence, and refractive index curves given by Wahlstrom (1955) on pp.32, 118,and 121.

fifthy per cent of the rock composition.

Microcline is present in a few varieties of the granitic gneiss. In these cases it appears to be present in preference to the monoclinic potash feldspar, orthoclase. Typical "grid" twinning (Wahlstrom, 1955, p.107) is evident in most of the grains. The negative refractive index (below 1.54), high 2V angle, and biaxial negative figure are characteristic of this mineral. In some specimens the microcline is rare and occurs as scattered grains between those of plagioclase and quartz; in others it makes up to 50 per cent of the felsic groundmass.

Normal unstrained quartz is abundant in all specimens and is generally interspersed with the plagioclase and potash feldspars. This mineral occurs in quantities up to 50 per cent and rarely below 30 per cent of the total.

Biotite generally appears as a minor essential mineral; however, it can make up 15 per cent of the total. This is the only mafic mineral present in the granitic gneiss. It is generally medium grained and subhedral to euhedral in crystal outline. Grains lying on faces parallel to the basal cleavage show elongation in one direction. There is a general tendency for these elongated grains to be aligned parallel to the gneissic banding. This gneissic banding is expressed by the tendency of biotite to cluster along preferred bands. In one thin section the biotite, in addition to being restricted to specific horizons, has a well-defined fascicular texture.

Sphere, apatite, muscovite, and magnetite form a group of intermittently occurring accessory minerals. These minerals are, for the most part, randomly scattered throughout the rocks.

The apatite is generally in randomly distributed rounded grains. The usual "primary" "rod-and-needle" apatite is not present in this rock-type. Sphere occurs only as a few scattered subhedral brownish grains.

The granitic gneiss forms bands varying from one to ten feet in width. These bands alternate with horizons of amphibolitic gneiss (biotite-hornblende-plagioclase gneiss).

Folding in this banded series has caused the less competant amphibolitic gneiss layers to pinch and swell between the more cohesive granitic gneiss bands. In a few cases the amphibolite gneiss tends to thicken into nodes at the crests of drag folds. The asymmetrical shape produced is undoubtedly due to the action of stresses greater than those normally involved in producing drag folds as they are defined by Billings (1955). In similar rocks in other parts of the map-area the minor folds are "normal" symmetrical drag folds.

Biotite-hornblende-feldspar gneiss:

The amphibolitic gneiss is a fine- to medium-grained biotite-hornblende-feldspar gneiss. It is black to green in color and has a schistose to gneissose structure. This structure is the expression of the parallel alignment of numerous platy and elongated grains. Gneissic banding is effected by interlayering of mafic- and felsic-rich components.

Table (6)

Thin Section Number	291	294	296	307	308	311
Minerals	%	%	%	%	%	%
Plagioclase	22.2	51.3	40.0	72.7	-	80.0
Orthoclase	-	-	-	-	-	-
Microline	-	-	-	-	-	-
Quartz	21.0	15.0	-	0.5	-	-
Augite	-	-	-	-	-	-
Hornblende	47.0	20.0	41.6	21.0	18.3	14.0
Anthophyllite	-	-	-	-	40.0	-
Biotite	2.9	13.3	6.6	Trace	38.3	-
Chlorite	-	-	-	-	-	-
Apatite	Trace	Trace	-	0.4	-	1.1
Epidote	-	-	-	-	-	-
Carbonates	1.0	-	-	-	-	2.7
Opaques	0.7	Trace	6.6	3.3	3.3	-
Sphere	-	-	-	-	-	1.0
An content of plagioclase	25-30	20-25	23	28-30	-	28-29
Average An content of plagioclase		An 25 - An 29				

Table (6) contains the results of microscopic analysis of six representative specimens taken from the amphibolitic rocks.

The essential minerals of this gneiss are plagioclase, hornblende, and biotite. In some cases quartz becomes an essential component. One representative specimen contains no plagioclase but has anthophyllite interspersed with biotite and hornblende. The subhedral anthophyllite represents 40 per cent of the total mineral content of the rock. Since, however, this specimen has been taken from a band only one foot in width it has been interpreted to represent an aluminum-rich horizon. Potash feldspars are rare and have not been identified in any of the thin sections examined.

A host of accessory minerals are present in the amphibolitic gneiss. Among these are apatite carbonates, sphene, and opaques. The opaques in this case are largely sulfides such as pyrrhotite and chalcopyrite, the latter of which occurs in subordinate quantities.

The percentage of plagioclase occurring in the amphibolitic gneiss is very variable. Values have been estimated all the way from 22 to 80 per cent. Since the samples appearing in table (6) are representative of the rock species, then the average plagioclase content is in the order of 53 per cent.

