THE PETROLOGY OF THE MYRNA LAKE AND FRASER LAKE BASIC INTRUSIVE BODIES

A Thesis

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Master of Science

by

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ILLUSTRATIONS

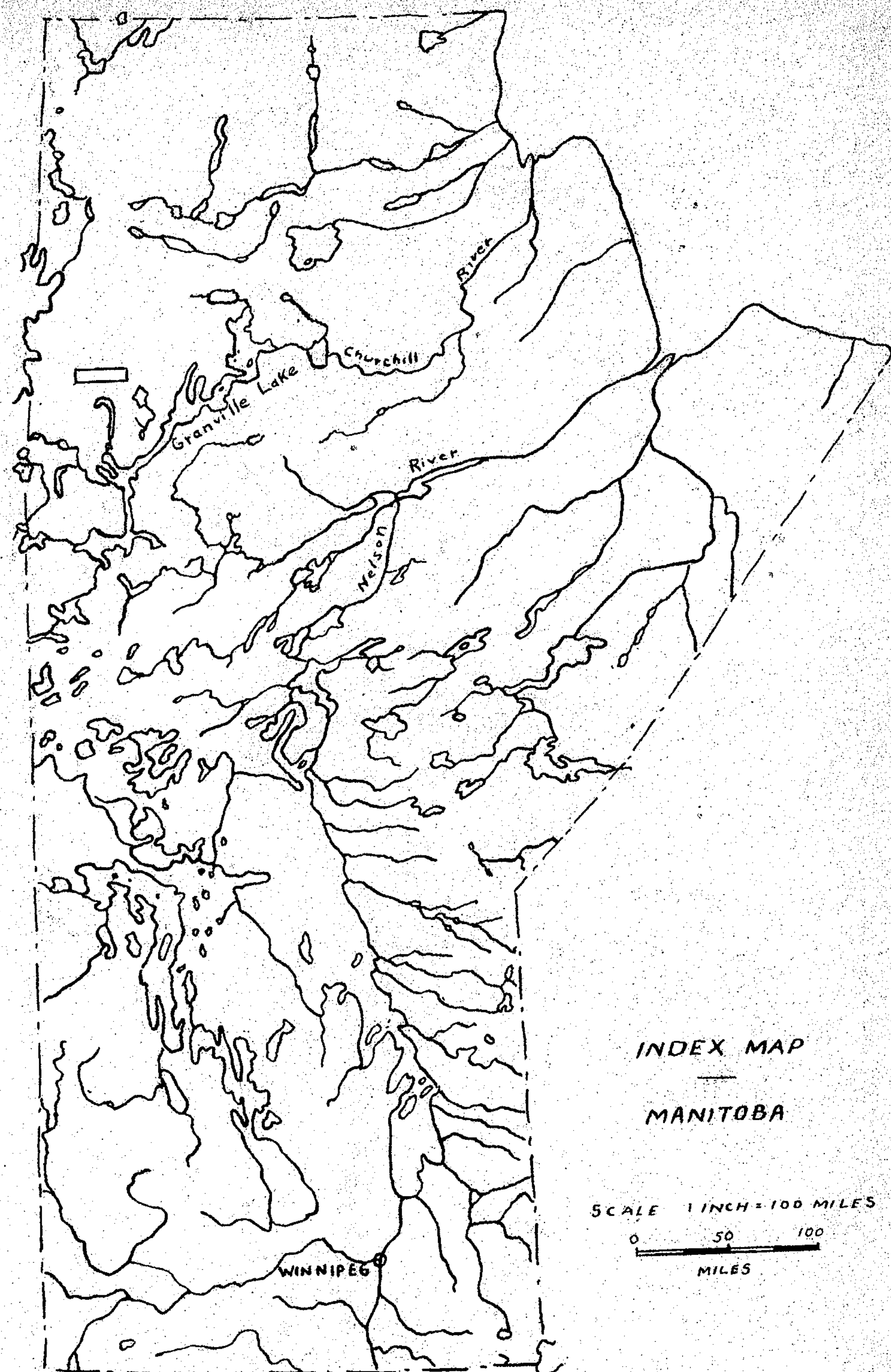

Churchill
River
Granville Lake
River
Nelson
WINNIPEG
INDEX MAP
MANITOBA
SCALE 1 INCH = 100 MILES
0 50 100
MILES

FIGURE I

CHAPTER I

INTRODUCTION

General statement -- During 1945 Sherritt Gordon Mines announced the discovery of nickel bearing sulphides on the shore of Lynn Lake in Northern Manitoba. This disclosure caused a staking rush to the Lynn-Barrington Lakes Area during the years 1946 to 1948.

