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HART-JAUNE RIVER AREA, SAGUENAY COUNTY

QUEBEC DEPARTMENT OF NATURAL RESOURCES

Honorable Paul-E. Allard, Minister

MINES BRANCH

Geological Report 132

HART-JAUNE RIVER AREA

Saguenay County

by
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GEOLOGICAL EXPLORATION SERVICE

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HART-JAUNE RIVER AREA

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L. Kish

INTRODUCTION

The Hart-Jaune River area covers the course of this river from its mouth at Manicouagan lake northeast to its headwaters in Petit Manicouagan lake. It corresponds to the Rivière Hart-Jaune (22 N/9), Lac Raudot West (22 O/12), and (roughly) the Little Manicouagan Lake West (22 O/13) sheets of the National Topographic series.

The geological survey of this area was carried out in the summers of 1961, 1962, and 1963. The results of each season's work have been summarized in Preliminary Reports (Kish,1962; 1963; 1965). Magnetite layers in the Raudot Lake massif and sulfide mineralization in the eastern part of the area were given particular attention.

Location

The area is in Saguenay county about 170 miles north of Baie-Comeau on the north shore of the St. Lawrence. It lies between longitudes 67°45' and 68°30', and between latitudes 51°30' and 51°45' except in the east where it extends north to latitude 51°53'. It covers about 650 square miles, and includes Brien, Jauffret, and parts of Quertier, Berthelet, Godefroy, Conan, Hesry, Fagundez, and Belle-Roche townships, and some unsurveyed ground.

Access

In the western part of the area, Manicouagan lake and a few smaller lakes are suitable for plane landings. Manicouagan lake is connected by a canoe route leading southward along Manicouagan river to Dam-5, from where a motor road runs south to Baie-Comeau.

In the central and eastern parts, four small lakes can accommodate float-planes, and most parts of the upland can be reached either by helicopter or on foot.

The northern part of the eastern third is readily accessible from Petit Manicouagan lake and from a motor road that connects Jeannine lake with a hydro-electric power plant on Hart-Jaune river near the western limit of Fagundez township. The railway that carries the iron ore from Gagnon to Port-Cartier also traverses this northern part.

Field Work

The base maps for the western two thirds of the area were compiled from aerial photographs taken for Hydro-Quebec. For the eastern third, topographic maps of the Department of Mines and Technical Surveys, Ottawa, were enlarged to a scale of 2 inches equals 1 mile.

In the wooded area north of Hart-Jaune river pace-and-compass traverses at half-mile intervals were made. In the Manicouagan upland south of the river a good coverage was possible by spot-identification from the aerial photographs.

Acknowledgements

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In 1961, J.N. Schindler, J. Depatie and N.A. Butt; in 1962, H.B. Redman, J. Guindon and M. Fecteau; and, in 1963, J.P. Mills, F. Dallaserra and P.W. Ranson assisted in the field work. The help of these students is gratefully acknowledged.

Previous Work

A general study of the Manicouagan-Mouchalagane region was made by Hammond (1945), who reported highly metamorphosed sedimentary gneisses and granitic intrusive rocks. Rose (1955) investigated the circular feature formed by Manicouagan and Mouchalagane lakes and reported

"Grenville type" rocks along the shores of the Manicouagan valley. Bérard (1962) also studied the circular belt and adjacent areas.

Description of the Area

Flora and Fauna

The western third of the area and the northern parts of the central and eastern thirds are forested. Here black spruce is common, and birch grows in patches. In the sand flats and on low sand-gravel hills the spruce is short and is mixed with tamarack. Alders occur along small streams.

In the southern parts of the central and eastern thirds the climate, flora, and fauna differ from the surrounding areas, and the sparse vegetation is transitional from subarctic to arctic type. Some valleys are wooded, but the hills are covered by grasses and low, thick spruce.

Moose are the big game in the forested areas, and caribou in the uplands. Trout are abundant near the rapids on Hart-Jaune river and in the small lakes and ponds of the upland. Pike are numerous in Manicouagan lake.

Weather

The precipitation is high, and the climate is generally cold. In the uplands, the lakes are frozen till the end of June and snow remains in some valleys until mid-summer. West winds are strong and make landing difficult on the generally north-south-trending lakes.

The Department of Lands and Forests Fire Protection Service operates a fire look-out tower north of Boissinot lake during the summer months. The tower can be contacted by radio for information on weather conditions.

Topography

The area includes two distinct types of topographies; the dividing line is a major fault that trends about N.60°E. from the outlet of Hart-Jaune river to the eastern limit of the area.

Two thirds of the area is south of this dividing line and belongs to a large, dissected plateau or upland that extends from Manicouagan lake eastward beyond the area. For convenience, this area is referred to in this report as the "Manicouagan upland".

The upland is characterized by rounded hills with intervening, deeply incised, linear valleys. Its general elevation is about 3,000 feet. Prominent hills that stand above the general level include Tom mountain (3,494 feet) north of Boissinot lake, Loaf mountain (3,623 feet) west of the south end of Joyel lake, and Lucie mountain (3,592 feet) southeast of Lucie lake. The topography of the Manicouagan upland is illustrated in Plates IA and IB. Along its western margin the elevation of the upland drops sharply to Manicouagan lake (645 feet).

North of the above-mentioned dividing line the elevation locally reaches 2,000 feet but is generally around 1,500 feet. Hart-Jaune river originates from the western arm of Petit Manicouagan lake in the northeast corner of the area. The river flows west-southwest and falls nearly 1,000 feet before it reaches Manicouagan lake. At the Hart-Jaune falls (Plate IIA) the river drops about 120 feet through a series of steps.

In the Manicouagan upland outcrops are abundant. In the lower ground to the north most of the bedrock is hidden under glacial debris.

Drainage

The main tributary to the Hart-Jaune is Beaupin brook, which drains part of the upland. The trends of streams and lakes in the upland are largely controlled by the bedrock structure.

The northern part of the area is drained by Hart-Jaune and Racine-de-Bouleau rivers. The latter runs parallel to, and enters Manicouagan lake west of, the western border of the area. Racine-de-Bouleau river and the streams north of the Hart-Jaune have a meandering pattern and many are bordered by sand terraces or eskers. The small streams have a dendritic pattern. Manicouagan lake drains through Manicouagan river to the St. Lawrence.

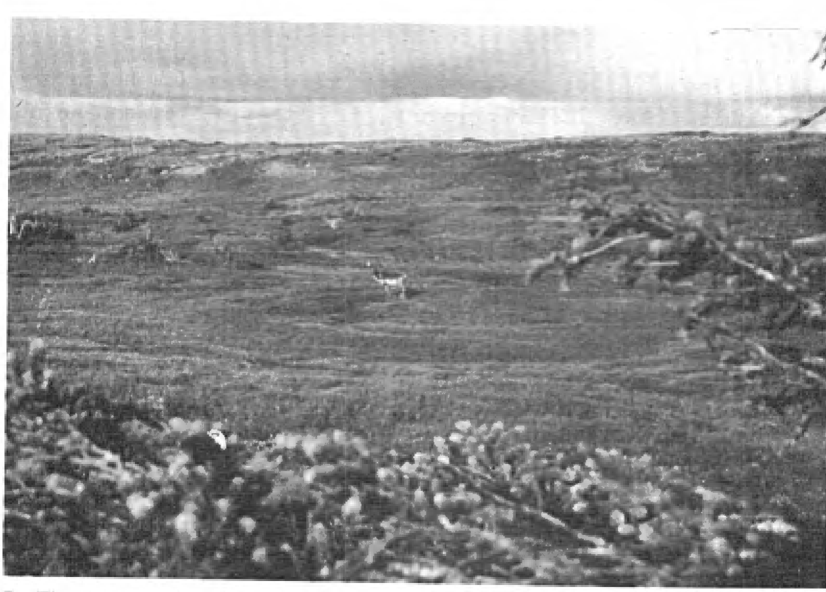
The construction of an embankment and storage dam between Petit Manicouagan lake and Hart-Jaune river raised the level of the lake and flooded considerable ground.

GENERAL GEOLOGY

The area is in the northeastern part of the Grenville subprovince. It includes Precambrian, Middle Ordovician, and post-Middle Ordovician rocks, the last two groups being confined to the southwest corner of the area, south and west of Manicouagan lake.

PLATE I

A- The topography of the Manicouagan upland west of Joyel lake.



B- The topography of the Manicouagan upland west of Joyel lake.

The Precambrian is represented by igneous rocks and by metamorphic rocks of the granulite and the amphibolite facies. The fault that runs from the outlet of Hart-Jaune river northeasterly divides the area both topographically and lithologically. Metamorphic rocks of the granulite grade as well as an igneous complex occupy the upland area south of the fault, whereas amphibolite-grade gneisses and granitic intrusives are the major rock types north of the fault.

The metamorphic complex of the Manicouagan upland includes highly metamorphosed sedimentary and igneous rocks. The metasedimentaries, which were argillaceous and siliceous, are now sillimanite-bearing gneisses, quartzite, and diverse pyroxene-bearing felsic rocks. A quartz-pyroxene-andesine gneiss may be of igneous origin. Quartz-diopside-calcite gneiss and metamorphic pyroxenite are derived from calcareous sedimentary rocks. Some thermally metamorphosed inclusions have pyroxene-hornfelsic assemblages such as wollastonite-quartz-garnet and plagioclase-scapolite-quartz-garnet-diopside.

The "granulitic gabbros" are metamorphosed igneous rocks that have a simple diopside-hypersthene-labradorite mineral assemblage. They occur in large and homogeneous outcrops in the western half of the area, but are interlayered with the metasedimentary rocks in parts of the eastern half. A beige, leucocratic, hypersthene granite is also part of the layered sequence in the east. Varieties with antiperthitic feldspar have the mineral composition of enderbite.

The metamorphic rocks are complexly folded and are cut by coarse, massive, anorthositic gabbros. In a zone along the northern margin of the complex the formations are sheared and amphibolitized.

The amphibolite-grade metamorphic rocks lie north of the Hart-Jaune fault. They include biotite, kyanite-biotite, and hornblende-biotite paragneisses, with layers of quartzite and crystalline limestone. The orthogneisses are mainly hornblende-plagioclase types, some of which are derived from basic igneous rocks, and others are of doubtful origin. Biotite-plagioclase paragneisses in the northeastern part of the area are similar to the rocks that underlie the quartz-specularite iron-formations at Jeannine lake. Abundant granitic material has intruded the ortho- and paragneisses and formed mixed gneisses, which are common throughout the area north of the Hart-Jaune fault.

Intrusive rocks of the anorthosite-gabbro family crop out mainly between the two groups of metamorphic rocks. Their main mass is in the eastern part of the area, south of the Hart-Jaune fault, where they range in composition from anorthosite through troctolitic rocks to dunite. The southern edge of this mass is layered, and contains abundant olivine

Table of Formations

PLEISTOCENE	Sand, gravel, boulders, till	
POST-MIDDLE ORDOVICIAN	Volcanic and satellitic rocks	Quartz-latite and medium-grained satellitic variety
MIDDLE ORDOVICIAN	Sedimentary rocks	Limestones, some with fossils
PRECAMBRIAN	Intrusive rocks	Diabase
		Peridotite
		Coronitic gabbro
		Green syenitic gneiss and associated pink "speckled"gneiss
		Granitic pegmatite Granitic gneisses and granites
		Anorthosite, troctolitic anorthosite, anorthositic gabbro, troctolite, dunite, and metamorphosed varieties; associated dike-rocks
	Metamorphic rocks of the amphibolite grade	Mixed gneisses Hornblende-plagioclase gneisses, Biotite paragneiss, Kyanite-biotite gneiss Hornblende-biotite paragneiss Crystalline limestone, Dolomite, Quartzite
	Metamorphic rocks of the granulite grade and associated intrusive rocks	"Marginal" amphibolite
		Pyroxenite
		Hypersthene granite and related enderbitic rocks
		Granulitic gabbros
		Sillimanite-bearing gneiss, Quartzite, Diverse pyroxene-bearing felsic rocks, Quartz-pyroxene-andesine gneiss, Quartz-diopside-calcite gneiss, Metamorphic pyroxenite, Scapolite rock, Calc-silicate rock and pyroxene-hornfelsic rocks

and magnetite. The northern margin is metamorphosed and is cut by pink granite. In the central parts the coarse facies are made up of calcic labradorite and the main mafic mineral is olivine.

A smaller anorthositic-gabbroic mass, which is in the center of Brien township and north of the fault, is metamorphosed and is partly transformed to hornblende-plagioclase gneisses.

The Lucie Lake intrusive lens, near the southeastern corner of the area, is surrounded by metamorphic rocks of the upland.

Granitic intrusive rocks are associated with gneisses of the amphibolite grade and are especially common near the Hart-Jaune fault. There are at least three different types of granites (including granitic pegmatites), and they are thought to represent different periods of intrusion.

Minor intrusive rocks include pyroxene-bearing, green syenitic gneisses and pink garnetiferous speckled gneisses; scattered lenses of corona-gabbros and dikes of ultrabasic rocks; and one exposure of garnetiferous peridotite. All these intrusives are north of the Hart-Jaune fault. Diabase dikes cut the main mass of anorthosite gabbro and the metamorphic rocks of the Manicouagan upland. Post-Precambrian rocks include small patches of Middle Ordovician sedimentary rocks on the shore of Manicouagan lake, and post-Middle Ordovician, unmetamorphosed volcanic rocks southwest of the lake.

THE METAMORPHIC COMPLEX OF THE MANICOUAGAN UPLAND

The rocks of the Manicouagan upland are either homogeneous or layered, and they vary in composition from silica- and alumina-rich felsic rocks to pyroxenite. They have anhydrous mineral assemblages and, because of the absence of platy minerals, the schistosity is generally poorly marked except in the silliminate- and graphite-bearing varieties. Interlayered acidic and basic rocks (Plate IIB) are common in the eastern half of the upland. The thickness of the layers is variable, and sharp changes in composition across the strike occur. Homogeneous rocks, which are common in the western half of the upland, are highly metamorphosed basic igneous types, mainly granulitic gabbros. On the map the geological boundaries are drawn on the basis of relative abundance of one or the other rock type, and outcrops which are indicated as homogeneous granulitic gabbros may contain some layers of siliceous rocks.

PLATE II

A- Aerial photograph of Hart-Jaune falls.

B- Layered metamorphic rocks of the Manicouagan upland.

Field classification of the very fine-grained rocks is different because their composition can be recognized only in thin-sections. Consequently these rocks were mapped in one group, and were subdivided only after laboratory study. Thus, the classification adopted is somewhat forced.

Paragneisses

Sillimanite-bearing Gneisses

Sillimanite-bearing felsic layers are common east of Joyel lake and around Mora and Lucie lakes. The rock is pale gray and weathers rusty-brown. Sillimanite and graphite are visible in some hand specimens, and the rock is slightly schistose if these minerals are oriented. However, most of the rocks are fine and very fine grained, and the schistosity is not obvious. Garnet is in pinkish,irregular grains.

Table 1*

Modal Compositions of the Sillimanite-bearing Granulitic Gneisses

	L-78-4	L-81-4	P-48-7	P-48-8
Perthitic K-feldspar	8	9	33	5
Plagioclase	2	-	8	11
Quartz	47	62	48	56
Sillimanite	15	12	3	7
Garnet	24	11	6	16
Graphite	3	4	1	3
Rutile and opaque	1	2	1	2

* The modal compositions are based on point counts and are volume per cent.

Modal compositions of four specimens given in Table 1 reveal great variation in the proportion of the minerals. Commonly, quartz makes up about half of the rock, but some approach the composition of an impure quartzite. Varieties with a high content of sillimanite and only traces of quartz also exist.

An inequant granular texture is seen under the microscope. Most grains are smaller than 1 mm., and the garnet and sillimanite are irregularly distributed in the thin-sections. A common texture is illustrated in Plate IIIA.

Sillimanite occurs commonly as stubby prisms, but in some thin-sections sheaves of minute needles are also seen. The prismatic sillimanite is associated with garnet, and the less common fibrolite occurs with traces of biotite. In rare instances, sillimanite makes up 50% of the rock, other minerals being garnet and K-feldspar.

Quartz forms sutured mosaics with the feldspars. Minute needle-like inclusions common in the quartz are too small for optical determination. Quartz may be present also as larger plates or lenses, and may include minute grains of garnet.

K-feldspar is invariably microperthitic. The characteristic hair-like perthitic lamellae are more abundant near the centers of the grains. Some of the lamellae are noticeable only in high magnification. Acicular inclusions of an unidentified mineral occur in the K-feldspar and in one thin-section the needles form at least two oriented sets.

Plagioclase (sodic andesine) forms clear, twinned grains. The borders of some crystals show myrmekitic texture.

Garnet is invariably anhedral and colorless in thin-section. In some specimens it forms plates with irregular outlines and contains abundant inclusions. It occurs also as uniformly scattered discrete granules or as rims around grains or aggregates of sillimanite. In some thin-sections the garnet is concentrated in 4-6 mm. layers.

Spinel, found in some thin-sections, appears as bright green, discrete grains surrounded by sillimanite or garnet, or both.

Graphite is uniformly distributed in the thin-sections, but local concentrations may be seen in hand specimens.

Rutile, the common accessory mineral, is distinctly reddish. Zircon is rare. Magnetite and, exceptionally, pyrite are the opaque accessories. Biotite is rare and is mixed with the fibrolitic sillimanite.

Quartzite

Some layers from localities south of Joyel and Lucie lakes are impure, pale gray to dirty whitish quartzites. They occur parallel, and adjacent to, sillimanite-bearing granulitic gneisses and pyroxene-bearing felsic rocks. On fresh surfaces, some yellowish feldspar grains are noticeable in the glassy quartz.

Quartz has a wavy extinction, and in some thin-sections contains minute needle-like inclusions. The outlines of the quartz grains are very irregular, and the size is variable, but most grains are smaller than 0.5 mm. in diameter.

Table 2

Modal Composition of Quartzite Layers

	L-71-9/A	L-72-4	L-77-9
Quartz	78	76	58
Plagioclase	21	20	28
Garnet	-	2	13
Accessory	1	2	1

Plagioclase is slightly sericitized, and in this respect it differs from the plagioclase of the other rocks in the Manicouagan upland However, the twinning is still recognizable although many of the lamellae are bent.

Garnet is present in some specimens. Adjacent to the sillimanite-bearing gneisses, the tenor of the garnet in the quartzite is high (Spec. L-77-9, Table 2). Rosy garnetiferous layers 2-5 mm. wide make these garnet-rich quartzites appear foliated.

Accessory minerals include graphite, biotite, hypersthene, and a pale green, hydrous, alteration product.

Diverse Pyroxene-bearing Felsic Rocks

These rocks of diverse compositions are fine to very fine grained and medium to dark gray. They occur as parts of the layered sequence adjacent to the quartzite and sillimanite-bearing gneisses and also, at the contacts of the granulitic gabbros and siliceous metasedimentary rocks.

The pyroxene-bearing felsic rocks are common as well defined layers south of Joyel lake and in many places in the southern part of the eastern third of the map-area. Significant differences in composition became obvious only after study of the thin-sections.

Hypersthene-bearing siliceous rocks are abundant in the southeast corner of the area and south of Joyel lake. The minerals found in thin-sections are: quartz, plagioclase, K-feldspar, hypersthene, graphite, and accessory biotite and sphene. The texture is microgranoblastic and the grains are commonly less than 0.4 mm. in diameter. Colorless hypersthene and flaky graphite are distributed uniformly in a fine-grained aggregate of quartz and feldspars. The quartz contains minute acicular inclusions. Microperthitic K-feldspar, also with inclusions, has a moderate to small axial angle. The plagioclase is a clear, twinned andesine. Biotite (up to 2%) is associated with graphite or is adjacent to the pyroxene anhedra. Sphene is the common accessory mineral and is wine-brown and pleochroic. Accessory magnetite also occurs.

Graphite-bearing perthite-pyroxene rock crops out east of Joyel lake and on the eastern border of the central third of the area. The modal composition of a thin-section is as follows:

K-feldspar	68%	Graphite	7%
Pyroxene	24%	Sphene and quartz	1%

The graphite is uniformly disseminated in the thin-section, but local concentration is seen in hand specimens. The perthitic K-feldspar contains very thin, hair-like lamellae and minute acicular inclusions. The pyroxene is colorless diopside and has a moderately large positive axial angle. The accessory sphene is strongly pleochroic.

Thinly layered felsic rocks with pyroxene as the mafic mineral occur near contacts and deformed zones. The thin layers are readily seen when the rock is stained for K-feldspar, but they are not obvious in hand specimens. In a thin-section from the southeast corner of the area the thin layers alternate as follows: 1) plagioclase mixed with 0.1-0.2 mm. anhedral biotite; 2) plagioclase with opaque dust; 3) aggregate of K-feldspar, pyroxene and opaque mineral; and 4) mixture of K-feldspar and quartz.

A thin-section of a layered gray specimen near the east border of the central third of the area consists of: 1) pyroxene-plagioclase-garnet (massive); 2) cataclasticly deformed pyroxene-plagioclase-garnet-quartz; 3) undeformed pyroxene-plagioclase; and 4) quartz-rich layer. In the deformed zones the plagioclase (calcic-andesine) is partly scapolitized. The quartz contains trails of near submicroscopic bubbles and minute needle inclusions.

Quartz-pyroxene-andesine Gneiss

This member of the layered sequence resembles granulitic gabbro but differs from the gabbro in the presence of quartz, the andesinic composition of the plagioclase, the finer grain size, and the lighter color. The rock is slightly foliated, medium gray, and up to 1 mm. in grain size.

The minerals are andesine, quartz, ortho- and clinopyroxenes, and an accessory opaque ore mineral. K-feldspar occurs as antiperthitic patches in the twinned plagioclase. The pyroxenes are colored and are similar to those in the granulitic gabbro. Garnet was seen is one variety.

Quartz-diopside-calcite Gneiss

Diopside-bearing, calcic, fine-grained (average 0.3 mm.) rocks occur in the layered sequence southeast of Mora lake and around Boissinot lake. The minerals seen in thin-section are quartz, plagioclase, diopside, and calcite.

Quartz has a wavy extinction, and lacks needle inclusions. The diopside is colorless, and has a moderately large (+) axial angle and well-developed cleavages. Calcite grains are interstitial to the other minerals and are generally in contact with the diopside. The plagioclase is clear, twinned andesine. Biotite and pyrrhotite are accessory minerals in some sections, and garnet was noted in one.

Metamorphic Pyroxenite

Metamorphic pyroxenite occurs north of Joyel lake, near the eastern border of the middle third of the area, in discontinuous outcrops extending about 2 miles along the strike.

The northern part of the pyroxenite is interlayered with granulitic gabbros. Near the southern end of the outcrop area is a contact zone of pyroxenite with quartz-pyroxene-andesine gneiss. About 15 feet northwest of the gneiss a dark specimen contains 25-30% sodic labradorite, and the rest of the rock is pyroxene; the plagioclase forms parallel, oriented, discontinuous streaks which have a confused contact with the dark pyroxene. Twenty feet farther the plagioclase is sharply reduced, and its calcity is higher. One specimen near the northwestern end of the outcrop area contains about 10% scapolite, and 5% plagioclase (An_{80}) besides the pyroxenes; another specimen is pyroxenite with traces of Ca-bytownite; some specimens contain clinopyroxene, abundant garnet, and relic crystals of calcite. The diopside is partly amphibolitized.The accessory minerals are magnetite and spinel.

