IRON FORMATIONS AND ASSOCIATED ROCKS

IN THE MOUNT WRIGHT AREA (QUEBEC)

by

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IRON FORMATIONS AND ASSOCIATED ROCKS IN THE MOUNT WRIGHT AREA (QUEBEC)

INTRODUCTION

General Statement

This thesis is a study of iron-bearing formations and associated rocks in an area approximately 24 miles SSW of Mount Wright in Central Quebec.

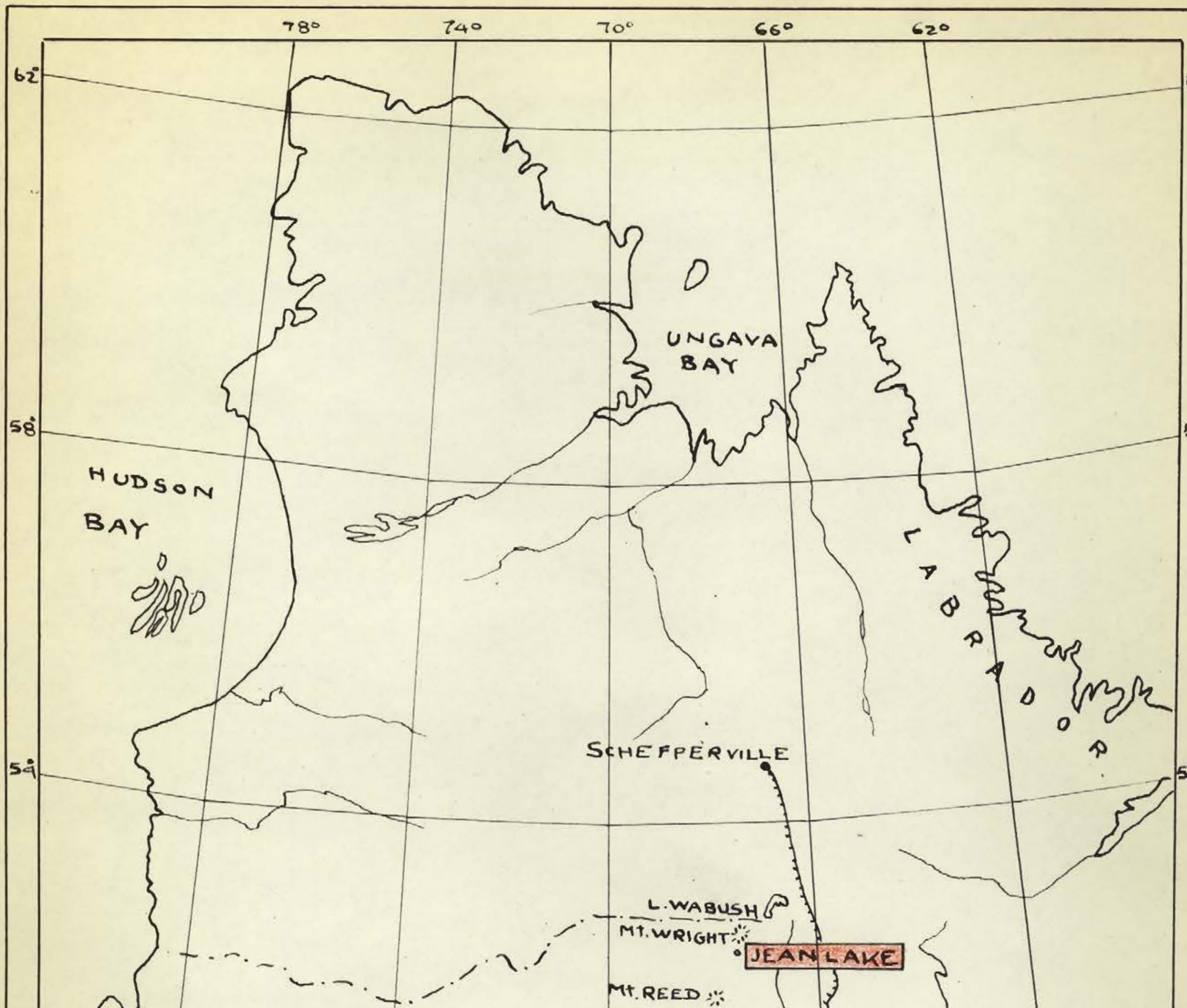
During the summer of 1958, the writer had the opportunity to map in detail an area of about four square miles. This area is a part of a concession held by Quebec Cartier Mining Company, for whom the survey was undertaken.

The mapping roughly followed a series of anomalies outlined by an aero-magnetic survey.

Acknowledgements

The Quebec Cartier Mining Company kindly granted permission to use the information obtained from field mapping.

The writer gratefully acknowledges the assistance and criticism of Dr. E.H. Kranck, of McGill University. Appreciation is expressed to Dr. J.S. Stevenson, also of McGill, who directed the work for this thesis. The writer wishes to thank Dr. P.R. Eakins and his wife for their valuable suggestions and help.


78°
74°
70°
66°
62°
62°
58°
54°
50°
46°
UNGAVA BAY
HUDSON BAY
LABRADOR
SCHEFFERVILLE
L. WABUSH
Mt. WRIGHT
JEAN LAKE
Mt. REED
L. MISTASSINI
CHIBOUGAMAU
SEVEN ISLANDS
N. B.
QUEBEC
MONTREAL
U.S.A.
INDEX MAP
Miles 0 100 200

Location and Means of Access

Jean Lake is situated in the Ashuanipi district at latitude 52° 23' north and longitude 67° 35' west, in Saguenay County approximately 24 miles SSW from Mount Wright and 159 miles NNW from Seven Islands.

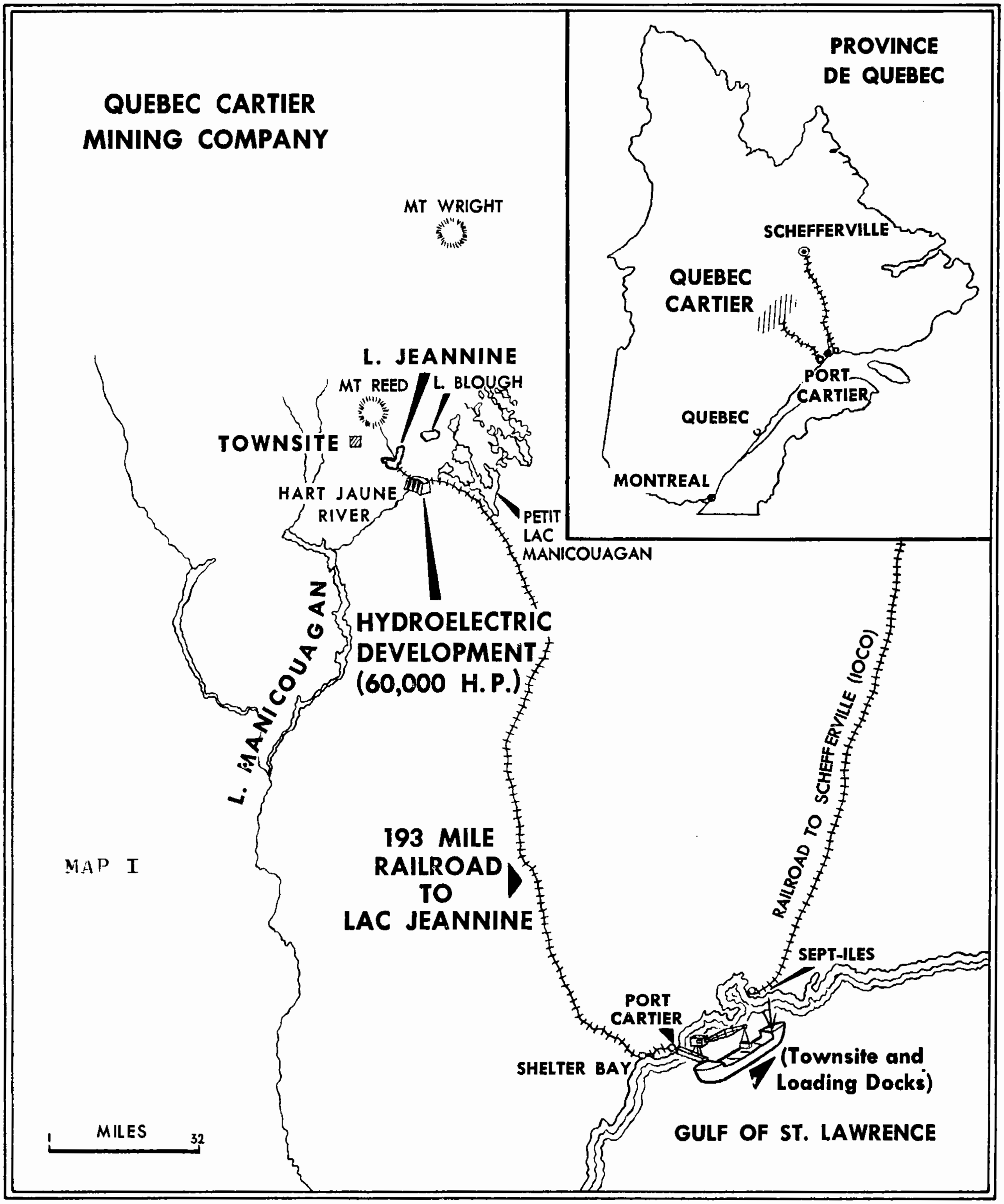
The area can be reached by hydroplane from Seven Islands or from Roberval. A newly constructed road connects Lake Jeannine, which is 42 miles SSW of Jean Lake, with Seven Islands. A proposed railroad will connect Port Cartier (the site for a town and loading docks on the St. Lawrence near Shelter Bay) to the ore deposits of Lake Jeannine, about 190 miles away. (Map 1)

Mapping Procedure and Coverage

A series of surveyed base lines, 12 feet wide, were cut through areas of anomalies. Picket lines were cut at right angles to the base lines at 200 foot intervals. These picket lines were planned to cover all the area of anomaly and to extend into the formations associated with the iron bearing rocks.

The area was mapped on a scale of 1" = 200'. Field data were plotted on field sheets and later transferred to base maps.

The amount of outcrops in the surveyed area varies greatly from place to place. Average exposure is not more than 5 to 10%.


QUEBEC CARTIER
MINING COMPANY
PROVINCE
DE QUEBEC
SCHEFFERVILLE
QUEBEC
CARTIER
PORT
CARTIER
QUEBEC
MONTREAL
MT WRIGHT
L. JEANNINE
MT REED
L. BLOUGH
TOWNSITE
HART JAUNE
RIVER
PETIT
LAC
MANICOUAGAN
L. MANICOUAGAN
HYDROELECTRIC
DEVELOPMENT
(60,000 H.P.)
RAILROAD TO SCHEFFERVILLE (IOCO)
193 MILE
RAILROAD
TO
LAC JEANNINE
SEPT-ILES
PORT
CARTIER
SHELTER BAY
(Townsite and
Loading Docks)
GULF OF ST. LAWRENCE
MILES
32

MAP I

Sources of Information

This thesis is based mainly on the writer's detailed geological mapping of Jean Lake area and Lake Lamelee area. More than 1500 feet of diamond drill core from Jean Lake area were available for study. The laboratory work was mainly petrographic. Eighty thin sections and 25 polished specimens were examined. Chemical analyses and fluorescence X-ray determinations were done in the McGill University laboratories. The optical properties of some of the minerals were determined using oil-immersion methods.

Previous Work

Gill, Bannerman and Tolman (1937) did reconnaissance mapping in the area south and west of Wabush Lake. In 1949, Ross mapped the area around Manicouagan Lake, 50 to 60 miles south of Jean Lake. G.A. Gross, in 1955, submitted a thesis at the University of Wisconsin entitled "The Metamorphic Rocks of the Mount Wright and Matonipi Lake Areas of Quebec". In 1956, K.L. Currie wrote a report on Peppler Lake which lies a few miles south-west of Jean Lake.

The Jean Lake area was systematically mapped for the first time by the writer.

TOPOGRAPHY AND GLACIAL GEOLOGY

The topography of the Jean Lake area reflects the geology and structure of the bedrock. Relief is moderate, nowhere exceeding 300 to 400 feet above lake level. (Fig. 1) Prominent ridges and hills are usually underlain by resistant rocks such as granite gneiss or less frequently, quartzite. The area drains into the St. Lawrence River basin. The drainage pattern has been modified by glaciation and the numerous lakes in the area are connected by small streams and rapids.

Glaciation rounded and polished the more resistant outcrops. Glacial striae, chatter marks and nail head grooves are common features. (Fig. 2). The glacial till is mainly sand and silt of fluvioglacial origin with few pockets of gravel. On the west side of Jean Lake diamond drilling showed the sands to be more than 140 feet thick.

Fig. 1. Photograph showing the topography and type of vegetation in the Jean Lake area.

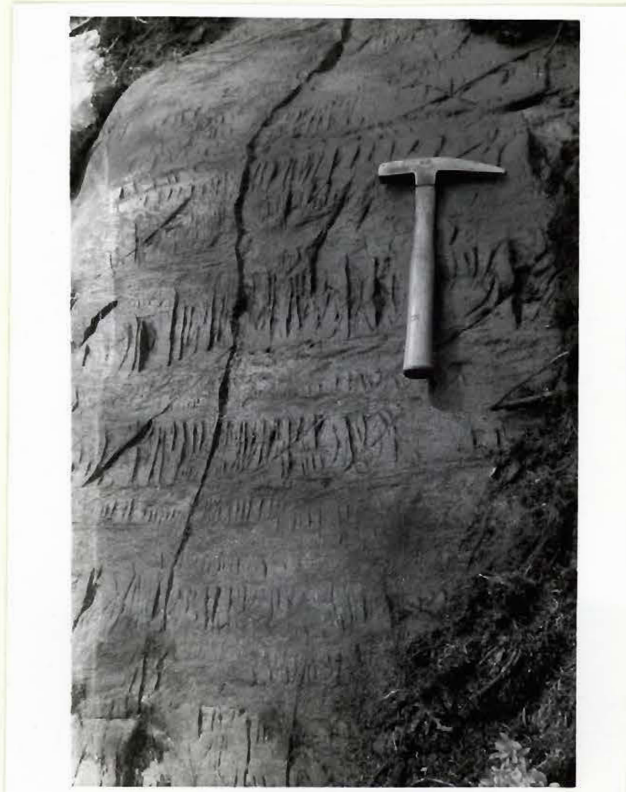


Fig. 2. Photograph of chatter marks on a quartz-magnetite outcrop.

GENERAL GEOLOGY

All the consolidated rocks of Jean Lake and Lake Lamelee area, which is situated 3 miles east of the SW shore of Jean Lake, are of pre-Cambrian age. These areas lie in the Grenville sub-province, near the Grenville front and are part of the southwest segment of the Labrador Trough. The rocks in these areas represent sedimentary units of the Trough which have been engulfed in Grenville-type regional metamorphism.

The rocks have been folded into open overturned to the east structures trending NW and commonly doubly plunging. In the southern part of Jean Lake, the formations have been folded about NE trending axes. A later folding took place in a ENE direction.

Both the metamorphosed iron-bearing rocks with their minor recrystallized chert and the associated marble, quartzite and garnet gneiss are of Huronian type. This whole assemblage of rocks appears to be associated with metamorphism of the amphibolite facies. The geological formations are listed in chronological order in the table of formations.