The plagioclase of this rock-type is somewhat more calcic than the corresponding feldspar of the biotite-quartz-plagioclase (granitic) gneiss. The average composition is in the range of An_{25} to An_{29}.

This mineral is generally fine- to medium-grained, and where it is abundant it forms the groundmass of the felsic-rich bands. There is very little saussuritization of this feldspar and the polysynthetic twinning is clear and well developed.

<u>Hornblende</u> and anthophyllite are the only two amphiboles found in the amphibolitic gneiss. The average content of hornblende is in the order of 27 per cent. This mineral is generally euhedral to subhedral and elongated in the direction of the c-axis. Good prismatic cleavage parallel to the third order prism is evident in most grains lying with the c-axis in the plane of the microscope stage. The color is persistantly green with only minor variations in shades of green.

The optical properties of the hornblende are as follows:-

> biaxial positive and negative; 2V 45^{o}; relief moderately high; extinction angle Z C = 0 - 15^{o}; pleochroic in green and yellow.

Another amphibole, an orthorhombic variety, anthophyllite, has been outlined in a single horizon and identified in thin section. The distinguishing optical properties are:-

> parallel extinction; 2V greater than 60^{o}; biaxial positive and negative; colorless to white in plain light.

The narrow prismatic habit of the grains is also characteristic of this mineral.

Quartz has an erratic quantitative distribution in the amphibolitic gneiss. Some specimens have up to 21 per cent while others have no observable amount of this mineral. When present it is seen as fine grains disseminated among the plagioclase grains or as individual bands in the felsic bands. In general the mineral shows little straining.

The accessory minerals occur in variable amounts from mere traces up to greater than 6 per cent. Of these the opaques occur in greatest quantity. Pyrrhotite, with subordinate quantities of chalcopyrite, has been estimated in quantities up to 3.3 per cent. Elsewhere disseminated magnetite makes 6 per cent of the total mineral content. However, only selected zones contain sulphides in such high proportions and, it may be suggested, that the sulphide-rich specimen seen in table (6) is not truly representative for the sulphide minerals. The opaque-rich amphibolites are found in close association with isolated patches of anorthositic-gabbro.

The carbonates are largely calcite. Although these have been found as disseminated grains in the amphibolitic gneiss a few calcite veinlets are present in outcrops nearing the anorthositic intrusives.

Apatite forms a trace mineral. When present it appears as anhedral grains (snow-like) associated with the amphibole-rich laminae.

Klugman (1956, pp. 27 - 34) has pointed out the difficulties involved in distinguishing amphibolites associated with meta-sediments, "para-amphibolites"; and those associated with intrusives, "ortho-amphibolites". From microscopic evidence he concludes that one of the most reliable methods of identifying the genesis of amphibolites is a consideration of the "relationships between hornblende, sphene, and magnetite". He proposes that in "orthogneisses" the magnetite, sphene, and hornblende tend to be intimately related; whereas, in "para-amphibolites" the sphene and magnetite are generally scattered throughout the rock. In the latter case he goes on to say; "They show little relationship to one (sphene and magnetite*) another, and are seldom in contact with the hornblende or related to the hornblende.".

Unfortunately, insufficient data have been compiled from the present map-area to make great use of this theory.

Hogan (1953) suggested a number of properties which he believes are characteristic to each of the two major types of amphibolites. Under "ortho-amphibolites" he has listed the following features:-

"1. Gneissic structure
2. Relict igneous textures
3. Grade into gabbro
4. Resist migmatization
5. Occasionally criss-crossed by hornblende veinlets
6. Contain inclusions of paragneiss
7. May pinch and swell along strike
8. pyroxene (especially hypersthene and augite) as relict minerals"

He continues; "The characteristic features of the para-amphibolites are:-

1. Strongly foliated
2. May contain alternate paragneiss layers
3. Easily migmatized
4. Uniform width along strike
5. Quartz as an accessory mineral."

* Author's note.

An attempt to apply these "rules" to the rocks of the present area has given questionable results. It is found, however, that if certain generalizations are made, and if at the same time, the relationships of the rocks are kept in mind, some valid conclusions can be drawn.

The specimens shown in table (6) represent a cross section of the structure from the border of the highly metamorphosed granulite facies to the vicinity of the anorthositic intrusives. Specimen number 311 is taken from an outcrop which shows a gradation of amphibolite into anorthositic-gabbro whereas, specimen number 291 comes from an amphibolite close to the region of granulitic rocks.

It is evident from the table that, although quartz is present in the specimens from rocks most remote to the intrusive rock, it is almost entirely absent from the closer outcrops, and is entirely absent in specimen number 311. The implication here is that the more remote (from the intrusive rock) amphibolites are "para-amphibolites" whereas the closer varieties are genetically related to the anorthositic intrusive.