Interest centered upon the basic intrusives of the area, as the Sherritt Gordon ore occurs within such rocks. Despite intensive exploration by geophysical and geological methods no other nickel deposit of commercial size was found, although most of the basic intrusives seem to be of a nature favorable to such deposits.

The object of the present study was to carry out a petrological investigation of certain of these basic bodies to ascertain the controlling factors in the occurrence or non-occurrence of the nickel deposits.

Location and character of the area -- The Lynn-Barrington Lakes Area comprises five fifteen minute map-areas between longitudes 100 degrees 00 minutes and 101 degrees 15 minutes west and between latitudes 56 degrees 45 minutes and 57 degrees 00 minutes north. The total area enclosed by the five sheets is about 800 square miles. (Fig. 2, p. 6)

The topography of the area is similar to much of the Precambrian shield; muskegs and lakes fill depressions between rounded hills or steep ridges few of which have a relief of more than one hundred feet.

Outcrops are small and scattered owing to the abundance of glacial drift. Field work is further hampered by deadfall and heavy brush in certain parts of the area.

The two main river systems, the Keewatin and the Hughes, are broken by numerous rapids and falls which render travel by either system impractical.

The area is usually reached by aircraft from Sherridon or Flin Flon, about 120 miles south of Lynn Lake. During the winter months a tractor train is operated between Sherridon and Lynn Lake.

Previous geological studies of the area -- The Geological Survey of Canada mapped the area as part of the Granville Lake Sheet in 1932, 1933 and 1935. The results have been published as Summary Report 1933, Part C, and maps 343A and 344A on a scale of 4 miles to 1 inch. The McVeigh Lake Area was mapped by the Geological Survey on a scale of 1500 feet to 1 inch and a map was issued in 1945.

The five 15 minute sheets were mapped by the Manitoba Mines Branch Survey, during the field seasons of 1946 to 1949. Mapping was done on a scale of 1/2 mile to 1 inch. At the time of this writing the Cockeram Lake Sheet has not been published; the reports on the Lynn Lake, Hughes Lake, Farley Lake, and Barrington Lake Sheets have been published as Preliminary Reports 46-2, 47-3, 47-5 and 47-6 respectively.

Present geological studies -- The writer first had the opportunity to study some of the rocks of the area during the summer of 1948 while employed by the Manitoba Geological Survey. At that time he was an assistant on the party, headed by Dr. J. D. Allan, that mapped the Cockeram Lake Sheet.

In 1949 the writer returned to the area and under the supervision of Dr. Allan re-mapped part of the Lynn Lake Sheet and had the opportunity to study many of the basic intrusives of the Lynn-Barrington Lakes Area. It was during this field season that material was collected for the present study.

Within a very few miles of the ore-bearing Lynn Lake intrusive are several other basic bodies in which no pentlandite-pyrrhotite ore has been found. Two of these bodies, the Myrna Lake and Fraser Lake intrusives, have been selected for study and comparison with the ore-bearing rock.

The writer mapped these intrusives during the 1949 field season and mapped parts of the Lynn Lake body in both 1948 and 1949. However, as Mr. H. E. Hunter, employed by the Sherritt Gordon Mining Company in 1949, made a detailed study of the Lynn Lake rocks, the writer will rely upon his work for details concerning that body.