STRUCTURAL GEOLOGY

Structurally the Jean Lake area is part of an orthotectonic region characterized by isolated longitudinal belts of intensely folded sediments showing cleavage and schistosity.

The general structural features of this area resulted from folding about two sets of axes. The dominant set, ranging in strike from N 40° W to N 30° E, is crossed by a poorly developed set trending N 70° E. Detailed mapping of the scanty rock exposures and data obtained from diamond drilling revealed that the structural elements in the northern part of the area consist of a series of minor open folds overturned to the east. These minor doubly-plunging folds have developed on the western flank of a major overturned anticline which has its crestal line trending NE and roughly parallel to the south-west shore of the lake.

Locally the iron-bearing formations appear to be a superficial cover over the granite gneiss and were folded independently of their substratum. Examination of cores from diamond drill holes #14E-2 and #255 revealed a zone of faulting and brecciation where the quartzite and marble are missing, and where the quartz-magnetite lies directly on the granite gneiss. From this evidence it appears that the relatively incompetent iron-bearing rocks were folded and upthrust onto the more rigid granite-gneiss.

No direct evidence of faulting on outcrops was observed in mapping the area. A series of en-echelon trenches, however, striking approximately N 30° E and locally truncating the belts of outcrops suggests the presence of cross-faulting separating zones of folding.

A set of joints striking approximately S 60° W were the openings which controlled the emplacement of a transgressive pegmatite at the end of base line No. 3.

Ptygmatic folding is common in the quartz-specular hematite rock and in the garnet-gneiss formation. While in the first case the ptygmatic contortions are probably a result of plastic buckling on boundary planes due to differential response of the rock to internal deformations, those in the garnet gneiss appear to be associated with mobilization during orogenic movements and are not restricted to planar surfaces.

Banding and foliation in the garnet gneisses appear to be parallel to the original bedding planes and to define contacts between formations. All the rocks in this area show mimetic recrystallization.

TABLE OF FORMATIONS - JEAN LAKE AREA

		Approximate thickness	
RECENT			Alluvium Glacial Till (Fluvioglacial sand and gravel)
PRECAMBRIAN	HURONIAN		PEGMATITE
		300 ft.	QUARTZ-SPECULAR-HEMATITE
		0 - 50ft.	GARNET GNEISS
		10 - 300ft.	QUARTZ-MAGNETITE
		0 - 150ft.	IRON-SILICATE
		5 - 150ft.	QUARTZITE
			UNCOMFORMITY
	GRENVILLE	10 - 200ft.	MARBLE
			GRANITE GNEISS AND MIGMATITE

DESCRIPTION OF ROCK FORMATIONS

GRANITE GNEISS

The granite gneiss, also, referred to as the basement gneiss is of widespread occurrence in the Jean Lake area. These rocks which are abundantly exposed on tops and sides of hills were examined in a cursory manner. Under the term of "granite gneiss" the following types of gneiss were mapped:

1. A pinkish, coarse grained granitic gneiss often ptygmatically folded.
2. A white-gray, variety characterized by coarse quartzitic layers and containing local lenses of flaky biotite.
3. A composite or migmatitic variety probably produced by injection of granitic magma along foliation planes.

In the white gray variety gneissosity appears to have been derived from an original bedding. Drilling of holes #14E - 3 and #255 revealed an area of intense shearing and brecciation in the quartz-magnetite rock at the contact with the granite gneiss. The marble and quartzite horizons in this particular place are missing.

THE MARBLE FORMATION

The diopside marble of Jean Lake lies comformably on the granite gneiss and is overlain by quartzite. This formation is widely distributed, constitutes a good stratigraphic marker and attains locally a maximum thickness of 200 feet.

As a rule, parallel bands of pale green diopside, often regularly spaced, alternate with even layers of granular crystalline limestone. (Fig. 3). The diopside bands consists of crystals which are often lamellar massive and twinned. Because of differential weathering, the diopside bands stand out in white ridges whereas the calcite occupies the depressions between the diopside bands and exhibits yellow to dark brown weathered surfaces.

Under microscope, the calcite grains are arranged in an inequigranular granoblastic mosaic. In both the calcite and diopside bands nearly rectangular sections of wollastonite are present. (Fig. 4). Accessories are scapolite, phlogopite, and amphibole (possibly cummingtonite), antigorite after forsterite and enstatite altered to bastite. The amphibole forms a corona around enstatite grains.

Diopside marble of this nature is the characteristic product of regional metamorphism of siliceous dolomitic limestone. The presence of wollastonite in this case would not indicate that the temperature of the wollastonite mineral phase was attained, but, as H.L. Bowen (Jour. Geol.,

1940) pointed out, solutions could induce the formation of wollastonite providing that the solutions were not saturated with CO_2.

Fig. 3. Photograph showing the contact zone between diopside marble and quartzite, D-diopside; L-crystalline limestone; Q-quartzite.

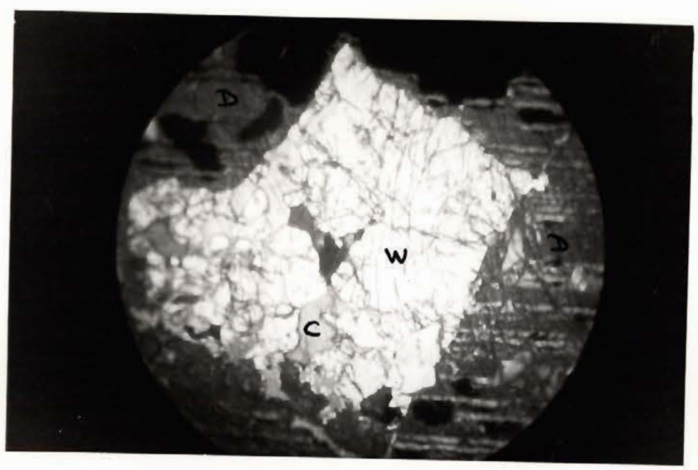


Fig. 4. Photomicrograph of a rectangular cross section of Wollastonite in twinned diopside. W-Wollastonite; D-Diopside; C-Calcite. Cross Nicols. Low power. X 9

THE QUARTZITE FORMATION

In the Jean Lake area, the quartzite formation always overlies the marble and is overlain by the iron silicate formation. The stratigraphic thickness of quartzite in the northern part of the Jean Lake area ranges from 20 to 150 feet or more. In the south, the quartzite horizon is only about 5 to 10 feet thick. The wavy irregular nature of the contact between the marble and the quartzite and the presence of debris of eroded marble within the quartzite in the contact zone, is evidence that a period of erosion and non-deposition occurred before the quartzite was deposited on the marble erosional surface. (Fig. 3). Near the end of base line No. 3, the quartzite formation is locally missing and the marble is overlain by the iron formation with slight angular uncomformity. Small marble fragments were found imbedded in the iron formation.

Currie (1956), in his study of the quartzite of Peppler Lake concludes that the variable thickness of the quartzite horizon was the result of accumulation of quartz sands in hollows on the erosional surface of the marble. This was probably the case if the deposition on a regional scale is considered. There is local evidence, however, that a period of erosion occurred after the quartzite was deposited.

The quartzite formation in the Jean Lake area is a well-defined readily recognizable horizon. It was mapped as the "silica-quartz" formation. Exposures of this quartzite are characterized by massive, rounded and often polished surfaces, and by milky-white to light brown colour. Weathered surfaces exhibit, locally, a pinkish tinge and thin layering of contrasting colour and texture which would appear to be a relict after an original stratification. Small voids and rounded cavities oriented along parallel lines and partly filled with a green clayey material or with brown goethite are present.

Under the microscope, these rocks display a mosaic of uneven but chiefly coarse grains ranging in size from 0.5 to 1.5 mm. The milky-white dense variety is characterized by: absence of preferred orientation or elongation of grains by intense crenulation of borders of the grains and by numerous sub-microscopic rutile inclusions aligned in parallel rows within the quartz grains. Sub-parallelism of the elongated grains and severe fracturing and absence of interlocking of grains is noticeable in the layered pinkish variety. In most of the thin sections examined, the quartz grains are closely interlocked in a granoblastic texture. Strain shadows are quite pronounced. They appear to be related to metamorphic conditions instead to be inherited. Some grains are anomalously biaxial and exhibit Bohm striations and marginal granulation. No signs of outlines or patterns suggesting authigenic growth or addition of quartz to the original grains were detected.

Quartzites which are relatively thick and closer to the marble horizon than to the iron formation are exceptionally pure (95 per cent quartz). The pink layered variety in proximity to the iron formation contains up to 15 per cent of garnet grains. These garnet grains are small, commonly euhedral and are aligned in rows usually along the quartz grain boundaries. Layers of small granoblastic quartz grains accompanied by numerous garnet grains alternate with layers of elongated coarse-grained quartz devoid of garnet grains. It would appear that the garnet grains as well as minor phlogopite and an amphibole, presumably tremolite, were derived from metamorphism of interstitial clays rich in calcium and magnesium. Numerous rounded drop-like rutile grains are present in some of the garnet-rich layers. (Fig. 5).

Calcite in the quartzite is definitely interstitial and is present in negligible amounts. Close to the marble formation, however, as much as 10 per cent calcite is present, usually along cracks. The calcite in this case was probably introduced in the quartzite from the adjacent marble during regional metamorphism rather than being derived from penecontemporaneous precipitation or introduced by meteoric waters.

Tiny flakes of chalcopyrite and pyrite are locally present in the quartzite.

The Epiclastic Origin of the Quartzite Formation

This type of quartzite is evidently the result of regionally metamorphosed well-sorted first-cycle orthoquartzite which was deposited under sub-aerial conditions following a period of intense base leveling. The presence of rutile is diagnostic of an allogenic origin. No cross bedding, grain gradation, or other features characterizing deposition of clastic material in shallow water conditions were observed.

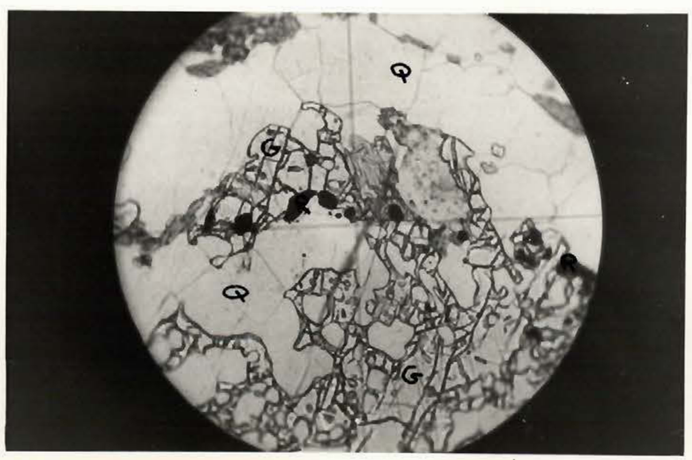


Fig. 5. Photomicrograph of quartzite with detrital drop-like grains of rutile. Q-quartz; G-garnet; R-rutile. Plain polarized light. Medium power. X 28.

QUARTZ ROCK

Thin lenses of dense cherty, light gray quartzite occur within the iron formation. This type of quartzite consists of small interlocking quartz grains in a granoblastic texture. Quartz is predominant (95 per cent) accompanied by interstitial calcite and clay minerals. A few grains of magnetite are visible along quartz boundaries. The general appearance of this quartz rock, the fine crystalline granular fabric and the absence of heavy minerals of detrital type and most important, its position within the iron formation are proof that this quartz rock was produced by recrystallization of a chert.

GARNET GNEISS

The garnet gneiss, also referred to as the mafic gneiss, is a fine to medium grained rock often displaying a well developed foliation and a poorly developed cleavage. This rock occurs both on top of and within the iron formation. Locally, it rests comformably on the quartzite or on the marble member. The contacts are macroscopically sharp. As a rule, the contact is between quartz magnetite and gneiss rather than between quartz specularite and gneiss. The thickness of the garnet gneiss ranges from few inches up to fifty feet or more.

Augen and ptygmatic structures consisting of microcline and quartz aggregates are a characteristic feature of some of these gneisses. Pegmatite bodies occur within or close to the garnet gneiss and are spatially and genetically related to them.

The garnet gneiss of Jean Lake are of three distinct varieties: feldspar - hornblende - biotite gneiss; feldspar - quartz - biotite gneiss and feldspar - quartz - mica - cordierite gneiss.

Most of the feldspar - hornblende gneiss was encountered by diamond drilling in the northern portion of Jean Lake area, whereas the gneiss rich in cordierite is well exposed in the southern portion of the area, at the end of base line No. 3. The banding in the gneiss is locally emphasized by layers rich in biotite or biotite hornblende alternated with layers of light coloured minerals such as quartz and feldspars. With a decrease in feldspars and/or quartz and an increase in biotite and hornblende, a transition from granoblastic to lepidoblastic fabrics take place. Biotite occurs locally in decussate arrangement.

Feldspar - hornblende - biotite gneiss.

The feldspar (commonly orthoclase and minor microcline or albite and oligoclase) is the dominant mineral. Hornblende exceeds biotite or is present in equal amount. Quartz is subordinate to feldspar, hornblende and biotite, and never forms more than 15 per cent of the total composition. Myrmekitic structures are common. Garnet grains of the almandine variety are abundant and are idioblastic and often poikilitic. (Fig. 6). Locally the garnets forcibly thrust apart the biotite folia. Accessories minerals are: apatite, magnetite, sphene, zircon. Apatite and magnetite are always present in amounts varying, respectively, from 2 to 5 per cent for apatite and from 5 to 7 per cent for magnetite. Scapolite is seldom present as an alteration product of the plagioclase.

Feldspar - quartz - biotite gneiss

Orthoclase, quartz and biotite are the dominant minerals. Orthoclase is preponderant and occurs in the form of augen and aggregates. Hornblende is absent. Other subordinate constituants are almandine garnets and apatite. Accessories are magnetite, zircon and rutile.

<u>Feldspar - quartz - mica - cordierite gneiss</u>

This variety is characterized by the presence of equal amounts of microcline, quartz, biotite and muscovite. This muscovite-rich gneiss contains considerable cordierite (up to 15 per cent) which is anhedral and often occurs in formless, elongate grains. Most of the grains, and especially the margins, are altered and veined by fine-grained sericite (pinite). (Fig. 7). Garnet porphyroblasts, which make up 5 per cent of the total composition, are riddled with inclusions of quartz, cordierite, microcline and biotite. Cordierite is also poikilitic and encloses quartz and biotite. The inclusions in the cordierite and the cordierite itself may have persisted from an early metamorphic stage. An attempt to establish a sequence of crystallization from the study of inclusions in the poikiloblastic structures agrees, however, with the generalized sequence of the idioblastic order, which in the case is:

1. biotite, quartz, microcline,
2. cordierite,
3. garnet.

Presence of cordierite would indicate high-grade regional metamorphism at high temperature and relatively lower stress. The amount of garnet in the gneiss seems to be related to the presence of hornblende; hornblende-rich varieties containing considerable garnets.

The mineralogical composition points to a definite sedimentary origin for these gneisses. The following features, characteristic of paragneisses, were observed in this garnet gneiss formation:

<u>a.</u> considerable variation in grain size in a mineral species;

<u>b.</u> pronounced mineralogical banding involving biotite and quartz;

<u>c.</u> abundance of biotite in the hornblende feldspar type;

<u>d.</u> presence of zircon and rutile in small rounded grains of definite detrital origin.