Further to this, there is a tendency for a better developed foliation and an appearance of interbedded felsic gneiss in the more remote sectors; and, in addition, "uniform width along strike" is more evident here.

From these observations there is a favourable suggestion that the amphibolitic gneiss somewhat removed from the intrusives are "para-amphibolites".

It is obvious from the foregoing discussions that evidence for a sedimentary origin of the rocks in the "Amphibolite Facies" zone is mounting; however, there is still considerable doubt as to the genesis of amphibolites found in contact with the anorthositic intrusives.

Roselea Lake Group:

In the vicinity of Roselea lake a series of foliated rocks with a general east-west trend lies parallel to the long axis of the lake itself. This series is in contact with the anorthositic intrusive which bounds the series to the north.

Bradley (1957) has referred to the series as "a variety of metamorphosed sedimentary and volcanic rocks". He refers to the lithologic units encountered as "coarse quartz-feldspar gneiss......interlayered with diabase either as sills or flows". He also outlines an "augen granite gneiss" and suggests that the "augen strongly resemble pebbles". At the western end of the lake he has identified "cross-bedded quartzites" which are apparently interlayered with the augen gneiss.

According to Bradley the Roselea Lake series grades into a "garnetiferous granite gneiss series" to the south. He has estimated a thickness of 3500 feet for the "Roselea Lake series" and a minimum thickness of 5000 feet for the "gametiferous granite gneiss".

Augen Gneiss: Work carried out by the writer tends to corroborate the ideas put forth by Bradley. Thin section studies of the augen gneiss have shown the rock to be composed of a mass of fine-grained quartz surrounding

Fig. (12)

Roselea Lake

Photo taken from an aerial photograph of the structure evident south of Roselea lake.

Fig. (13)

Roselea Lake

Similar photograph to Fig. 12 but taken slightly to the east of the latter.

"eyes" of microcline feldspar (see fig. 14). The rounded nature of the feldspar "augens" would suggest a pebble origin. Small quantities of granular microline are scattered throughout the groundmass. The character of the "eyes" and the composition of the groundmass tends to lend considerable support to the idea that the augen gneiss was, before metamorphism an arkosic conglomerate.

Diabase or Basalt: Evidence for the presence of "diabase sills or flows" is found in a fine-grained concordant mafic rock. The composition of this rock has been found to be as follows:-

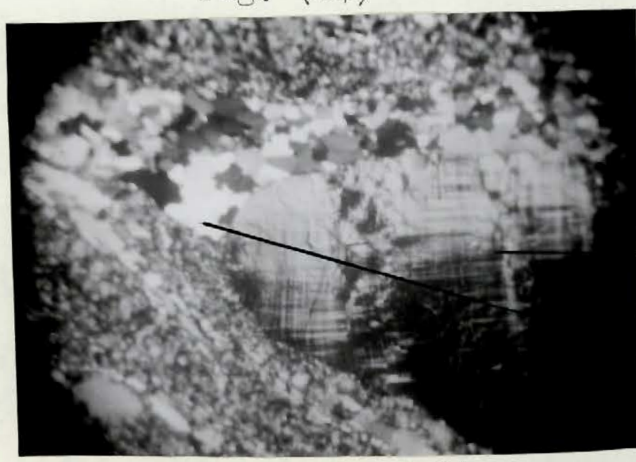
Hornblende	-	41 per cent
Pigeonite	-	19 per cent
Plagioclase (An_{25}- An_{28})	-	31 per cent
Opaques (magnetite)	-	9 per cent
Apatite	-	Trace

Pigeonite has been identified by the following optical properties:-

biaxial positive; 2V 35^{o};
birefringence - 0.022; high dispersion
r   v.

From the composition graph of Hess (1949) it is evident that this variety of pigeonite is a magnesium rich member; that is between Fe_{20} and Fe_{25}.

Fig. (14)



Photomicrograph of fine-grained
quartz-potash-feldspar matrix
about microcline "eye".
Polarized light.
Field diameter 4.8 mm.

The presence of this mineral in a mafic-rich rock is suggestive of an igneous origin. According to Bowen (1930) orthorhombic pyroxenes of the (Mg, Fe) SiO_3 series invert to pigeonites (clinopyroxenes) at temperatures which range from 955°C - 1140°C. From this determination it is obvious that the rock has, at one point, been subjected to temperatures sufficiently high to bring about complete melting (Bowen, 1930). Thus it can justifiably be classed as a "diabase".