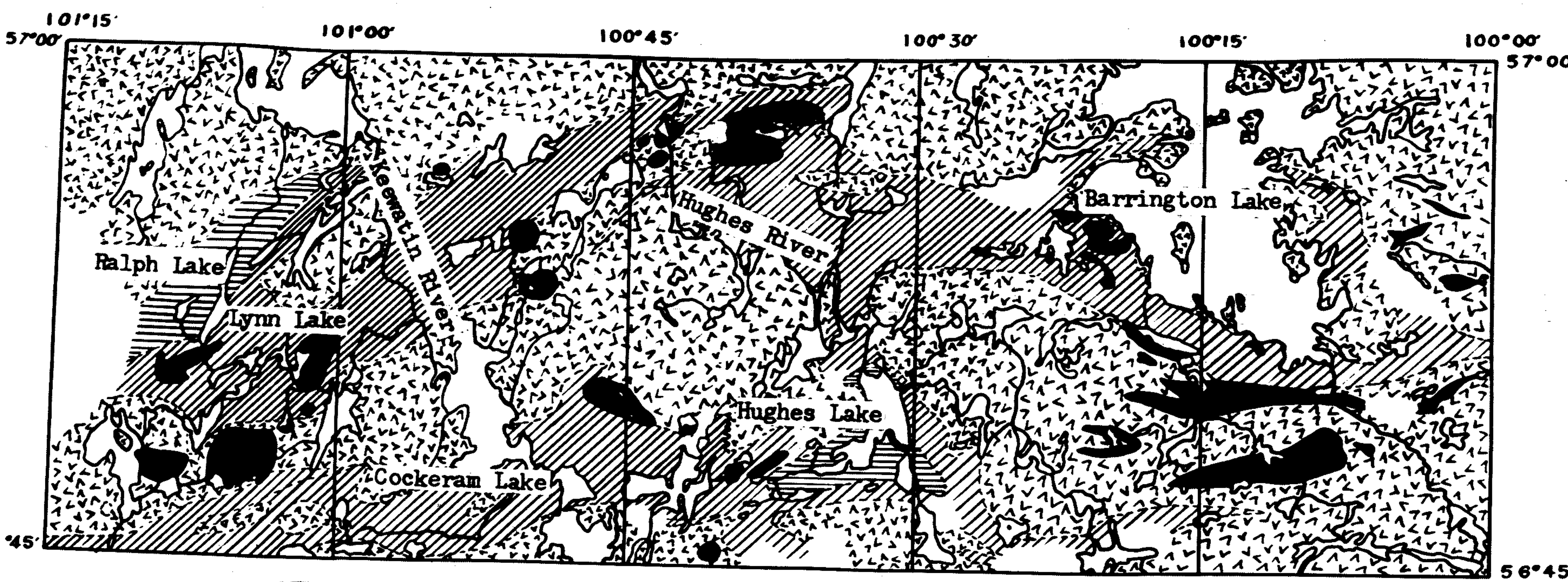
The Fraser Lake intrusive was mapped on a scale of 1/2 mile to 1 inch, and the work was plotted on vertical aerial photographs. The area was traversed by pace and compass methods. Particular attention was paid to areas which might yield information as to the relative ages of the basic body and the surrounding granitic rocks. About 150 samples of the intrusive and country rocks were collected, and 40 thin sections were prepared from these samples.

The Myrna Lake intrusive was mapped on a scale of 1/4 mile to 1 inch. Mapping was controlled by picket lines cut at intervals of 100 feet in an east-west direction. Approximately 100 samples were collected from which 50 thin sections were prepared.

In the laboratory the petrological investigation of these bodies entailed a detailed petrographic study and a study of heavy mineral assemblages.

Acknowledgments -- The writer is indebted to Dr. C. E. B. Connybeare for much helpful guidance and criticism during this study, and to the other members of the staff of the Department of Geology of the University of Manitoba for advice and assistance in particular phases of the work.

Many thanks are due to Dr. J. D. Allan who suggested the study and gave very valuable advice and criticism in the field work, and to the Manitoba Mines Branch for providing the opportunity to carry out the field work.



LYNN LAKE - BARRINGTON LAKE AREA

4 0 4 8 12

Scale in Miles

L E G E N D

Granite and related rocks.

Sickle sediments.

Gabbro, Norite, Diorite.

Wasekwan volcanics and sediments.

FIGURE 2

CHAPTER II

GEOLOGY OF THE LYNN-BARRINGTON LAKES REGION

Rocks of the Region

The rocks of the region are divided into three major groups: (1) the Wasekwan Series of volcanic and sedimentary rocks overlain unconformably by (2) the Sickle Series of sediments, and (3) later intrusives ranging from gabbro to granite.

Allan (1949) outlines the following table of formations for the area:

PRECAMBRIAN	Intrusives	Basic dykes, pegmatites, quartz feldspar porphyry and felsite. Granite, diorite, quartz diorite, gneissic and sheared equivalents. Diorite, quartz diorite, granodiorite, gabbro. Amphibolite
	Sickle Series	Arkose, greywacke, quartzite, conglomerate, derived schist.
	UNCONFORMITY	
	Granitic Intrusives	
	Wasekwan Series	Volcanics: basic to acid lavas, breccia, tuff and derived hornblende schist. Sediments: quartzites, impure quartzites, greywacke, iron formation, derived mica schist and gneiss.

Wasekwan series -- The predominant rocks of the Wasekwan Series are fine-grained volcanics which were originally of basalt composition. Porphyritic, amygdaloidal, and ellipsoidal flows, volcanic breccia, tuffaceous agglomerate, tuffs, and sediments are occasionally intercalated with the massive flows. Rhyolite and trachyte flows occur in parts of the series, but form a minor part of it.

The sedimentary rocks associated with the flows and tuffs are mostly dark-grey to brown impure quartzites. There is a notable exposure of these quartzites along the east shore of Frances Lake.

The iron formation is a distinctive member of the Wasekwan Series. It is composed of light-grey cherty material and has a high content of magnetite, either disseminated or in crystals as much as 1/8 inch across.