The feldspar - quartz - mica - cordierite gneiss probably originated from an argillaceous sediment rich in magnesium, whereas the hornblende-rich type may have derived from quartzose sediments containing dolomite or calcite-chlorite.

Fig. 6. Photomicrograph of poikiloblastic garnets in feldspar-hornblende-biotite gneiss. Cross nicols. Low power X 9.

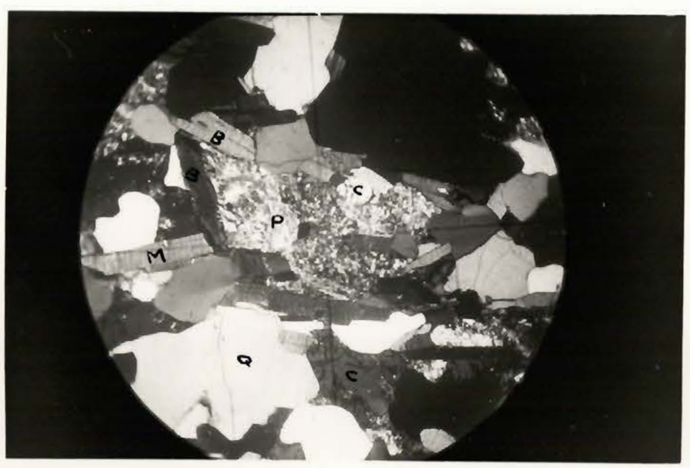


Fig. 7. Photomicrograph of feldspar-quartz-mica-cordierite gneiss. C-cordierite; P-cordierite altered to pennine; Q-quartz; B-biotite; M-muscovite; Cross nicols. Medium power. X 28.

THE PEGMATITE PROBLEM

General Statement

Five distinct types of pegmatite were investigated in detail. (Map II). Thin sections from them were obtained and analysed petrographically. These five types are:

1. A transgressive wedge-shaped branching pegmatite in banded quartz-magnetite and iron-silicate.

2. Concretion pegmatites in a garnetiferous feldspar-quartz-mica-cordierite gneiss.

3. Ptygmatically folded pegmatites in a garnetiferous feldspar-quartz-mica-cordierite gneiss.

4. A lens-shaped comformable zoned pegmatite in banded iron-silicate.

5. A lens-shaped comformable pegmatite in a garnetiferous biotite-hornblende-quartz-feldspar gneiss.

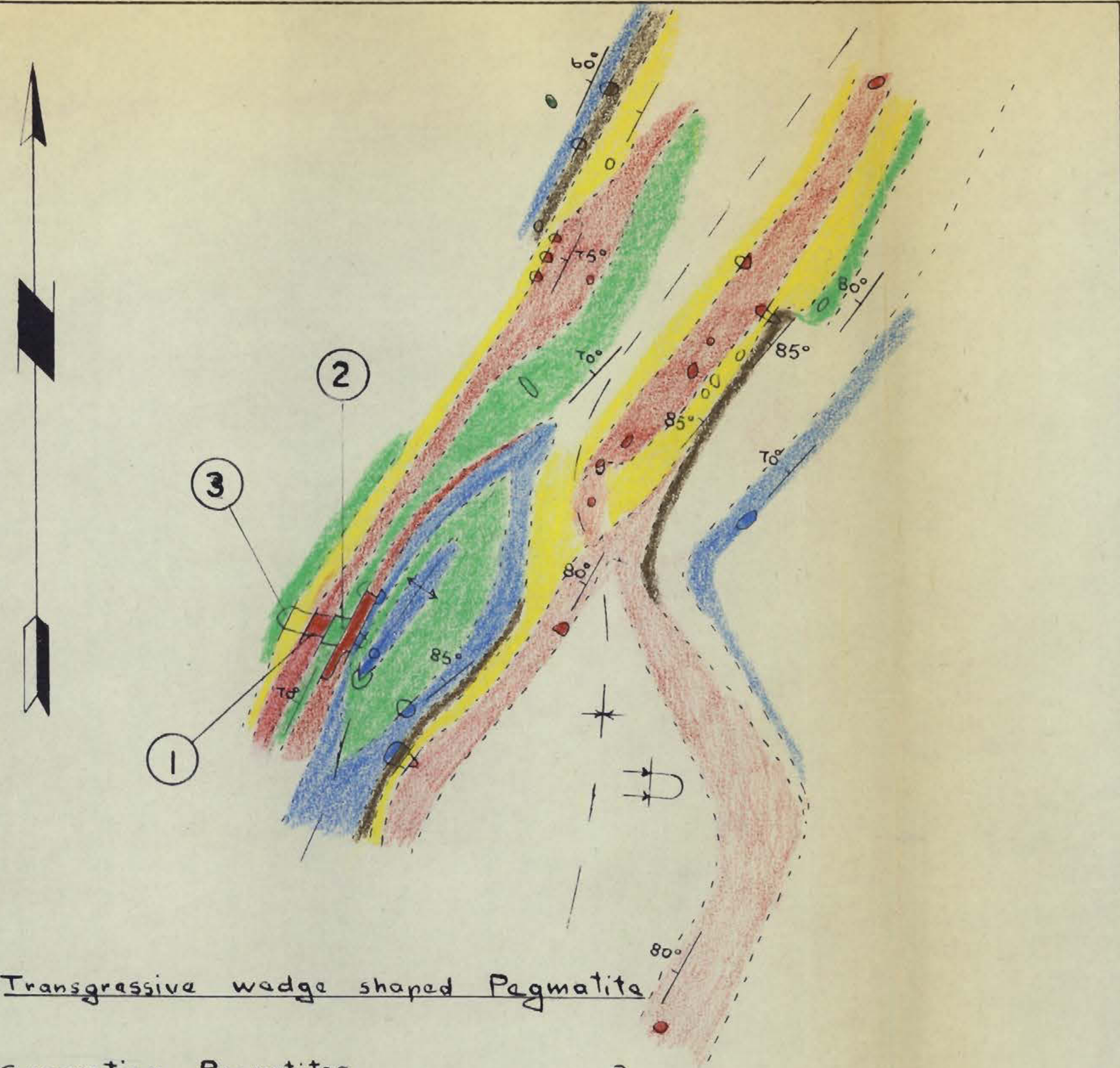
The pegmatites are made up of quartz and feldspars crystalloblasts which are equigranular to inequigranular and dominantly anhedral. Localization of these five different types of pegmatite was controlled by the following factors:

Mechanical properties of the host rock; local tectonic evolution which gave rise to folding, faulting, and jointing; and grade of metamorphism.

The mechanism of emplacement was:

Permissive (type 1-4-5), with crystallization in openings where the pegmatitic material was emplaced by a

MAP II



(1) Transgressive wedge shaped Pegmatite

(2) Concretion Pegmatites

(3) Ptygmatically Folded Pegmatites

GEOLOGICAL LEGEND

Iron formation (spec.)	Marble
Iron formation (mag.)	Garnet Gneiss
Iron Silicates	Pegmatite
Quartzite	Basement Gneiss

200 100 0 200 400

SCALE IN FEET

process of diffusion.

Concretionary (type 2-3), with the pegmatitic material locally derived from the host rock.

Transgressive Wedge-Shaped Pegmatite

This cross-cutting pegmatite consists of an equilateral wedge transecting a banded quartz-magnetite, iron-silicate horizon. (Fig. 8). The sides of the wedge are roughly seven feet long, non gradational, and locally macroscopically sharp. The outline of the contacts is irregular, but the northern and eastern sides present a certain linearity since they coincide respectively with a minor fault and with a tension joint. The branches are short, tongue-shaped, and noncomformable.

The rock is essentially a white, medium-grained, quartz-feldspar pegmatite with minor garnets and biotite. Although this occurrence cannot be considered a zoned pegmatite senso-stricto, a well-defined border zone, an intermediate zone, and a central zone are present. The border zone is of irregular thickness, is coarser-grained, and consists chiefly of almandine garnets. (Fig. 9). The garnet crystalloblasts attain sizes up to an inch in diameter and contain up to 10 per cent magnetite. Other inclusions in the garnets are:

Chlorite of the penninite variety.

Staurolite altered to fibrous sillimanite.

Allanite which produced numerous expansion cracks. (Fig. 10)

Helicitic structure, suggesting rotation of the garnet crystalloblasts during growth, is absent. Other minerals accompanying the garnets in the border zone are:

Biotite, locally altered to epidote and chlorite, orthoclase microcline and minor amounts of undulose quartz.

Micro-myrmekitic intergrowths of quartz and acidic plagioclase are rare, but are present in the border zone. Incipient metasomatic replacement of biotite by feldspar can be seen locally. The intermediate zone consists essentially of an aggregate of medium-grained albite-microcline and undulose quartz. Antiperthite intergrowths are common. Although biotite and garnets are invariably present in the intermediate zone, they are not preponderant as they are in the border zone. The core, or central zone, is not a well-defined one, but differs from the intermediate zone because of its higher content of garnets and biotite. Basic inclusions within the pegmatitic body consist chiefly of altered biotite and hornblende with minor amounts of potassium feldspars.

The garnet-biotite reaction border zone was formed because of the chemical incompatibility between quartz-feldspars and the silicates of the amphibole group of the host rock.

The iron formation transected by this pegmatite, along with the other adjacent sedimentary members, is part of a tightly-folded overturned syncline-anticline system. A minor fault striking S 60° W and of unknown dip forms the contact line between the quartz-magnetite and the iron-silicate formation in the proximity of the pegmatitic body. A set of joints striking in a direction perpendicular to the bedding and supposedly parallel to the direction of compression were with the fault the openings which controlled the emplacements of the pegmatite material.

Quartz-magnetite and iron-silicate, which are brittle and competent rocks, are not susceptible to plastic flowage, but rupture readily under tension, thereby creating favourable sites for the emplacement of pegmatites. Incipient zoning and lack of orientation of the pegmatitic minerals perpendicular to the contact walls would suggest that mobility was very limited.

Concretion Pegmatites

Individual concretions consist of small lenses, pods, augen, and schlieren arranged parallel to the foliation of the gneiss. Well-developed augen reach a maximum length of three inches; small lenses, pods and schlieren are only fractions of an inch long. (Fig. 11). The concretions are grains of microcline or aggregates of grains of microcline and quartz. A selvage of biotite muscovite plates forms the bordering zone between the concretions and the matrix. The matrix, which is fine-grained and exhibits a well-developed foliation, is characterized by the presence of an equal amount of mica (biotite and muscovite), microcline and cordierite. The quartz is undulose and not as abundant as the microcline.

Idioblastic garnets contain numerous inclusions of quartz, biotite, microcline and cordierite. Few grains of apatite and zircon were identified. The host gneiss contains up to 30 per cent by volume of concretions.

The host gneiss of the concretions overlies the banded quartz-magnetite-iron-silicate member transected by the wedge-shaped pegmatite. Environmental conditions and structural setting were therefore similar to those previously described in the case of the transgressive wedge-shaped pegmatite. According to T.F.W. Barth, diffusion along activity gradients and successive excess of pressure would account for the formation of the concretions.

Ptygmatically Folded Pegmatites

The shape of the ptygmatic folds is best illustrated by the figure. (Fig. 12). They are irregular and have locally-attenuated limbs and thickened hinges. The average length of a fold is one foot, but smaller folds are quite common. These folded pegmatites are white to light cream in colour; aggregates of quartz grains within the pegmatites have a greasy lustre. Microscopic examination of the pegmatitic material revealed the presence of microcline in preponderant amounts, accompanied by undulose quartz and negligible albite. The host rock is a fine-grained garnetiferous feldspar-quartz mica-cordierite gneiss. A microscopically visible rim or border zone of biotite muscovite, locally altered to chlorite, appears to follow the contortions of the ptygmatic folds.

The local tectonic evolution, which is related to the origin of the ptygmatically folded pegmatites and the host gneiss, was identical to the one briefly outlined in describing the syncline-anticline system in connection to the transgressive pegmatite. The lineation planes in the gneiss are sub-parallel to the fold axes of the ptygmatic veins; this would indicate that the folds were formed in the crystalline state as a result of compression of the plastic incompetent gneiss, perpendicular to its linear structure (Ramberg). The above-mentioned structural characteristic would entail a synkinematic folding process rather than a post-emplacement folding process.

Lens-Shaped Comformable Zoned Pegmatite

Because of the paucity of outcrops in this particular area, only one exposure of this lens-shaped comformable pegmatite was examined. It has not been possible to establish the length of the body, but there are indications that it is less than 100 feet long, and never attains a width greater than five feet.

A definite zoned structure is apparent here. The border zone exhibits conspicuous biotite flakes oriented perpendicular to the walls. The outer zone is characterized by graphic texture where sub-parallel quartz rods penetrate coarse crystals of oligoclase. The central, or inner, zone consists mainly of quartz, exhibiting a mosaic of undulose extinction, and garnets. The garnets were partially replaced and locally penetrated by the quartz. Noticeable in the garnets are the absence of inclusions and the presence of zoizite veinlets. A micropegmatite, consisting of quartz, microcline, and acidic plagioclase, with local micro-myrmekitic structure, is part of the central zone. The plagioclase of the border zone appears to be slightly more basic than the plagioclase from the central portion. The host rock to the pegmatite in this case is the iron-silicate formation, where banded silicates of the amphibole group alternate with quartz magnetite bands.

The emplacement of this comformable pegmatite was definitely controlled by a tension fracture resulting from refolding along a ENE direction. It is significant that the lens was emplaced where refolding was most intense. Zoning in pegmatite is ordinarily considered a criterion for mobility.

Lens-Shaped Comformable Pegmatite

No surface outcropping of this pegmatite is visible. The occurrence was encountered by D.D.H. No. 253 at 80 feet from the collar, and by D.D.H. No. 254 at 391 feet from the collar. The pegmatites revealed by D.D.H. No. 253 consist of a few augen and streaks in a fine-grained, well-foliated gneiss, overlain by the quartz-magnetite member. The pegmatite cut by D.D.H. No. 254 is at least 25 feet wide and is also overlain by quartz-magnetite. The contact between the pegmatite and the iron formation is comformable and macroscopically sharp. The mineralogical composition of this pegmatite does not differ greatly from the composition of the pegmatites previously described, and consists mainly of sub-euhedral grains of quartz, microcline, minor microperthite, and subordinate amounts of muscovite epidote and magnetite. A calcite vein cuts through the quartz grains. Augen and streaks encountered by diamond drill hole No. 253 are concretionary aggregates of quartz, albite and orthoclase grains, linearly arranged in planes parallel to the foliation. The host rock is a garnetiferous quartz-hornblende biotite alkali-feldspar gneiss.

Due to the scarcity of structural data, it can only be inferred that these two different pegmatitic sections belong to the same occurrence. The portion cut by diamond drill hole No. 254 was localized by a tension fracture in a tightly-folded minor syncline, whereas the concretions formed in a relatively unsheared area.

Fig. 8. Photograph showing a transgressive wedge shaped pegmatite in banded quartz-magnetite and iron silicate.

Fig. 9. Photograph showing the garnet border zone of the transgressive wedge shaped pegmatite. B-border zone.