The texture of the rock is somewhat porphyritic. Nodes containing pigeonite, brown hornblende (after pigeonite), and magnetite are evenly distributed in a fine-grained plagioclase-rich groundmass. The texture of the rock is characteristic of porphyritic basalt and not a diabase as was suggested by Bradley.

In general the rocks become increasingly more thin-banded towards the contact with the anorthosite. An outcrop within ten feet of this contact is composed of extremely thin-banded, foliated, hornfelsized rock. The bands of this "baked" complex are composed of alternating mafic-rich and mafic-poor laminae.

The limits of the thin-banded gneisses are within several hundred feet south of Roselea lake. There is a southward transition into hypersthene-granulite.

Table (7)

			Plagioclase										
No.	Qtz.	Orth.	Alb.	Olig.	And.	Hyp.	Hbld.	Gar.	Ap.	Biot.	Op.	Carb.	Scap.
407	65.0	-	-	14.0	-	3.0	-	16.0	-	-	2.0	-	-
410	19.0	2.0	-	-	58.0	3.0	-	8.5	-	-	2.5	6.0	-
418	53.0	38.0	-	-	-	8.0	-	-	-	-	1.0	-	-
420	-	-	-	-	56.0	41.0	Tr.	-	Tr.	-	1.0	-	2.5
421	33.5	56.0	-	-	-	-	-	-	0.3	9.0	0.5	-	-
427	25.0	30.0	33.0	-	-	4.0	-	6.0	0.5	-	2.0	-	-
439	33.0	3.0	-	53.0	-	7.0	1.0	-	Tr.	-	Tr.	-	-
446	40.0	-	-	-	50.0	-	Tr.	5.0	-	-	1.0	-	-
450	1.5	-	-	-	38.3	55.5	-	Tr.	4.6	-	Tr.	-	-

Table (6) contains compositions for a group of specimens taken on a general north-south line from the lake to a point approximately 2½ miles to the south. The table is arranged with specimen numbers increasing from south to north.

It is noteworthy that, with the exception of an increase in quartz, potash feldspar, and garnet, the rock compositions generally resemble those of the hypersthene-granulite which outcrop on Little Manicouagan lake - see Table (4). Hypersthene and plagioclase (An_{32} - An_{37}) are the most abundant minerals - if the other three be excepted. The presence of these three minerals is not held as a significant lithologic compositional change since they are obviously "foreign" to the rocks in which they have been discovered. These three minerals are related to intrusion and metamorphism associated with late deformation.

The general cataclastic nature of the hypersthene-granulites (see figs. 15 and 16) accompanied by the transecting character of the quartz-potash feldspar material provides proof of deformation accompanied by intrusion. The presence of garnet is not entirely understood; however, this mineral has been shown to exist in the "fringe" zone of the granulites on Little Manicouagan lake and may therefore be primary; that is, pre-intrusive.

It is felt that the thin-banded gneisses of the Roselea Lake series are genetically related to the amphibolite-granite gneisses on Little Manicouagan lake. However, in the Roselea Lake area these rocks appear to have undergone considerable alteration as a result of heat and stress produced by the emplacement of the anorthositic massif. It must be pointed out that correlation of this type is not based on compositional similarity as much as on structural continuity and general lithologic similarity.

Fig. (15)

quartz-feldspar

"intrusive"

Photomicrograph showing
fine-grained quartz-feldspar
mass cutting mylonitized
hypersthene-granulite.
Length of field 4.8 mm.
Polarized light.

Fig. (16)

quartz-feldspar

"intrusive"

Photomicrograph showing a
mass of fine-grained
quartz-feldspar intrusive
material around mylonitized
hypersthene-granulite.
Field diameter 4.8 mm.
Polarized light.

Rocks South of the Manicouagan Range:

On the southern side of the Manicouagan range there is a marked similarity in the distribution of rock-types to that of the northern region. In this sector of the map-area the hypersthene-granulites give was to a series of interbedded hypersthene-plagioclase and garnet-diopside-plagioclase granulites. These in turn are replaced to the south by biotite-quartz-feldspar (microcline and plagioclase) and biotite-hornblende-feldspar gneisses.

The latter group represents the southern equivalent of the "Amphibolitic Facies" group outlined on Little Manicouagan lake. The granitic gneisses predominate to the south and continue into a broad belt of Grenville-type gneisses.

It is interesting to compare compositions of the granitic gneisses from the southern outcrops with those which outcrop on the Little Manicouagan lake.