The average pyroxenite, away from the contact, is even grained and dark, and in places contains feldspathic layers. The minerals are diopside, less abundant hypersthene, and minor amounts of magnetite, spinel, and reddish garnet. The secondary minerals are minor amphibole on pyroxene grains and some unidentified greenish alteration product.

The diopside is pale green (+) 2V 50-60°. The pinkish hypersthene has a large negative axial angle. The garnet has the following physical properties:

Density: 3.80
Refractive index: 1.756
Unit-cell edge: 11.54 Å
Approx. composition: Pyr_{34} Alm_{52} Gro_{14}

Scapolite Rock

On the eastern limit of Jauffret township between mileposts XI and XII, a bed of light-colored scapolite rock occurs in the layered rocks. The bed is deformed and forms oval-shaped boudins up to about 10 feet thick.

The rock is generally pale creamy green. Well-cleaved scapolite crystals (up to 8 mm. long) and glassy quartz are visible throughout, and near the contact sphene crystals up to 2 inches long occur. In thin-section, diopside, a pale amphibole, and magnetite are also seen. The refractive index of the scapolite indicates the predominance of the marialite molecule.

Calc-silicate Rock

Along the strike, but about 2 miles east of the scapolite rock and near the northern edge of the metamorphic complex, a massive, sugary rock resembles skarn. A specimen contains about 50% calcite. The other common minerals are quartz, diopside, and probably grossularitic garnet. Traces of very calcic plagioclase and accessory sphene were noted. The diopside shows twinning and wavy extinction.

The metamorphosed igneous rocks in the southeastern corner of the area contain inclusions, a few of which are well preserved. They are very fine grained, and the compositions can be established only by microscopic examination. They range in size from 10 to 25 cm., and are spread over an area of about 4 square yards.

One pale beige inclusion is surrounded by a 10 mm. thick, porous (leached), dark reaction border. Under the microscope, the minerals determined were wollastonite, quartz, garnet, and accessory sphene. The wollastonite and garnet (grossularite?) form a mixture in which quartz is interstitial. In the porous margin around the inclusion some opaque dust is mixed with garnet. Chemical analyses indicate extremely low alkali content of the inclusion: Na_2O=0.02% and K_2O=0.03%.

Another inclusion has a pale gray, cherty aspect. In thin-section, scapolite, plagioclase, quartz, diopside and garnet were seen. The diopside occurs as anhedral dots in a mosaic of low-relief minerals. The garnet appears as incomplete rims between the quartz on one side, and plagioclase-scapolite on the other side. The plagioclase is twinned, clear labradorite.

Discussion

The facies classification of the metamorphic rocks as outlined by Fyfe et al. (1958) is followed in this report. According to these authors the granulite facies is defined as the "association of regionally metamorphosed rocks characterized by the pair of sillimanite-garnet in place of micas and diopside-hypersthene in place of amphiboles." Sillimanite- and garnet-bearing paragneisses are common rocks in the Grenville subprovince, but they are usually associated with amphibolites, and biotite is a regular constituent; thus most of them were metamorphosed in the upper amphibolite grade (sillimanite-garnet subfacies). The anhydrous mineral assemblages of the metasedimentary rocks of the Manicouagan upland, however, clearly indicate that they belong to the granulite facies.

High grade of metamorphism and complex deformation have obliterated the primary features, igneous or sedimentary, and the origin of some of the rocks cannot be inferred from the present compositions. An attempt to represent the mineral assemblages on the triangular compositional diagrams is only partly successful, because of the peculiar composition of some of the rocks. Nevertheless the AFC-type diagrams of Figures 1 and 2 are useful for the purposes of classification. The diagrams indicate that by the present mineral composition the rocks described fall into three groups:

1) Rocks which approach the "ideal" mineral assemblages of the regionally metamorphosed granulite-grade rocks.

2) Rocks with pyroxene-hornfelsic assemblages.

3) Rocks which cannot be classified with the above two groups.

The Origin of the Rocks of Group 1

Sillimanite-bearing gneisses.-

The presence of garnet and graphite and the abundance of quartz suggest that the sillimanite-bearing rocks are derived from aluminous sedimentary rocks. The regularly interlayered character of the sillimanite-bearing rocks with quartzite support this view.

It is also concluded that the sillimanite in the gneisses of the Manicouagan upland is a metamorphic and not a metasomatic mineral. The present composition of the gneisses, as is shown below, disproves the possibility of intensive metasomatism.

The tenor of K_2O and Na_2O of two specimens from the Manicouagan upland and those of five specimens from southern Quebec are listed in Table 3. The sodium and potassium contents of the average sandy shale, shale and graywacke are also given for comparison. Figure 3, the diagramatic illustration of the data from Table 3, shows that the total alkali content of the Manicouagan sillimanite-bearing rocks is generally low and that potassium predominates over sodium. The Na_2O content of the specimens from the Grenville of southern Quebec is similar to that of the Manicouagan specimens. The K_2O of two specimens from Papineau county is relatively high and is not comparable to that of the sillimanite-bearing rocks of the present study. Figure 3 illustrates also the similarity of the composition of the Manicouagan specimens to the average sandy shale. The average graywacke differs significantly from the quoted specimens by the predominance of Na_2O over K_2O.

The alkali content of the sillimanite-bearing gneisses of the Manicouagan upland is lower than that of any granitic rock in the area and there is no reason to believe that the bulk of the gneisses have been significantly affected by metasomatic changes.

The origin of the quartzite is not discussed separately from the sillimanite gneisses, because its composition and layered nature make its origin obvious. The compositions correspond to impure sandstones.

Hypersthene-bearing siliceous rocks.-

The mineral assemblage of this rock type is similar to that of the sillimanite-bearing rocks except that hypersthene appears in place of the sillimanite. The abundance of quartz, the presence of graphite, and the association with quartzite indicate a sedimentary origin. The virtual absence of biotite and the presence of perthitic feldspar point to the same high temperature as generally affected the rocks of the Manicouagan upland.

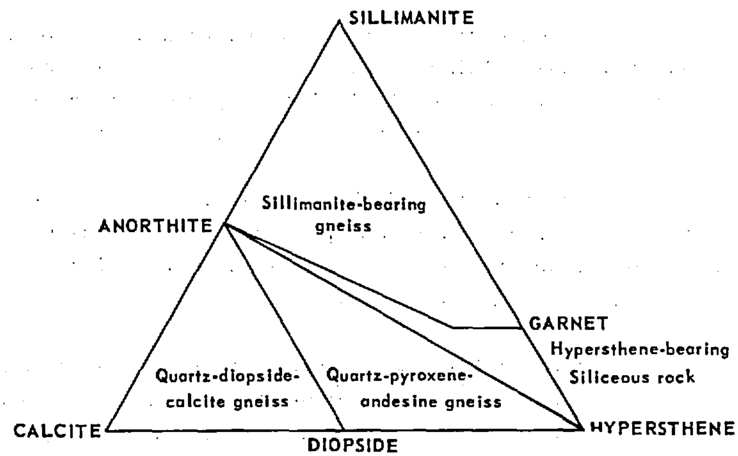


Figure 1

THE MINERAL ASSEMBLAGES OF THE GRANULITE–GRADE METAMORPHIC ROCKS OF THE MANICOUAGAN UPLAND WITH EXCESS SILICA.

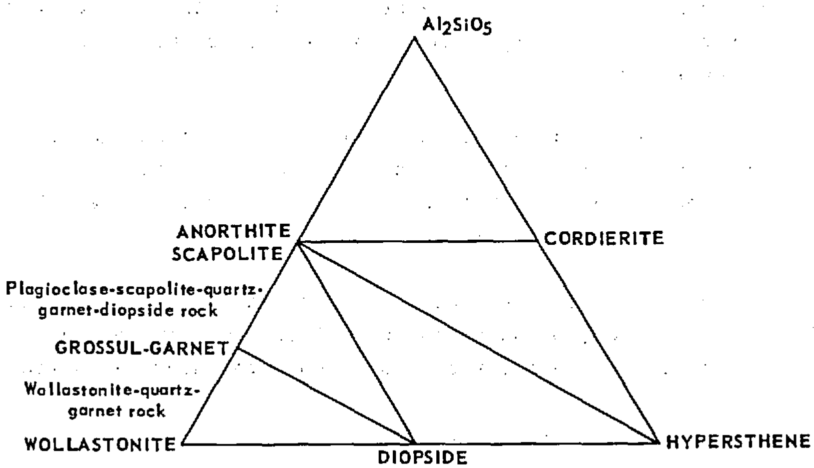


Figure 2

THE PYROXENE–HORNFELSIC ASSEMBLAGES WITH EXCESS SILICA

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Table 3

The Tenor of K_2O and Na_2O in the Sillimanite-bearing Gneisses

No.	Na_2O	K_2O	Source
1	0.40	1.70	Manicouagan upland
2	0.62	1.50	Manicouagan upland
3	0.42	1.32	Osborne, 1936; Shawinigan
4	0.79	2.50	Wilson, 1925; Joliette county
5	0.60	5.72	Wilson, 1925; Papineau county
6	0.42	0.95	Wilson, 1925; Montcalm county
7	0.73	4.57	Wilson, 1925; Papineau county
8	1.00	2.60	Sandy shale (Pettijohn, 1949, p. 271 — one part average sandstone and two parts average shale)
9	1.30	3.24	Average shale by Clarke (From Engel and Engel, 1953; p. 1085)
10	3.40	2.00	Average of 11 graywackes (Pettijohn, 1949, p. 250)

In most of the siliceous rocks the axial angles of the perthitic K-feldspar is small (less than 40°).

Quartz-pyroxene-andesine gneiss.-

This rock type has a basic mineral assemblage, but it differs from the granulitic gabbros in the somewhat lower calcity of the plagioclase and in the presence of quartz and K-feldspar. It is probable that this pyroxenic rock represents the marginal or contact zones of the gabbros.

Quartz-diopside-calcite gneiss; and metamorphic pyroxenite.-

The mineral assemblage of the gneiss is clearly that of a highly metamorphosed, sandy, calcareous sediment. The incomplete silicification of the carbonate is "characteristic of the granulite facies and indicates moderately high partial pressure of carbon dioxide" (Fyfe et al.,

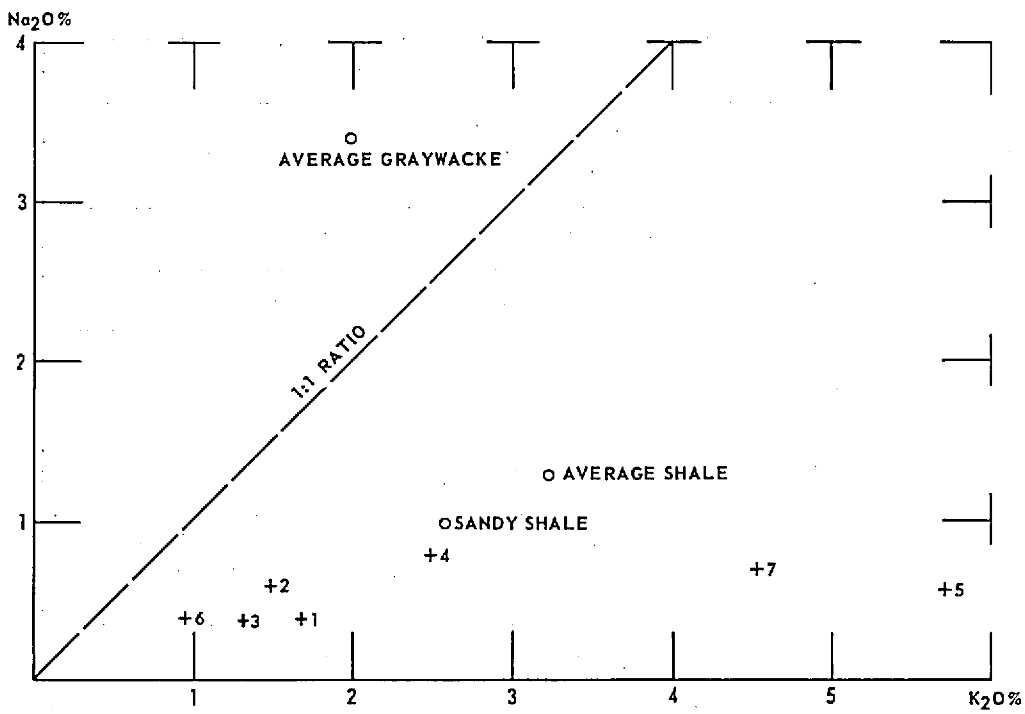

Figure 3

THE Na_2O CONTENT IS PLOTTED AGAINST K_2O CONTENT FROM THE SILLIMANITE-BEARING GNEISSES OF THE MANICOUAGAN UPLAND (1-2) AND FROM OTHER PARTS OF QUEBEC (3-7)

(Data from table 3)

Each cross represents an analyzed specimen

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1958, p. 159). Metamorphic pyroxenite is also thought to be of calcareous origin. Although it is included with the rocks of Group 1, the pyroxenite is not plotted in Figure 1 because it lacks free silica. The metamorphic pyroxenite is not homogeneous in composition. The increase in calcity of the plagioclase and the appearance of calcite away from the contact seem to demonstrate the limited rate of access of the constituents from the adjacent layer. This is shown also by the garnet, which is present in force only in the marginal facies of the metamorphic pyroxenite. The garnet is a pyrope-almandine type, which indicates regional metamorphism at considerable depth. It should be noted that crystalline limestone or dolomite was not found in the Manicouagan upland.

The Origin of the Rock of Group 2

The mineral assemblages of the rocks of this group are pyroxene-hornfelsic (see Figure 2). The wollastonite-quartz-garnet rock and the plagioclase-scapolite-quartz-garnet-diopside rock are both inclusions in metamorphosed basic igneous rocks. Though they are minor in quantity, their presence has an important bearing on the origin of the igneous rocks in which they occur (see discussion on granulitic gabbro). The compositions of these two rocks indicate that they are of calcareous origin. The thermal (contact) metamorphic effect is shown by the reaction border that surrounds the inclusions and by the typical pyroxene-hornfelsic mineral assemblages.

The Rocks of Group 3

Some rocks of the Manicouagan upland cannot be classified with the above two groups because they appear to be metasomatized, and their origin is uncertain. Thinly layered felsic rocks of several localities are sheared and contain secondary quartz and K-feldspar in narrow zones. The thin layers alternate in a millimeter scale and the average composition of the original rock cannot be estimated.

A graphite-bearing pyroxene-perthite rock contains 68% K-feldspar. Although the graphite suggests a sedimentary origin, this rock is unlike other rocks of sedimentary origin within the area. Introduction of potassium by metasomatism is questionable, because it would have occurred with the addition of quartz; however the rock in question is devoid of quartz.

A scapolite rock was found at one locality. The origin of the rock is suggested indirectly by its relation to the metamorphic pyroxenite and to the calc-silicate rock, both of which are on strike with the scapolite rock. This relation may indicate that the rock was derived from a calcareous bed, but the relatively high marialite in the scapolite suggests an introduction of some sodium.

Granulitic Gabbro

Granulitic gabbro, the most common rock type of the Manicouagan metamorphic complex, is medium grained and dark gray and is composed essentially of plagioclase and pyroxenes. It is believed to be a metamorphosed basic igneous rock.

The granulitic gabbro forms large and homogeneous outcrops in the western two-thirds of the area. Around Joyel lake and in large parts of the eastern third, the gabbro is interlayered with the above-described paragneisses.

In certain zones cataclastic augen gneisses and mylonitic rocks occur. These highly deformed rocks are described in a separate section below.

The pyroxene and plagioclase are readily recognized in hand specimen. The plagioclase is white and pale gray or pale beige, and forms an equant "pepper and salt" texture with the black pyroxene. Faint color layers in shades of gray are seen on some freshly stripped, glaciated surfaces. The specimens from the eastern third, where the layered rocks are abundant, are in general finer grained and somewhat darker than the granulitic gabbro of the large, homogeneous outcrops to the west.

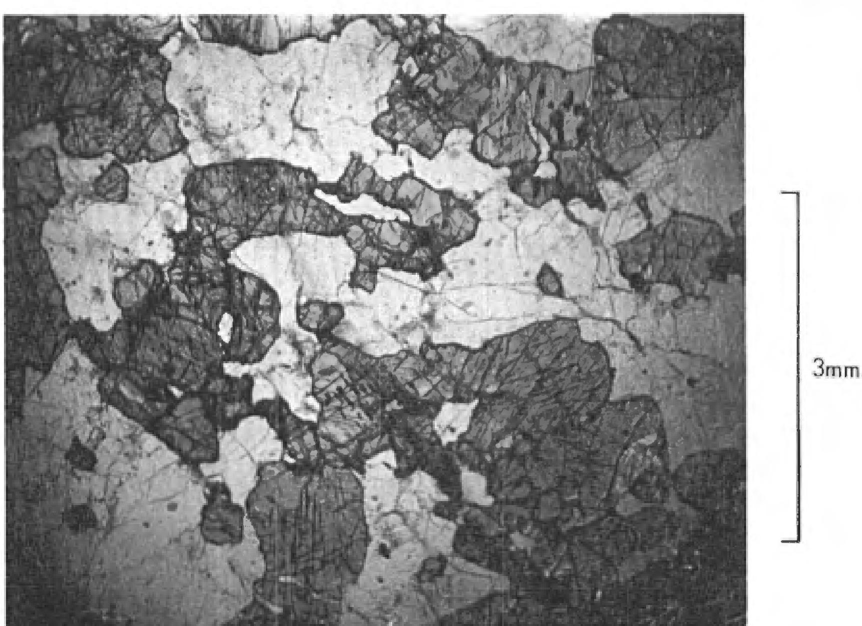
Modal composition of three representative specimens are given in Table 4. In thin-sections, the minerals form an even-grained, xenoblastic texture (Plate IIIB). The anhedral grains are fresh or only slightly altered. The commonly strained nature of the rocks is well shown by the bent twin lamellae of the plagioclase.

The plagioclase is labradorite. The average of 10 determinations is An_{52}. Most specimens are between An_{50} and An_{54} and the extreme limits are An_{45} and An_{60}. The plagioclase is clear, well twinned, and invariably anhedral.

Pyroxenes. Typically two pyroxenes (orthopyroxene and diopside) are present. The anhedral grains are fresh and have dark schiller inclusions. Narrow, greenish, alteration rims are seen around the pyroxene grains in thin-sections from the western third of the area. A golden brown alteration is seen in the irregular cracks of some grains. The orthopyroxene is a pleochroic hypersthene, with an absorption: X = purple-brown, Y = pale purple, Z = pale green. The negative axial angle commonly is 65°-75°, but in some specimens is near 90°. The diopside is slightly pleochroic in shades of pale green. The (+) axial angle is 50°-70°.

PLATE III

A- Spec. L-81-4. Photomicrograph. One nicol. Sillimanite-bearing gneiss. Sillimanite (S), garnet (G), Graphite (Gr), Perthite (P), Quartz (Q).



B- Granulitic gabbro. L-52-6. Photomicrograph. One nicol.

Table 4

Modal Compositions of the Granulitic Gneisses

	K-4-3	K-4-6	L-52-6
Plagioclase	46	38	41
Hypersthene	28	17	20
Diopside	17	16	35
Garnet	=	11	=
Opaque	4	15	2
Alteration	5	3	2

Garnet is local and many garnetiferous specimens are strained. It commonly appears in two forms: either as porphyroblasts, or as narrow rims on the opaque mineral. It was also seen as confused symplektite with some undetermined anisotropic mineral.

In some deformed granulitic gabbros the garnet replaces the plagioclase and the hypersthene. The plagioclase in a specimen with 26% garnet is recrystallized to a fine-grained mass and the relic grains have almost completely lost the twinning. Another specimen is made up of 4% plagioclase, 12% diopside, 10% hydrous alteration and opaque mineral, and 74% garnet. This garnet-diopside rock is surrounded by foliated granulitic gabbro which has scattered porphyroblasts of garnet. The properties of the garnet are:

Refractive index: 1.765
Cell edge: 11.53 Å
Density: uncertain because of the inclusions
Approx. Composition: Pyr_{42} Alm_{47} Gro_{11}

Hornblende and biotite. Locally, narrow amphibolitic margins on pyroxene occur. Discrete hornblende grains are noticeable adjacent to the pyroxene grains in some thin-sections. At one locality (east border of the middle third of the area) hornblende and biotite were found instead of pyroxenes. The plagioclase (An_{53}) of this unusual rock is granulated and recrystallized. The biotite is red-brown and the hornblende is a strongly colored, greenish brown variety. The rock contains garnet.

Opaque minerals. Magnetite is the common opaque mineral, having a tenor of 15%, which is exceptionally high.

Scapolite occurs rarely and in traces; its textures suggest local alteration from plagioclase.

Inclusions (Plate IVA) were noted in the granulitic gabbro of the eastern third of the area. They vary in shape and size and are seen well on freshly stripped rock surfaces.

Discussion

The metamorphic character of the granulitic gabbro is clearly shown not only by the pepper-and-salt texture, but also by the properties of the minerals. The lath shape of the plagioclase, which is a general characteristic of the anorthositic gabbros of the area, is absent in the granulitic gabbros. The plagioclase is not zoned. The pyroxenes have no exsolution lamellae. Locally a pyrope-almandine-type garnet is abundant. The associated sillimanite- and hypersthene-bearing rocks also reflect a high-temperature metamorphism.

The introduction of quartz and some K-feldspar into the granulitic gabbro is restricted to narrow cataclastic zones, but apart from these local changes only the proportion of the minerals varies. The limited compositional range of the granulitic gabbro compared with the diverse composition of the associated siliceous rocks leads to the conclusion that the original rock had an initially uniform composition.

A metamorphic rock of gabbroic-noritic composition may form by the metamorphism of a calcareous sediment, or by metamorphic recrystallization of a basic igneous rock. The variation in composition of the minerals in metamorphosed calcareous beds of areal extent is definitely greater than it is in the granulitic gabbro. A sharp increase in the calcity of the plagioclase in the metamorphic pyroxenite was mentioned above. No such changes occurred in the granulitic gabbros. It was also shown that during the metamorphism of the siliceous sedimentary rocks the pressures were high and prevented the complete thermal breakdown of carbonate. No primary carbonate mineral is present in the granulitic gabbro. The above considerations, and the presence of the inclusions, indicate that the granulitic gabbro is a recrystallized basic igneous rock.

The relation of other igneous rocks to the granulitic gabbro should be considered. A hypersthene granite, which was already present in the layered sequence when the main period of folding occurred, cuts the granulitic gabbro. The anorthositic rocks of the Lucie Lake lens are also later than the granulitic gabbro. These relations indicate that the parental rock of the granulitic gabbro was the earliest igneous rock in the area.