Sickle series -- The Sickle rocks consist of a basal conglomerate which passes upward into arkoses and greywackes. The strikes of the Wasekwan and Sickle Series are at an angle to one another indicating an unconformity between the two series.

At Hughes Lake the conglomerate is in contact with granite and diorite, and Allan suggests that the conglomerate rests unconformably upon these rocks.

Intrusive rocks -- The basic intrusive rocks of the area all have a somewhat similar petrological composition. The rock types are chiefly diorite, quartz diorite, gabbro and norite with some local anorthositic phases. All the basic bodies are cut by later pegmatite, felsite, and porphyry dykes and masses.

The granitic intrusives of the area range in composition from quartz diorite to granite, and some of the more basic phases are difficult to distinguish from rocks having affinities with the basic intrusives.

In the Cockeram-Hughes Lakes areas two or more distinct granite bodies have been recognized, and these are thought to belong, in part, to the last period of intrusion.

All these granites are cut by later aplite, pegmatite and felsite dykes which are in turn cut by basic dykes. Quartz veins were the last material emplaced.

Structural Geology

The sedimentary and volcanic bands form continuous belts across the north and south of the area. These belts converge towards the east, but no indication of folding was observed at the junction. The little evidence obtained indicated that tops are to the north in both belts.

Faults are widespread on both a major and minor scale.

Geological History

Allan (1949) outlines the following sequence of events for the area.

The formation of the Wasekwan Series is the first event of which there is any record. During Wasekwan times periods of volcanic activity were interrupted by periods of sedimentation. Subsequently the series was highly folded and intruded by granitic material.

A long period of erosion followed the folding of the Wasekwan; subsequently the Sickle sediments were deposited. Another period of folding occurred which lacked the intensity of the earlier period and was accompanied by a comparitively low grade of metamorphism.

Widespread intrusion followed folding or was in part contemporaneous with it. Basic intrusives preceded granitic intrusives. The last stages of this igneous activity gave rise to the felsite, aplite and pegmatite dykes which are cut in part by basic dykes.

Faulting and shearing followed the period of granitic intrusion, and quartz veins, carbonates, and sulphides were later introduced into the shear zones. A long period of erosion followed which reduced the land to a peneplane. Glaciation, which stripped off the weathered material and left the land in its present form, is the last geological event recorded.

LEGEND

PROBABLY POST-SICKLE

- Biotite quartz diorite
- Microcline granite
- Olivine hypersthene gabbro, uralite gabbro
- Quartz hornblende diorite (Minor quartz monzonite and volcanics)

WASEKWAN

- Volcanics

Symbols

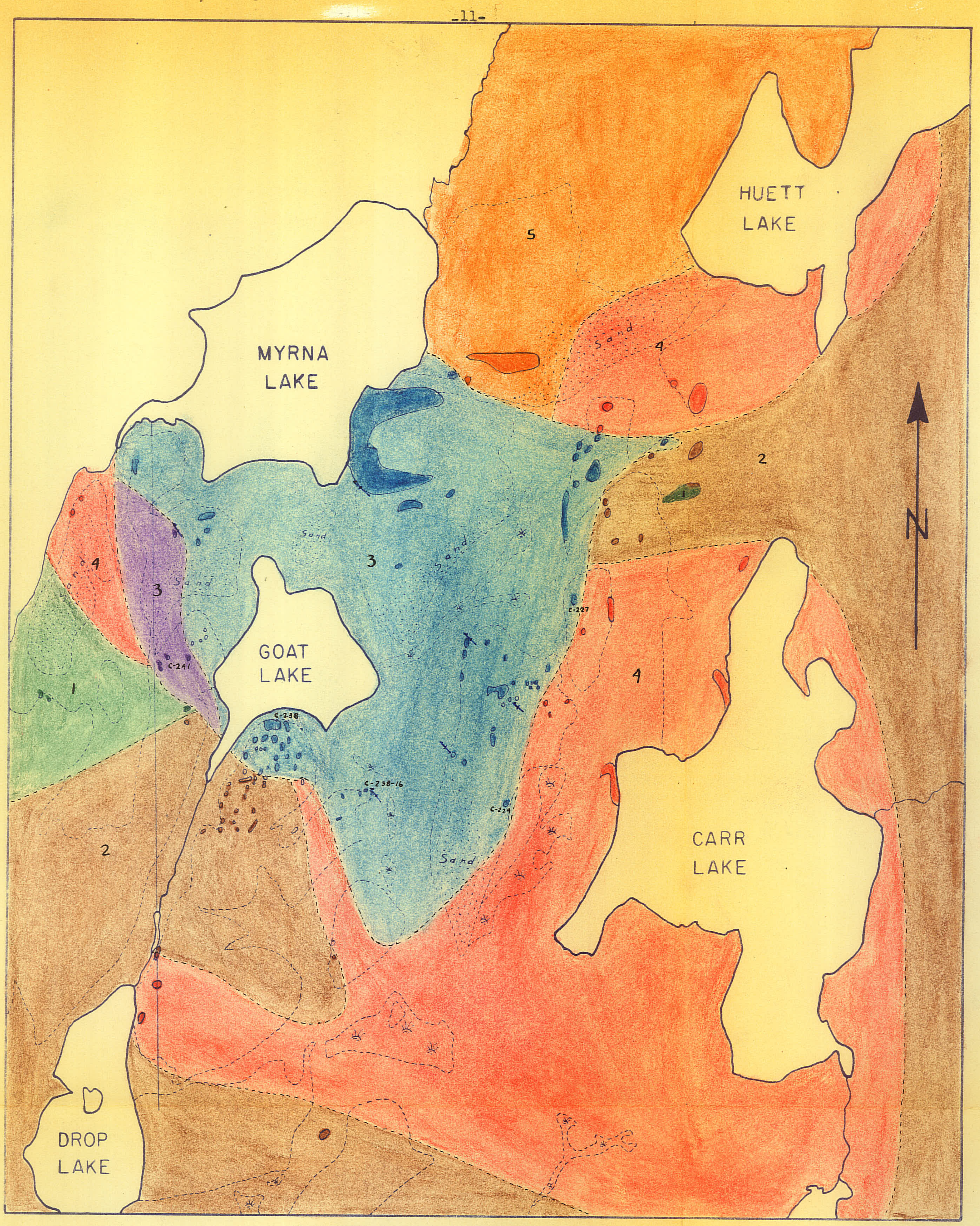
Flow lineation..