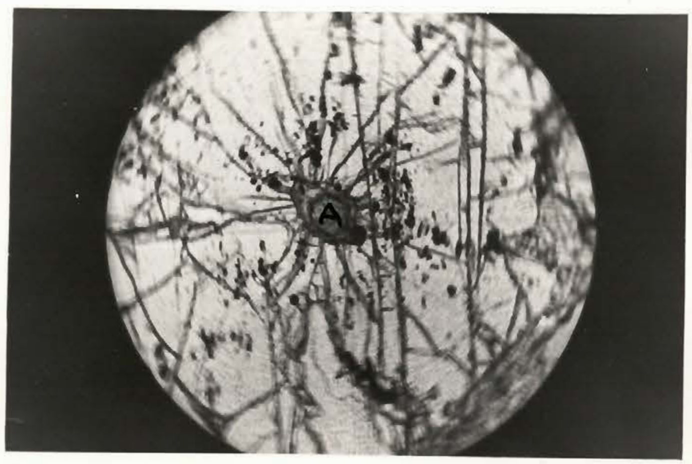


Fig. 10. Photomicrograph of a garnet of the border zone with expansion cracks and pleochroic halo produced by radioactivity in allanite. A-allanite. Plain polarized light. Low power. X 9.

Fig. 11. Photograph of concretion pegmatites arranged parallel to the foliation of the feldspar-quartz-mica-cordierite gneiss.

Fig. 12. Photograph showing ptygmatically folded pegmatites in a feldspar-quartz-mica-cordierite gneiss.

DISCUSSION

Summary

All the accumulated evidence shows that these ductless quartzo-feldspathic pegmatites are the result of metamorphic processes and formed by mechanical and aqueous diffusional transfer of material derived from quartz-feldspar biotite gneisses in regionally metamorphosed areas. The following discussion is an analytical study of the observations and data gathered in the light of Ramberg's theories on metamorphic pegmatites. The probable physicochemical conditions and milieu existing at the time of formation are also taken into consideration.

Structural Setting and Type of Metamorphic Facies

All the pegmatites examined occur in highly-folded rocks. There is a definite direct interrelation between the degree of folding and frequency and localization of pegmatites. All the pegmatites in the Jean Lake area were formed in highly deformed zones, where folding and re-folding were most intense. This was because the strain caused by creation of openings and minor fissures decreases the resistance against diffusion through rocks, favouring therefore the formation of pegmatites.

In the case of pegmatite No. 1, the fact that the transected wall rocks are consistently present on opposite sides of the pegmatite without offset would be proof of nondisplacement. Incipient zoning implies relative mobility. No rocks of magmatic origin have been found in the area.

The mineral assemblage and the presence of certain minerals which are good relative temperature indicators would place these pegmatites in the amphibole-facies complex. The presence of micro-antiperthite and microperthite could, however, indicate evolution at the P-T conditions of granulite-facies, because in a poly-component system of potash feldspar-albite, the top of the immiscibility gap is 550°C for the microcline (Laves 1952, pp. 436-450, 549-574). The presence of subordinate amounts of muscovite in the pegmatites would indicate high water pressure conditions at the time of formation.

A study of the gneissic rocks which are considered to be the source of the pegmatitic material yielded the following important information:

1. The gneisses and the pegmatites were formed under similar P-T conditions, and therefore the pegmatites conform to the degree of regional metamorphism of the source rock. This would not be possible if the pegmatite bodies were formed by injection and crystallization of a melt.

2. There is an evident lack of pegmatite-forming minerals in the gneisses close to the pegmatites bodies.

3. All the pegmatites occur within the gneissic rocks, or only a few feet from them; this is because transfer by diffusion takes place only over short distances.

P-T Conditions at Time of Formation

The temperature of formation of the pegmatites, which corresponds to the temperature of the boundary between amphibolite and granulite facies, was slightly below 600°C. The presence of such minerals as muscovite and epidote would indicate considerable water vapor pressure at the time of formation. Since all the pegmatite bodies examined are located close to the marble member, a CO_2 vapor pressure derived from the dissociation of carbonate rocks during regional metamorphism must also be taken into account, along with water as an active solvent.

Mobility and Diffusion-Transfer Mechanism

The reason why all the pegmatites examined consist of quartz, K-feldspars, and acidic plagioclase can be attributed to the high molecular mobility which is achieved in the quartzo-feldspathic rock during regional metamorphism; such mobility is considerably greater than that of basic rocks, conditions being the same. The fundamental driving energy of diffusion is the partial molal free-energy gradient. Diffusion is aiming at a complete thermodynamic equilibrium in the system. This condition is achieved if the high free-energy gradient, which rose above normal conditions during regional metamorphism, is lowered.

The molal free-energy of minerals and mineral aggregates is lowered when they are transferred into low pressure zones such as rock pores, minute cavities, zones of shear, fissures, etc.

The above-mentioned mechanism of transfer would explain why the driving energy of diffusion is molal free-energy, and why the pegmatites form in cavities, fractures, shears, etc, and occur in intensely deformed rocks.

In the case of concretionary pegmatites, or minerals which grew in clusters, the free-energy will decrease when clustering takes place. In the dimineralic concretions of pegmatite No. 2, forming of concretions took place because the host rock was supersaturated with quartz and microcline, which has a considerable force of crystallization and a strong chemical affinity for each other. While the biotite in the host gneiss was pushed aside by the force of crystallization of the growing quartz microcline, the garnets replaced and included quartz, microcline and biotite. Constant presence of biotite in the border zones of most of the pegmatite examined would indicate a reaction zone created because of chemical incompatibility between amphiboles and quartz feldspar. This reaction border zone of stable minerals such as biotite also represents a place of lower molal free-energy.

IRON BEARING ROCKS

General Statement

On the basis of physical properties, mineral composition and structural and textural characteristics the iron bearing rocks of the Jean Lake area have been mapped under the following classification: Quartz - Magnetite formation - Iron-Silicate formation and Quartz-Specular Hematite formation. (Map III - IV).

THE QUARTZ-MAGNETITE FORMATION

The quartz-magnetite formation was mapped as a separate unit. Because of its distinctive physical and lithological character and its areal extent, it constitutes a very important stratigraphic marker. The magnetite rocks are almost invariably associated with iron-silicates (hornblende, actinolite, grunerite, orthopyroxenes) and calcic silicates (diopside and tremolite). Because every gradation can be found between the two, a separation is often problematic. In the field, the separation is made on the basis of the iron content rather than on lithological criteria.

Outcrops of quartz magnetite rocks, when massive, are generally rounded, dark gray in colour, and resistant to weathering. The banded quartz-magnetite iron-silicate rocks exhibit prominent differential weathering, the thin magnetite bands standing out in relief and the iron silicate bands forming the troughs between ridges.

The local extent and distribution of the magnetite rock is well illustrated by the maps. (Map III - IV).

The quartz-magnetite formation and interlayered silica rocks are found underlain either by quartzite or marble, or by the granite gneiss. The garnet gneiss and the quartz hematite formation lie on top of the magnetite-rich rocks. It has not been possible to calculate the exact stratigraphic thickness of the magnetite horizon because of the possible presence of repeated beds. The quartz-magnetite formation is only a few feet thick in the area transected by base line No. 3. In the northern part of the area, however, the magnetite formation appears to be at least 300 feet thick.

Detailed mapping and examination of cores revealed that garnet gneisses and rocks of the iron silicate formation are almost always associated or adjacent to the quartz-magnetite formation and rarely to the quartz-hematite rock. This characteristic is significant and pertinent to determination of depositional environment.

In the quartz-magnetite rocks, abundant magnetite is the predominant iron oxide mineral; quartz is essential, and iron silicate is common. In the southwestern part of the area, parallel bands of green calcium-magnesium-iron silicates 1 to 2 inches wide alternate with thinner but prominent bands of quartz and quartz magnetite. The bands are commonly of uniform thickness but splitting and joining of bands is common. Outcrops of massive character consist of fine-grained equigranular quartz and magnetite with small amounts of iron silicate minerals. These outcrops exhibit thin layers of coarse recrystallized magnetite.

The quartz-magnetite-iron-silicate ratio shows considerable variation. The magnetite is relatively fine to medium-grained and occurs as octahedra, rounded minute particles, or elongated grains. Coarse grains of magnetite are conspicuous in zones of recrystallization and in border zones with transgressive pegmatites. The silicate minerals associated with the magnetite formation consist mainly of pale, apple-green diopside often altered to tremolite, tremolite altered to talc, and, more rarely, actinolite. A band of a brown-grey rock 3 feet thick and occurring within the magnetite appears to be composed chiefly of quartz, a pyroxene (possibly enstatite), and minor dolomite. Strongly pleochroic epidote of the pistacite variety occurs locally, along with actinolite, hornblende, and coarse tabular crystalline specularite. Accessories are garnet, apatite, quartz and pyrite. Calcite and minor dolomite are present in the quartz-magnetite rock but never exceed 5 per cent of the volume and appear to be secondary.

The average bulk composition of the magnetite rocks of Jean Lake, calculated by microscopic petrography, is as follows:

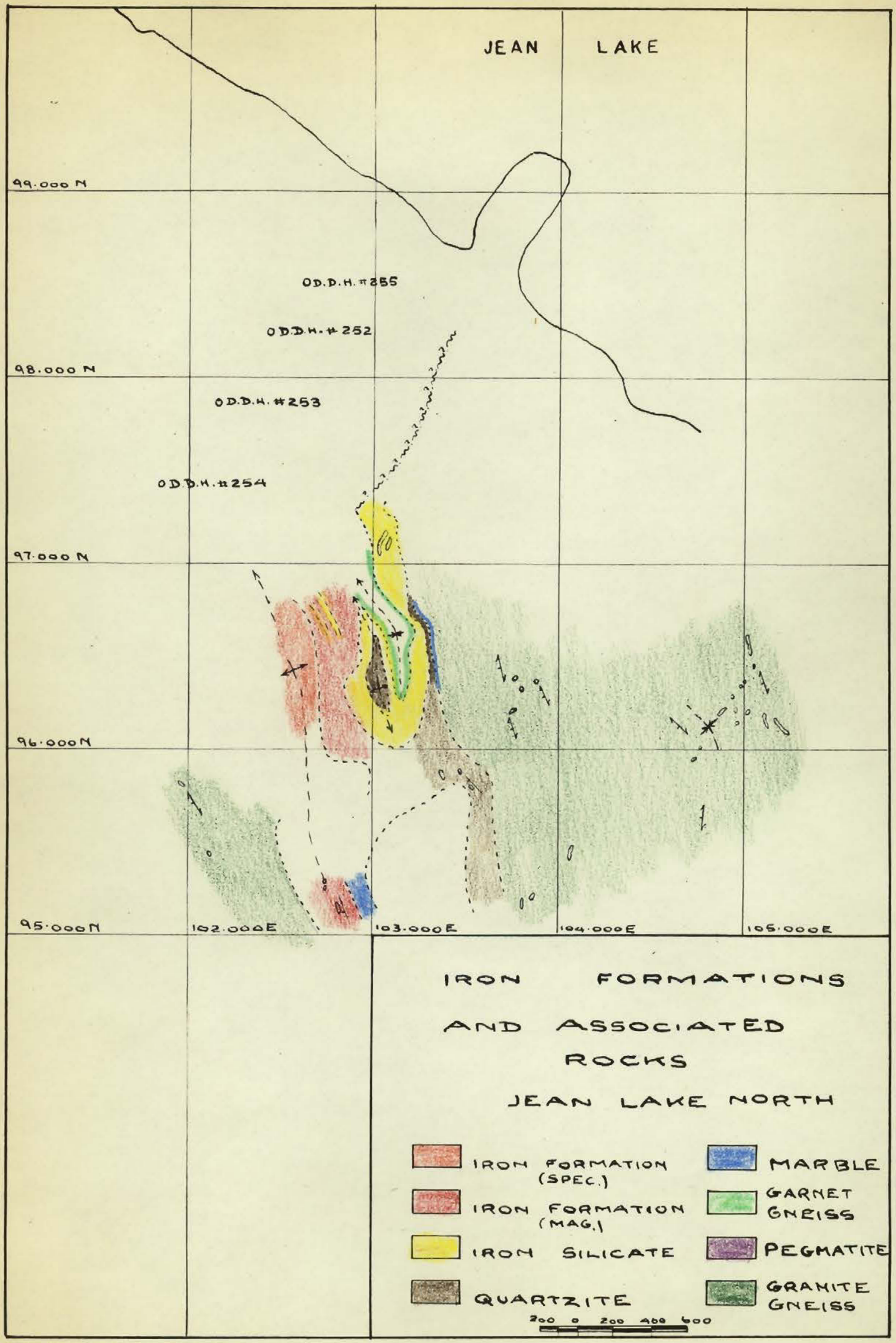
Magnetite	50%
Quartz	30%

Diopside	10%
Tremolite	5%
Calcite-Talc	5%

These magnetite rocks commonly exhibit inequigranular quartz and magnetite grains arranged in a granoblastic fabric. The grains of magnetite are chiefly anhedral and fine grained (0.2 to 0.5 mm. in diameter). Coarse recrystallized grains of magnetite attain up to 1 mm. in diameter and are associated with coarse grains of quartz and diopside. Quartz grains show undulatory extinction and minor fracturing.

Intricate folding is a characteristic feature of the highly banded magnetite rocks; the folds are mostly of small dimension, often ptygmatic, and in many places fractured and faulted. (Fig. 13).