The inclusions have an important genetic implication on the origin of the granulitic gabbro. The hornfelsic minerals, especially wollastonite, suggest thermal metamorphism under pressure conditions which allowed the escape of CO_2. "Development of wollastonite instead of calcite-quartz signifies a combination of high temperature and low partial pressure of carbon dioxide" (Fyfe et al., 1958). The narrow reaction borders around the inclusions suggest rapid cooling of the magma.

The synthesis of the conclusions arrived at above would be that the magma which formed the parental rock of the granulitic gabbro invaded sedimentary rocks as shallow intrusions, and part of the granulitic gabbro may be recrystallized lavas. This proposed mode of origin explains the uniform compositional characteristics of the gabbro as well as its relations to both the metasedimentary rocks and the igneous rocks of the area.

Hypersthene Granite and Related Leucocratic Rocks

Hypersthene granite is a common rock type in the southeastern part of the metamorphic complex. It is a massive to gneissic, beige or brownish, quartzo-feldspathic rock with hypersthene as its characteristic mafic mineral.

It is generally in layers 10 cm. to 50 feet thick that are conformable with the sillimanite-bearing and pyroxene-bearing acidic rocks, and with the granulitic gabbro. However, at several places the granite cuts the granulitic gabbro as veins and irregular stringers. Contacts between granite and adjacent layers are sharp. Inclusion-like, darker facies that may represent fragments from adjacent formations were noted in the hypersthene granite near the south shore of Lucie lake.

In hand specimen, only quartz and feldspar are readily seen. The feldspar is beige, pale brown, or, in places, greenish. The quartz occurs as dark glassy grains in the massive rock and as lenticles in the gneissic variety.

In thin-sections an interlocking mosaic texture of the anhedral grains is seen. The grain size varies between 0.1 and 3 mm. As Table 5 shows, a high tenor of K-feldspar and quartz and a low tenor of mafic minerals characterize the hypersthene granites. Two minor rock types deviate from this general composition. One differs from the average hypersthene granite in the absence of pyroxene and plagioclase, and can be properly called a quartz-perthite rock. The other is marked by the occurrence of antiperthite in place of K-feldspar and twinned plagioclase. Such compositional differences can be observed only in thin-sections.

Table 5

Modal Composition of Hypersthene Granites and Enderbitic Granites

<table>
<tr><th></th><th>P-50-8/A</th><th>M-49-28</th><th>P-55-6</th><th>M-73-8/A</th><th>R-54-8</th><th>Enderbite Tilley, 1936</th></tr>
<tr><td>Quartz</td><td>46</td><td>45</td><td>35</td><td>42</td><td>45</td><td>42.5</td></tr>
<tr><td>Perthite</td><td>38</td><td>38</td><td>48</td><td>56</td><td>-</td><td>-</td></tr>
<tr><td>Twinned Plagioclase</td><td>9</td><td>12</td><td>12</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Antiperthite</td><td>-</td><td>-</td><td>-</td><td>-</td><td>51</td><td>53</td></tr>
<tr><td>Hypersthene</td><td>5.5</td><td rowspan="2">3.5</td><td>4</td><td>-</td><td>3</td><td>3</td></tr>
<tr><td>Diopside</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Accessory</td><td>1.5</td><td>1.5</td><td>1</td><td>2</td><td>1</td><td>1</td></tr>
</table>

Quartz occurs either as small granules or as oriented lenticles. Needle-like inclusions can be seen under high magnification.

K-feldspar is perthitic and the lamellae appear either as minute hair-like lines in parallel orientation, or as stubby lamellae in random orientation. Twinned plagioclase is clear oligoclase. Antiperthite is untwinned and can be mistaken for perthite unless the slide is stained.

Hypersthene has a very pale pinkish pleochroism. The negative axial angle is large. Clinopyroxene is found in small amounts in some of the thin-sections. Magnetite in irregular grains is accessory.

Discussion

Field relations indicate that the hypersthene granites intruded the older rocks of the Manicouagan upland before the main period of deformation. The sillimanite- and diverse pyroxene-bearing gneisses, as well as the granulitic gabbro, are conformably interlayered with the hypersthene granites.

The modal analyses offer a two-fold subdivision: a major group is characterized by the perthite-plagioclase pair and a minor group contains antiperthite only. The chemical analyses show that in the perthitic hypersthene granites K_2O predominates over Na_2O. In the antiperthitic rock Na_2O is about three times as abundant as K_2O. The Na_2O and K_2O content of the analyzed specimens from the Manicouagan upland are compared to the hypersthene-granitic rocks of some other localities in Table 6. In Figure 4 the Na_2O content is plotted against the K_2O content. Some analyzed sillimanite-bearing gneisses from Table 3 are also given for comparison. The genetic differences of the rocks of sedimentary origin are obvious from the spread in Figure 4.

Table 6

Tenor of Na_2O and K_2O in Hypersthene Granites and Related Rocks

No.	Na_2O	K_2O	Source
1	3.14	3.66	Hypersthene granite (P-50-8/A) Manicouagan upland
2	2.55	3.50	Hypersthene granite (M-86-10) Manicouagan upland
3	3.03	4.38	Quartz-perthite rock (M-73-8/A) Manicouagan upland
4	2.57	3.79	Average of eight acid charnockites from Ceylon
5	2.87	3.99	Acid charnockite from Uganda
6	4.25	1.63	Enderbitic granite (R-54-8) Manicouagan upland
7	3.64	0.74	Enderbite, type specimen
8	3.60	1.08	Plagioclase-quartz-hypersthene granulite (enderbite) from Lapland

References: 1, 2, 3, 6 present report;
4, Adams 1929, p. 481;
5, Groves, 1935, p. 163;
7, Tilley, 1936;
8, Eskola, 1952, p. 144

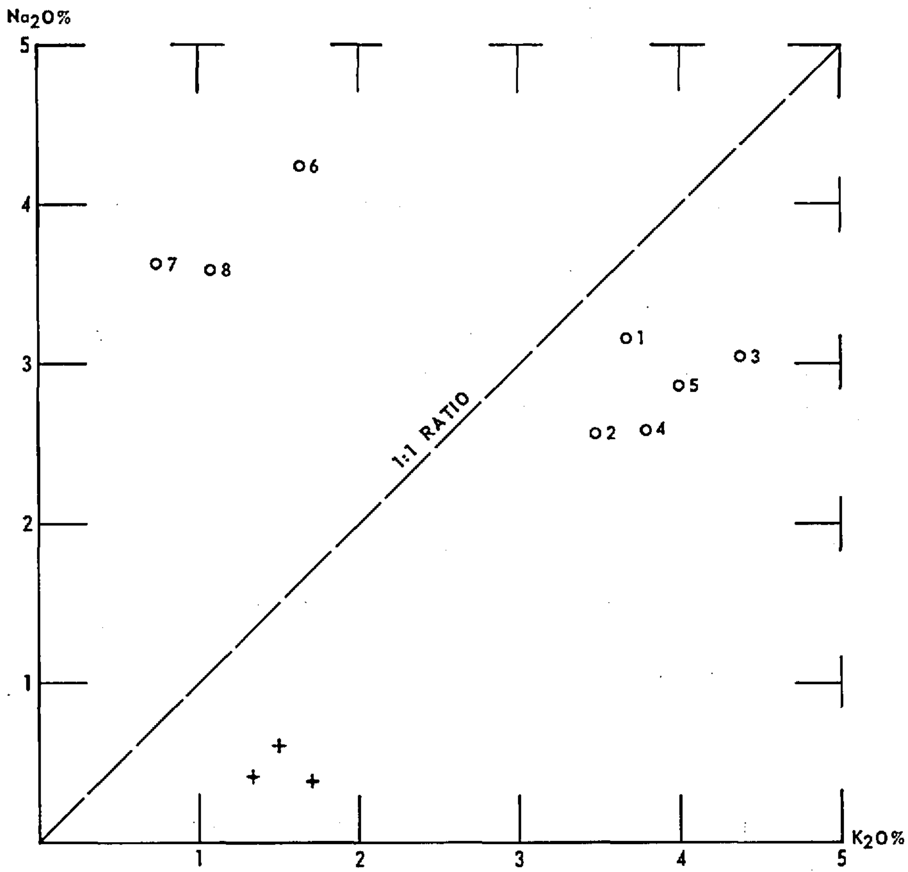


Figure 4

THE Na_2O CONTENT IS PLOTTED AGAINST THE K_2O CONTENT FROM HYPERSTENE GRANITES (1-5), ENDERBITIC GRANITES (6-8), AND SILLIMANITE-BEARING GNEISSES (INDICATED WITH CROSSES).

(Data from tables 6 and 3)

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Garnet-plagioclase Rock

Small, scattered outcrops of a peculiar garnet-plagioclase rock were found in the granulitic gabbros of the western third of the area and in the southeast corner of Brien township. The rock is spectacular in hand specimen with its white feldspar and spots of red garnet.

Thin-sections show extreme deformation of the plagioclase. The grains are intensively granulated and the twin lamellae are twisted. The composition ranges between An_{44} and An_{51}. Rarely it is antiperthitic. In spite of extreme deformation the plagioclase is clear, and there is no clouding or sericitic alteration. Randomly distributed garnet makes up about 50% of the rock. The garnet is euhedral (except in quartz-bearing specimens where it is anhedral) and some grains are up to 8 mm. in diameter. Quartz is present in some specimens in layers 2-3 mm. thick. Accessory minerals include rutile and zircon. In some thin-sections traces of pyroxene, epidote, and K-feldspar were seen. Some garnet grains contain inclusions of spinel and opaque ore minerals. Traces of biotite occur along the cracks of the garnet.

The origin of the garnet-plagioclase rock is not clear. The texture shows that the garnet developed after the deformation of the rock, and this suggests introduction of material. A metasomatic enrichment in alumina is a possible explanation.

Pyroxenite

Pyroxenite sills 2-5 feet thick form conformable layers with sharp contacts in the layered rocks of the Manicouagan upland. They are most abundant southeast of Lucie lake.

The orthopyroxene is pale pinkish hypersthene and has a (-)2V 86-88°. The colorless diopside has a (+) axial angle 72-74°. In some specimens from along fractures near the northern margin of the complex the pyroxene suffered slight hydrous alteration. Traces of calcic labradorite were noted in a few specimens.

Cataclastic Rocks

Cataclasticly deformed rocks are relatively common north of latitude 51°35'. In general the deformation is restricted to layers less than a foot thick. The deformation has affected all the metamorphic rock types, but is better seen in the granulitic gabbros because the grains are larger.

All variations between a strained rock and completely deformed mylonite exist. Marginal granulation of the plagioclase was observed in many thin-sections. Foliation of cataclastic origin was developed by the elongation of pyroxene grains in the granulitic gabbro. In a more advanced stage, rounded eyes of pyroxene, plagioclase, and garnet are surrounded by a crushed groundmass. In the cataclastic augen gneiss the eyes vary in size from 0.5-2 mm. The plagioclase is apparently less resistant than the garnet and pyroxene and much of it is pulled to wavy ribbons.

In spite of the high degree of deformation, the minerals did not change chemically. The granulated plagioclase is clear and some of the smaller grains are not twinned. The granulated pyroxene is pleochroic. Quartz is introduced along the plane of mylonitization.

In the layered rocks south of Raudot lake crushed zones 2-5 mm. thick alternate with undeformed layers. The plane of deformation is parallel to the compositional layers. In the deformed zones scapolite and quartz form flaser texture.

In thin zones the rocks are true mylonites, the composition of which cannot be determined by optical methods. The rock is gray or brownish with oriented black streaks that presumably represent a milled opaque mineral. Rare, tiny, late fractures cut across the mylonitic foliation and contain secondary calcite and some micaceous minerals.

The origin of the rocks by deformation is clearly indicated by the textures. The composition of the minerals shows that the deformation occurred after the main period of metamorphism, for some typical metamorphic minerals, such as garnet, form augen. The deformation was not accompanied by the development of hydrous minerals, but some quartz was introduced into the deformed zones.

The cataclastic deformation occurred at depth. The trails of disintegrated particles and "rolling" of the augen suggest that the deformation was a slow process.

Quartz Stringers and Deformed Pegmatite

Sets of quartz stringers and deformed pegmatites occur exclusively within the metamorphic rocks of the Manicouagan upland.

Sharply defined quartz stringers are especially common north and northwest of Boissinot lake. They are more resistant to weathering than the granulitic gabbro host rock, and stand out 3-5 mm. above it. The thickness of the sets of stringers varies along the strike and rarely exceeds 1 foot, but exceptionally may be as much as 3 feet. The quartz stringers are either straight or gently curved. Some sets break up, branch, or taper out.

In hand specimen the rock is pale gray and appears cherty. Thin-sections reveal that 75% or more of the rock is quartz. The other constituents are plagioclase, pyroxene, and garnet. These minerals, which are constituents of the granulitic gabbro host rock, are disintegrated and appear in streaks and trails in the fine quartz mosaic.

The quartz stringers are probably irregular fractures and joints recemented with quartz.

Deformed pegmatites are a minor rock type and occur near the northern border of the metamorphic complex. They are indicated on the map. The rock is made up mainly of quartz, perthitic K-feldspar, and plagioclase, but may contain minor amounts of clinopyroxene and garnet. The quartz and a leaf-gneiss texture stand out on the weathered surface. Some quartz stringers and deformed pegmatites occur on the same general strike, and this field relation suggests a genetic relationship between the two rocks. They many derive from the same pegmatitic solutions.

Pink granitic material and massive pegmatite found rarely in the upland are similar to the common granites and pegmatites north of the upland.

The Amphibolitized Northern Margin of the Metamorphic Complex

The common rock in the marginal amphibolite zone along the northern contact of the metamorphic complex is a fine-grained dark gneiss composed essentially of plagioclase and amphibole. The amphibolitized zone is generally between 1 and 2 miles wide. In the central part of the area it separates the rocks of the granulite grade from those of the amphibolite grade. The marginal zone in the east follows the edge of the Raudot Lake igneous massif.

a) The marginal zone in the central part of the area

The rock mainly involved in the changes in the central part of the area is the granulitic gabbro, which was changed to a fine-grained amphibolite. The change is gradational from south to north.

The initial change, noticeable in thin-sections, is the marginal recrystallization of the deformed minerals. Pale green amphibole forms margins on the pyroxene, and biotite surrounds some accessory opaque granules. Garnet is in symplektitic intergrowth with amphibole in some thin-sections. Under greater alteration (Plate IVB) nearly all the pyroxene is replaced by a fine-grained, pale bluish green amphibole or by a mixture of amphibole and biotite. Drops of quartz occur in the fine-grained mixture around relic pyroxene grains. Plagioclase is present as subrounded and strained relic plates. In a more advanced stage all the plagioclase is recrystallized and relics of pyroxenes are hardly recognizable. Garnet is commonly present as small euhedral grains, and is distributed randomly (Plate VA).

A completely recrystallized marginal amphibolite is a dark, fine-grained mixture of the above-mentioned minerals. Gneissic texture is shown by the streak-like elongation of the granulated plagioclase and opaque mineral. Scapolite occurs in minor amounts and ribbons of quartz are also present.

The optical properties indicate that the pale bluish green amphibole is calciferous. The recrystallized plagioclase is clear, but poorly twinned, andesine.

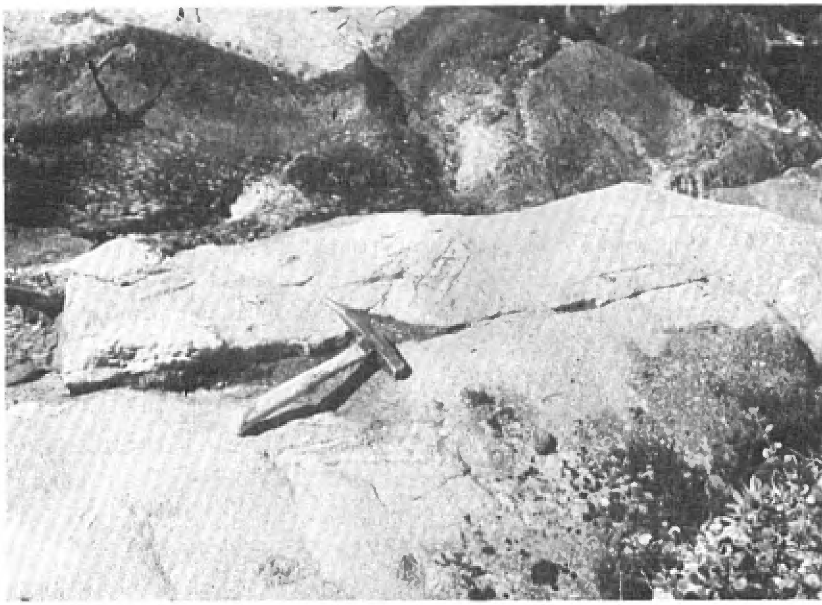
b) The eastern marginal zone

The eastern part of the amphibolitized marginal zone separates the metamorphic rocks of the upland from the Raudot Lake igneous massif. The amphibolitized zone narrows gradually eastward, and, at the eastern limit of the area, is confined to a narrow valley.

The eastern amphibolitized zone contains abundant light-colored layers besides the altered granulitic gabbro. The manner of transformation of the granulitic gabbro to fine-grained amphibolite was identical to that to the west. The composition of the recrystallized plagioclase varies from sodic labradorite to An_{38}. Some of the plagioclase contains minute plates or prisms as inclusions. The color of the amphibole varies locally from brownish to the more common bluish green.

The northern contact of the amphibolitized zone is marked by a well-defined valley, which follows the edge of the Raudot Lake igneous complex. Granite, syenitic pegmatite, and diabase were intruded into the rocks of the valley parallel to the contact. The introduced granite is gneissic, and the pegmatite is a coarse augen gneiss that occurs in discontinuous layers west of Raudot lake for several miles. The large augen of the gneissic pegmatite are perthitic microcline and plagioclase (An_{28-32}). The matrix is made up of biotite, less abundant muscovite, plagioclase, and quartz. Traces of garnet, diopside, hornblende, sphene, zircon, and opaque mineral also occur.

PLATE IV



A- P-77.3. Inclusions in granulitic gabbro east of Mora lake.

B- L-9-2. Photomicrograph. Crossed nicols. Granulitic gabbro to amphibolite. Note marginal granulation of plagioclase (Pl.) ginale du plagioclase (Pl.)

c) The contact between the marginal amphibolitized zone and the Raudot Lake igneous massif

Two miles west of the west end of Raudot lake the marginal amphibolite is separated from the edge of the igneous massif by a stream 10-15 feet wide. On the north side of the valley the igneous rocks form cliffs. In the flat valley area south of the stream a small outcrop is made up of fine-grained black rock, which has discontinuous white streaks. Thin-sections show that the dark fraction is made up of partly amphibolitized diopside and the light-colored fraction of scapolite. A layer of massive, white, sugary quartzite 8 feet thick is exposed on the south side of the diopside-scapolite rock. More than 90% of the rock is made up of quartz, in grains up to 1 mm. in diameter. In a thin-section, some twinned sodic plagioclase is distributed uniformly. The abundant accessory mineral is sphene, and traces of chlorite, muscovite, and epidote were noted. Near its northern contact the quartzite contains black bands 5-10 mm. thick. Thin-sections indicate that the dark bands are zones of cataclastic deformation, and in these zones granulated pale green diopside, sphene, and opaque dust are mixed with quartz.

A second contact zone is exposed at the east end of Raudot lake, where the amphibolitized margin is confined to the narrow valley. On the south side of the valley granulitic gabbro and interlayered siliceous rocks are cataclasticly deformed, but their pyroxene is not amphibolitized. The outcrop at the bottom of the valley is made up of alternating dark and light mylonites. The dark mylonite is a mixture of biotite, hornblende, feldspar, and opaque granules, and may be the mylonitized equivalent of a marginal amphibolite. The light mylonite has microaugen of garnet, hornblende and feldspar and may represent an extremely deformed variety of the augen gneiss west of Raudot lake.

Discussion

The amphibolitized marginal rocks are altered and slightly metasomatized equivalents of rocks of the Manicouagan upland. The most significant changes are the transformation of the pyroxenes to amphibole, introduction of quartz, and local scapolitization.

Amphibolitization of the pyroxenes in the highly metamorphosed rocks may occur, if water is present, when the P-T conditions become such as to permit the formation of hydrous minerals. However, the granulite-grade metamorphism occurred in essentially "dry" conditions. The fluids that caused the amphibolitization therefore must be derived from outside sources. The structure of the area offers the explanation:-

From the outlet of Hart-Jaune river a fault zone runs northeastward across the area. In the western part the amphibolitized margin of the granulite-grade rocks is separated from the ortho- and paragneisses by this fault. In the eastern part the same fault separates the Raudot Lake igneous massif from the gneisses. In a 1- to 2-mile-wide zone parallel to the fault, the rocks of the igneous massif are also metasomatized by penetrating fluids and deformed. It can be concluded, therefore, that the source of the solutions is related to the fault zone, and both igneous and metamorphic rocks were affected along the whole length of the fault.

In the east, solutions penetrated the southern margin of the Raudot massif, but their effectiveness greatly decreased towards Raudot lake, as is suggested by the sharply decreased width of the zone.

ORTHO- AND PARAGNEISSES OF THE AMPHIBOLITE GRADE AND MIXED GNEISSES

Ortho- and paragneisses are the common rocks north of the Manicouagan upland and Manicouagan lake. These rocks differ in many respects from the granulite-grade rocks, particularly in grade of metamorphism and character of the intrusions. The gneisses are mixed in many places with granitic material in complex relationships.

Outcrops north of the upland are less abundant than those in the upland, but are generally plentiful enough to permit interpretation of the geology.

Paragneisses

Biotite paragneisses

The biotite paragneisses are medium- to fine-grained rocks with abundant quartz and feldspars and with biotite as the chief mafic mineral. The biotite paragneisses north of Manicouagan lake and around Hart-Jaune falls are thinly layered, - the layers being marked by differences in ratios of the biotite to the light-colored fraction. Because of the thin layers and the oriented biotite flakes, the gneisses are strongly schistose. Wrinkles and small drag-folds point to plastic deformation. Porphyroblastic varieties,common in the west, have K-feldspar porphyroblasts up to 1 inch long and garnet porphyroblasts usually less than 10 mm. in diameter.

The colorless minerals of the biotite paragneisses are K-feldspar, plagioclase, and quartz. Great variation in the proportion of the minerals exists from place to place, and, because of the thinly layered character of the rocks, an average composition is hard to calculate. Locally the tenor of biotite may be as high as 80% and the flakes up to 6 mm. long.

On the other hand, some light-colored layers contain more than 50% quartz. Modal composition of the light- and dark-colored layers from an average specimen is given in Table 7. The specimen is from the falls area on Hart-Jaune river.

Table 7

Composition of the Biotite Paragneiss (L-18-6)

	Dark Color	Light Color	Average
Quartz	29	38	33.5
Plagioclase	38	36	37
K-feldspar	-	20	10
Biotite	30	6	18
Garnet	2	-	1
Accessory	1	-	0.5

In thin-sections the minerals look fresh. The plagioclase (well-twinned oligoclase) forms a mosaic with microcline and quartz. Traces of an altered mafic mineral were seen in the rocks around Hart-Jaune falls. The accessory minerals are apatite and an opaque ore mineral. Garnet grains in specimens from near the northern border of the central third of the area have a pinkish tint in thin-section and contain abundant inclusions.