Table (8)

Specimen Number		254	305
		%	%
Plagioclase		----	24.0
Microcline		56.5	43.3
Quartz		36.5	31.1
Biotite		6.8	1.0
Muscovite		----	Trace
Opaques		Trace	Trace
Zircon		0.1	----
	Total	99.9	99.4
An content of plagioclase		----	$An_8 - An_{12}$

Table (7) provides a sample comparison. Specimen number 305 is a representative taken from the lake area, whereas number 254 is from outcrops south of the range.

There is a lack of plagioclase and a slight increase in microcline in the southern granite gneiss specimen as compared to the one from north of the plateau. Figure (17) shows the mineralogical relationship of the sample specimen-number 254.

Accordingly, there seems to be a repetition on the southern granulite "fringe" of the series observed north of the plateau. It appears therefore that the degree of

Fig. (17)

Photomicrograph of
biotite -feldspar-gneiss.
Polarized light.
Field diameter 1.54 mm.

Fig. (18)

Photomicrograph of a
diabase dike specimen showing
typical diabase texture.
Ordinary light.
Field diameter 1.54.

Fig. (19)

Photomicrograph of a
diabase dike showing
typical diabase texture.
Polarized light.
Field diameter 4.8 mm.

metamorphism "dies-out" to the south in a similar manner to that described on the north side.

Structural Geology

The metamorphic rocks of the Little Manicouagan Lake map-area show a broad general northeast-southwest structural trend. Tyler (1954) and Bradley (1957) mapping outcrops along the northern portions of Manicouagan lake have described a series of isoclinally folded amphibolitic gneiss which strikes N. 65° E. to N. 115° E. with fold planes "pitching down dip". Dips of the beds are largely north to northeast at angles averaging 45°. This trend seems to have continued east to the present area, with a slight swing to the northeast.

Within the section of the Manicouagan Plateau covered by the map-area dynamothermic metamorphism has largely obliterated the original structure and only a general trend can be resolved. This trend is in a north-east-southwest direction with relic crenulated folià trending N. 10° E. to N. 80° E. A very persistant lineation is evident, dipping 50° - 70° to the southeast.

In the foliated gneisses ("Amphibolite Facies") north of the range there is a variation in strike. On the eastern shore of Little Manicouagan lake the strikes are from N. 20° E. to N. 45° E., with dips in the order of 30° - 50° to the southeast. The rocks of the western shore have an average strike of N. 65° E., and a mean dip of 50° S.

The foliated series of the Roselea Lake area has an east-west strike and varries in dip from 50° S. to vertical in the vicinity of the centre and eastern ends of the lake. To the southwest the thin-banded gneisses show a tendency to swing southeastward and then southward, and display dips of 80° S.W. and 60° E. respectively.

Faulting: The extent of faulting in the map-area is not entirely known since movement appears to have taken place along a multitude of shear surfaces which are intimately associated with the recrystallization of the rocks. Recrystallization and metasomatism along the failure surfaces have produced thin-banded felisitic gneisses whose banded structure parallels the planes of movement. The presence of this banding has generally facilitated the mapping of these structural features. The general trend is N. 55° E. with dips of 55° to 70° to the southeast. The dip angles have been found to coincide with the dip of the foliation in the adjacent hypersthene-granulites.

The presence of schist (graphitic) and mylonite along a number of the shear surfaces indicates recent movement parallel to the original surfaces along which metasomatism took place.

Folding: Some folding is evident in the foliated rocks of the "Amphibolite Facies" group. On Little Manicouagan lake a number of minor folds appear within single outcrops. The adjustment appears to have taken place by the failure of the amphibolitic gneiss bands between more competant granite gneiss layers. Some of these folds are symmetrical drag folds others are overturned and thrusted drag folds. All of these minor crenulations appear to be drag folds on the limbs of a major fold, the "nose" of which points south on Little Manicouagan lake.

Whether the latter is anticlinal or synclinal is not precisely known. The dip of the bedding indicates a southerly plunging anticlinal structure whereas the position of the axial plains of the drag folds indicates that the lake lies in the nose of a syncline. More structural evidence is required in order that this question may be solved.

In the Roselea Lake area structural trends indicate a major fold. The thin-banded gneisses, which strike east-west in the vicinity of the central and eastern part of the lake, show a sharp swing to the south-east near the southwestern end of the lake. These in turn change strike first to a south and then to a southwest direction two miles south of the lake. An inversion of the dip from 80° S.W. to 60° E. indicates an overturn in the folded structure..

Jointing: An early joint system is evident in the major lithologic-unit (i.e. granulites of the plateau-area) by the presence of "criss-crossing" amphibolite-bearing joint stringers.

In addition to this system a series of open joint planes lie parallel to the regional structure exhibited in the highland area south of Little Manicouagan lake.