MAP III


JEAN LAKE
99.000 N
98.000 N
97.000 N
96.000 N
95.000 N
102.000 E
103.000 E
104.000 E
105.000 E
O.D.D.H. #255
O.D.D.H. #252
O.D.D.H. #253
O.D.D.H. #254
IRON FORMATIONS
AND ASSOCIATED
ROCKS
JEAN LAKE NORTH
IRON FORMATION (SPEC.)
IRON FORMATION (MAG.)
IRON SILICATE
QUARTZITE
MARBLE
GARNET GNEISS
PEGMATITE
GRANITE GNEISS
200 0 200 400 600

MAP IV

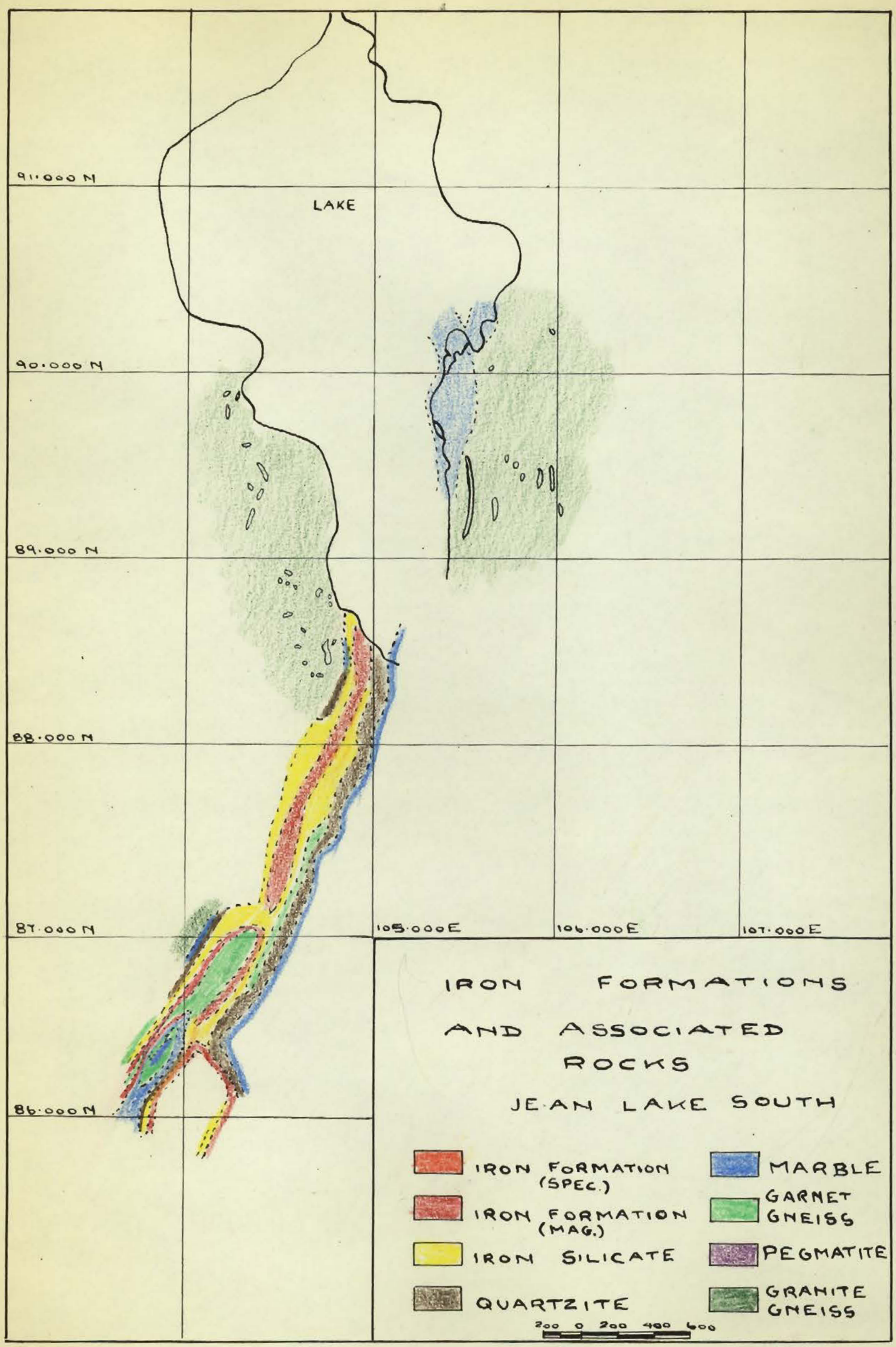

91.000 N
90.000 N
89.000 N
88.000 N
87.000 N
86.000 N
105.000 E
106.000 E
107.000 E
LAKE
IRON FORMATIONS
AND ASSOCIATED
ROCKS
JE.AN LAKE SOUTH
IRON FORMATION (SPEC.)
IRON FORMATION (MAG.)
IRON SILICATE
QUARTZITE
MARBLE
GARNET GNEISS
PEGMATITE
GRANITE GNEISS
200 0 200 400 600

Fig. 13. Photograph showing ptygmatic folding and jointing in quartz magnetite.

THE IRON SILICATE FORMATION

Under the term iron silicate were mapped all the calcium, magnesium and iron silicates, such as: hornblende, actinolite, grunerite, diopside, tremolite, orthopyroxenes. Rocks of the iron-silicate formation are intimately associated with those of the quartz-magnetite formation.

In the northern section of the Jean Lake area, iron-silicate rocks outcrop over a wide area and form prominent ridges and hogbacks which are resistant to weathering. The colour of the iron silicate rocks varies markedly but is commonly dark green, gray-green, or brown-green. The maximum observed thickness of the iron silicate formation is 150 feet. Most frequently, the iron silicate rocks lie conformably on the quartzite and are overlain by quartz-magnetite rocks or by the quartz-specular hematite formation.

Iron silicate rocks appears to be typical of a changing environment at the time of deposition and are therefore transitional between clastic and chemical deposition.

Banded iron silicate rocks consist of diopside-quartz, minor actinolite and calcite, alternated with thin bands of quartz-magnetite. The massive granular type of iron silicate rock consists chiefly of diopside altered to tremolite and actinolite or grunerite with minor hypersthene. Hornblende, biotite, quartz, garnets and occasionally cummingtonite are often present but in subordinate amounts.

Magnetite occurring in the massive iron silicate rocks consists of clusters and irregular concentrations of coarse recrystallized grains.

A singular feature in the massive iron silicate of the Jean Lake area is the occurrence of ellipsoidal-like bodies of concentric structure. These bodies attain as much as 1 foot in diameter and consist of an outer ribbonlike layer of hyperthene ½ inch thick and a nucleus of coarse quartz, hornblende and soft iron oxide. The enclosing matrix is made up of fibrous radiated, often nematoblastic, crystals of grunerite riddled with magnetite grains. (Fig. 14 - 15). Ribbonlike hypersthene layers are also found lining cracks and fractures. These structures are probably derived from concretionary bodies of chert and greenalite.

Dark brown oxidized bands of iron silicate, a few feet wide, are found in the southernmost end of the area. These bands consist of thin layers, 5 mm. wide, of iron oxide alternating with layers of granoblastic quartz-magnetite and hypersthene with minor calcite and magnetite. Other common mineral associations in the iron silicate formation are alternating layers of diopside quartz, and magnetite-garnet.

Fig. 14. Photomicrograph of a ribbonlike layer of hypersthene enclosed in a fibrous grunerite matrix. H-hypersthene; G-grunerite. Cross nicols. Low power. X 9.

Fig. 15. Photomicrograph showing a mass of fibrous grunerite of the iron silicate formation. Cross nicol. Medium power. X 29.

THE QUARTZ-SPECULAR HEMATITE FORMATION

Outcrops of specular hematite are exposed only in the tract cut by base line No. 1. This type of laminated iron bearing rock exhibits a splendent metallic blue colour and tends to be friable and easily weathered. This formation attains a maximum stratigraphic thickness of about 300 feet and lies on top of a well banded quartz magnetite and iron silicate rock.

The essential constituents of this formation are: specular- hematite, quartz, often with a pinkish cast and minor quantities of diopside, tremolite, actinolite and hornblende. Bands of quartz-specularite (5 mm.) alternate with diopside-quartz-specularite layers (2mm.). The specularite grains are flaky, equidimensional and elongated in the plane of banding. The quartz is also slightly elongated and undulose. (Fig. 16). Magnetite in the quartz-specular hematite formation occurs in bands a few feet thick but is usually erratically distributed. Bands a few millimeters thick of fine grained quartz-magnetite alternating with silky white fibrous aggregates of tremolite and minor magnetite were encountered in some of the drilled core. Bands of dense cryptocrystalline quartz rock, a few feet wide, with streaks of flaky specularite and thin layers of diopside occur within these hematite bearing rocks.

Specularite hematite grains have an average size of 0.3 mm. Coarse granular recrystallized hematite occurs mainly in zones of fracturing and in cavities. Cube-like rhombohedrons of hematite $\frac{1}{2}$ an inch across and finely striated were found along with slender prisms of actinolite partially replaced by hematite. Light coloured constituents in the laminated specular hematite consist, in order of abundance, of diopside, tremolite and actinolite. Subordinate amounts of hornblende and epidote are found with coarse granular hematite in zones of intense folding and fracturing. Calcite is present in irregular veinlets, as interstitial patches, and, along with talc, as a product derived from alteration of lime-bearing silicates.

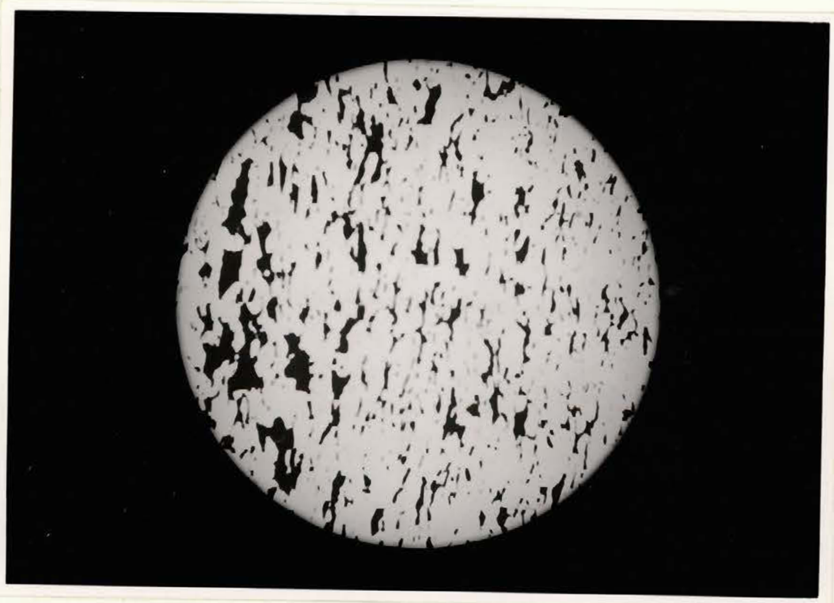


Fig. 16. Photomicrograph of quartz-specular hematite. Texture showing elongated grains of specular hematite in a quartz matrix. Plain polarized light. Low power. X 9.

PROBABLE ORIGIN, METAMORPHISM AND OXIDATION OF THE IRON BEARING ROCKS

Although this is not a study of the origin of iron bearing rocks, an attempt was made to visualize the type of environment and the conditions which prevailed at the time of deposition of the iron bearing rocks.

Mineralogical differences among the various formations can be ascribed mainly to the depositional environment and do not appear to be the result of metamorphic conditions.

The magnetite-silicate quartz rocks probably derived from ferruginous calcium-magnesium carbonates and interbedded chert. The following evidence supports this postulated origin.

1. Presence of abundant diopside. (Diopside is a characteristic mineral of regionally metamorphosed siliceous dolomitic limestone).

2. Stratigraphic relations. (Transition from the quartzite horizon to the overlying ferruginous carbonate-chert rock, which in this case was metamorphosed to a magnetite - silicate - quartz rock, could be interpreted as a change from shelf type deposition to deep basin type deposition. This change is in accordance with the generalized sequence followed by the tectonic evolution of a basin).

3. Rocks of a ferruginous carbonate - chert type are easily altered to a magnetite - silicate - quartz rock at relatively low temperatures.

The intimite association of the magnetite and the iron silicate rocks could be interpreted as the result of fluctuation of depositional environmental conditions. A mildly reducing environment and low O_2 atmospheric pressure at the time of deposition inhibited the formation of a higher oxide than magnetite. The calcium-magnesium-iron silicate of Jean Lake may represent an original greenalite-carbonate-chert sedimentary facies which was metamorphosed to grunerite-hypersthene-diopside and quartz. The garnet gneiss overlying the magnetite-silicate rocks and separating it from the quartz-specular hematite formation would represent a period of deposition of clastic material. The hematite is believed to have been chemically precipitated as a ferric hydrosol in shallow waters well aerated by wave action.

All the rocks of the Jean Lake area were subjected to a major regional tectonic evolution and to other deformations of local character caused by recurrences of orogenic forces.

As result of regional metamorphism, the hematite was changed to specularite, the chert was recrystallized to granular quartz, and magnetite-silicate-quartz rocks were formed, probably from ferruginous-carbonate-chert. The retrograde-metamorphism features present are interpreted as the effects of a later stage metamorphism superimposed on the more intensive early metamorphism. Diopside, which is a widespread mineral all through the iron bearing rocks, is often associated with calcite in narrow tectonized zones.

At the contact between these zones and quartz rock layers, granulation is intense. (Fig. 17). Retrograde metamorphic changes are evident, especially in zones of intense folding and fracturing. As a result of retrograde reactions, diopside was partially amphibolitized to tremolite. Passage from the amphibolite facies to the epidote-amphibolite facies is characterized by formation of iron rich epidote, actinolite and chlorite. The actinolite needles are sometimes replaced by hematite. (Fig. 18).

Diagenetic changes such as rearrangement and recrystallization of magnetite and hematite grains are also associated with folding and dislocation, and probably were penecontemporaneous to the orogenic forces which caused the retrograde metamorphic changes.

Investigation of several polished sections revealed various stages of martitization of magnetite. This process of oxidation is associated with zone of brecciation, microfolding, faulting, and water seepage. The alteration to hematite is most pronounced at the margins of the magnetite grains and proceeds inward along cracks and along the octahedral planes. (Fig. 19 - 20 - 21).

Sections of core from diamond drill hole No. 253 in a zone of microfolding show progressive oxidation along octahedral planes in a fine Widmanstatten-like texture. (Fig. 22). Small octahedra of hematite pseudomorphous after magnetite are often present and are characterized by weak anisotropism, twinning, and a higher reflectivity index than normal hematite. Some crystals of specular hematite exhibit textures similar to growth zoning where a number of smaller crystals are stacked together in almost parallel orientation.

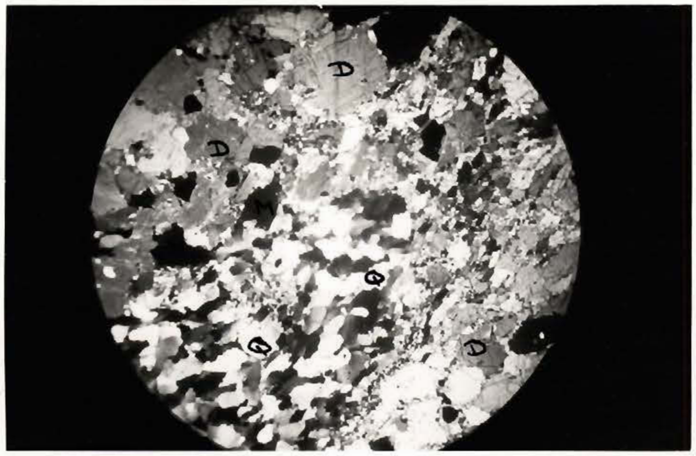


Fig. 17. Photomicrograph showing the contact between quartz rock and diopside zone. Q-quartz rock; D-diopside; M-magnetite; G-granulation. Cross nicols. Low power. X 9.

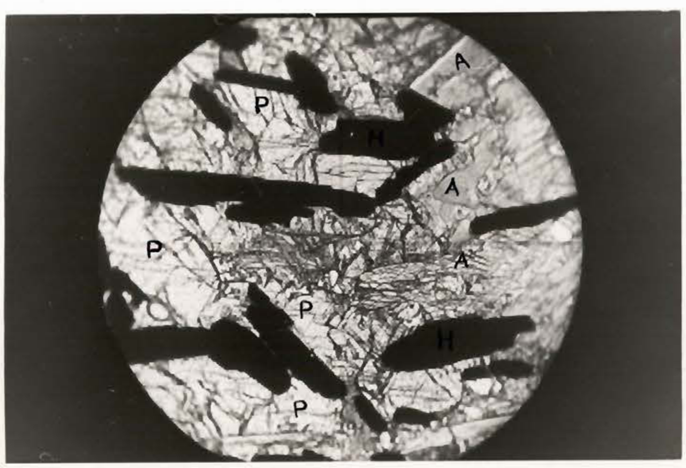


Fig. 18. Photomicrograph of a retrogressive metamorphic zone. A-actinolite; P-pistacite; H-specular hematite pseudomorph after actinolite. Plain polarized light. Medium power. X 29.