The common biotite paragneisses in the northern part of the eastern third lack K-feldspar, and may be properly called biotite-plagioclase gneisses. In some specimens from this area the gneisses are well segregated, and layers 5-15 mm. thick are composed essentially of quartz and plagioclase. In the layers rich in biotite the flakes are densely packed and oriented (Plate VB).

Kyanite-biotite Paragneiss

Kyanite-biotite paragneisses are widely associated with biotite gneisses but are less abundant. On the northern shore of Manicouagan lake, west of North bay, they are thin-layered, porphyroblastic rocks with conspicuous azure-blue blades of kyanite.

In thin-sections (Plate VIA) the minerals are fresh. The K-feldspar is microcline, in part microperthitic, and plagioclase is scarce. The feldspars form a mosaic texture with quartz, but the K-feldspar occurs also as porphyroblasts. The biotite is pleochroic from straw-yellow to red-brown. The garnet is slightly pinkish. Muscovite and graphite are minor constituents. The accessory mineral is apatite.

Table 8

Modal Composition of Kyanite-biotite Paragneiss

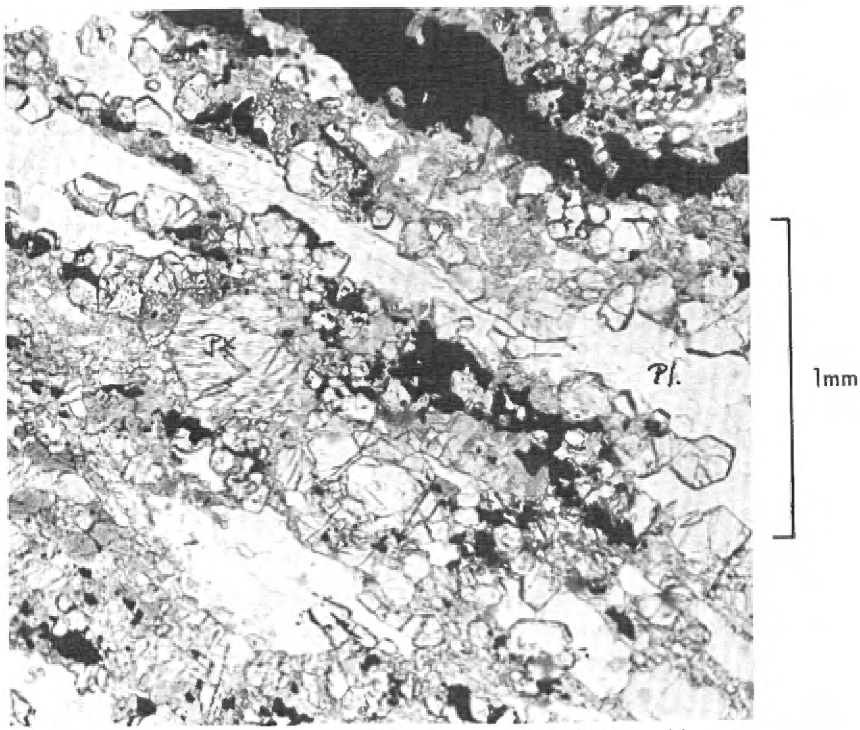
	(light) K-11-2/C	(dark) K-11-2/B	Average
Quartz	35	75	55
K-feldspar	28	19	23.5
Plagioclase	3	-	1.5
Biotite	19	5	12
Garnet	9	-	4.5
Kyanite	5	-	2.5
Others	1	1	1

A fine-grained, kyanite-bearing paragneiss about 4 miles north of Manicouagan lake is thinly layered, has abundant garnet, and lacks feldspar porphyroblasts. The kyanite is visible only in thin-section. The plagioclase/K-feldspar ratio is higher in this rock than in those along the shore of the lake. The quartz and feldspars form an inequant mosaic texture.

At Hart-Jaune falls, kyanite-bearing gneiss lying between dolomite and quartzite is made up to 40% quartz, 34% K-feldspar, 20% biotite, 4% kyanite, and 2% graphite, tourmaline and rutile. This composition compares with that of the rock on the shore of Manicouagan lake, both being characterized by a low tenor, or absence, of plagioclase.

The kyanite-bearing gneisses in the northeastern part of the area are different from those described above. They are medium to coarse grained and the suboriented blue blades of kyanite may be as long as 6 mm. A specimen from the southeast corner of Conan township lacks K-feldspar and carries quartz, plagioclase (twinned An_{20}), biotite, kyanite, and garnet.

PLATE V



A- R.-4-3. Photomicrograph, One nicol. Granulitic gabbro to amphibolite. Transformation of pyroxene (Px) to amphibole. Granular plagioclase (Pl).

B- Biotite-plagioclase paragneiss. C-101-27. Photomicrograph. Crossed nicols.

Biotite-hornblende Paragneiss

The hornblende-bearing biotite paragneisses are similar in mode of occurrence and hand specimen to the above-described biotite gneisses. Specimens from Berthelet township are thinly layered. The tenor of mafic minerals between layers is from 5% to 60%. The thickness of layers is also variable. Quartz, orthoclase, and plagioclase form mosaic textures with grains that vary in size between 0.5 and 1 mm. The plagioclase (An_{32}) is twinned. The hornblende is a strongly colored, green variety. The biotite is pleochroic from straw-yellow to dark brown. In some specimens sievey garnet is present. Minor minerals are scapolite, diopside, and accessory apatite. A specimen from 2 miles north of Pappour lake,and near the western border, contains 45% quartz, 42% plagioclase, and only minor quantities of K-feldspar. Specimens from northeast of Pappour lake contain abundant scapolite which forms a mosaic-like aggregate with quartz and twinned plagioclase. The biotite and hornblende are randomly distributed in the rock.

Hornblende-bearing biotite gneisses occur southeast of Espadon lake, A specimen, which was taken about 1 mile southeast of the lake, has a modal composition as follows:

Quartz	15%	Diopside	3%
Plagioclase	35%	Garnet	6%
K-feldspar	10%	Scapolite	2%
Biotite	10%	Accessory	1%
Hornblende	18%		

In thin-sections a fine-grained crystalloblastic texture is seen. The quartz contains minute bubbles.

In the eastern third the hornblende-bearing biotite gneisses are generally mixed with granitic material, and it is difficult to distinguish between light-colored gneiss and the injected material.

Biotite Paragneiss with Diopside

Some biotite gneisses in the northwestern part of the area contain diopside. This paragneiss has the general fine-grain and thinly layered properties of the other paragneisses, and differences can be seen only in thin-sections. About two thirds of the rock is made up of oligoclase, quartz, and K-feldspar, the last being perthitic in part. Diopside, biotite, and garnet make up the rest of the specimen.

Crystalline Limestone and Dolomite

At the north end of North bay on Manicouagan lake, a layer about 20 feet thick of crystalline limestone is folded with the gneisses. The contact of the limestone layer is marked by a dark reaction zone composed of diopside and calcite.

The crystalline limestone is massive and pale rose. The calcite crystals are 2-5 mm., and are coarsest towards the margin of the layer. Away from the contact the diopside is pale brownish, and colorless phlogopite is present. An average specimen is composed of 90% calcite, 8% diopside, and 2% phlogopite.

In thin-section (Plate VIB) the calcite shows intensive twinning and diopside forms subrounded, drop-like grains. The diopside is pale green and very faintly pleochroic near the contact but colorless farther away. The phlogopite is also colored near the contact and is pleochroic from pale green to olive. Towards the center of the layer, the mica is nearly colorless. Scattered dolomite crystals occur with the calcite. Pyrite is accessory.

A band of limestone about 3 feet wide lies adjacent to diopside-plagioclase gneisses at the point of a peninsula southeast of North bay.

A dolomite bed at least 12 feet thick is conformable with paragneisses and quartzite at Hart-Jaune falls. The quartzite overlies the dolomite, and the two beds are separated by a layer of biotite-paragneiss which contains kyanite. The dolomite is intercalated with mica-rich layers 1-2 inches thick. The sequence dips 35° southeast.

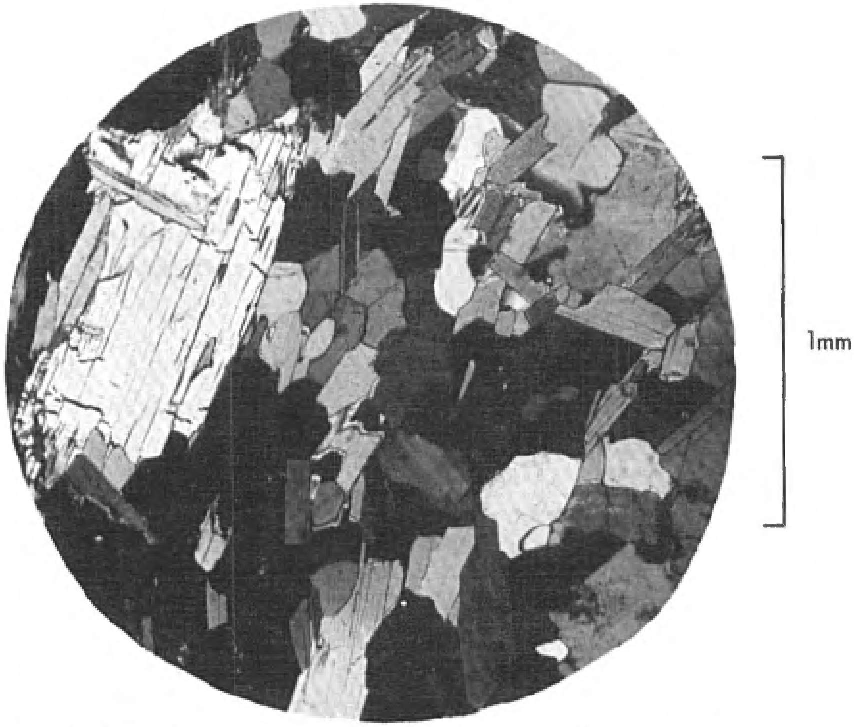
The dolomite is massive, pale gray, and medium grained. A stained specimen indicates less than 10% calcite as discrete grains mixed with dolomite. The phlogopite is in unoriented yellow flakes, and the diopside in scattered, round, brownish grains.

Dolomite (white marble) was found in the eastern third only in a pit in overburden north of the storage dam. At the edge of the exposure it is interlayered with hornblende-biotite gneiss. The dolomite is coarse grained and some layers have a faint greenish tint. The associated silicates are colorless diopside and fibrous or prismatic tremolite.

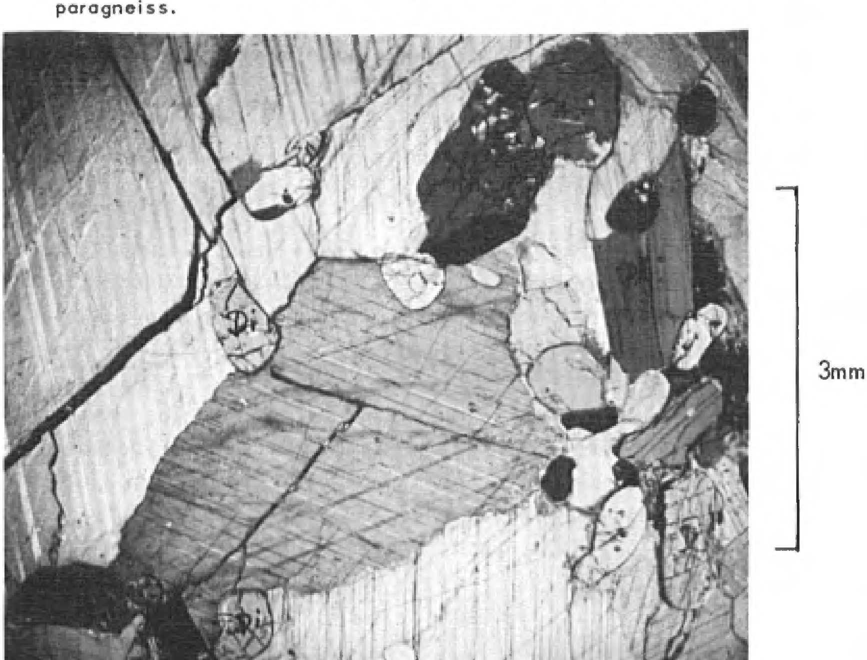
Quartzite

Thin layers of quartzite occur at several places in the western half of the area. Near the crystalline limestone bed in North bay

PLATE VI



A- K-11-2/C. Photomicrograph. Crossed nicols. Kyanite-biotite paragneiss.



B- S-62-1/A. Photomicrograph. Crossed nicols. Crystalline limestone with diopside (Di) and phlogopite (Ph).

on Manicouagan lake, quartzite of unknown thickness is tightly folded with hornblende and diopside gneisses. The rock is fine grained and light gray to bluish gray. It contains 85-90% quartz with sodic plagioclase, pale green diopside, and accessory sphene. The fine, interlocking quartz grains are elongated in one direction and have a shadowy extinction.

About 1.5 miles northeast of North bay, 2- to 3-foot-thick quartzite layers alternate with paragneisses and form a series of low ridges. The quartzites are made up of about 75% quartz, 20% feldspars, and some biotite (partly chloritized), green hornblende, sphene, and opaque ore mineral. The feldspar grains are oval and oriented.

A graphite-bearing quartzite outcrop 1 mile east of Espadon lake is fine grained and dark gray. As biotite forms oriented flakes with the graphite, the rock is foliated. Kyanite and garnet are the minor minerals.

The quartzite above the dolomite bed at Hart-Jaune falls is about 3 feet thick, and is overlain by hornblende-bearing gneisses. It varies from light gray to rose and is fine grained. Modal composition of a thin-section is as follows:

Quartz	86%	Biotite and muscovite	4%
K-feldspar	9%	Graphite and opaque dust .	1%

The feldspar crystals are elongated parallel to the biotite flakes, and the rock is foliated.

Beds of quartzite are mixed with granitic rocks north of Beaupin brook. Here the feldspars are sericitized, and chlorite is present besides muscovite.

Hornblende-plagioclase Gneisses

The general characteristic of the hornblende-plagioclase gneisses is the virtual absence of quartz and K-feldspar.

Garnetiferous hornblende andesine gneisses form discontinuous layers which extend north-northeast from the north shore of Manicouagan lake. The rock is dark gray, medium grained, hard, and poorly foliated. In some 2-10 mm. layers the tenor of hornblende is higher and the grain is coarser than in the rest of the rock. Evenly distributed garnet is seen in hand specimens.

Table 9

Modal Composition of the Hornblende-andesine Gneisses

	K-17-5	K-12-7/B
Plagioclase	59	58
Hornblende	30	29
Garnet	11	8
Others	-	5

The plagioclase is clear or only slightly sericitized well-twinned, calcic andesine (An_{47-50}). The hornblende is pale green. The garnet is colorless in thin-sections and the grains tend to be euhedral. Along hair-fractures chlorite and epidote have developed, and there are traces of secondary calcite. Biotite is minor in some of the thin-sections. The accessory minerals are sphene and, less commonly, opaque ore mineral.

Garnetiferous hornblende-andesine gneisses around the Brien anorthositic and gabbroic rocks. - The Brien township anorthositic and gabbroic rocks form topographic peaks north of Hart-Jaune river. The southern slopes of the peaks and the area as far south as Hart-Jaune river are underlain by medium to coarse basic gneisses that probably are the altered equivalents of anorthosite. The hornblende is concentrated in parallel streaks that emphasize the foliation. In thin-section the minerals are fresh, the plagioclase is poorly twinned calcic andesine, and the hornblende is pleochroic from pale green to bluish green and has a very large negative axial angle. The properties of the garnet are as follows:

Refractive index: 1.766
Density: 3.89
Cell edge = 11.53 Å
Approx. composition : Pyr_{42} Alm_{48} Gro_{10}

Near Hart-Jaune river the hornblende-plagioclase gneiss is altered, and the properties of the minerals are changed. The plagioclase is gray in hand specimens and has a confused contact with the amphibole. In thin-sections hair fractures are seen in the plagioclase (An_{46}) and the grains are somewhat sericitized. The hornblende is only slightly pleochroic and contains opaque dust. Deep blue chlorite appears in fractures and as pseudomorphs after garnet. Along the shores of Hart-Jaune river fibrous green chlorite and epidote are visible in hand specimens.

Garnetiferous hornblende-andesine gneisses also occur around a peridotite lens northeast of Espadon lake. There they are gray, medium to fine grained, are composed mainly (over 50%) of dark minerals, and are strongly foliated. The clear andesine is poorly twinned, and is mixed with scapolite. Strongly colored green hornblende is mixed with relic grains of diopside. Garnet is abundant and distributed uniformly. However, close to the peridotite garnet is absent and the hornblende is pale. The negative 2V of the hornblende is 85° and its pleochroic formula is : X = very pale yellow; Y = pale greenish brown; Z = pale greenish yellow. In one specimen, the plagioclase is sodic-labradorite.

At the northern limit of the central part of the area garnetiferous hornblende-andesine gneiss forms a semicircular outcrop area on the east side of which scapolite is common. A specimen from the western end of the outcrop area contains considerable plagioclase (An_{47}), and some bright green hornblende.

Diopside-hornblende-oligoclase and diopside-oligoclase gneisses are found along the shores of North bay on Manicouagan lake, and southeast of the bay. The gneiss with hornblende is dark gray and poorly foliated. Much of it is injected by pink granitic material, but the two fractions are readily distinguishable. The modal composition of an average specimen is as follows:

Plagioclase	44%	Sphene	3.5%
Hornblende	49%	Others	0.5%
Diopside	3%		

In thin-sections the grains (1-2 mm.) form an equant mosaic texture. The clear oligoclase has broad albite-twin lamellae. The hornblende is strongly colored from straw-yellow to green to dark green and the negative axial angle is 45-50°. The diopside is pale green. Brownish pleochroic sphene is relatively common.

Around the point southeast of the bay the hornblende-bearing gneiss grades into thinly layered diopside-oligoclase gneisses with rare hornblende. The latter gneisses form cliffs facing the lake. A 3-foot-thick limestone layer is isoclinally folded with the gneisses. The diopside of the gneiss is pale green, and sphene is an abundant accessory.

Hornblende-oligoclase gneiss with variable amounts of diopside occurs around the outlet of Beaupin brook and near Hart-Jaune falls. The modal compositions of two specimens are listed in Table 10. The oligoclase is poorly twinned, slightly sericitized, and some grains enclose granules of quartz. The green hornblende is strongly colored and has a (-)2V 40-50°. The texture suggests a transformation of diopside to hornblende. Sphene is an abundant accessory.

Most of the hornblende-plagioclase gneisses in the eastern third of the area are the dark fraction in the mixed gneisses. They contain microcline as well as plagioclase (An_{20-22}). Relic crystals of diopside occur in association with hornblende. Minor constituents include biotite, scapolite, sphene, calcite, apatite, epidote, and opaque mineral.

Table 10

Modal Composition of Hornblende-oligoclase Gneisses

	L-18-3	L-1A-5
Plagioclase	44	42
Hornblende	42	40
Biotite	12	-
Diopside	-	6
Sphene	1	4
Opaque	-	6
Others	1	2

Hornblende-oligoclase gneisses occur as narrow layers in the paragneisses in the northern part of the western third of the area. The rock is dark and massive or only slightly gneissic and may be called amphibolite. Hornblende makes up nearly two thirds of the rock, and the presence of quartz distinguishes this type from the other hornblende-plagioclase gneisses. Biotite and garnet may be present also.

Scapolite-hornblende-plagioclase gneisses. In rare instances scapolite may make up one third of the gneiss. The modal composition of a specimen from northeast of North bay is as follows:

Scapolite	31 %	Diopside	5.5%
Plagioclase	28.5%	Sphene	5 %
Hornblende	30 %	Opaque	Traces

The rock is fine grained and thinly layered. The plagioclase is intermediate oligoclase. The high tenor of sphene is conspicuous.

Discussion

The paragneisses and hornblende-plagioclase gneisses are the products of high-grade regional metamorphism. The origin of some of the gneisses can be inferred from the present compositions, but injection and complex folding have confused the relations between the ortho- and paragneisses, and a stratigraphic sequence is impossible to reconstruct. Metamorphism obliterated primary features, leaving foliation and compositional layers as the main structural characteristics of the gneisses. There are some indications that the layers represent original compositional differences, the outcrop at Hart-Jaune falls being an example. Here parallel layers of dolomite, kyanite-bearing paragneiss, and quartzite are relatively well preserved. This sequence is clearly the metamorphosed equivalent of original limestone, shale and sandstone. Some layers may have formed by lit-par-lit injection or by metamorphic segregations.

The almandine amphibolite facies is subdivided into three subfacies (following Fyfe et al. 1958), namely, staurolite-quartz kyanite-muscovite-quartz, and sillimanite-almandine subfacies. The presence of kyanite and absence of staurolite in the gneisses of proper compositions indicate a metamorphism above the stability range of the staurolite. Thus, the gneisses of the Hart-Jaune River area north of the Manicouagan upland were metamorphosed in the upper amphibolite facies.

Biotite gneisses are very common rocks in the Grenville subprovince and the main compositional difference between various localities, as inferred from geological reports, is in the K-feldspar/plagioclase ratios.

The significance of the alkali ratios in the Grenville gneisses is discussed by Engel and Engel (1953). Considering the possible sedimentary antecedents of the gneisses, they write (p. 1085): "an excess of Na_2O over K_2O ... seems to be characteristic of certain graywackes found particularly in the eugeosynclinal association and is certainly the most significant difference in the chemical compositions of these rocks as contrasted with shales, silts, or sandy sediments derived as residual weathering products".

K_2O predominates over the Na_2O in the kyanite-bearing gneisses north of the upland, and this seems to be valid for the other associated biotite gneisses. It can be concluded, therefore, from the composition and the associated thin quartzite and calcareous layers, that the biotite gneisses of the Hart-Jaune River area are comparable to those gneisses of the Grenville subprovince which derive mainly from shales.

The quartzites associated with the amphibolite-grade rocks differ from each other as much as they differ from the quartzites of the granulite-grade area. A similar environment of deposition cannot be inferred from their present composition although both are probably derived from poorly sorted sandstones. Diopside and sphene are the minor minerals in the quartzite near Manicouagan lake, and diopside gneisses are the interstratified rocks. Dolomite underlies the quartzite at Hart-Jaune falls. East of Espadon lake and north of the falls the minor minerals in the quartzite are graphite and kyanite, and the calcareous member was not found. The diverse associations suggest that the quartzites of different localities do not represent the same stratigraphic level.

Crystalline limestone and dolomite near Manicouagan lake are made up of nearly pure calcite. Dolomite is the main constituent of the marbles in the central and eastern thirds (one occurrence in each). Diopside and phlogopite are the associated silicates near Manicouagan lake, and tremolite appears in dolomite of the eastern section. Crystalline limestone as such was not found in the area of the granulite-grade rocks.