The open joints which parallel the regional structure are transected by a set of major joints which cross the northeast-southwest striking Manicouagan plateau in a north-south direction (average strike - N. 10°- 20° W.). It is along the joint planes of the latter set that the major stream valley, and canyons* have developed.

In the foliated and banded rocks jointing is confined to surfaces parallel to the laminae.

* Canyons - The canyons are believed to have developed partly by stream erosion, and partly by glacial action (see "Glacial Geology").

Glacial Geology

Evidence:

As in many parts of the Canadian Shield, glaciation has played a major role in the surface sculpture of the Little Manicouagan Lake area. It is somewhat difficult to evaluate the total effect of glaciation in this region since post-glacial surface weathering and erosion have eradicated much of the evidence; howev er, a number of scatterred features of obvious glacial origin have been identified.

Among the more pronounced glacial features, erratics, eskers, and a drumlinized surface have been noted. The erratics are found scattered throughout the region bothe in the loowland areas and on top of the high plateaus. Bradley (1957) has pointed out that blocks of iron-bearing quartzite and gneiss, that are characteristic of the lithology north of Little Manicouagan lake, have been identified as far south as Roselea lake. Erratics of similar rock-types have been identified by the writer as far south as the Manicouagan pass, and in one case, several boulders of iron-bearing quartz-rock have been discovered as far south as mile 122, more than sisty miles from their place of origin. In the

Roselea Lake region a number of boulders of carbonate rock have also been identified. This rock type, along with the iron-bearing quartzite and gneisses, has been described as part of the "Cartier Series" by H. Lepp (1955) and Bradley (1957) in their respective reports to the Quebec Cartier Mining Co.

The second type of glacial evidence, the eskers, have been identified by their sinuous nature and the high degree of sorting which they show internally. Four such ridges have been observed near Little Manicouagan lake; one on the west side near the northern foot of the Tyler hills, a second on the west shore of the eastern arm of the lake, and the other two east of the lake.

The third type of ice sculpture which has been recognized in the region, the drumlinized surface, is located in the north-eastern quadrant of the map area. This reworked morainic material has a peculiar corrugated surface made up of sub-elliptical hummocks which have a lineation parallel to the direction of ice movement - azimuth of 150°.

Only one other type of pro-glacial evidence has been observed - the roche moutonnees of the mountainous areas. Surface weathering accounts for the lack of such glacier erosion features as striae, glacial polish and chattermarks, none of which have been observed in areas examined. It is noteworthy that Bradley (1957), has made reference to several "glacial striations" on outcrops in the Roselea Lake region.

It may be concluded that the only clear evidence of ice erosion remains in the form of eskers, a drumlinized till plain, and the roche moutonnees. According to Thornbury (1956, pg.384), land forms such as these can be attributed to erosion by glaciers of the "continental ice cap" type. Therefore, as is generally recognized, this region of the Province of Quebec has, at least once during its history, lain beneath an extensive ice sheet.

History:

That the Little Manicouagan Lake area has been markedly affected by ice movement has been established by the evidence put forth in the foregoing section. This is not unique, for it has been generally recognized that the north-central section of the Province of Quebec was the region of snow accumulation or the "feeder" for the Pleistocene continental ice-cap. That is to say, from this focal "point", the ice moved forward to the south, the southwest, and southeast, carrying with it, by traction and suspension, vast quantities of debris provided the tools to rasp and scour the surface over which it rode.

Other authors have referred to glaciation in the portion of the Province bordering Labradoe. R.D. Westervelt (1956), writing about the "Trough" near Schefferville, Quebec, contends that his area is near the centre of ice movement - as he wrote: was relatively close to the central region of the ice sheets." However, he has recorded movements, and finding that they have taken place in several directions he suggests, "that the ice movement was chiefly controlled by topography." It is assumed by the writer that this is meant to be the reason for suggesting the geographic proximity of the "glacial centre". Assuming this conclusion to be correct, it is obvious that the focal point of ice movement lay considerably to the north of the Little Manicouagan Lake map-area. As a final corroboration of the ice movement in the latter region J.E. Gill (Gill,1937), working in neighbouring areas to the northeast (1933), had this to say:-

> "All of the country as far north as Ashuanipi and Wabush Katsao Lakes have been glaciated. The mountain summits have been rasped by the prolonged passage of slowly moving debris-burdened ice. The valleys are clogged with drift. The flatter ground in the interior is generally covered by ground moraines, with here and there groups of kame-like hills."

It is doubtful that the various pulsations of the Pleistocene continental ice sheet which have been identified in regions of the northern United States and southern Canada have been effective in areas geographically close to the "ice-centre". In fact, it seems reasonable to assume that at best the local effect would be a mere thinning of the ice and a possible northerly shift of the centre-of-accumulation. Accepting this argument then, it seems reasonable to assume that the whole region, of which the Little Manicouagan Lake area is an integral part, remained under a heavy ice cap until final recession of the Pleistocene glacier. If this were so, local ice movement would have been continuous during the entire period of ice occupation.