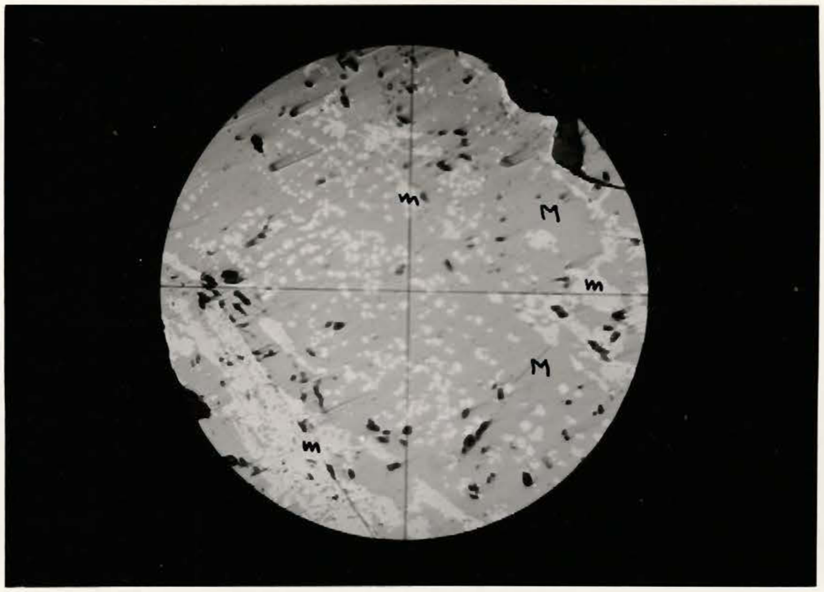


Fig. 19. Photomicrograph showing martitization of magnetite in a zone of brecciation and micro-folding. M-magnetite; m-martite. Reflected light. Medium power. X 84.

Fig. 20. Photomicrograph of martitization along margins of magnetite grains and along cracks. M-magnetite; m-martite. Reflected Light. Medium power. X 84.

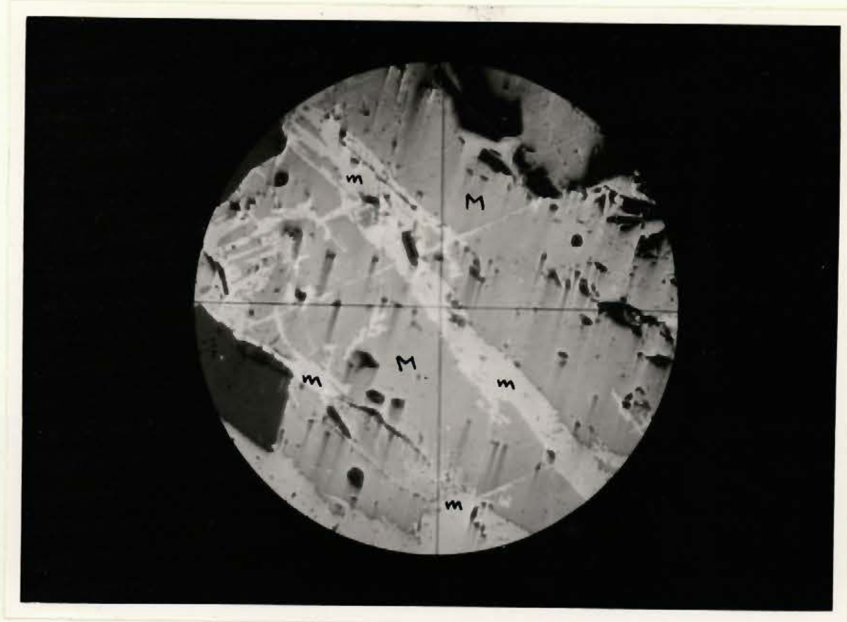


Fig. 21. Photomicrograph showing martitization of magnetite along octahedral planes. M-magnetite; m-martite. Reflected light. Medium power. X 84.

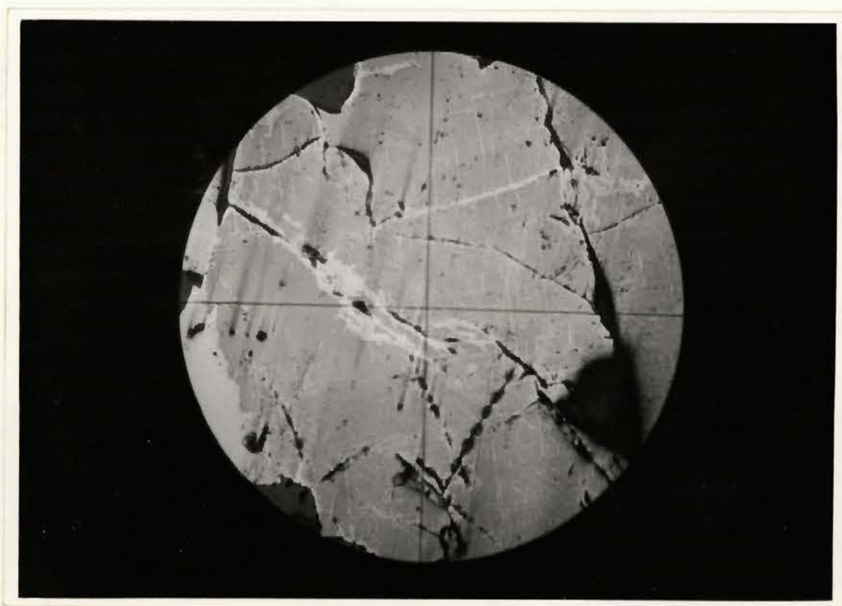


Fig. 22. Photomicrograph showing martitization of magnetite along cracks. Note the Widmanstatten texture. Reflected light. Medium power. X 84.

ANALYSES OF IRON BEARING SAMPLES

FROM THE JEAN LAKE AREA

	% Fe	% MnO	% TiO_2	% P_2O_5
Representative Sample of quartz-specular hematite	35.50	.09	.03	.07

	% Fe	% MnO	% TiO_2	% P_2O_5
Representative Sample of quartz magnetite	30.00	1.24	.02	.05

Analyst: Dehn H., Geochemical Laboratory,
McGill University.

THE MAGNESIAN TACTITE[1] ZONE OF LAMELEE LAKE

Geological Setting

A tactite zone in the nose of a northwesterly plunging syncline overturned to the west lies comformably between the quartz-magnetite and the quartz-specular hematite horizon. The syncline structure resulted from folding about two sets of axes. A dominant NW trending set is crossed by a later developed ENE striking set. (Map VI)

The tactite zone consists of the following elements:

1. A serpentinite derived from the alteration of an ultrabasic rock.
2. An enstatite-chlorite aureole.
3. A cummingtonite schist aureole.
4. A hypersthene-dolomite aureole.

THE SERPENTINITE ROCK

Only three small outcrops of this easily weathered serpentinite rock were seen. This rock is fine grained, dense, black to clouded dark green, and mottled with red

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1. According to F.L. Hess (Am. Jour. Sci., 4th. Ser., Vol. 48, 1919) a tactite may be defined as a rock of complex mineralogic composition formed by contact metamorphism and metasomatism of carbonate rock.

stains of iron oxide. Masses and disseminated grains of olive-green olivine frequently coloured honey-yellow, brown or red by oxidation of the iron are present in this serpentinite.

Under the microscope, this rock appears to consist chiefly of a structureless mass of serpophite, talc and minor flaky antigorite. (Fig. 23). Accessories are: residual grains of an olivine, magnetite, spinel of the pleonaste type, ilmenite, dolomite, and zircon. Thin sections of the serpentinite often show a peculiar structure like the meshes of a net; the lines marked by minute grains of magnetite follow the original cracks and cleavage direction of the olivine. (Fig. 24). The nature of the original minerals of the serpentinite can thus be inferred and in this case is mostly olivine and pyroxene.

THE ENSTATITE-CHLORITE AUREOLE

The enstatite-chlorite rock constitutes the innermost zone of the contact metamorphic aureole and locally surrounds the serpentinite rock. The outcrops of this rock are rounded, well exposed, and resistant to weathering. (Fig. 25 - 26). Rosette structure consisting of prismatic radiating aggregates of enstatite is a conspicuous textural element of this tactite rock. The rosettes are light to dark gray in colour with a silky lustre and attain as much as 6 inches in diameter. (Fig. 27). The enclosing matrix consists mainly of translucent pale leek-green foliae of chlorite (antigorite-clinochlore) and granular magnetite. The antigorite, which has a thin lamellar structure, shows plicated foliation.

The optical data on a rosette of enstatite are as follows:

Biaxial positive.

Parallel extinction.

Low to moderate birefringence.

nB Index = 1.670

$n\gamma$ Index = 1.672

$n\gamma$ = 1.672 corresponds to En93 which on the decimal classification is enstatite.

Fluorescence X-ray analysis of rosette material revealed the following chemical composition:

Fe_2O_3 .... 20%

CaO 1.05%

Under the microscope, the enstatite rosettes appear to be riddled with grains of magnetite. (Fig. 28). Minor bastite alteration and a fibrous aggregate of amphibole, probably tremolite, is present in some of the rosettes. Green pleonaste seldom occurs along cracks. The following minerals were identified in thin sections of representative enstatite-chlorite rock:

<u>Essential Minerals</u>:

Enstatite

chlorite:
- Antigorite, nB = 1.564
- Serpophite
- Clinochlore, nB = 1.588

Forsterite (Fig. 29)

Magnetite.

Accessory Minerals:

Spinel (Pleonaste)

Cordierite

Dolomite

Garnet

Accessory minerals include a peculiar strongly pleochroic variety of olivine and few grains of a dark brown mineral believed to be sapphirine.

The texture of this rock is porphyroblastic. Plication of the chlorite foliae and granulation of some of the minerals are common.

THE CUMMINGTONITE SCHIST AUREOLE

A band of cummingtonite schist a few inches wide, occurs at the contact between the serpentinite rock and the hypersthene-dolomite aureole. This rock consists of yellow-gray acicular crystals and is soft and friable. Under the microscope, a nematoblastic texture is exhibited; some of the needles are partially replaced by magnetite. (Fig. 30).

THE HYPERSTHENE-DOLOMITE AUREOLE

The hypersthene-dolomite rock, which constitutes the outer aureole of the tactite zone, lies comformably on the quartz-magnetite horizon. Outcrops of this rock exhibit a pitted, often corroded, surface and are rusty brown in colour. The magnetite and dolomite content of this rock becomes noticeably higher at the contact zone with the quartz-magnetite where, also, the original bedding is partly preserved. The composition of the hypersthene-dolomite rock based on the average of estimated amounts in five thin sections of representative rock is as follows:

Hypersthene	40%
Dolomite-Ankerite (Fig. 31)	20%
Magnetite	15%
Amphibole (Anthophyllite-Cummingtonite)	10%
Spinel (Pleonaste)	5%
Clinochlore	5%
Olivine	3%
Cordierite	2%

Garnet is an accessory mineral. The hypersthene is strongly pleochroic from green to deep pink. Ankerite is present in subordinate amounts and is characterized by its tendency to form euhedral crystals and by brown stains around the borders of the grains and along cleavage cracks. The texture of this rock is granoblastic and the inequigranular component minerals are oriented at random. The transition from the enstatite-chlorite rock to the hypersthene-dolomite aureole takes place within a few feet and is marked by an increase in dolomite content and gradual disappearance of the enstatite rosettes.

THE PLEOCHROIC OLIVINE AND THE SAPPHIRINE OF THE TACTITE ZONE

Tablets and, more rarely, porphyroblasts of a peculiar bright yellow mineral are found both in the enstatite-chlorite aureole and in the hypersthene-dolomite rock. This mineral is associated with hypersthene, dolomite, colourless chlorite, spinel and magnetite.

According to S. Kranck, a similar mineral from Hobdad Lake has the following characteristics: Pleochroism strong (Y and X, Yellow; Z, Orange).

Biaxial positive

2V = 69^{o}

Twinned (Fig. 32)

Cleavage poor

The mineral has the following chemical composition (S. Kranck[2])

SiO_2	35.9
Al_2O_3	3.4
Fe_2O_3	2.2
Fe O	11.4
Mg O	45.4
Mn O	0.06
Cr O	0.3
Na_2O	0.05
K_2 O	0.01
	98.7

2. Personal communication (March 1959)

This mineral has the chemical composition and the X-ray diffraction pattern of a variety of olivine. S. Kranck thinks that the anomalous colours are result of incipient alteration to iddingsite.

Green spinel of the pleonaste variety is particularly abundant in the hypersthene-dolomite rock. Spinel is always associated with, and, often surrounded by magnetite. (Fig. 33).

A few tablets and disseminated grains of a mineral believed to be sapphirine occur in the enstatite-chlorite aureole as a minor constituent. (Fig. 34). In thin sections, this mineral appears light to smoky brown, has high relief and faint pleochroism. The axial angle appears to be large, but cannot be easily measured. Under polarized light, polysynthetic twinning and translucent thin edges in red are common features. This mineral is always closely associated with spinel and appears to have formed at the expense of it.

It has not been possible to obtain all the optical characteristics of this mineral but the mode of occurrence and its association are typical of sapphirine.

COPPER MINERALIZATION AND HEMATITE-ILMENITE IN THE TACTITE ZONE

On a high, nearly vertical, slickensided face at the contact between the serpentinite and the enstatite chlorite rock numerous green stains and patches of malachite are visible. Examination of polished sections revealed the presence of the following copper minerals in order of abundance:

Chalcocite

Malachite

Covellite

Bornite

Azurite.

The sulphides occur in tiny cracks and as replacement of magnetite and of crystalline dolomite. (Fig. 35 - 36). Bornite is locally present with chalcocite. (Fig. 37). Covellite locally penetrates chalcocite along fractures and cleavage planes. (Fig. 38). Most of the chalcocite invades the core of magnetite grains leaving the rims unreplaced. Secondary minute granular magnetite outlining the boundary of the original crystals is also sometimes replaced by chalcocite.

The chalcocite is orthorombic and clearly of supergene origin replacing bornite or chalcopyrite.

Seriate arrangement of ilmenite exsolution bodies unmixing from hematite is commonly found in the enstatite rock at the contact with the serpentinite. (Fig. 39). Ilmenite and exsolving hematite are present in the serpentinite.

Fig. 23. Photograph of serpentinite altered to serpophite. D-dolomite; C-chalcocite; S-serpophite. Cross nicols. Medium power. X 29.

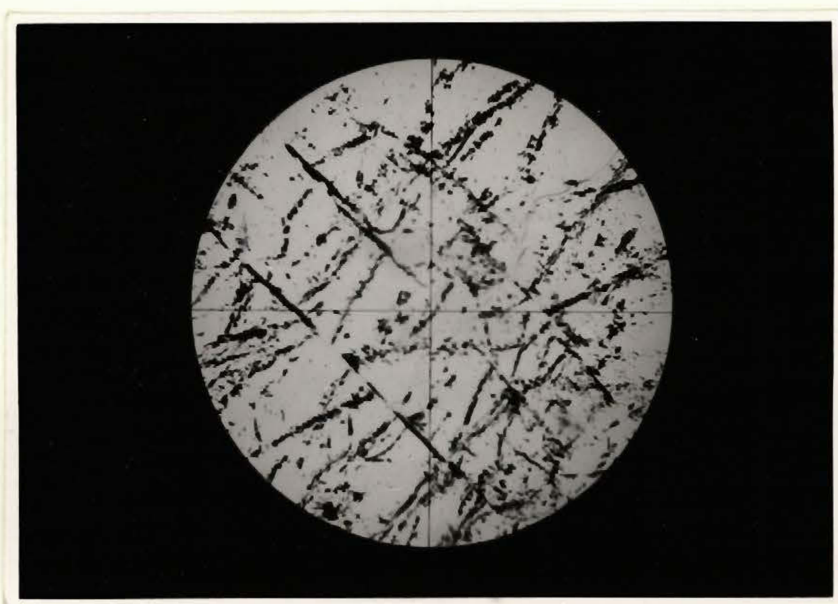

Fig. 24. Photomicrograph showing minute grains of magnetite in serpophite..The grains follow the original cracks and cleavage direction of the olivine. Plain polarized light. Medium power. X 29.