In summary, a facies change is noticeable from Manicouagan lake northeastward. Near the lake, the biotite gneisses are porphyroblastic and contain abundant K-feldspar, and calcite is the associated carbonate, whereas plagioclase is the main feldspar in the biotite gneisses, and dolomite is the associated carbonate rock of the gneisses in the northeastern corner of the area. The biotite-plagioclase gneisses are very similar to those that underlie the quartz-specularite iron-formations at Jeannine lake, and a genetic relation between the two formations is highly probable.

The diopside-hornblende-oligoclase and diopside-oligoclase gneisses are associated with relic limestone beds and formed by silicification of the carbonates. Their plagioclase is less calcic than that in the metamorphosed calcareous rocks in the upland area (labradorite and bytownite) and this is thought to be related to the degree of metamorphism.

The hornblende-andesine gneisses south of the Brien anorthositic rocks clearly represent altered facies of the anorthositic gabbro. The gradual transformation from massive igneous rock to basic gneisses has been observed at several places. The garnet of the dark gneisses is a pyrope-almandine type and indicates a high temperature metamorphism. The chlorite and epidote occurrences in the hornblende-plagioclase gneisses near Hart-Jaune river are related to the fault that separates these gneisses from the rocks of the Manicouagan upland. A low-temperature chloritic-epidotitic alteration affected all the rocks along the fault, and occurred after the metamorphism of the garnetiferous hornblende-andesine gneisses.

The garnetiferous hornblende-andesine gneisses near the western limit of the area form discontinuous but conformable layers in the paragneisses. By their composition these rocks may derive either from basic igneous rocks or from calcareous sedimentary rocks.

The problem of the hornblende-plagioclase gneisses north of Hart-Jaune river is complicated by the local abundance of scapolite, which in some thin-sections makes up nearly one third of the rock and is in apparent equilibrium with the plagioclase, amphibole, and diopside. Scapolite is a typical metamorphic mineral, with a stability range that extends from the amphibolite facies to the granulite facies. Its formation may be the result of metasomatism or regional metamorphism. Transformation of plagioclase to scapolite was noted in the granulitic gabbros south of the Hart-Jaune. However, in the hornblende-plagioclase gneisses north of the river the scapolite is in apparent equilibrium with the other minerals and these gneisses are likely of calcareous sedimentary origin.

Thin and widely scattered layers of amphibolites in the northern part of the western third of the area are probably early basic dikes or sills which, by complete recrystallization, lost their igneous textures.

Mixed Gneisses

The paragneisses and hornblende-plagioclase gneisses are commonly interlayered or mixed with pink granitic material, the proportion of which varies from a minute fraction in some thin-layered varieties to a very large part in true gneissic granites and granite-pegmatites. In most cases the contacts between the older gneisses and the injected material are sharp.

The injected material may form regular and relatively thin layers, giving a *lit-par-lit* structure. Or, the mixture may be complex and irregular, and the layers of older gneisses distorted or broken. Both varieties are widespread north of the Hart-Jaune fault.

Regular *lit-par-lit* type mixed gneisses are common along the shores of North bay and north of the bay (Plate VIIA). The dark fraction is hornblende-biotite paragneiss. Plastic deformation of the *lit-par-lit*-type injected beds occurs in the same general area, and the subparallel nature of the two rock types is preserved in the folded state.

Along the northern shore of Manicouagan lake the dark fraction of the mixed gneisses is in angular or rounded masses some of which are lensoid or rod-like and may be aligned parallel to the foliation (Plate VIIB).

The mixed gneisses in the northeastern part of the area may be in regular layers or irregularly mixed. The layers in the *lit-par-lit* type mixed rocks are very thin and it is hard to distinguish between light-colored layers of paragneiss and granitic material. The modal composition of a specimen from the dark fraction of the mixed gneiss is as follows:

Quartz	31%	Biotite	27%
Plagioclase	39%	Others	3%

The minor minerals are muscovite, chlorite, K-feldspar, and an opaque ore. The modal composition is identical with that of the common biotite-plagioclase gneisses of the northeastern part of the area.

INTRUSIVE ROCKS OF THE ANORTHOSITE-GABBRO FAMILY

Raudot Lake Intrusive Massif

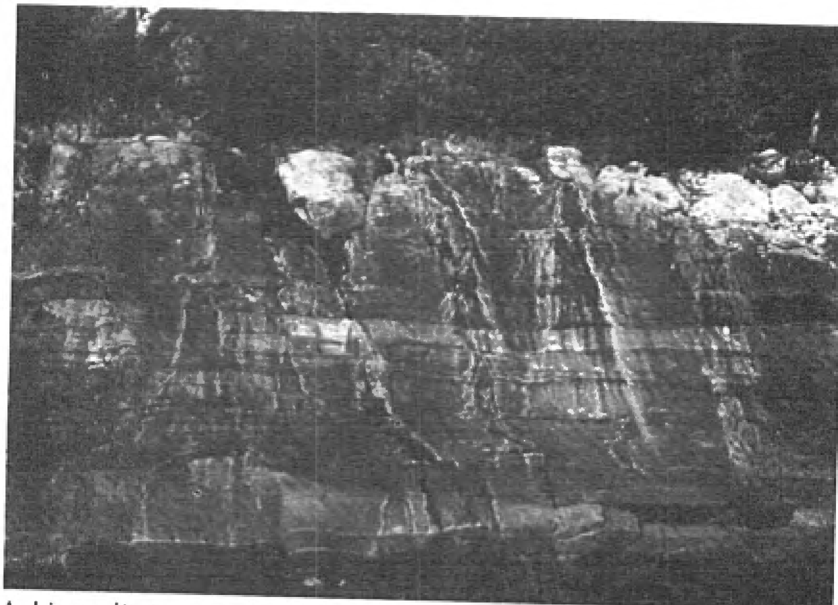
Four bodies of anorthosite-gabbro are known in the area. The largest of these is the Raudot Lake massif in the northeast. Its northern limit coincides with the edge of the Manicouagan upland, and is marked by the N.60°E.-striking Hart-Jaune fault. At the southern limit of the massif, cliffs face an east-west-trending valley, part of which is occupied by Raudot lake. The rocks in this contact zone are the sheared equivalents of the metamorphic rocks of the upland. The longer diameter of the massif trends east-northeast and is about 14 miles long within the area. The extent of the intrusive mass to the east of the map-area is not known. The southern part of the complex is well exposed but outcrops are scattered in the northern third.

The southern and central parts of the massif are unaltered. The western and northern parts are deformed, metamorphosed and, in part, metasomatized.

Unaltered Rocks

Along the southern edge of the massif, magnetite-rich layers alternate with magnetite-gabbro and dunite layers (Plate VIIIA). The thickness of the layers is variable, and facies rich in mafic and opaque minerals predominate. The lowest exposure, at the east end of Raudot lake, contains a magnetite layer at least 6 feet thick. The magnetite grades into gabbroic anorthosite through a transitional magnetite gabbro. At the west end of Raudot lake, there are compositional layers within 1,000 feet of the contact. An outcrop 1/2 mile west of the lake consists of layers of magnetite-rich gabbro and olivine-bearing anorthositic gabbro. Facies with higher tenors of plagioclase become gradually more abundant northward towards the center of the massif. Coarse anorthosite layers 2-3 feet thick are followed by troctolitic layers or dunite. The general strike of the compositional layers is east-west and the dips average 35°N.

PLATE VII



A- Lit-par-lit type mixed gneisses. The dark layers are paragneiss. North bay, Manicouagan lake.

B- Mixed gneisses on the north shore of Manicouagan lake.

A slight increase in dips and in thickness of layers was noted from east to west. Magnetite-rich gabbro layers, about 15 feet thick, alternate with anorthosite and dip 40-45°N. in the northeast corner of Jauffret township.

The tenor of the ilmenitic magnetite opaque mineral decreases gradually away from the southern contact and, in a distance of 3,000-4,000 feet, the layers are less regular and divert from the east-west trend. Discontinuous layers were noted up to 2 miles north of the southern border. Large outcrop areas of massive and coarse anorthositic gabbro and gabbroic anorthosite were found in the central part of the massif, and facies of troctolitic gabbros were roughly outlined. The diverse rock types grade into each other and their distribution is irregular. Rarely, inclusions of coarse anorthositic rocks occur in the gabbroic facies.

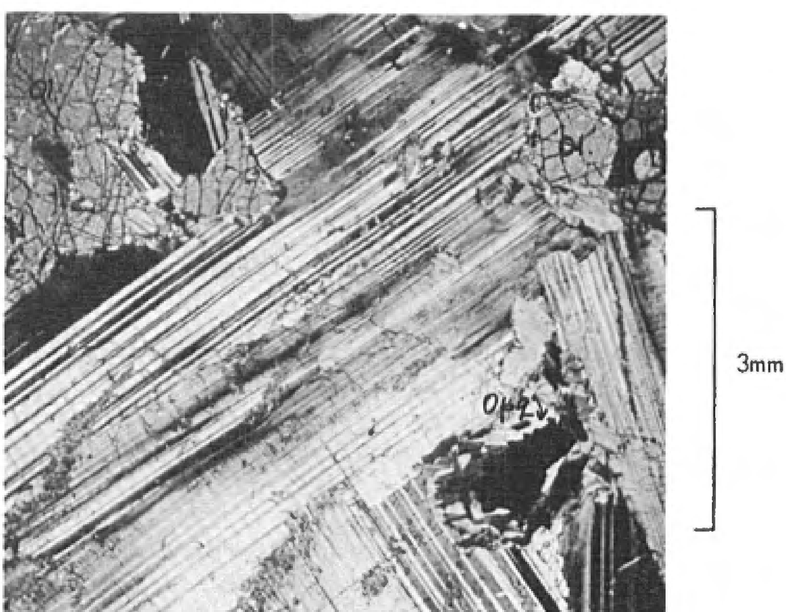
Anorthosite proper is relatively rare and is dark bluish gray. It was found north of the east end of Raudot lake, at several places in the southwest corner of F~gundez township, and north of Jorian (Bucko) lake. The shiny plagioclase laths are commonly up to 1 inch long, but larger crystals also occur. Rarely the plagioclase is granulated and the bluish central part of the crystals is surrounded by greenish or pinkish margins. The mafic mineral is olivine, and accessory magnetite may be present. Near the northern metamorphosed part of the massif, the plagioclase is strained and fractured. In thin-sections, sericite is seen along the cracks, minor scapolite has developed, and the olivine is loaded with opaque dust. Biotite and accessory calcite occur in some specimens.

Anorthositic gabbro and troctolitic anorthosite are the most common rocks. They contain 20-30% dark minerals, and the coarse-grained variety grades into the anorthosite proper. The minerals are fresh and the rocks are massive. The common mafic mineral is olivine, but in the specimens north of the east end of Raudot lake some biotite, traces of clinopyroxene, and accessory apatite were found; here also 1-2 mm. fractures are filled with a greenish hydrous mineral, and near the fractures the olivine is altered to orange-brown iddingsite and greenish bowlingite. Red-brown biotite is concentrated around magnetite grains. A narrow rim of alteration occurs between olivine and plagioclase. The texture of a troctolitic anorthosite is shown in Plate VIIIB. On the weathered surface the olivine is dark or rusty brown or, rarely, olive-green.

Olivine gabbros (troctolites) occur either as layers in the southern part or as irregular patches inside the complex. Some specimens contain 3-5% pyroxene besides olivine. Rarely the plagioclase laths are oriented and the rock has a primary foliation, but in general the gabbro is massive. In thin-sections the minerals are clear except the pyroxene, which is dusted. The plagioclase has a slight brownish tint.

PLATE VIII

A- Layers in Raudot Lake massif near its southern edge.



B- P-24A-4 Photomicrograph. Crossed nicols. Troctolitic anorthosite north of Raudot lake. Note tiny margin of alteration around olivine (01.) and biotite rim on opaque mineral (Opq).

A very narrow double rim separates the olivine from the plagioclase (Plate IXA). The rim is colorless (probably pyroxene) against the olivine and dirty green against the plagioclase. The reaction products are too fine grained for definite optical determination. Rims are found also at the contact of plagioclase with an opaque mineral, but reaction borders did not develop between the opaque mineral and olivine.

Magnetite gabbros occur near or at the extreme southern margin of the massif and, with a decreasing tenor of plagioclase, they grade into massive magnetite layers. The magnetite gabbro is composed of 40-50% plagioclase, 20-35% magnetite and spinel, and variable amounts of pyroxene (up to 8%), olivine, biotite and alteration products. In thin-sections the plagioclase has a slight brownish tint. The plagioclase is separated from the opaque and spinel grains by a narrow pale-green rim of alteration which is probably amphibole. Incomplete rims of bright red biotite occur around some opaque grains. Orthopyroxene is present as a fine-grained aggregate and only a few well-developed grains can be seen; the center of the larger grains is loaded with opaque dust. The clinopyroxene may be partly altered to pale green amphibole and biotite. At the edge of the massif, alteration products are common and the rocks are devoid of olivine.

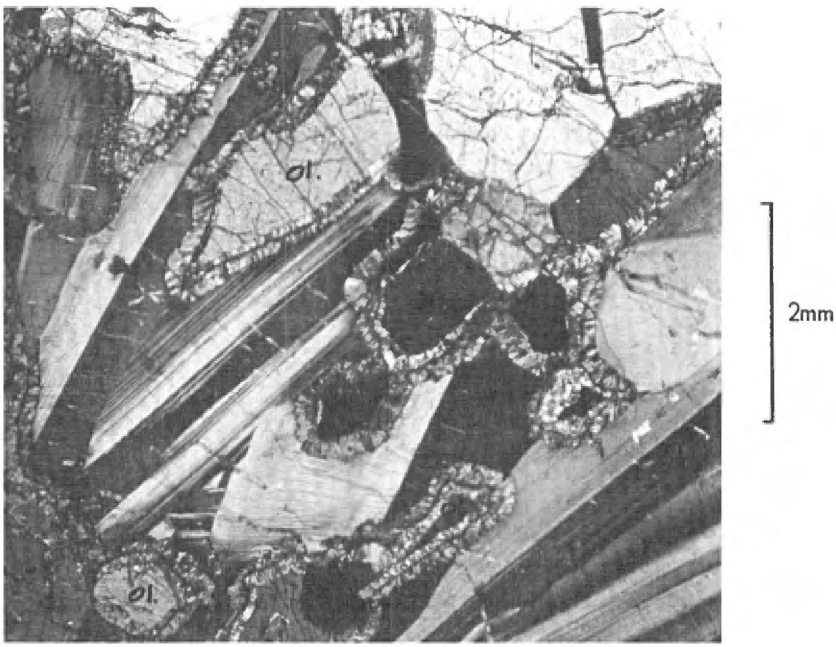
Layers of magnetite-olivine rock are abundant in the southern part of the massif, and occur as far as 1 1/2 miles to the north. The olivine is in subrounded 1-5 mm. grains embedded in the iron-oxide matrix, and is coarsest away from the contact. Specimens from the west end of Raudot lake are made up of about 65% olivine, 25-30% opaque ore mineral, some green spinel, up to 10% plagioclase, and a variable amount of alteration product. This rock grades into magnetite-gabbro with increasing tenor of plagioclase. The modal composition of a specimen (Plate IXB) from about 1 1/2 miles north of the southern edge of the massif is as follows:

Olivine	44%
Opaque ore mineral ...	52%
Spinel	4%

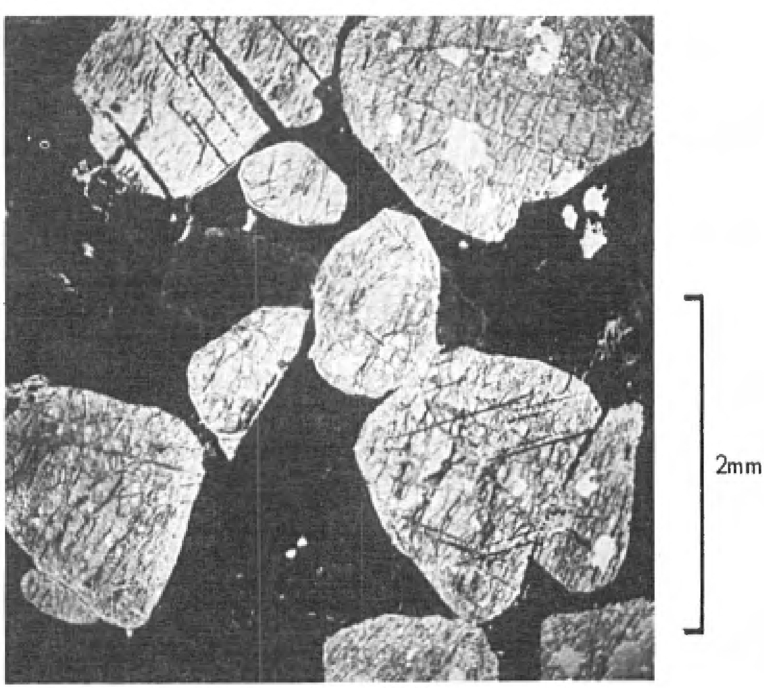
Massive magnetite layers of variable thickness occur at the southern margin of the massif. In polished sections, needles of ilmenite are seen in the magnetite matrix. One analyzed specimen contains 50.27% iron and 6.37% titanium. The opaque ore, when hit with a hammer, breaks along microjoints.

Dunite layers are common in the southern, layered part of the massif. A 5-mm.-thick weathered zone is rusty brown but the rest of the rock is fresh. A typical specimen from the southwest corner of Fagundez township is composed of: olivine 88%, plagioclase 7%, rim material 5%, traces of opaque mineral and spinel.

PLATE IX



A- P-33-7/A. Photomicrograph. Crossed nicols. Olivine gabbro (troctolite). Note double coronas between olivine (01.) and plagioclase.



B- P-33-11. Photomicrograph. One nicol. Magnetite-olivine rock. The olivine is serpentinized. Sp = Spinel.

In thin-section (Plate XA) the olivine forms an equigranular mosaic with rimmed plagioclase in the interstices.

The mineral compositions of the unaltered rocks in the southern and central parts of the massif are summarized below. The plagioclase crystals in all determined specimens are clear and well twinned. A brownish tint, which is common in thin-sections, is probably related to the dark bluish gray color of the hand specimens. Its presence or absence does not seem to be related to the calcity of the plagioclase. The composition in 24 specimens is between An_{66} and An_{59}. Two determinations near the southern edge of the massif indicate An_{56}; both specimens contain pyroxene.

The olivine varies in composition between Fay_{24} and Fay_{37}. It is fresh except in the magnetite-olivine rock where there is some serpentinization. A narrow reaction border, 0.1-0.2 mm. thick, occurs between the plagioclase and olivine.

Ortho- and clinopyroxene are rare minerals. The orthopyroxene is colorless hypersthene with a nearly 90° axial angle. The clinopyroxene is diopsidic,judging from the scanty data available.

Syenitic Dikes

Dikes up to 1 foot thick cut the southern margin of the massif at several places. Their regular thickness and sharp contacts, with no chilled margin, are characteristic.

The rock is coarse and massive, and superficially resembles anorthosite. Plagioclase, biotite, and interstitial mafic mineral are seen in hand specimens. The coarse plagioclase euhedra are randomly oriented, and the margin of the grains weathers whitish. In thin-sections, the plagioclase is well twinned and the grains show partial resorption. Perthitic K-feldspar surrounds the plagioclase and at their contact the plagioclase is zoned. The cores of the grains have a composition of An_{38}, and the margin is less calcic. Quartz is minor, and may occur with the K-feldspar or be mixed in the aggregate at the granulated border of a plagioclase. Red-brown biotite is concentrated around the accessory opaque ore mineral. Hypersthene and diopside are minor and present only in some specimens.

Altered Rocks of the Raudot Lake Massif

The rocks in the northern and western parts of the massif are variably altered and deformed, the intensity increasing from south to north. The width of the altered zone is up to 3 miles.

The slight changes in alteration are noticeable only in thin-sections, and are marked by transformation of the olivine to pale bluish green amphibole. The hand-specimen properties of the plagioclase are changed only in a more advanced stage of alteration, which is characterized by fracturing of the rock. In the more altered rock the feldspar is light gray and the mafic mineral forms very fine-grained clusters. In thin-sections, needles of amphibole are seen along the grain borders and in the fractures of the plagioclase (Plate XB). Near the northern border of the massif, the plagioclase is partly or completely recrystallized and the contacts between light and dark minerals are blurred. The composition of the plagioclase is sodic labradorite in the slightly altered rock and calcic andesine in the more altered types. The rocks close to the northern contact of the massif contain chlorite and biotite besides the amphibole, and the primary texture is rarely recognizable. In some completely altered varieties scapolite and epidote are present, and the small granules of plagioclase form an aggregate with needles or prisms of amphibole and biotite.

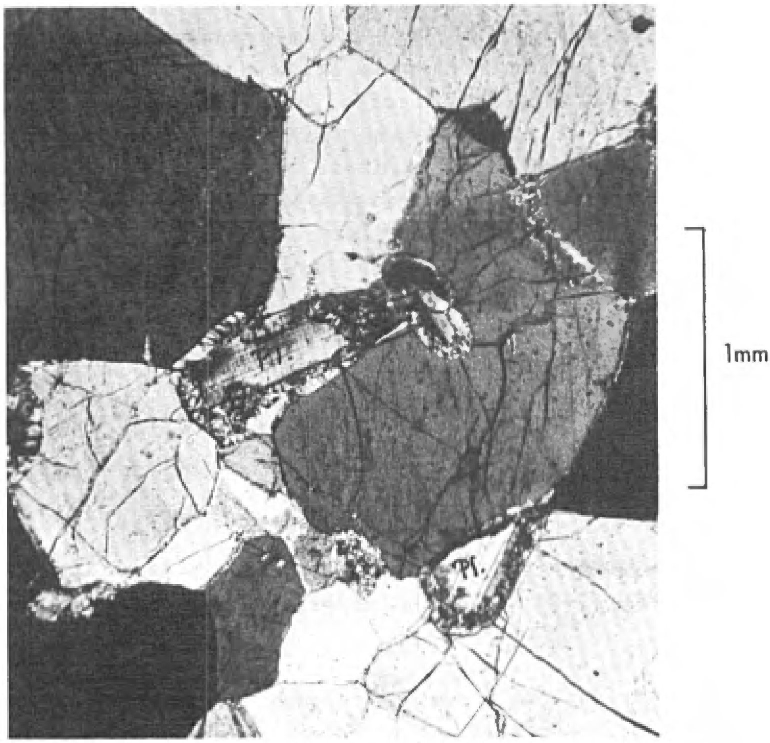
Staurolite occurs in some of the altered rock. The crystals vary in size and shape from minute blades to well-developed and twinned euhedra.

In discontinuous shear zones near, and parallel to, the northern edge of the massif the rocks are fine grained and the minerals are distinguishable only in thin-sections. Relic crystals of plagioclase are surrounded by a mixture of scapolite and fine-grained plagioclase. Some shear zones are drag-folded and the rock is thinly layered. Pink granitic material forms dikes and veins in the margin of the complex. Scapolite, chlorite, and epidote have developed in the deformed rock adjacent to the granite.