Geological boundary (Observed, assumed)..............

Outcrop...

Ridge...

Swamp...



MYRNA LAKE AREA

SCALE 1/4 MILE TO 1 INCH

MILES 1/4 0 1/4

FIGURE 3

CHAPTER III

GEOLOGY OF THE MYRNA LAKE AREA

Location and Character of the Area

The Area considered here is about seven and one half square miles in area. It is included in the Cockeram Lake Sheet and is located about three miles northeast of Cockeram Lake.

Country Rocks

General Statement

The Myrna Lake intrusive body is roughly circular, about one square mile in area, and lies south of Myrna Lake. The body is surrounded by volcanic rocks of the Wasekwan Series and post-Sickle intrusive rocks ranging in composition from diorite to granite.

Volcanic Rocks

Distribution and occurrence -- A part of the western contact of the gabbro body is marked by volcanic rocks. These rocks form a belt that strikes northwest across the northern part of the Cockeram Lake area.

Outcrops are small and scattered near Myrna Lake, but elsewhere in the area the volcanic rocks form steep sided ridges. The belt is invaded from the north and south by acid intrusive bodies.

Petrology -- The volcanic rocks are for the most part altered andesite and basalt flows with some intercalated tuffs. Thin-bedded sediments are interbedded with the volcanic flows. Near the west contact of the gabbro, the flows are porphyritic.

Most of the volcanic flows are altered to green-black or green-grey amphibole schists, which exhibit a general trend of north 40 degrees east. Near the acid intrusives, alteration of these schists to porphyroblastic hornblende schists and biotite schists is common . Recrystallization and granitization have produced local areas of medium-grained plagioclase amphibolite of dioritic appearance that is difficult to distinguish from rocks of intrusive origin.

The porphyritic flows near the Myrna Lake gabbro body are altered to a rock composed of 50 per cent mafic minerals, chiefly hornblende and actinolite and some antigorite. The actinolite, an alteration product of the hornblende, is pleochroic from medium-green to yellow-green. The fibres roughly retain outline of the replaced hornblende. Remnants of hornblende are commonly enclosed within areas of actinolite fibres, which penetrate into the hornblende. The hornblende is a compact medium-green variety.

A compact form of antigorite replaces both the amphiboles. This is best observed under polarized light. The remnants of actinolite and hornblende, enclosed within the antigorite, are then easily distinguished from the antigorite, and from each other, by their birefringence.

In a few places biotite is an alteration product of the actinolite.

From the thin sections the composition of the feldspar was found to be Andesine ($Ab_{62}An_{38}$). The phenocrysts are fractured and chlorite is present along the fractures.

West of the gabbro body, near the contact of the flows with the granite, the volcanic rocks have been altered to a rock composed of diopside, epidote, calcite and chlorite.

Small epidote grains surround and embay irregular masses of diopside, suggesting that the epidote has formed by the alteration of the diopside.