Fig. 25. Photograph of an outcrop of enstatite-chlorite rock.

Fig. 26. Photograph showing large enstatite rosettes in a chlorite and magnetite matrix.

Fig. 27. Photograph of prismatic radiating crystals of enstatite slightly bent to indicate rotation during growth.

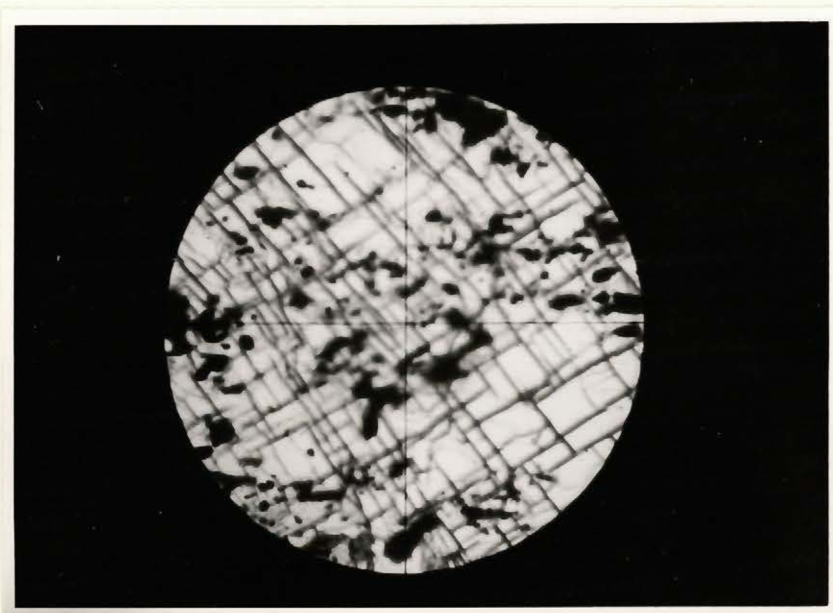

Fig. 28. Photomicrograph of a rosette of enstatite showing pyroxene cleavage and dark grains of magnetite. Plain polarized light. Medium power. X 29.

Fig. 29. Photomicrograph showing forsterite tablets altering to serpophite and antigorite. F-forsterite; A-antigorite; M-magnetite. Cross nicols. Medium power. X 29.

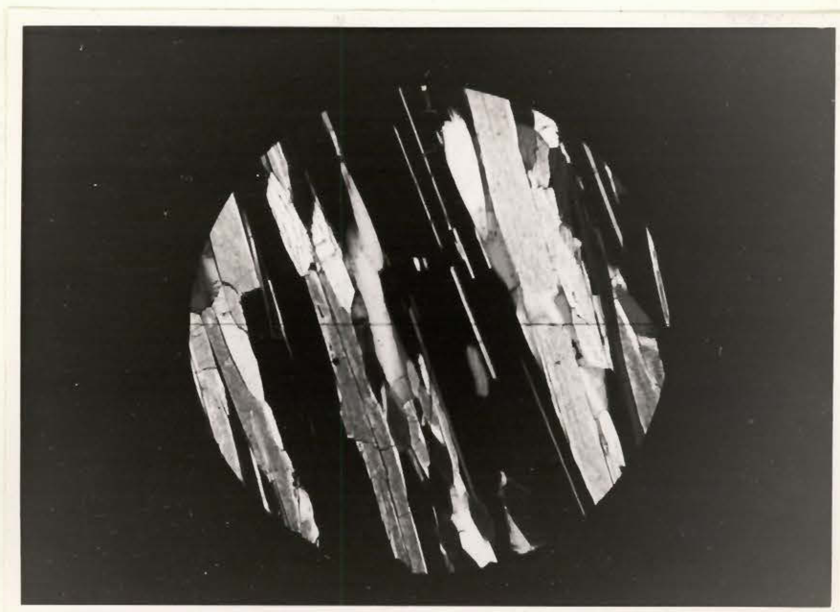

Fig. 30. Photomicrograph of cummingtonite schist exhibiting a nematoblastic texture. Cross nicols. Medium power. X 29.

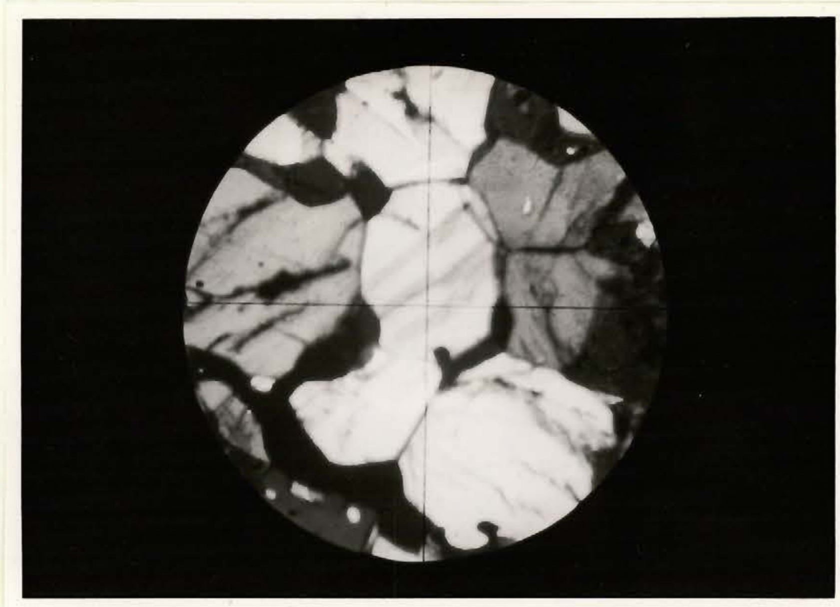

Fig. 31. Photomicrograph of euhedral crystals of dolomite in the hypersthene dolomite aureole. Cross nicols. Medium power. X 29.

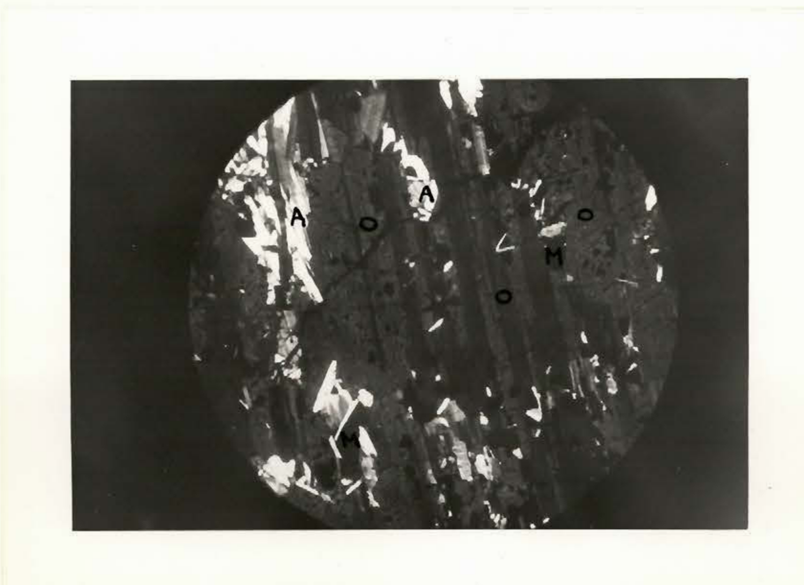

Fig. 32. Photomicrograph of twinning in olivine. O-olivine; A-antigorite; M-magnetite. Cross nicols. Medium power. X 29.

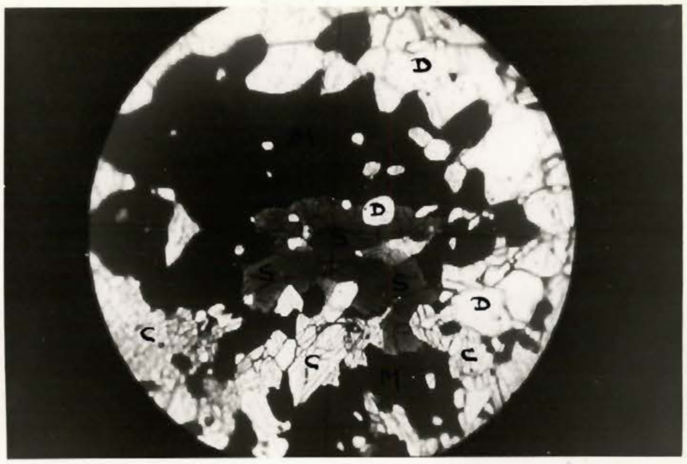

Fig. 33. Photomicrograph of green spinel (pleonaste) and magnetite in the hyperstbene-dolomite aureole. S-spinel; M-magnetite; D-dolomite; C-cummingtonite. Plain polarized light. Medium power. X 29.

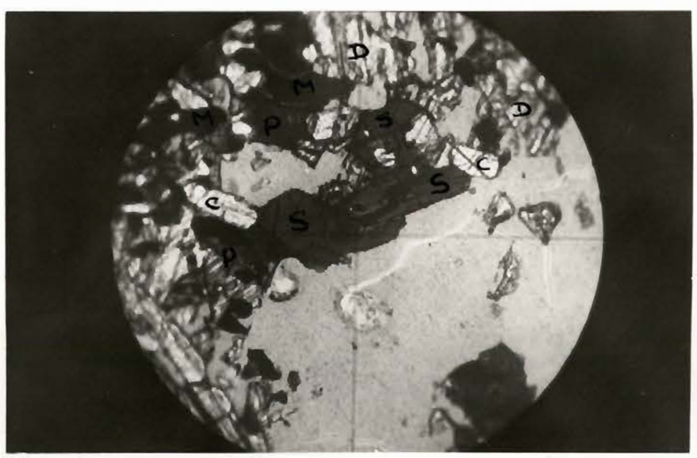

Fig. 34. Photomicrograph showing sapphirine. S-sapphirine; P-pleonaste; M-magnetite; C-cordierite; D-dolomite. Plain polarized light. Medium power. X 29.

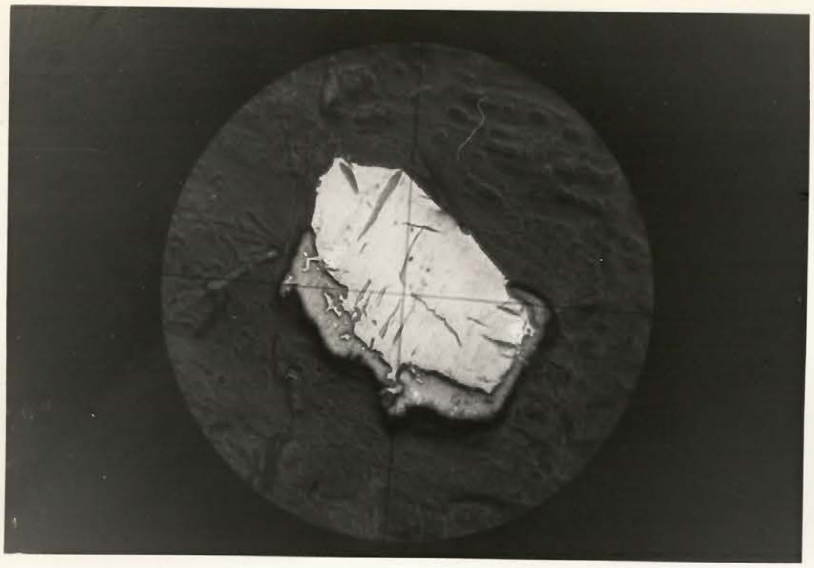

Fig. 35. Photomicrograph showing chalcocite replacing a magnetite grain. Reflected light. Medium power. X 84.

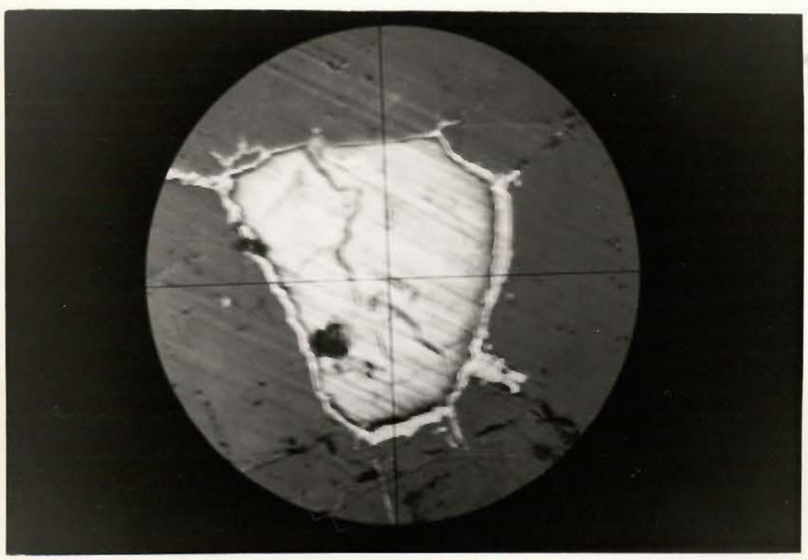

Fig. 36. Photomicrograph of atoll structure. Chalcocite core with unreplaced rim of magnetite. Reflected light. Medium power. X 84.

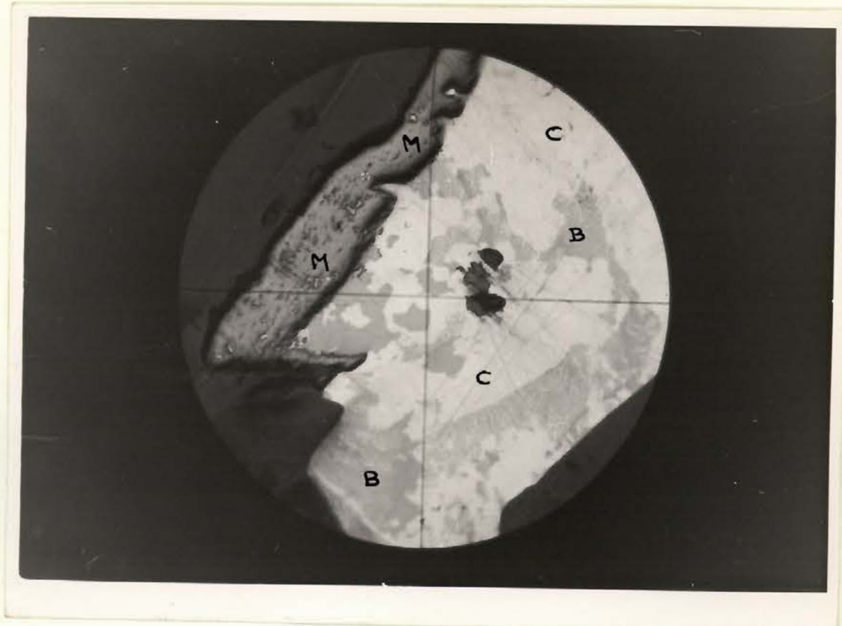

Fig. 37. Photomicrograph of chalcocite and bornite replacing magnetite. B-bornite; C-chalcocite; M-magnetite. Reflected light. Medium power. X 84.