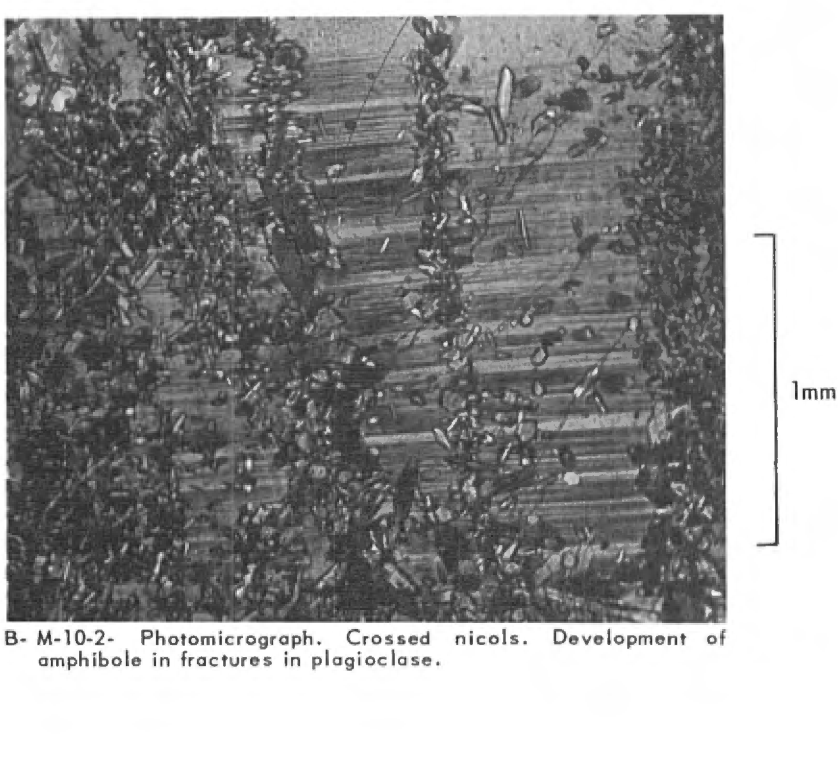
Near the railway in the northeastern corner of the area, the transformation of the primary mafic minerals is complete, but the physical deformation is not intensive. The rocks are very coarse, and the plagioclase in some anorthositic facies is up to 1 foot long. The interstitial mafic mineral is altered, and well-developed corona structure, some of it giant, is seen on the weathered surface. The center of the irregular mafic blebs is a fibrous serpentinized alteration product of olivine. A regular rim, which is developed against the plagioclase and may be 2-3 cm. thick, is composed of a pale bluish amphibole.

The alteration of the rock at the western end of the massif is similar to that described above. Coronites (Plate XIA) are common and the primary minerals are altered, but the original outlines are shown by a relic garnet rim. The center of the garnet rim is occupied by fibrous amphibole. Amphibole needles between the garnet and plagioclase are perpendicular to

PLATE X



A P-34-22. Photomicrograph. Crossed nicols. Dunite. Note rims between the plagioclase (Pl) and olivine).



B- M-10-2- Photomicrograph. Crossed nicols. Development of amphibole in fractures in plagioclase.

the garnet corona. Rarely the garnet occurs as porphyroblasts. The tenor of opaque ore mineral is low and ultrabasic rocks are exceptional in the western and northern parts of the massif.

Discussion

The two main modes of occurrences of anorthosites and associated gabbroic rocks may be summarized as follows (Buddington, 1939, p. 208; Turner and Verhoogen, 1960, p. 322):-

1) Anorthosites occur as layers in stratified basic sheets, lopoliths, etc. and may attain a thickness of several thousand feet. The plagioclase is commonly calcic labradorite or bytownite, and the mafic minerals are pyroxenes and, less commonly, magnesium-rich olivine.

2) More commonly they occur as masses of various, but mostly large, sizes which have no obvious compositional stratification. In many cases the shape of the intrusive body is not obvious but some observations indicate steeply outward-dipping contacts and domical roofs. "Domical anorthosites" occur in Precambrian terranes and, in Canada, they are one of the characteristic rocks of the Grenville subprovince. A large part of the Adirondack intrusive rocks is anorthosite and (after Buddington, 1939) the term "Adirondack type anorthosite" went into general usage parallel with "domical anorthosites". The composition of the latter is characterized by sodic labradorite or andesine, and the mafic minerals in the usually irregular gabbroic facies are pyroxenes, with rare olivine.

In Quebec, the anorthosites are essentially restricted to the southern, or Grenville, province of the Canadian Shield.

The differences between the two main types of anorthositic occurrences are structural and compositional. Evidence is convincing that the layered bodies originated by differentiation in place from a liquid gabbroic magma. A similar hypothesis however does not explain the formation of the large anorthositic masses. In the Quebec occurrences, there are compositional differences between different localities, but within the individual units the composition varies only slightly, and the trend of differentiation is not obvious. If the anorthosites are the plagioclase-rich fraction of a differentiated basic magma, the mafic minerals should have accumulated in the hidden parts of the bodies. Gravity measurements, however, disprove the presence of ultrabasic masses beneath the anorthosite massifs. Therefore, one may repeat Buddington's conclusion that "there is no indication that the anorthosite is itself a differentiate of a magma of more basic composition. It appears to have been intruded as an anorthosite magma or perhaps as a mush of plagioclase crystals".

The southern contact of the Raudot Lake massif is a shear zone. The highly metamorphosed rocks south of the massif are folded, and the general north-south trend is turned to east-west near the massif. The compositional layers in a 3,000-5,000-foot marginal part of the massif have a general 30-40° dip to the north. Coarse syenite dikes cut the edge of the massif, but are not found in the metamorphic rocks adjacent to the south. Their absence in the latter rocks probably was the result of uplift of the metasedimentary formations relative to the igneous rocks. Thus, there has been a relative upward movement of the metamorphic rocks adjacent to the massif.

The above structural analysis indicates that the southern margin of the massif represents a lower level and the central part an upper level of the intrusive body. The layers apparently are primary, and they suggest that the Raudot Lake massif is an intrusive sheet or laccolith and not a domical or batholithic body.

The neavy minerals (olivine and magnetite) are concentrated in the layered part of the massif. Assuming that the massif was emplaced as a liquid, one may conveniently explain the origin of the regular layers by differential settling velocities of the early crystallizing plagioclase and olivine. The differences between rock types are mainly in the proportion of the minerals, and the calcity of the plagioclase is nearly the same in anorthosite as in dunite layers. A restricted range of differentiation is shown from An_{66}-Fay_{24} to An_{60}-Fay_{37}.

The composition of the massif is more basic than the common anorthosites of the Grenville subprovince, and in this respect it shows more resemblances to the layered complexes than to the Adirondack-type occurrences. The anorthosite of the Moisie River area (Faessler, 1945) and facies of the Tchitogama body (Philpotts) near Lake Saint-Jean are somewhat similar in composition to the Raudot Lake body because they contain troctolitic facies. However, their plagioclase is less calcic. The structure of the Raudot Lake massif resembles the layered bodies in its sheet-like form and differs from them in the absence of regular layers in the upper (central) parts.

Magnetite is concentrated in the layered zone of the massif. The regular and intimate interlayering and the textural evidences leave no doubt about the primary origin of the ore. The abundance of the magnetite in the layered part of the massif means a relatively early appearance of the iron oxides in the sequence. In this respect it differs from many anorthosites in which the ore layers have crystallized from the residual liquid (e.g., the ore deposits at Allard lake, Hargraves, 1962).

Brien Anorthositic Gabbro

Anorthositic gabbros and their altered varieties underlie about 5 square miles in the central part of Brien township, north of the Hart-Jaune fault. The peaks in the western part of the massif are made up of dark massive anorthositic and gabbroic rocks, and rocks of the downslope to the south are hornblende-plagioclase gneisses.

The least altered rocks are coarse, massive, and similar to the anorthositic gabbros of the Raudot Lake massif (Plate XIB). The bluish plagioclase is calcic labradorite. Olivine and pyroxene, the primary mafic minerals, are highly altered. Olivine is present as corroded remnants, most of its original volume being transformed to clear granular pyroxene. The transformation seems to have been accompanied by the segregation of an opaque dust. The secondary pyroxene is separated from the plagioclase crystals by reaction borders of pale amphibole and garnet. The primary hypersthenic pyroxene is dusted with minute opaque particles and has a narrow marginal alteration to bright green hornblende. The accessory minerals are opaque ore mineral and biotite.

Mineralogical and textural changes can be followed from the massive, coronitic, anorthositic gabbro to the hornblende-plagioclase gneisses. The degree of deformation increases gradually southward.

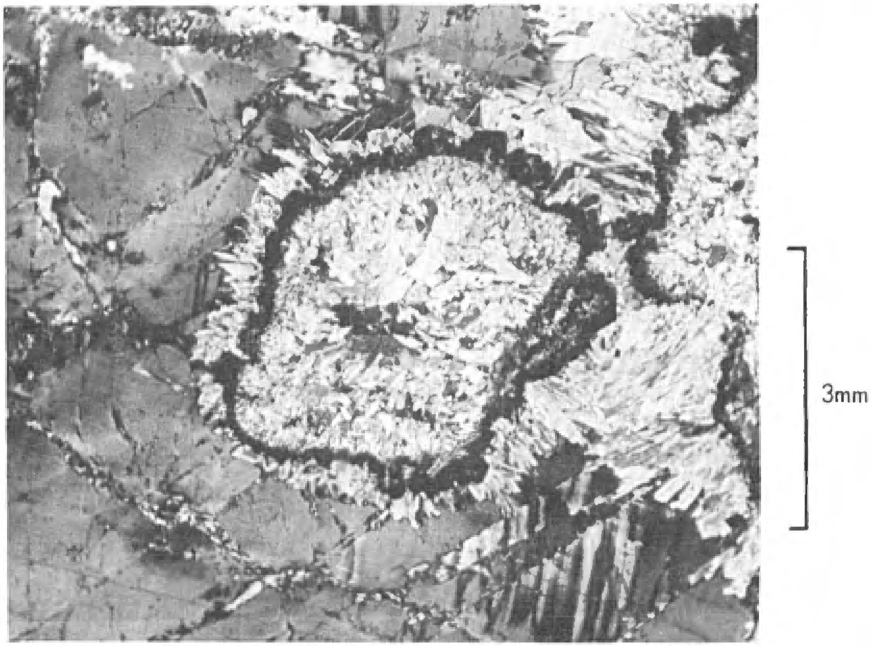
In an initial stage of deformation the rock is massive, and although the color of the plagioclase becomes white its composition does not change markedly. The mafic mineral is in aggregates of pale green amphibole, which mottle the rock. Garnet and scapolite are present in some specimens and the garnet as minute dots may be concentrated around the amphibole aggregates.

In an advanced stage of deformation a gneissic texture developes (Plate XIIA). The mafic minerals are elongated and form parallel streaks. Garnet is present as scattered euhedral grains. The fine-grained, poorly twinned plagioclase of the gneissic rock is calcic andesine.

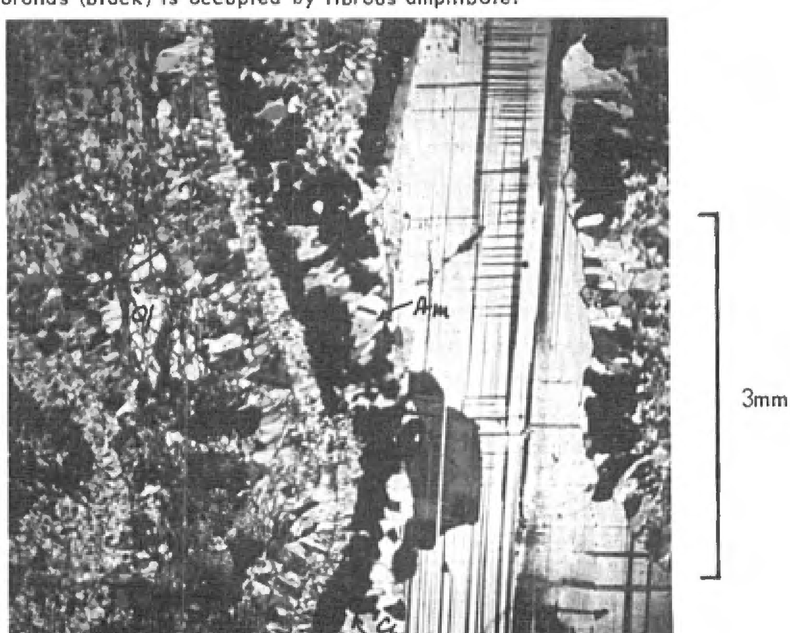
Farther south, near Hart-Jaune river, the rocks are typical hornblende-plagioclase gneisses and the texture does not reveal their origin.

The structural relations of the Raudot Lake massif and the Brien body to the Hart-Jaune fault suggest that before the development of the fault the Brien rocks were connected with the Raudot Lake massif. The genetic relations between the two are suggested by similarity in composition. A higher tenor of hypersthene in the Brien rocks may be explained if these rocks were later differentiates; in such case, an enrichment of pyroxene relative to olivine would be expected.

PLATE XI



A- L-63-2. Photomicrograph. Crossed nicols. Altered gabbroic anorthosite with corona and fractured plagioclase. The center of garnet coronas (black) is occupied by fibrous amphibole.



B- K-109-8. Photomicrograph. Crossed nicols. Brien anorthositic gabbro. Corroded olivine (ol) surrounded by secondary pyroxene (px) and garnet (G). Part of the plagioclase is replaced by amphibole (Am).

Two separate metamorphic events can be distinguished. An earlier, regional metamorphism transformed the Brien anorthositic gabbros to coronites. In a later stage the southern part of the body was subjected to shearing stresses, and with the development of the hornblende-plagioclase gneisses the corona structure was destroyed.

In general, the development of the coronites is similar to that in the metagabbros in the northern part of the area, and the causes of their formation are probably also the same, namely, the instability of the olivine-plagioclase pair of minerals under certain regional metamorphic conditions.

Lucie Lake Intrusive Lens and Related Rocks

An anorthositic lens of about 8 square miles lies north of Lucie lake in the southeast corner of the area. The lens is elongated east-west and is surrounded by metamorphic rocks of the Manicouagan upland.

Narrow depressions and shallow stream channels mark most of the contact zone between the intrusive lens and the surrounding layered rocks. At several places the contact is exposed, and near the contact the intrusive rocks are foliated. Dikes from the intrusive lens cut the surrounding layered rocks on the northern shore of Lucie lake.

The rock of the Lucie Lake lens is commonly anorthositic gabbro, but this grades irregularly to coarse anorthosite and to medium-coarse dark gabbro. The gabbroic facies is more abundant towards the northeast. Extremely coarse anorthosite was found slightly north of the center of the lens. Parallel layers were not seen. Two parallel coarse anorthosite dikes, 2 and 5 feet thick respectively, cut anorthositic gabbro in the south-central part of the lens.

In hand specimen pyroxene and plagioclase can be recognized. The <u>plagioclase</u> is light gray or pale bluish gray and forms well-developed prisms or laths; in some specimens it is granulated. Rarely the laths are oriented, and in extremely coarse anorthosite, they are up to 1 foot long. In thin-section the plagioclase is clear and well twinned. Near the contact it shows wavy extinction, and some granulated grains contain minute prisms or rods as inclusions. It is calcic labradorite An_{62}-An_{71}.

<u>Orthopyroxene</u> is colorless or very slightly pleochroic in pink. Local variation in the composition is suggested by the optical properties: hypersthene in the northeastern part of the lens; enstatite in the western part of the lens. Clear, colorless <u>diopside</u> occurs with the orthopyroxene, but it is less common.

A common microscopic feature of the pyroxenes is the association of vermicular, green spinel. The irregular myrmekitic lines of the spinel are thinner at the margin of the grains.

Olivine, found in two gabbroic specimens, is a magnesium-rich variety present as small relic crystals surrounded by pyroxene.

Amphibole appears to replace part of the pyroxene and also occurs rarely as poorly developed, independent grains. Some of it contains vermicular spinel.

Pyroxenite dikes cut the Lucie Lake lens at several places. The dike rock is massive and medium grained, and the composition is similar to that of the pyroxenite sills in the layered rocks of the upland.

Two gabbroic dikes in the southwestern part of the lens strike N.20°W. The dike rock is fine grained and massive, and is composed of plagioclase, ortho- and clinopyroxenes, and accessory spinel and opaque mineral.

Other Anorthositic-gabbroic Rocks within the Manicouagan Metamorphic Complex

An oval lens about 2 miles long lies in the area of the granulitic gabbros near the eastern limit of Jauffret township. The rocks are coarse to very coarse, and have the same hand specimen properties as those in the Lucie Lake lens except for a higher degree of granulation of the plagioclase. However, large plagioclase prisms and local ophitic texture are recognizable. The composition of the plagioclase (An_{62-63}) is uniform within the lens.

Coarse anorthositic gabbro and coarse gabbroic facies, thought to be related genetically to the Lucie Lake mass, form small patches in the layered and homogeneous granulitic gabbros. In comparison with the granulitic gabbros, the Lucie Lake-type rocks are coarser grained and have a relic ophitic texture, and the plagioclase is more calcic than An_{60}.

Discussion

The lack of any contact effect on the country rock indicates that when the Lucie Lake anorthositic gabbro was emplaced the layered rocks were hot and the intrusion occurred at great depth. As the crystals of the intrusive rock are coarse to very coarse the rate of crystallization was very slow. The deformed and granulated coarse crystals near the contact of the lens suggest that the intrusive liquid contained substantial amounts of solid phase at the time of the intrusion.

The absence of regular compositional layers, the presence of abrupt and irregular changes in the grain size and in the proportion of pyroxene and plagioclase, and the presence of anorthosite dikes in the anorthositic gabbro, suggest that conditions during crystallization were disturbed.

The presence of olivine instead of pyroxene is the main mineralogical difference between the Raudot Lake (olivine) and the Lucie Lake massifs. Some pyroxene grains are clear, and others contain vermicular spinel. Relic grains of olivine are surrounded by pyroxene in two thin-sections and this relation indicates that some of the pyroxene is secondary after olivine. Experimental studies of the system Diopside-Forsterite-Anorthite suggest that at high-magmatic temperatures forsterite-anorthite and spinel can coexist but "pyroxene and spinel are not compatible" (Osborn and Tait, 1952, p. 432). However, at lower-temperature "spinel and diopside coexist under equilibrium conditions but not calcic plagioclase and olivine. Therefore at some moderate temperature an accumulation of calcic plagioclase and magnesian olivine crystals becomes a metastable assemblage which will, if conditions are appropriate, transform to the low-temperature stable assemblage of pyroxene, spinel, and plagioclase .... (below about 900°)". Thus, it is possible that the pyroxene and the associated vermicular spinel are metamorphic minerals. A reaction between olivine and plagioclase was common in the coronitic gabbros and troctolites, and may have produced diverse mineral assemblages.

Partial amphibolitization of the pyroxene is mentioned above. The amphibole also contains vermicular spinel; thus the formation of the spinel is earlier than the amphibolitic alteration. It should be emphasized that the rocks which surround the Lucie Lake lens are made up of anhydrous minerals, and therefore the partial amphibolitization of the pyroxene may be an autometamorphic effect.

The geological history of the Lucie Lake lens differs in many respects from that of the Raudot Lake massif, and the genetic relations between the two are doubtful.

GRANITIC ROCKS AND MINOR INTRUSIVE ROCKS

Granitic gneisses, granites, pegmatites, and a number of minor intrusive rocks, all of which occur north of the Hart-Jaune fault, are included here.

Granitic Gneisses and Granites

Granitic rocks occur either as lenses or irregular bodies or as part of the mixed gneisses. The complex relations within the mixed gneisses have been described above.

Thin-sections show that granitic rocks with apparently similar properties differ significantly in their feldspar ratios, and that the general pinkish color does not necessarily indicate an abundance of K-feldspar.

The modal compositions of 10 specimens are listed in Table 11. Specimens 1-4 were collected along and near the northern shore of Manicouagan lake, where the rocks are medium and fine grained and only slightly foliated. An exception (Specimen 2) is rich in quartz and microcline and is medium to coarse grained. In thin-sections, a mosaic texture is seen. The anhedral grains of the feldspars are unaltered. The plagioclase, An_{6-11}, is well twinned, and some microcline is microperthitic. Brown biotite is the significant mafic mineral, and is concentrated in 2-3 mm. thin layers. The minor minerals are hornblende, opaque ore mineral, apatite, zircon, sphene, allanite, and, in one specimen, epidote.

The abundant pink granitic rocks (specimens 5 and 6) of the northern part of the western third are foliated, and in many specimens the quartz forms lenticles or leaflets (leaf-gneiss texture). The plagioclase is albite or rarely oligoclase, and the K-feldspar is orthoclase or microcline, some of it being microperthitic. The mafic mineral is biotite, and the minor accessories are hornblende, chlorite, zircon, and opaque mineral. Some granites in the northern part of the central third contain accessory garnet.

Chlorite is the mafic mineral in the gneissic granites north of Beaupin brook, near Hart-Jaune river in the central third, and north of the Raudot Lake massif (specimens 8, 9, and 10). The chlorite granite is complexly mixed with paragneisses in many outcrops north of Beaupin brook. In hand specimens the quartz is dull gray and the feldspars have a reddish iron-oxide stain. The accessory minerals are hornblende, biotite, sphene, epidote, apatite, and opaque mineral.

Considerable alteration of the minerals is seen in thin-sections. The feldspars are clouded and hair-fractures are filled with epidote, calcite, and sphene. The chlorite granites north of the Raudot Lake massif contain some muscovite and some specimens look like aplites. The degree of alteration and the granitic fraction of the mixed gneisses decrease northward.

The northern edge of the Raudot Lake massif is deformed and sheared and is cut by granitic dikes up to 1 foot thick; some of the dikes extend parallel to the edge of the massif. The dikes are pink, fine grained, and gneissic. In thin-section, granulation of the feldspar and a flaser texture of the quartz are seen. Muscovite (also seen in hand specimen) has a peculiar sievey texture which was not seen in the micas of the other granitic rocks.

Table 11

Modal Composition of the Granitic Rocks

	1. K-11-3	2. K-17-4	3. R-64-2	4. K-11-10	5. K-33-2
K-feldspar	47	45	8	7	37
Plagioclase	21	3	57	60	34
Quartz	24	49	30	30	26
Biotite	6	2	3	2	3
Chlorite	-	-	-	-	tr
Others	2	1	1	1	-
	6. K-75-7	7. L-82-3	8. R-15-1	9. L-62-9	10. R-23-4
K-feldspar	37	27	19	20	43
Plagioclase	28	40	36	38	31
Quartz	30	25	32	33	17
Biotite	3	5	tr	tr	tr
Chlorite	tr	tr	11	7	7
Others	2	3	2	2	2

The granitic gneisses and granites have various modes of origin. Some occur in well-defined layers or as lenses and have sharp contacts with, or contain inclusions of, the paragneisses. Such relations indicate an origin by consolidation from magmas.