A few remnants of plagioclase are present. In some places these irregular remnants are surrounded by a mat of fine chlorite fibres that replace the crystal along fractures. Other plagioclase crystals are deeply embayed by irregular masses of calcite and commonly, the entire central portion of the crystal is replaced by calcite. It is assumed that most of the calcite and chlorite in the rock formed in this way.

Quartz Hornblende Diorite

Distribution and occurrence -- The zone shown on the map as quartz hornblende diorite is actually a mixed rock zone. Although the quartz hornblende diorite is the predominant rock, it is intimately associated with outcrops of microcline granite, volcanic rocks, and quartz monzonite. Each of these rock types are discussed under separate headings. This zone, of predominantly quartz hornblende diorite, occurs along the eastern contact of the gabbro body just north of Carr Lake and also in a band that extends southwest from Goat Lake. The contact of the quartz hornblende diorite with the microcline granite is transitional.

Petrology -- The medium to medium coarse-grained quartz-hornblende diorite weathers spotted green and white. The average composition as estimated from hand specimens is 50 per cent green-black amphibole, 40 to 50 per cent grey white anhedral feldspar and as much as 10 per cent quartz. Quartz is visible on the weathered surface in many places. In the more coarse-grained varieties the hornblende crystals commonly have a square porphyroblastic outline.

In thin section the quartz-hornblende diorite is seen to be composed of plagioclase, quartz, hornblende, chlorite, and biotite and minor amounts of magnetite and sericite. Garnets are present in some of the specimens, but they are rare.

The plagioclase is andesine ($Ab_{52}An_{48}$), and the crystals show polysynthetic albite twins. They are extensively altered to chlorite, but contain only a small amount of sericite and no kaolin. The chlorite, that replaces the feldspar, occurs as feathery fibres along cracks in the plagioclase or penetrates into the crystals from their borders.

In most sections irregular patches of compact medium-green hornblende are present. These patches are surrounded and penetrated by fibres of light-green actinolite in a manner that suggests the actinolite was formed by alteration of the hornblende.

Much of the actinolite is altered to chlorite and biotite. The chlorite that replaces the actinolite retains the outline of the actinolite fibres, and contains remnants of the actinolite.

Quartz Monzonite

Distribution and occurrence -- The quartz monzonite occurs only in a few outcrops along the west edge of the ridge that extends south from Goat Lake. A small inclusion of this rock is enclosed in the quartz-uralite gabbro south of Goat Lake.

Petrology -- The quartz monzonite is a coarse-grained rock which weathers grey or slightly pink. The weathered surface shows no lineation, but the gneissic texture of the rock is shown by the alignment of ferromagnesian minerals. The feldspars are grey-white on the fresh surface.

The average mineral composition as estimated from the hand specimens is 20 per cent quartz, 65 to 70 per cent feldspar, and hornblende plus biotite in varying proportions 10 to 15 per cent.

A Rosiwal analysis of a typical thin section gave the following composition: 17 per cent quartz; 25 per cent andesine ($Ab_{62}An_{32}$); 47 per cent orthoclase; 7 per cent biotite; 3 per cent amphibole and a minor amount of magnetite, epidote, calcite, and apatite.

The feldspar crystals have been so extensively altered to kaolin that the albite twin lamellae are almost obliterated. The andesine crystals are subhedral in outline and show albite twins. The anhedral orthoclase crystals are either untwinned or form simple carlsbad twins.

The properties of the blue amphibole are: pleochroism deep-blue to green-blue; maximum extinction angle (with respect to the cleavage) 10 degrees; biaxial negative; 2V greater than 80 degrees; prismatic sections are length fast; cleavage is generally indistinct. Except for the larger extinction angle of the blue amphibole, the properties listed above are the same as those given for the mineral riebeckite. The blue colour of riebeckite is presumably due to the high sodium content of the mineral. Therefore, the similarity in properties between the blue amphibole and riebeckite suggests that the mineral is a sodium-rich variety of amphibole.

Some of the amphibole is altered to biotite in most of the sections studied. In one section the amphibole has been replaced by calcite, quartz, and epidote.

Using the classification proposed by Johannsen the rock may be designated 226''.

Microcline Granite

<u>Distribution and occurrence</u> -- The microcline granite has a peripheral distribution about the southern half of the gabbro body, from south of Goat Lake to north of Carr Lake. In the area about Carr Lake and south of the basic body the granite grades into the quartz-hornblende diorite zone. A narrow zone of the granite extends northwest from the gabbro contact to Huett Lake. This zone is bounded to the north by the biotite-quartz diorite and grades into the quartz-hornblende diorite to the south. The granite commonly forms low rounded outcrops along the sides of the ridges.