Prolonged continual movement could account for the complete removal of any pre-glacial mantle, and the associated abrasive action would be responsible for the reduction of high mountains to mere rounded hummocks on a more or less flattened plateau. However, no matter how extensive the abrasive action may have been it apparently did not reach proportions great enough to completely eradicate all the pre-glacial physiographic features. Evidence for this lies in the existance of deeply entrenched structurally controlled stream valleys, many of which lie in directions traverse to the direction of ice movement.

It may be urged that the structures which controlled pre-glacial drainage patterns (joints, faults, shears, bedding planes, etc.) would still be present after the glacier receded, and would therefore be capable of influencing the formation of a post-glacial drainage system similar to the system before ice occupation. However, the existence of glacial drift, along the walls of major valleys, and the presence of vast till plains, such as the one northeast of Little Manicouagan lake, provides conclusive evidence that the sum total of post-glacial erosion has been small. Obviously, erosion of such a minor degree could not have developed so "mature" a drainage system.

There is little doubt that canyons such as the Manicouagan pass were pre-glacial features. It may therefore be supposed that such a gorge would contain a valley glacier when continental glaciation had receded to the higher latitudes, and higher altitudes, during the "dying" stages of the last ice sheet. If this were so, considerable deepening by gouging, and widening by plucking action, would account for the present proportions of the "wing gap". As a possible source of evidence for the presence of a valley glacier the vast deposits of gravel at the southern end of the pass - in the vicinity of Blouin lake - could be examined for composition and type of deposition. It is not presently known whether these gravels are glacio-fluviatile or strictly fluvial deposits, though they are presumed to be one or the other. Other types of evidence, such as striae and polish on the canyon walls and lateral moraine remnants, could be searched for. Time restrictions on the survey did not permit examination for evidence of these kinds. The most reliable evidence is found in a number of cirque-like structures along the tops of the high canyon walls. These are not true cirques; they are merely small "perched" lakes with rapid outlets that cascade to the floor of the canyon. The very nature of the canyon and its relationship to these high pond-lakes suggests that the gorge was once occupied by a valley glacier which provided rapid local degradation.

SUMMARY AND CONCLUSIONS

The Little Manicouagan Lake map-area lies on the north shore of the River St. Lawrence, one hundred and fifty miles northwest of Shelter Bay, Quebec.

All of the consolidated rocks in the area are of Precambrian age. The lowland areas and depressions in the highland areas are overlain by a mantle of unconsolidated Pleistocene and Post - Pleistocene deposits.

Metamorphic rocks predominate; however, anorthositic intrusives cover almost one third of the map-area, and are mostly restricted to the northwestern sector.

High grade metamorphism developed under dynamothermal conditions is evident in the major metamorphic rock-type-hypersthene-plagioclase and garnet-diopside-feldspar granulite complex. This complex shows a gradational transformation into a series of inter-associated hornblende-biotite-plagioclase and biotite-microline-plagioclase gneisses. The latter group have been correlated with similar rocks of the Grenville province described by earlier workers in other areas of the Quebec North Shore. These gneisses belong to a grade of metamorphism coincident with the epidote-amphibolite facies described by Eskola.

Dynamothermal metamorphism has brought about partial replacement and recrystallization through the action of metasomatism and, to some degree, melting. These recrystallized rocks form the complex which has been designated as the "Granulite Facies". Except for the presence of relic structures and a strong lineation these granulites resemble an intrusive igneous mass.

Following recrystallization the granulites developed a multiple joint system along which siliceous solutions moved. These solutions brought about alteration of the adjacent pyroxenes to amphiboles and eventually the joints became filled with amphibolite stringers.

Subsequent deformation accompanied by the addition of potash-aluminum-rich siliceous solutions developed laminated quartz-feldspar rocks parallel to the shear surfaces. These laminations resulted from the intrusion.of the siliceous ion-bearing solutions along parallel surfaces.

The deformations involved in the granulite rocks did not occur in the adjacent "Amphibolitic Facie" rocks. The forces involved in the deformation appear to have "died out" within the confines of the granulite zone.

The belt of granulites appear to represent recrystallized and deformed Grenville-type gneisses. Since, this lithologic complex lies immediately south of a lithologic province previously described as highly metamorphosed "Trough" rocks - therefore, Proterozoic in age - and north of a broad belt of "normal" Grenville-type granitic and augen gneisses, it is considered to be coincident with the "Grenville front". The "front" in this area is manifested by a broad belt of dynamothermally metamorphosed rocks that have a general northeast-southwest trend and a steep southward dip.