In some mixed gneisses the association between the granitic fraction and the paragneisses is very intimate, and the granitic fraction may have been formed either by injection along the plane of foliation or by metamorphic segregation. However, the intrusive granites predominate.

The modal albite, anorthite, and K-feldspar contents of eight specimens plotted in Figure 5 suggest that the granitic rocks can be divided into three groups: 1) two feldspar granites, 2) albite granites, and 3) microcline granites.

The composition of the two feldspar granites falls midway between the K-feldspar-albite joint on the compositional diagram, and the feldspar ratios correspond to those of the "normal" granites. The plot in Figure 5 suggests that the pink granitic gneisses of the western third of the area (e.g., specimens 5, 6, and 7 in Table 11), and the chlorite granites (e.g., specimens 8, 9, and 10) may be genetically related, and that the textural differences as well as the chloritization of the biotite are due to local modifying conditions.

As the main mass of chlorite granite extends parallel to the Hart-Jaune fault, a relation between the emplacement of the granite and the tectonic activities that caused the fault is suggested. The chloritization of the biotite, as well as other mineralogical alterations in a broad zone along the fault, is thought to be the effect of volatile-rich solutions which ascended along the fault. These solutions may be hydrothermal differentiates of the same magma from which the granite originated.

Gneissic granite cuts the northern edge of the Raudot Lake massif. The shear zones into which the granite is intruded presumably formed contemporaneously with the fault. Both granitic intrusion and fault are, therefore, younger than the basic complex.

Albite granite. Some of the pink granitic rocks on the northern shore of Manicouagan lake contain a high tenor of albitic feldspar (e.g., specimens 3 and 4 in Table 11); correspondingly they plot near the albite apex of the compositional diagram. The high sodium content is confirmed by chemical analysis, which indicates 6.25% Na_2O and 0.61% K_2O.

As the paragneisses associated with the albite granite are potassic the high sodium content of the granites cannot be a metasomatic enrichment. It appears, therefore, that the present composition of the albite granite is primary. The fact that rocks several miles apart have strikingly similar modes supports this conclusion.

The intrusion of the albite granite does not seem to be related to tectonic activity, as is the case with the chlorite granites. Cross-cutting relations between the two types of granites were not found and their relative ages are not known.

Microcline granite is considered as a variety of the pegmatites and is described below.

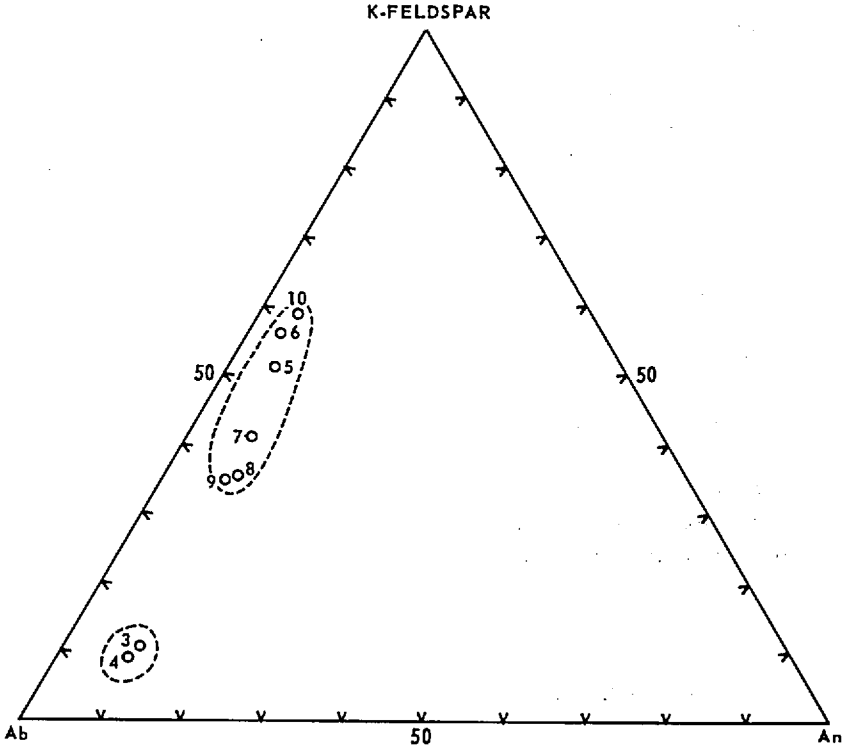


Figure 5

THE ALBITE, ANORTHITE, AND K-FELDSPAR CONTENTS OF EIGHT GRANITIC SPECIMENS ARE SHOWN. THE PLOT IS BASED ON THE MODAL COMPOSITIONS OF TABLE 11.

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Granitic Pegmatites

Veins, dikes, and small sills of massive, pink, granitic pegmatites are common in the diverse gneisses north of the Hart-Jaune fault. The essential constituents are quartz and microcline. In places plagioclase, biotite, and magnetite are present. The biotite is irregularly distributed and commonly forms plates or books up to 10 cm. in diameter.

Three kinds of textures are common, and there are transitions between them:- 1) Pegmatitic texture. In the extremely coarse pegmatites the microcline phenocrysts are up to 1 foot long. Such pegmatites are common near the intersection of Hart-Jaune river and longitude 68°00'. 2) Graphic textured pegmatites are found across the area, but are most common in the eastern third. 3) Hypidiomorphic granular or granitic textured pegmatites differ from the other pink granites in their very high microcline plagioclase ratio.

Garnetiferous (pyrope-almandine) pegmatite was found at two places in the southeastern part of Berthelet township. One occurrence is near the peridotite body.

It is concluded from the diversity of modes of occurrence and of composition that the pegmatites represent several periods of intrusion. Some are cataclasticly deformed and others are metamorphosed with the country rock. The very coarse microcline pegmatite and the graphic variety appear to be the youngest Precambrian intrusive rocks in the northern part of the area.

Green Pyroxene-syenitic Gneisses; Speckled Gneisses

Pyroxene-syenitic gneisses occur in two larger, irregular masses and as several small patches in the northwestern part of the area. The larger units are on the northern border of the area and their extent to the north is not known. The syenitic bodies are separated from each other by paragneisses and pink granitic gneisses. The foliation of the surrounding gneisses in the vicinity of the syenitic rocks is confused.

The pyroxene-syenitic gneisses are green where fresh, beige or gray weathering, and medium to fine grained. The foliation is marked by aligned mafic minerals. The modal compositions are summarized in Table 12.

In thin-sections, the anhedral grains form an equant mosaic. The K-feldspar is microperthitic and has a negative axial angle of 40-45°. The twinned plagioclase is albite. The clinopyroxene is pale green, slightly pleochroic and has a large (+) axial angle. The orthopyroxene is slightly brownish, and has a noticeable absorption, and strong dispersion. The axial angle is near 90°. Hornblende and 2% of quartz were found in one thin-section. The hornblende is bright green. The biotite is strongly colored and has an absorption from pale brown, to greenish brown, to dark brown. The anhedral grains of garnet are pinkish and contain inclusions. Rutile is the common accessory mineral, but apatite, zircon, and opaque granules were also seen.

Speckled pink syenite gneisses generally form extensions of the green syenitic gneisses and, like the latter, lie within granitic gneisses and paragneisses. Actual contacts with the granitic gneisses were not found.

Table 12

Modal Composition of Green Pyroxene-syenitic Gneisses

	K-68-11	K-70-11	K-69-10
K-feldspar	48	43	39
Plagioclase	35	42	38
Quartz	-	-	2
Clinopyroxene	9	5.5	6
Orthopyroxene	3.5	2	3
Hornblende	-	-	7
Garnet	2	2.5	2.5
Biotite	1.5	3	1.5
Others	1	2	1

The rock is pale pink where fresh and beige-yellow where weathered. The mafic minerals (less than 5%) appear as dark specks in a matrix made up essentially of plagioclase (An_{12}) and K-feldspar. The feldspars form an unequant mosaic texture. The K-feldspar is perthitic in some thin-sections. Quartz up to 5% is common, but in one specimen 18% quartz was found. Hornblende and diopside are the mafic minerals. Garnet is in anhedral grains and traces of biotite were seen in several thin-sections.

The green syenitic gneiss is a distinctive rock type, the mineralogy of which differs significantly from that of the adjacent amphibolite-grade gneisses. The pyroxene and perthite indicate a high temperature of formation. Judging from descriptions, the "green rocks" of the southwestern Grenville of Quebec are comparable to the pyroxene-syenitic gneisses. The "green rocks" contain orthorhombic and monoclinic pyroxenes and perthite, and occur either as small bodies in the gneisses or as marginal facies around anorthosites. They are igneous and are considered to be younger than the anorthosites.

The pink "speckled" gneisses are thought to be genetically related to the green syenitic facies because some transitional varieties between the two exist. The variable amounts of quartz present in the "speckled" gneisses suggests that their composition may have been considerably affected by the surrounding granitic rocks.

Coronitic Gabbros

Metagabbro lenses up to 1/2 mile in diameter occur in the northwestern part of the area. Only a few occurrences are indicated on the map. The gabbros are bluish gray, rusty brown weathering locally, medium to coarse grained, massive, and ophitic.

Thin-sections show an intensive alteration of the major primary minerals, which are plagioclase, olivine, and clinopyroxene. The plagioclase (An_{35}) is crowded with minute anisotropic needles or prisms, or is altered to a nearly opaque mass. Different degrees of alteration of the plagioclase may occur within the same gabbroic lens: some grains are recrystallized to a clear, granular aggregate, or are in part replaced by garnet, or trails of garnet grains may mark the original outline of the plagioclase.

The primary pyroxene of the gabbro is dusted with minute opaque rods and is partly recrystallized; it shows no reaction relations with other minerals.

Reaction rims (Plate XIIB) have developed between the olivine and plagioclase, and around the opaque ore mineral. The olivine is partly replaced by the reaction products, but the relic grains are fresh. A narrow rim of clear, secondary pyroxene (diopside ?) surrounds the olivine. A second rim around the olivine is composed of garnet or a confused symplektite of garnet and some anisotropic mineral (pyroxene ?).

Rims around opaque grains consist of red-brown biotite and brown hornblende. Green spinel and a translucent pleochroic mineral occur with the opaque grains.

The degree of alteration is variable and in many instances the original texture of the gabbro is greatly modified by an intensive

PLATE XII

A- Hornblende-plagioclase gneiss developed from altered anorthositic gabbro. Scale = 1:1.

6mm. diameter

B- S-93-6. Photomicrograph, diameter 6mm. Crossed nicols. Coronitic gabbro. Rim of secondary pyroxene and garnet around olivine (Ol). Pl = plagioclase, Px = primary pyroxene.

development of secondary minerals. In some extreme examples more than 50% of the original volume of the plagioclase is replaced by garnet, the small euhedra of which may be aligned parallel to the cleavages of the plagioclase, or may appear in uneven distribution.

The primary minerals and the original texture clearly indicate that the coronites are derived from olivine-bearing gabbros. It is evident, also, that the reaction minerals were formed after the complete crystallization of the rock; thus the reactions are postmagmatic and probably the result of regional metamorphism.

Peridotite

An outcrop area about 3,000 feet long of ultrabasic rocks rises slightly above the general elevation near the southeast corner of Berthelet township. The outcrops form two lenses, which are elongated east-west and are separated by a depression. Two types of rock are represented but the relations between them and their relative abundance are not known.

One is an olivine-rock approaching the composition of dunite (specimens 1 and 2 in Table 13). The other is garnetiferous hornblende-peridotite (specimen 7).

The olivine-rock was collected from the southern edge of the eastern lens. It is dark olive-green, massive and medium grained, and has an equigranular sugary texture. Near surface the rock is crumbly and breaks easily along the grain borders. The southern downslope of the hill is covered by olivine sand.

The garnetiferous hornblende-peridotite is at the eastern and western sides of the outcrop area. On the dark fresh surface, uniformly dispersed red garnet is readily distinguishable from the olivine and amphibole. The weathered surface is dark rusty brown. The amphibole crystals are aligned and the rock is foliated.

In thin-sections of the dunite the minerals are fresh and the grains form a mosaic texture. The olivine (Fay_{29-31}) is clear and the anhedral grains contain irregular cracks, some of which are filled with opaque dust. The tenor of the hypersthene is generally low. The negative axial angle varies between $84-78^{\circ}$. The grains are pleochroic from colorless to pale pink. The optical properties of the amphibole present suggest that it is a member of the pargasite-ferrohastingsite series (as described in Deer _et al_. 1963, pp. 264 and 298).

Table 13

Modal Compositions of Garnetiferous

Peridotites (1-6) and Dunites (7-9)

	Oliv.	Garnet	Ortho-pyrox.	Clino-pyrox.	Amphib.	Chlor.	Opq.	Alter.
1) K-98-20/A	49	7	2	-	39	-	3	-
2) K-98-18	45	7	8	-	27	-	12	1
3) A-6	50	10	40	-	-	-	-	-
4) A-2	40	15	15	25	5	-	-	-
5) N-69	35	20	10	30	5	-	-	-
6) N-26	55	15	-	25	5	-	-	-
7) K-98-20	85	-	2	-	5	6	1	1
8) N-6	70	-	15	-	10	5	-	-
9) N-3	65	-	10	-	15	10	-	-

Source - Data outside of the present study are from O'Hara and Mercy (1963)

1) Present study - Garnetiferous hornblende-peridotite
2) Present study - Garnetiferous hornblende-peridotite
3) Garnet Harzburgite from Kimberlite pipe, South Africa
4) Garnet lherzolite, Switzerland
5) Garnet lherzolite, Norway
6) Garnet wehrlite, Norway
7) Present study - Dunite
8) Dunite (harzburgite), Norway
9) Dunite (harzburgite), Norway

The garnet is anhedral and has no inclusions. The properties of the garnet from specimen K-98-20/A are as follows:

Density 3.90
Refractive Index 1.764
Cell edge _a_ .... 11.50 Å
Approx. composition .... Pyr_{46} Alm_{52} Gro_2

Optically positive chlorite occurs as well developed flakes. The flakes are randomly oriented, and are pleochroic in shades of pale bluish green. The accessory minerals are magnetite and dark green spinel.

At the western end of the outcrop area the peridotite contains 12% magnetite. The amphibole is pale brown and some gold-yellow alteration material is present in suboriented stringers that cut the grains.

In the eastern part of the outcrop area the peridotite is cut by several irregular veins up to 3 feet wide. The contacts of the veins are sharp and the olivine in the adjacent peridotite is unaltered. The vein material is a white, fibrous anthophyllite.

At one locality, a veinlet (8 cm.) of coronitic gabbro cuts irregularly into the peridotite. The plagioclase in the gabbro is loaded with minute greenish rods and plates, but the twinning is still recognizable. The primary mafic minerals are transformed or recrystallized to fine-grained pyroxene. Relic grains of olivine are recognizable in the centers of some of the aggregates. A rim of garnet or a symplektite of garnet and pyroxene occurs at the contact of the plagioclase and mafic minerals.

The cores of the secondary pyroxene aggregate are composed of colorless orthopyroxene, and there is diopside in the periphery. Brown amphibole surrounds the accessory opaque mineral and the intensity of the color decreases away from the opaque grains.

The contacts between peridotite and gabbro are sharp and readily observable in thin-sections. There is no indication of chilling in the gabbro or any alteration in the peridotite adjacent to the contact.

Rocks of peridotitic composition are thought to constitute the upper mantle of the earth, and their study has been greatly expanded in recent years in an effort to ascertain the physicochemical conditions that exist below the Moho discontinuity and the origin of the primary basalt magmas.

A summary of recent studies of ultrabasic rocks scattered throughout the Canadian Shield is given in the Canadian Progress Report, International Upper Mantle Project, 1964. Peridotitic and dunitic rocks in the Grenville subprovince are rare. Lyall (1958) reported hornblende-pyroxene rock (with 2% olivine and 2% garnet), and hornblende peridotite from southwest Quebec. In Lyall's opinion the garnetiferous layers "have resulted from an original compositional or textural bias which was accentuated during metamorphism".

Other Ultrabasic Rocks

Two north-south ultrabasic dikes south of the peridotitic rocks are dark, massive and coarse grained. In thin-sections, alteration and recrystallization of the olivine and orthopyroxene are seen. Garnet and pale green amphibole are secondary minerals, but brown biotite and pale bluish chlorite are also present in places. Opaque ore mineral and spinel are the accessory minerals. The field relations of the ultrabasic dikes are obscure and the high degree of recrystallization masks their origin. The compositions resemble that of the peridotite, except that in some specimens minor plagioclase is present.

One outcrop of magnetite-pyroxenite, found near the intersection of latitude 51°45' and longitude 68°15', and extending north of the map-area, is surrounded by hornblende-plagioclase gneisses which may be altered gabbros. The rock is medium grained, massive and black, and is composed of 58% clinopyroxene and 37% magnetite and minor limonitic alterations, orthopyroxene, brownish amphibole and biotite. The rock shows no genetic resemblances to any other rock within the area.

In the northeast corner of Godefroy township a sill-like pyroxenite body is surrounded by mixed gneisses. Most of the primary mineral of the rock is transformed to amphibole.

About 500 feet north of Hart-Jaune river on longitude 68°00', one isolated outcrop of layered pyroxenite strikes parallel to the river and dips gently north. Thin quartz and magnetite-rich layers alternate in the pyroxenite. The rock somewhat resembles highly metamorphosed iron-formations which are abundant north of the map-area. The outcrop is on the limit of the map-area and is surrounded by overburden; its relations are not known.

Diabase

Dikes of diabase up to 40 feet thick cut the igneous and metamorphic rocks of the Manicouagan upland, but diabase was not found north of the Hart-Jaune fault. Narrow linear valleys common in the southcentral and southeastern parts of the area were once occupied by diabase; many of the dikes are now represented only by remnants of chilled borders. The narrow (1-2 feet) dikes are well preserved and in some places occur as parallel sets.

Most of the rocks are very fine grained and only rarely are individual minerals apparent in hand specimens. In thin-sections an ophitic texture is seen. The plagioclase (An_{55-58}) blades are deformed and clouded and some crystals are bent or twisted to an S-shape. The pyroxene is colorless pigeonite. Magnetite and strongly colored biotite are accessory minerals. Garnet replaces part of the plagioclase in some intensively altered varieties.

The diabase dike in the amphibolitized zone south of the Raudot Lake massif is about 10 feet wide and extends parallel to the foliation of the other rocks. The pyroxene of this diabase contains abundant irregular opaque granules and about half of its volume is altered to pale yellowish green amphibole.

The diabase dikes cut all the major rock types south of the Hart-Jaune fault, but they were not found north of the fault. Their age is therefore uncertain. The alterations, especially the development of garnet and the clouding of the plagioclase, are indications of a regional metamorphism, and thus the dikes are probably Precambrian in age.

POST-PRECAMBRIAN ROCKS

Middle Ordovician Sedimentary Rocks

Unmetamorphosed sedimentary rocks were found at several places on the western shore of Manicouagan lake. An unconformity is exposed between Precambrian rocks and overlying sedimentary rocks at the outlet of a stream near the western border of the area (F-1 on the map). Under the unconformity the Precambrian rocks are fractured to a depth of several feet and some fine-grained clastic material has been washed into the fractures. The recemented subrounded particles on the top of the Precambrian "floor" form a basal conglomerate (Plate XIIIA).

The conglomerate is overlain by a sandstone bed 15-20 cm. thick (Plate XIIIB). The matrix of the sandstone is colored reddish by iron-oxide. A green-gray shale on the top of the sandstone is followed by a light gray to beige, fossiliferous limestone. Similar fossiliferous limestones were found at localities F-2 and F-3. The strike varies from locality to locality, and the dips are 25^{o}-45^{o} northerly.

At locality F-1, the following fossils were collected 5-10 feet above the base:-

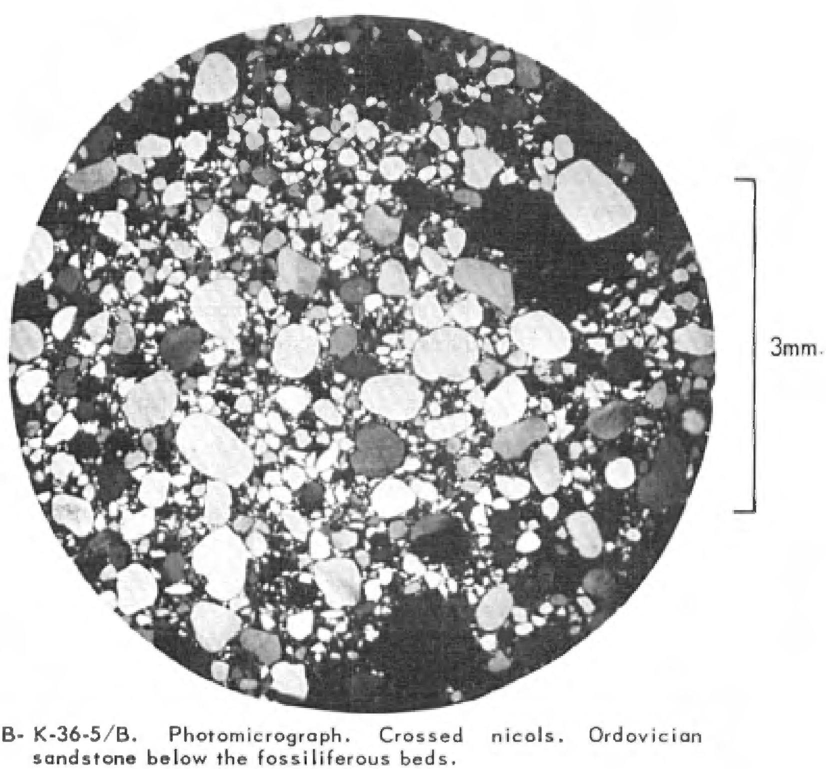
Receptaculites, *Streptelasma*, Crinoid fragments, Ramose bryozoa, *Diplograptus*, *Hormotoma*, *Lophospira*, *Trochonema*, *Maclurites*, *Vaginoceras*, *Ephipiorthoceras*, *Westonoceras*, *Isotelus*, *Cryptophragmus*.

F-2 and F-3 are small outcrops with a poorly preserved fauna. Cephalopods and trilobite fragments were found at F-2, and bryozoans, crinoid fragments and strophomenid brachiopods at F-3. Fossiliferous outcrops occur along the western shore of Manicouagan lake south of the present map-area (Bérard, 1962). The beds are Middle Ordovician in age, but it is uncertain whether they are Upper "Black River" or Lower "Trenton".

Outliers of Paleozoic strata are found at several places on the Canadian Shield. Their ages range from Cambrian to Middle Silurian,

PLATE XIII

A- Ordovician basal conglomerate at locality F-I, western edge of the area.



B- K-36-5/B. Photomicrograph. Crossed nicols. Ordovician sandstone below the fossiliferous beds.

but outliers of Ordovician age are the most common. The Ordovician seas, as the scattered outliers indicate, extended widely over the Shield areas of Quebec and Ontario.