<u>Petrology</u> -- The microcline granite is a fine-grained to medium-grained rock of granitic texture. Pink feldspar and sugary textured quartz are the chief constituents of the granite. Biotite is the only mafic mineral present, and it is not abundant. The high quartz and low ferromagnesian content are characteristic features of the microcline granite.

Local phases of the microcline granite contain a milky blue quartz which presents a striking contrast with the bright pink of the feldspar crystals. These phases are generally higher in content of dark minerals than the average specimen of the rock.

In thin section the rock is estimated to be composed of 40 per cent quartz, 27 per cent microcline, 16 per cent plagioclase, ($Ab_{70}An_{30}$), 9 per cent orthoclase, 6 per cent oligoclase, and less than 2 per cent biotite. In Johannsen's classification the rock is designated 126''.

The microcline in the granite northeast of the gabbro forms anhedral crystals which commonly have sutured borders. A narrow zone of crushed microcline and quartz surrounds the sutured microcline grains. Fractures filled with crushed and introduced quartz cut across the feldspar grains but generally terminate at the large quartz grains. The microcline is slightly altered to kaolin but is much less altered than the plagioclase.

In a few places the microcline forms deep, rounded embayments into the plagioclase, suggesting that it replaces the plagioclase to a certain extent. This is probably a deuteric effect, produced by the reaction of the potassium-rich residual fluids upon the plagioclase crystals.

In thin sections, made from specimens of the granite south and west of the gabbro body, the crushed texture described above is absent. A small amount of myrmekitic intergrowth of quartz in orthoclase is present. This intergrowth is well developed in the blue quartz phase of the granite which also contains a microperthitic intergrowth of the plagioclase in orthoclase.

The biotite is of the common brown variety. Because there is no evidence of a secondary origin it is assumed that the biotite is primary.

Biotite-Quartz Diorite

<u>Distribution and occurrence</u> -- The biotite-quartz diorite extends northeast from the east shore of Myrna Lake to the southwest shore of Arbour Lake. The southern contact with the microcline granite extends

northeast to the south shore of Huett Lake. The northern and western limits were not defined.

One of the best exposures of the diorite is on top of the large ridge east of Myrna Lake. Other smaller outcrops occur along the tops and sides of all the ridges between Myrna and Arbour Lakes.

Petrology -- The biotite-quartz diorite is a massive medium-grained, greyish white weathering rock of uniform appearance. The fresh surface of the rock is somewhat whiter in colour and is flecked with biotite. The composition as estimated from an average hand specimen is 60 per cent feldspar, 30 per cent quartz and 10 per cent biotite.

An average composition, as determined by Rosiwal analyses, is 54 per cent plagioclase, 18 per cent biotite, and 26 per cent quartz.

The plagioclase crystals are subhedral. All the crystals show albite twins and in addition about thirty per cent of the crystals are zoned. These zoned crystals are characteristic of the biotite-quartz diorite. The composition of the zones could not be determined, but the unzoned crystals have the composition ($Ab_{70}An_{30}$) which is on the dividing line between oligoclase and andesine. The feldspars are unaltered.

Quartz, the next most abundant mineral, is anhedral and does not show strain shadows.

Biotite, the only mafic mineral in the rock, is yellow-brown in colour. Because of the lack of any evidence to the contrary, the biotite is assumed to be of primary origin.

Myrna Lake Gabbro

General Statement

The petrological description of the Myrna Lake Gabbro Body will be given under three headings:

(1) Uralite gabbro

(2) Olivine hypersthene gabbro

(3) Associated dyke rocks

Subsequently, an attempt will be made to explain the significance of the features described.

Uralite Gabbro

Distribution and occurrence -- The major part of the Myrna Lake intrusive body is uralite gabbro. This rock is distributed in a pear shaped area east and southeast of Myrna Lake. The southwestern contact passes a few hundred feet below Goat Lake as shown in Fig. 3.

The country rocks which form the north, east, south and southwest contacts of the uralite gabbro have been described previously. The west contact is marked by the olivine hypersthene gabbro phase and the zone of gradation between the two rock types is less than a foot wide.

Petrology -- Megascopically the uralite gabbro is fairly uniform in appearance. Weathering of the outcrop generally has removed the feldspar, leaving the amphibole standing out in relief, and giving the rock a green colored 'scoria-like' weathered surface. The composition ranges from 30 per cent green amphibole and 70 per cent smoky mauve feldspar to 60 per cent green amphibole and 40 per cent feldspar. Locally as much as 15 per cent biotite, derived from the amphibole, is present. In the biotite-bearing specimens the feldspars are commonly lustrous black in contrast to the normal smoky mauve hue.