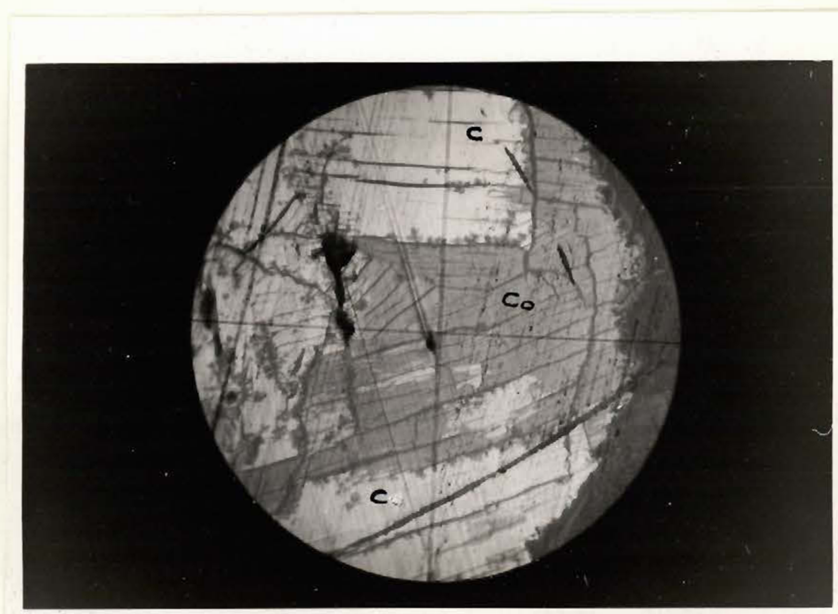

Fig. 38. Photomicrograph of covellite exsolving from chalcocite. C-chalcocite; Co-covellite. Reflected light. Medium power. X 84.

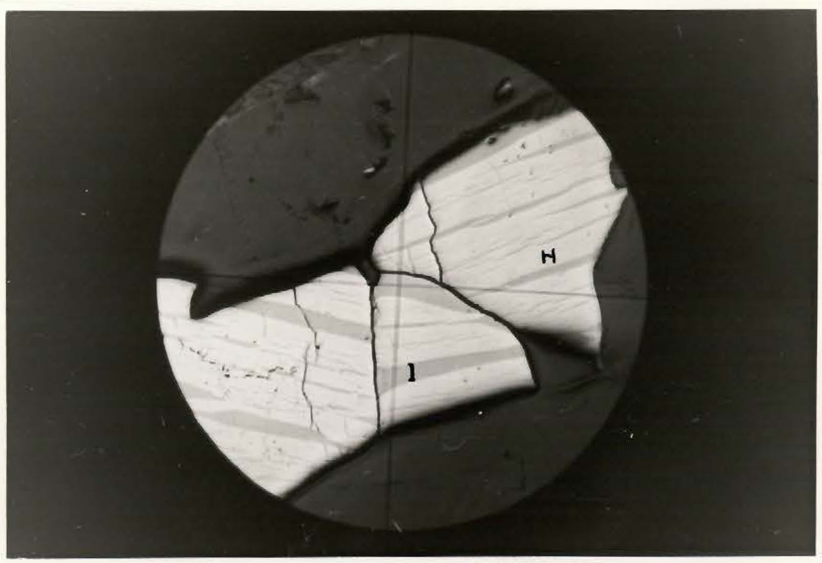

Fig. 39. Photomicrograph of seriate arrangement of ilmenite ex-solution bodies unmixing from hematite. I-ilmenite; H-hematite. Reflected light. Medium power. X 84.

PROBABLE SEQUENCE OF EVENTS WHICH LED TO THE FORMATION OF THE MAGNESIAN TACTITE ZONE OF LAMELEE LAKE

1. Deposition of ferro-magnesian carbonates and pelitic sediments.

2. Folding

   (Regional metamorphism to amphibolite facies)

3. Intrusion of ultrabasic magma.

   (Contact metamorphism to pyroxene-hornfels facies; hematite ilmenite exsolution).

4. Refolding

   (Retrograde kinematic metamorphism with formation of the enstatite-chlorite aureole by complete dedolomitization of the hypersthene-dolomite rock).

5. Hydrothermal alteration

   (Formation of hydrous metamorphic minerals accompanied by introduction of copper sulpides).

ANALYSES OF SAMPLES FROM THE MAGNESIAN TACTITE ZONE OF LAMELEE LAKE

	% Cu	% Ni	% TiO_2	% Cr_2O_3
Representative sample of serpentinite with malachite stains.	4.00	.03	.13	.03

	% Cu	% Ni	% TiO_2	% Cr_2O_3
Representative sample of the enstatite-chlorite aureole	.03	.08	2.65	.08

Analyst: Dehn H., Geochemical Laboratory,
McGill University.

CONCLUSION AND DISCUSSION

The magnesian tactite complex of Lamelee Lake appears to have originated from polymetamorphism of silica-deficient ferro-magnesian carbonates and pelitic sediments. Excess of (Mg, Fe)O and Al_2O_3 and a striking deficiency of SiO_2, K_2O, Na_2O and CaO characterize this zone. The widespread occurrence of spinel and forsterite would indicate a silica-poor milieu, whereas absence of plagioclase indicates a deficiency in sodium and potassium. Occurrence of olivine and sapphirine indicates an iron and alumina excess and a deficiency in silica.

Deposition of ferro-magnesian carbonates and pelitic sediments, which were later metamorphosed into a tactite zone, followed the deposition of the quartz magnetite formation. This could be interpreted as a change from shelf type deposition to deep basin type deposition.

Because the intensity of regional metamorphism appears to be quite uniform throughout the area, it would appear that the rocks of Lamelee Lake were also initially metamorphosed to the amphibolite facies. The minerals of the tactite zone such as hypersthene, forsterite, spinel cordierite and minor pleochroic olivine and sapphirine are characteristic of high temperature contact metamorphism of the pyroxene-hornfels facies and are related to basic intrusions. The minerals listed above are silica-deficient, magnesium and alumina rich metamorphic derivatives of ferro-magnesian and pelitic sediments.

The cummingtonite schist aureole represents a temperature of metamorphism equivalent to the amphibolite facies; such a temperature was not sufficient to obliterate the schistosity of the parent rock.

Most of the sapphirine occurrences referred to in the literature seem to be associated with ultrabasic intrusions and are invariably accompanied by spinel, and less commonly by enstatite, hypersthene and olivine. The high temperatures reached in the vicinity of the basic intrusion is indicated locally by the complete recrystallization of the magnetite of the quartz magnetite horizon.

Assimilative reactions with conversion of the wall rock in immediate contact with the ultrabasic magma to those phases of pyroxene and olivine with which the reacting magma was saturated, would be further proof that the serpentinite was originally an olivine and pyroxene-rich magma.

Several well-exposed, quartz-magnetite outcrops located in the nose of the syncline and overlain by hypersthene-dolomite and by the enstatite-chlorite rock exhibit a cataclastic texture, in which granules and scattered eyes of coarse quartz and quartz-magnetite are set in a fine matrix of quartz-magnetite. The quartz specular hematite rock overlying the enstatite-chlorite aureole is also strongly deformed and shows local intense ptygmatic folding. (Fig. 40)

Under the microscope, the colorless chlorite flakes of the enstatite-chlorite rock exhibit strain-slip cleavage due to microfolding. The prismatic radiating crystals which form the enstatite rosettes are often slightly bent as if the enstatite porphyroblasts were rotated during the growing process.

All the accumulated data on the structural characteristics of the rocks located in the nose of the syncline show that while deformation in the quartz-magnetite and quartz-specular hematite was achieved essentially by mechanical processes, deformation in the enstatite-chlorite rock was predominantly crystalloblastic and achieved by chemical processes. In the enstatite-chlorite aureole, dedolomitization was complete.

Heikki V. Tuominen and Toivo Mikkola (1950) consider that during folding, thick competent beds occurring as phacolithic core fillings in folds glided laterally whereas the incompetent beds flowed towards the hinges of the folds. Under these movements, the rock recrystallized to sheet minerals such as chlorite, etc. and simultaneously the excess constituents emigrated and caused an enrichment in Mg and Fe within the residue. This process, according to Tuominen and Mikkola, took place under hydrothermal conditions.

In the case of the enstatite-chlorite aureole of Lamelee Lake, it is probably unnecessary to postulate an iron-magnesia-silicate metasomatism derived from adjacent intrusions (Eskola 1914).

The magnesia of the enstatite-chlorite zone of Lamelee Lake was probably derived from the dolomite contained in the rock prior to metamorphism. The following factors, however, appear to be important in connection with the genesis of the enstatite-chlorite aureole of Lamelee Lake:

1. The enstatite-chlorite aureole has been localized on the nose of the syncline.
2. Presence of numerous veinlets of crystalline dolomite at the contact between serpentinite and enstatite-chlorite rock is clear evidence that magnesia was introduced during an hydrothermal phase. (Fig. 41).

In conclusion, the enstatite chlorite aureole of Lake Lamelee may be explained as a product of Kinematically controlled metamorphic differentiation. The folding and deformation probably took place simultaneously with hydrothermal reactions which were characterized by waters charged with carbon dioxide, magnesia, and copper sulphides. The talcose and serpentine rocks derived from the ultrabasic rock may also be the product of hydrothermal alterations.

Fig. 40. Photograph showing ptygmatic folding in quartz-specular hematite.

Fig. 41. Photograph of veinlets of dolomite at the contact between serpentinite and enstatite-chlorite rock.

GENERAL SUMMARY

This thesis presents a detailed description and discussion of the iron formations and associated rocks of Jean Lake and Lake Lamelee areas, these are located 24 miles SSW of Mount Wright in central Quebec. The rocks of these two areas represent sedimentary formations of chemical and clastic origin which have been intensely folded, and engulfed in the Grenville-type regional metamorphism.

It is concluded that the ductless quartz-microcline pegmatites of the Jean Lake area are the result of metamorphic processes and are formed by mechanical and aqueous diffusional transfer of material derived from the adjacent garnetiferous paragneisses. All these pegmatites are genetically and spatially related to zones of intense deformation.

The magnesian tactite zone which lies in the nose of the syncline of Lake Lamelee is thought to be the result of regional, contact and Kinematic metamorphism of ferro-magnesian carbonates and pelitic sediments.

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BASELINE
BASELINE 2A
MIF
GG
GEOLOGICAL LEGEND
922 HIF Iron formation (spec.)
924 MIF Iron Formation (mag.)
929 LIF Iron Formation (lean)
915 924 SIF Silicate-Magnetite Mixture
915 S Silicates
946 SQF Silicate Quartz Formation
918 QR Quartz Rock
903 M Marble
909 GG Granite Gneiss
910 MG Mafic Gneiss
931 P Pegmatite
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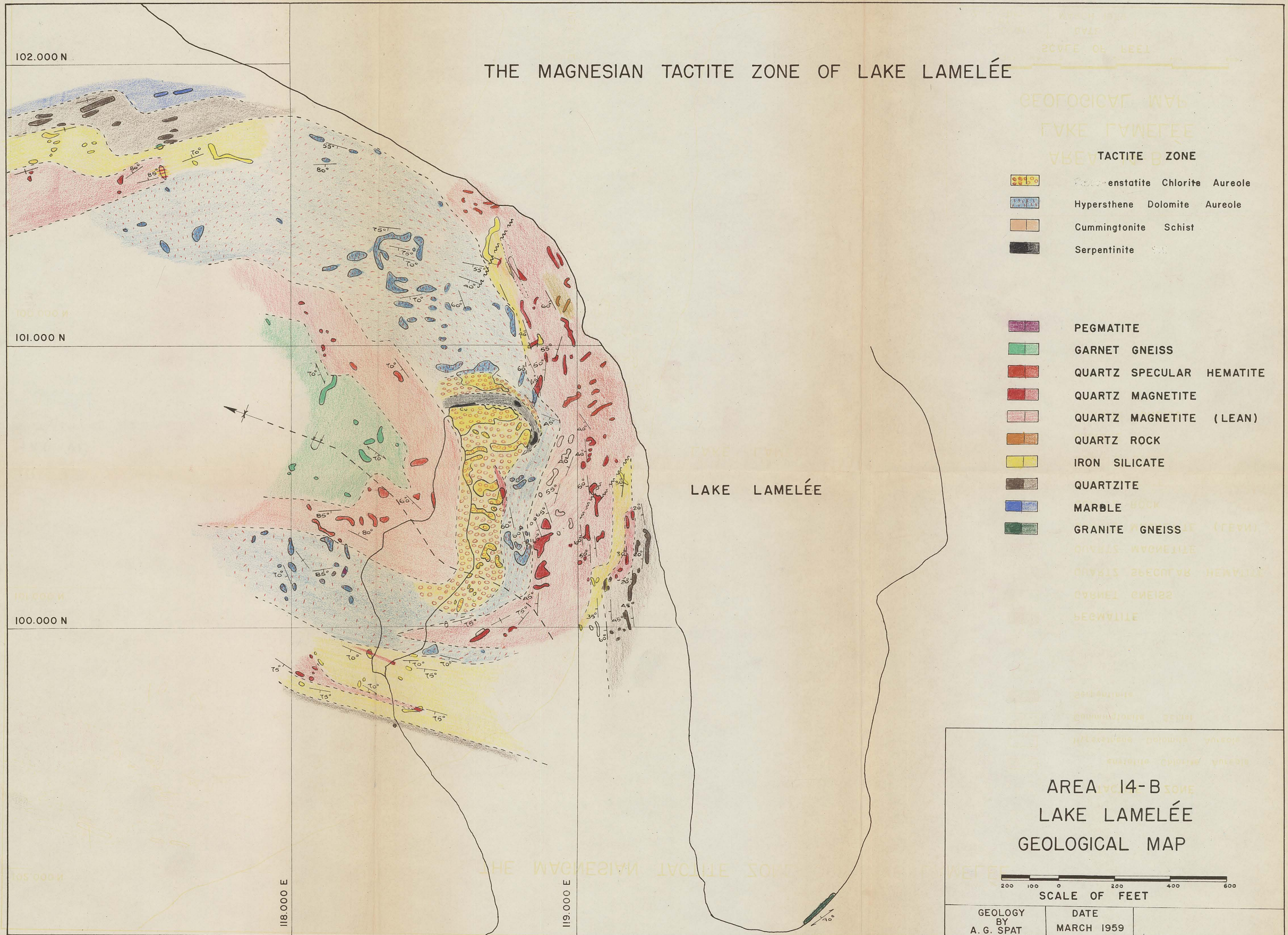
THE MAGNESIAN TACTITE ZONE OF LAKE LAMELÉE
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LAKE LAMELÉE
TACTITE ZONE
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Hypersthene Dolomite Aureole
Cummingtonite Schist
Serpentinite
PEGMATITE
GARNET GNEISS
QUARTZ SPECULAR HEMATITE
QUARTZ MAGNETITE
QUARTZ MAGNETITE (LEAN)
QUARTZ ROCK
IRON SILICATE
QUARTZITE
MARBLE
GRANITE GNEISS
AREA 14-B
LAKE LAMELÉE
GEOLOGICAL MAP
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