Post-Middle Ordovician Igneous Rocks

The southwestern corner of the area is underlain by igneous rocks which are part of a larger unit that extends southwest and was outlined on a reconnaissance scale by Bérard (1962). The rocks of the present area are classed as fine grained and medium grained. Evidences given below indicate that the fine-grained rocks are extrusive.

Fine-grained Variety

An irregular zone of these rocks roughly parallels Manicouagan lake and represents the periphery of the igneous body. Polygonal joints developed locally. The color of the hand specimens varies from dirty brown through reddish brown to gray. Common macroscopic features are vesicles and inclusions.

The vesicles are oval or rounded in cross-section, and most are less than 1 cm. in diameter. Some vesicles contain minute needles normal to the wall but most are empty. Inclusions vary greatly in size and composition. They consist of rounded or angular fragments of Precambrian gneisses, granitic rocks, and particles of unmetamorphosed igneous material.

Near the western border of the area and about 1.5 miles south of the lake, a large inclusion of Middle Ordovician limestone is surrounded and veined by the vesicular extrusive rocks. At the contact the carbonate is decomposed and in the reaction zone the transformed limestone is greenish and very hard. Near the contacts the igneous material is dark green and contains baked particles from the limestone.

In thin-sections the extrusive rocks show a microporphyritic texture (Plate XIVA). Feldspars and pyroxene form microphenocrysts, and much of the groundmass is cryptocrystalline. The microscopic study is not informative as to the composition of the rock, and an inclusion-free specimen has been chemically analyzed (specimen K-13-1, Table 15).

Medium-grained Variety

An area of about 28 square miles is underlain by massive, holocrystalline, medium-grained, gray to reddish brown igneous rocks. The grains generally are up to 2 mm., but some shiny pyroxene crystals are as long as 5 mm. The rocks are devoid of inclusions and vesicles. There is a complete transition between these medium-grained rocks and the fine-grained extrusive variety.

Thin sections show a hypidiomorphic granular texture. The early crystallized plagioclase is partly resorbed and is either in contact with the pyroxene or is enveloped by K-feldspar (Plate XIVB). The grains tend to be euhedral, are clear, well twinned, and normally zoned. The cores have a composition of An_{66-62}. The determination of the margin of the grains is less definite because of the resorption and the K-feldspar envelopes; the calcity given by calculation from the chemical analysis is $An_{36.5}$.

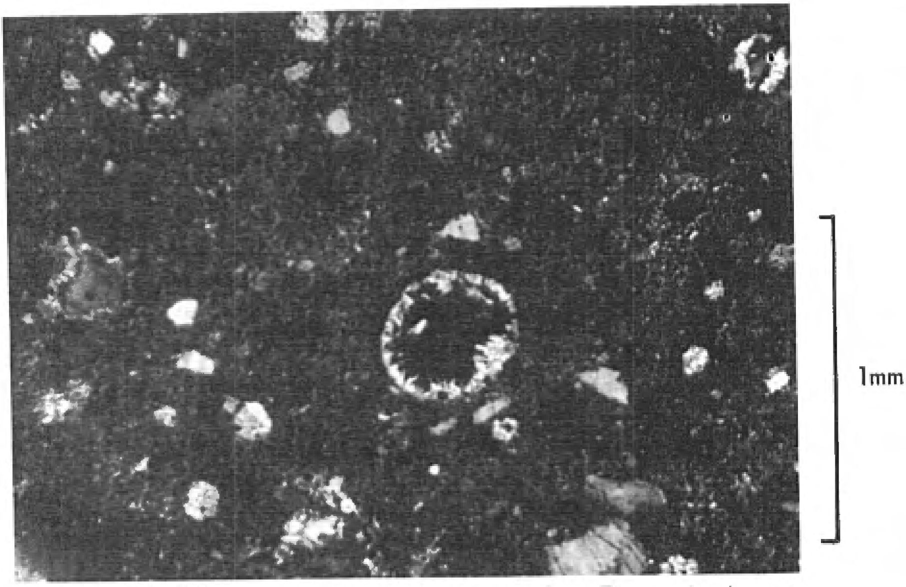
Clino- and, less commonly, orthopyroxenes appeared in the liquid after the plagioclase, as some small plagioclase laths are enclosed by the pyroxene. The clinopyroxene has the optical properties of diopside, and the orthopyroxene is a very pale-pinkish hypersthene which has a large, negative axial angle. In some thin-sections orthopyroxene was not seen. Brownish alteration around the margin of the pyroxene is common, and some pale green antigoritic (?) alteration also occurs.

Table 14

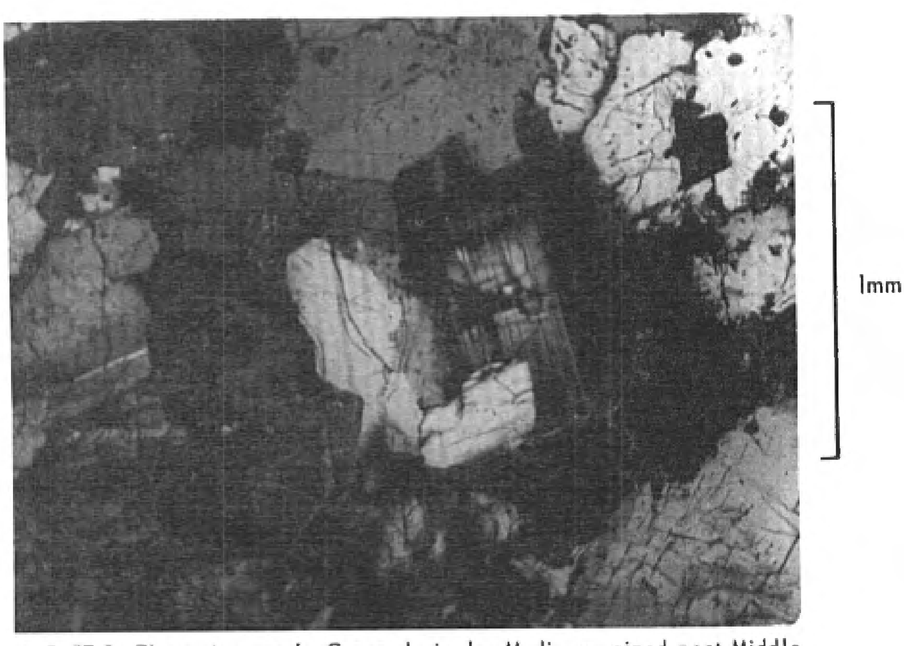
Modal Composition of the Medium-grained Variety of Post-Ordovician Igneous Rocks

	Plagioclase	K-feldspar	Quartz	Pyroxene	Opaque and altered
1) K-57-8	37.3	35.3	7.5	7.2	12.7
2) K-47A-18/B	45.6	29.1	11.7	8.8	4.8
3) K-47A-15	37.4	28.4	8.4	18.8	7.0
4) K-58-1	41.2	32.8	11.7	6.8	7.5
5) K-47-8	38.7	40.1	11.1	4.5	5.6
6) K-61-4	35.9	32.1	11.8	16.8	3.4
7) G-14-1	33.1	36	11.7	15.3	3.9
8) K-53-3	42.1	25.8	8.3	12.4	11.4
Average mode	38.91	32.45	10.28	11.32	7.04
Norm K-53-3	53.1	17.4	9.2	14.7	5.3

PLATE XIV



A- S-55-7/A. Photomigrograph. Crossed nicols. Fine-grained post-Middle Ordovician igneous rock. Vesicle in the center.
le centre.



B- D-57-8. Photomicrograph. Crossed nicols. Medium-grained post-Middle Ordovician igneous rock. Zoned plagioclase is surrounded by K-feldspar.

Table 15

Chemical Analyses of a Fine-grained (K-13-1) and a Medium-grained (K-53-3) Variety of Post-Ordovician Igneous Rocks

	K-13-1	Nockolds' Average Calc-alkali Doreite (Variety of mangerite)	K-53-3
SiO_2	58.18	56.	58.23
TiO_2	0.78	1.29	0.80
Al_2O_3	16.32	16.81	16.38
Fe_2O_3	3.27	3.74	4.50
FeO	3.18	4.36	1.72
MnO	0.13	0.13	0.14
MgO	3.31	3.39	3.82
CaO	6.36	6.87	5.99
Na_2O	3.86	3.56	3.68
K_2O	2.85	2.60	3.06
P_2O_5	0.23	0.33	0.13
H_2O +	0.79	0.92	0.70
H_2O -	0.35	N.D.	0.15
F	0.12	N.D.	N.D.
S	0.06	N.D.	0.01
BaO	0.13	N.D.	0.20
SrO	0.09	N.D.	0.06

K-feldspar and interstitial quartz crystallized late. The K-feldspar is untwinned, and the small negative axial angles indicate sanidine.

Table 16

Normative Compositions of Rocks in Table 15

	K-13-1	Nockolds' Average Calc-alkali Doreite (Variety of mangerite)	K-53-3
Quartz	7.8	7.2	9.2
K-feldspar	17.2	15.6	17.4
Plagioclase	54.3	52.1	53.1
Diopside	9.3	5.1	8.0
Hypersthene	6.3*	10.5	6.7
Magnetite	3.5	5.3	2.4
Hematite	-	-	1.8
Ilmenite	1.1	2.4	1.1
Apatite	0.5 An_{35}	0.8	0.3 $An_{36.5}$

* With 14.7% Ferrosilite

Discussion

The rocks described above belong to a larger mass that occupies the major part of the circular area enclosed by Manicouagan and Mouchalagane lakes. Rose (1955) and Bérard (1962) investigated the larger mass. Bérard estimated that "effusive rocks cover about 75% of the surface area between Manicouagan and Mouchalagane lakes". These authors also reported the presence of an intrusive massif, named essexite-anorthosite by Rose, in the center of the circular area. According to Bérard's description, the plagioclase (An_{60}) of the anorthosite is altered, and the rock contains garnet. In places the lavas are in sharp contact with the anorthositic rocks and inclusions of the latter occur in the lavas. Judging from the descriptions, there seems to be a significant difference between the compositions of lavas and anorthositic rocks, and a genetic relation between the two is doubtful.

The circular area is explained by some authors as being the result of meteoric impact. Some evidences, like the disturbed nature of the sedimentary beds along the inner shores of the lakes, support this theory. However, the anorthositic rocks are hard to explain by "central uplift" of the Precambrian basement, because they appear to be different in composition from any other known anorthositic rock in the Manicouagan area.

The contact relations between the post-Ordovician igneous rocks and the Middle-Ordovician sedimentary rocks indicate that the igneous rocks are the younger, but the exact age of their emplacement is not known.

Evidences indicating that the fine-grained rocks were lavas and cooled rapidly include gas bubbles, polygonal shrinking joints, and, south of the area (Bérard, 1962) tuffs and volcanic breccias. Evidences of successive flows were not found.

The medium-grained rocks were crystallized under conditions which allowed the rock to develop a holocrystalline texture. The composition of these crystalline rocks, estimated from the modal analyses, suggest that they are quartz latites.

The major oxides of two analyzed specimens, one fine-grained and the other medium-grained, are significantly different only in the FeO/Fe_2O_3 ratios. Two additional specimens were analyzed for FeO and Fe_2O_3. The analyses of the four specimens showed a gradual increase in the tenor of Fe_2O_3 southwestward. This indicates an increasing oxidation level of the iron from the margin inward.

The increasing tenor of Fe_2O_3 in the rocks studied therefore means higher level of oxidation in the inner (deeper) parts which cooled slowly, and the escape of the volatiles was prevented by a chilled cover of the flow. It appears probable, therefore, that the rocks described crystallized from "wet" melt. In summary, the medium-grained rocks are considered as the satellitic variety of the quartz latite. The two rock types are identical in chemical compositions, and the difference is in the oxidation of the iron.

GLACIAL GEOLOGY

Because of the high elevation of the Manicouagan upland the effect of glaciation was mainly erosional, whereas in the lower ground to the north it is mainly depositional.

Glaciation of the Manicouagan Upland

The evidences of glaciation in the upland are polished rock surfaces, glacial striae, and subrounded hills. The glacial striae, considered to represent the direction of the last ice movement, trend S.10°-20°E.

Most of the post-glacial melt water drained through a broad valley, which is now marked by the upper course of Beaupin brook. The valley in places is more than a mile wide and is filled by glacial debris on which Beaupin brook meanders. The trend of other valleys is controlled by the structure of the bedrock.

Subrounded erratic boulders are widespread but not abundant, and are found even on the highest points of the upland. Some granitic boulders moved at least 8 miles southward.

Angular and subrounded particles of pebble size have been washed into some depressions and compacted and cemented in a limonitic matrix. The tenor of the limonite is high enough in places to classify the deposits as gossans.

Weathering is active on the granulitic gabbro hill-tops, and produces coarse sand.

Glaciation of the Area North of the Upland

Till covers the bedrock in most of the area north of Hart-Jaune river. The unstratified deposits consist of boulders of various sizes and compositions, and the sandy matrix, in contrast to the sand of the upland, contains abundant quartz. Post-glacial waters removed the sand fraction of the till, and this resulted in large boulder accumulations in parts of the central and western thirds of the area. The transported fine material is found in sand flats and terraces. The most extensive sand flats are between Beaupin brook and Hart-Jaune river in the center of the area. Sand terraces are abundant near some waterways. Remnants of high level terraces occur along Hart-Jaune river and on the shore of Manicouagan lake near the western border of the area.

Stratified drift is found in the vicinity of North bay on Manicouagan lake, only a few feet above the present level of the lake.

With short disruptions, one esker about 6 miles long extends southward on the western side of the stream that enters Hart-Jaune river from the north at the falls, and continues on the eastern shore of the river.

STRUCTURAL GEOLOGY

The area has the structural complexity of a highly metamorphosed terrane that was subjected to folding, faulting, and repeated injections. The main structural features of the metamorphic rocks of both the granulite and the amphibolite grades are foliation and compositional layers. In the Manicouagan upland, layers are relatively consistent and are more useful in establishing structure than foliation. However, the gneisses of amphibolite grade occur with abundant biotite and are foliated. The foliation and the injected, parallel granitic material are useful in the structural interpretation of these rocks.

Folds in the Manicouagan Upland

The granulitic gabbro, the metasedimentary formations, and the hypersthene granite behaved as one unit. During a major period of deformation the rocks were folded along approximately north-south-trending axes.

Folds are not obvious in the west, where siliceous layers in the granulitic gabbro are rare. Here the foliation strikes N.35-45°E., and the average dip is 65°SE. A succession of anticlines and synclines alternate in the southeastern part of the area. The folds are generally tight and the axial planes are nearly vertical. A synclinal structure about at longitude 67°55' appears to be the northern part of a basin, judging from aerial photographs. East of the inferred basin the structural pattern is confused by the east-west Lucie Lake intrusive lens. The intrusion of the lens occurred at great depth and the country rock yielded plastically, such as is shown by siliceous layers that are parallel to the northern arc of the lens.

A departure from the generally north trend occurs along the northern margin of the Manicouagan upland. The axial plane of an overturned anticline south of the Raudot Lake massif strikes parallel to the easterly-trending edge of the massif. An upward movement of the metamorphic rocks of the upland titled the igneous massif. The east-west deformation is related to the uplift, and is younger than the north-south folding. It cannot be estimated how much time elapsed between the two deformations, and it is possible that one was the direct continuation of the other. Cataclastic augen gneisses and mylonites are thought to have formed during the final stages of this relative uplift, after the rocks became rigid.

Folds and Foliation in the Amphibolite-Grade Gneisses

Such markers as quartzite and limestone beds can be followed only for short distances, and lithological differences suggest that the scattered occurrences are not indications of the same stratigraphic horizon. The foliation of the gneisses in the west strikes N.25-30°E. and dips 35-45°E., except near the green syenitic gneisses, which appear to occupy the noses of folds. However, the foliation between the outlet of Hart-Jaune river and North bay is nearly perpendicular to this general trend. Here, isoclinal folds in the vertical cliffs that face Manicouagan lake have axial planes that strike S.70-80°E. and dip 65-75°N.

In the northern parts of the central and eastern two thirds of the area granitic injections confuse the relations, and the foliation changes within short distances. Where granitic rocks are less abundant adjacent to the Conan-Godefroy township line the paragneisses trend northwesterly.

Faults and Shear Zones

The Raudot shear zone extends parallel to, and south of, the Raudot Lake igneous massif. Cataclastic augen gneisses and mylonites in the metamorphic rocks of the upland are related to the waning stages of the second period of deformation of these rocks.

The most important single structural feature of the area is the Hart-Jaune fault, which extends from the outlet of Hart-Jaune river northeasterly 28 miles across the area. It separates the granulite-grade rocks of the upland to the south from the amphibolite-grade gneisses to the north. The evidences of the fault are both lithological and structural and may be seen in a zone of variable width. They include:

a) Western third of the area - Fracturing and dislocation of gneissic layers near the fault; veins of pink granite and stringers of epidote; unusually abundant lenses of sphene in some fractured hornblende gneisses; sericitization of plagioclase and chloritization of garnet.

b) Central third of the area - the abundance of chlorite granite; shearing of paragneiss with alteration of mica to talcose material on shiny slip-surfaces; replacement of some hornblende in dark gneisses by pistacitic epidote; brecciated and recemented basic gneisses; basic dikes are altered and contain scapolite and epidote.

c) Eastern third of the area - brecciation; mineralogical alterations similar to those in the central third.

The fault was formed by upthrusting, but the information on lineation is not sufficient to estimate the amount of displacement.

The contrasting differences between the Raudot shear zone and the Hart-Jaune fault should be pointed out. The cataclastic augen gneisses and mylonites of the shear zone are the result of a milling process at depth that was not accompanied by chemical alteration of the minerals. The brecciation and fractures of the rocks of the Hart-Jaune fault suggest that release of stress occurred in the upper level of the crust and was followed by intrusion of granitic material. The formation of the Raudot shear zone is the earlier event and occurred within the metamorphic rocks of the upland, which were squeezed against a large and resistant igneous body. The Hart-Jaune fault is the result of an uplift of the igneous and metamorphic rocks of the upland to the level of amphibolite-grade gneisses. The east-west-trending shear zone is cut by the Hart-Jaune fault in the central part of the area. The partial hydrous alteration of the rocks of the shear zone was most effective near the fault, and gradually decreased eastward.

Minor faults are indicated by the apparent termination of formations and sudden changes in direction of foliation. A fault runs east-southeast about 4 miles and separates hornblende-plagioclase gneisses from mixed gneisses; thus, it appears to be younger than the intrusion of the gneissic granites. Another short fault exposed on the western shore of the northern part of Manicouagan lake is indicated by a zone of breccia.

Joints

Joints are abundant in the granulitic gabbro, and are the only secondary structural features of the post-Middle Ordovician igneous rocks. A regional joint pattern is shown by the elongation of lakes and trend of streams in the granulitic gabbro area. It was probably developed long before glaciation of the area, although the trend of some valleys is parallel to the direction of the expanding ice sheet, which carried away part of the loose material and left step-like slopes. The vertical joints are commonly accompanied by a horizontal set.

Three prominent sets of joints in the igneous rocks of the southwest corner of the area strike N.-NE., N.-NW., and W.-NW. In addition, horizontal sheeting is common.

Lineation

The axes of drag-folds were recorded in the northeastern part of the area, but the granitic intrusion confused the relations and an analysis of the lineation was not conclusive as to the attitude of major folds.

ECONOMIC GEOLOGY

The southeastern part of the area has been prospected, which fact is shown by pits (blasted) and diamond drill-holes. There is no information available on the results of prospecting, and no assessment work has been reported on the three groups of claims southeast of Joyel and Mora lakes, which are held by Quebec Cartier Mining Co.

Rusty zones and gossan

Rusty brown rock surfaces are readily noticeable in the southeastern part of the area, where the vegetation is sparse. Some were formed in place by the oxidation of disseminated sulfides, and others originated by precipitation of limonitic material in joints or in depressions. In several places around Mora lake the rusty surfaces indicate gossans of loosely packed unsorted particles cemented in a limonitic matrix.

Copper, nickel

Several mineralized outcrops indicated on the map contain sulfides of copper and iron and oxides of iron.

Disseminated and, rarely, massive sulfide mineralizations occur in the granulitic gabbros and the associated siliceous layers in the southeastern part of the area. The most significant massive sulfide mineralization found is on a hill slope about one mile east-southeast of Mora lake. Here an irregular sulfide vein cuts the granulitic gabbro. The outcrop surface has been blasted and the sulfide vein is exposed over a length of about 5 feet. The width of the vein is about 2 feet at the bottom as exposed and thins out upward. The sulfide minerals, as seen in hand specimen, are pyrite, pyrrhotite, and chalcopyrite. Partial chemical analysis of a grab sample indicates nickel,0.91%; copper,0.82%; zinc,0.1%; and cobalt,0.1%.

Iron, titanium

Massive magnetite layers, magnetite gabbros, and magnetite-olivine rocks are interlayered with the anorthosite rocks in the southern margin of the Raudot Lake massif. There are transitions between these rock types, and the relative percentage of the magnetite can be estimated only after a systematic study. The magnetite-olivine rocks and magnetite gabbros contain up to 50% magnetite and are relatively abundant up to 4 miles west of Raudot lake.

A massive magnetite layer up to 6 feet thick may be seen about 1,500 feet east of Raudot lake, on the northern side of an easterly trending valley. This layer contains 50.27% iron and 6.37% titanium. The titanium is present in the form of delicate needles of ilmenite.

Iron-formation

An isolated outcrop of quartz-magnetite pyroxenite 500 feet north of Hart-Jaune river on longitude 68°00' may be a highly metamorphosed iron-formation. Geophysical investigation would possibly reveal the extent of the pyroxenite.

Sand, gravel

Large quantities of sand and gravel for construction and road building are available in the terraces along Manicouagan lake and some rivers.

Exploration Work in the Hart-Jaune River Area

Three groups of claims are held by Quebec Cartier Mining Co. in the southeastern part of the area. A group of four claims is located 1 mile east of Joyel lake in proposed township No. 1852 (License 175883, claims 3,4,5, and License 160949, claim 1). This group of claims is underlain by diverse siliceous layers of sedimentary origin (some with sillimanite and graphite) and quartzite. Some layers contain disseminated sulfide mineralization, which is oxidized near and on the outcrop surface and stains the weathered rocks rusty brown.

A second group of claims is about 1/2 mile east of Mora lake in proposed township 1853 (License 175887, claims 2,3,4,5). In the eastern, mineralized part of this claim group, the granulitic gabbro contains abundant siliceous layers; in the western part, the rock is mainly granulitic gabbro. Electromagnetic surveys indicated anomalies over part of this group of claims and a diamond drill-hole intersected a zone of disseminated sulfide mineralization over a length of about 50 feet.

The third group of claims is 2 miles southeast of Mora lake (License 175886, claims 1,4, and License 174068, claims 1,5). Here, also, some electromagnetic indications were tested by diamond drilling, and a mineralized zone of about 13 feet and two minor mineralized zones were intersected.

Part of the map-area outside the above-mentioned groups of claims has been prospected, such as is shown by stripped surfaces and pits (blasted).

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ALPHABETICAL INDEX