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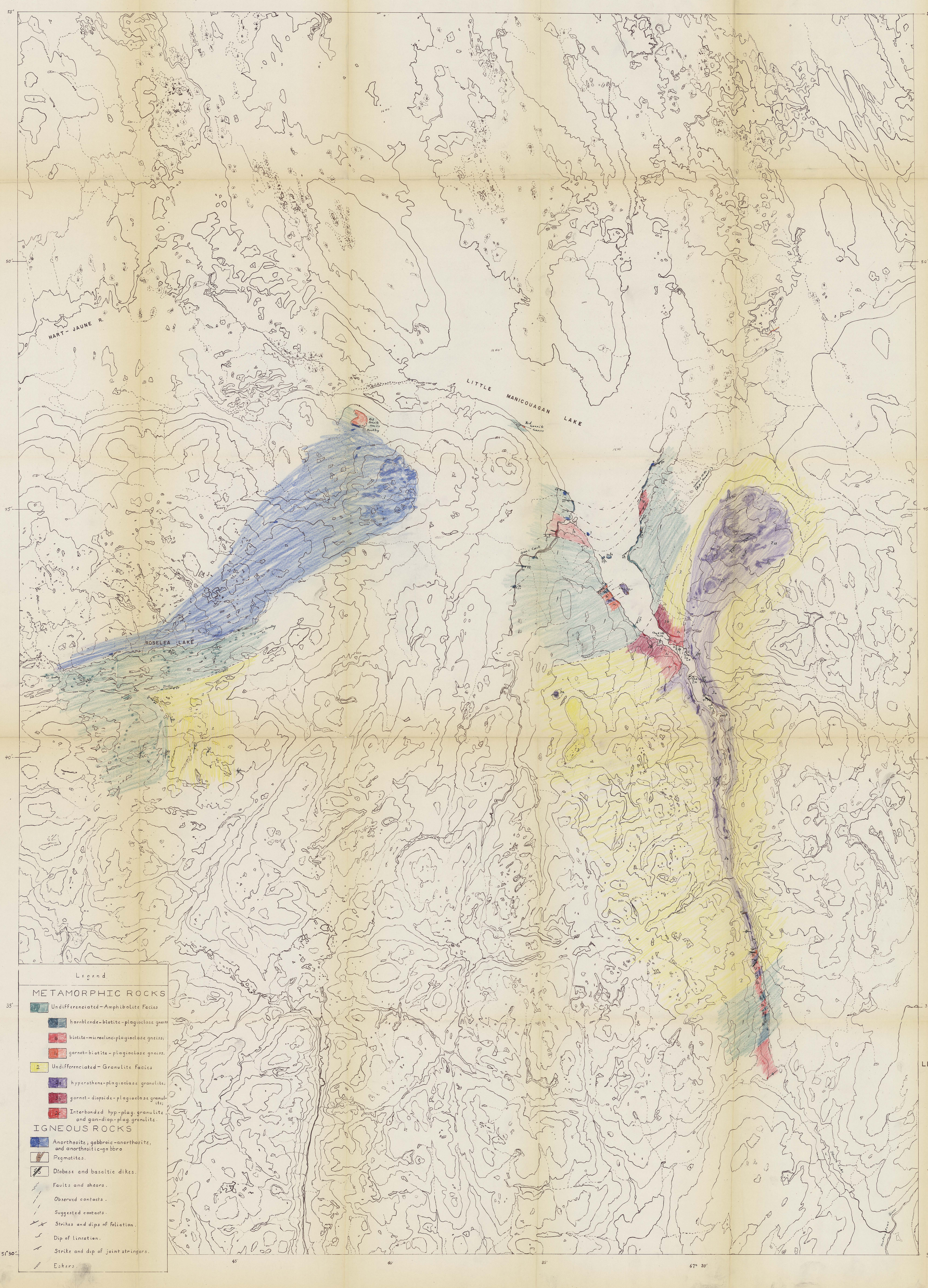
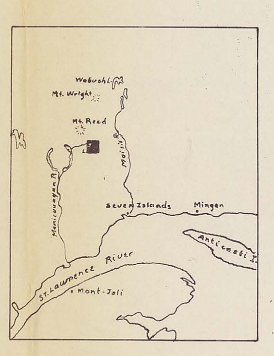
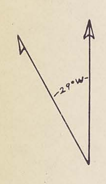




GEOLOGICAL MAP

LITTLE MANICOUAGAN LAKE AREA

SCALE 1" = 40,000



Magnetic declination

By: E. D. BLACK