The gabbro is fine grained along the contact with the quartz-hornblende diorite both west of Carr Lake and south of Goat Lake. The coarse-grained phases show a striking development of feldspar crystals, some of which attain lengths exceeding 3/4 of an inch. The feldspar crystals exhibit a general alignment at 140 degrees, but individual crystals show considerable departure from the general trend. The dip of the lineation is vertical.

The fine to medium-grained phase of the uralite gabbro in outcrop C-238 south of Goat Lake is notable for the presence of numerous quartz 'eyes'. These 'eyes' are variable in distribution and constitute from 10 to 15 per cent of the rock. The quartz is usually blue and stands out on the weathered surface of the outcrop which is spotted green and grey in colour. Despite the relatively fine grain of the rock, the feldspar crystals remain markedly euhedral in outline. On the fresh surface some specimens of the rock have a bronze cast similar to that of the olivine-hypersthene gabbro. A representative hand specimen contains 10 to 15 per cent quartz, 20 to 25 per cent amphibole and 60 to 70 per cent feldspar. A similar rock occurs at station C-236 along the eastern contact. The quartz in this rock is believed to have been introduced from the nearby acid rocks. This will be discussed more fully later. These local variations of the uralite gabbro have been called quartz-uralite gabbro.

The uralite gabbro is composed of variable amounts of plagioclase, hornblende, actinolite, chlorite, biotite, and antigorite and minor amounts of pyroxene, quartz, apatite, epidote, magnetite, sericite, and kaolin. The plagioclase has a compositional range from ($Ab_{42}An_{58}$) to ($Ab_{32}An_{68}$) in the labradorite division. The crystals are euhedral and exhibit albite twinning. Simple carlsbad twins are occasionally combined with the albite twins. Rarely pericline twins are present. Pyroxene is present in a few sections as small subhedral or rounded crystals enclosed in compact hornblende. A few of the larger grains are augite but most of the crystals are too small to identify. The process of alteration of the pyroxene to hornblende is clearly shown in a unique section from south of Goat Lake. This section is composed of 80 per cent labradorite, 15 per cent hypersthene, and 5 per cent hornblende and minor quartz, magnetite, and biotite. The labradorite of this section is unaltered.

In the first stages of the alteration the hornblende forms a narrow border along the edges of the hypersthene crystals. As the alteration proceeds, the core of pyroxene is gradually reduced until the entire crystal has been replaced by amphibole. Nothing was observed to indicate that cracks or cleavage controlled the alteration. The boundary between the two minerals is marked by an incipient change of colour.

The hornblende in the section is light green and has a low birefringence in contrast to the medium-green hornblende that has a medium birefringence (second order colours).

Other sections, in which compact hornblende encloses pyroxene, differ from the one described previously in that hornblende has the colour and birefringence normally associated with that mineral. In these sections, there is an incipient alteration of the pyroxene to antigorite, so that in many places the hornblende encloses areas of antigorite which are of the same shape as the replaced pyroxene remnant. Much of the compact hornblende is surrounded and penetrated by actinolite fibres indicating replacement by the actinolite. The end product of the alteration is a rock containing only actinolite, antigorite and minor biotite.

The actinolite is colourless to light green and occurs as acicular or feathery fibres. Most of the actinolite fibres are rimmed by a bluish green amphibole which is the same as that found in the northern part of the intrusive. The bluish green amphibole is best developed in the area east of Myrna Lake where it is the only amphibole in the rock. It occurs as well-developed fibres which are length slow and have a maximum extinction angle of 20 degrees. The mineral is strongly pleochroic from bluish green to yellow-green. The optic figure is biaxial negative with a large 2V. The properties are partly those of actinolite and partly those of hornblende. Following the terminology used by Wandke and Hoffman (1928) the mineral will be referred to as blue-green actinolite, to distinguish it from the compact mineral that has the same color.

In the gabbro near the biotite-quartz diorite dyke east of Myrna Lake the blue-green actinolite is extensively altered to biotite; the entire sequence of alteration from the appearance of an incipient brown colour on the actinolite to true biotite flakes was observed. In an intermediate stage, a brown micaceous mineral that retains the amphibole cleavage is formed.

All the feldspars of the uralite gabbro are slightly altered to sericite, kaolin and chlorite. Alteration of the labradorite to epidote is extensive in the quartz-rich phases. In general, alteration to chlorite is most extensive in the area east of Myrna Lake. In the rocks in this vicinity the chlorite fibres have grown normal to the contact of the plagioclase with the actinolite, and have penetrated deeply into the feldspars. Fractures in the feldspar also serve as loci for the alteration. The feldspars contain minute rod-shaped crystals that are also believed to be chlorite. These crystals show a tendency to lie with their long axes parallel to the cleavage of the feldspar.

At station c-224 near the southeast contact, the feldspars are mylonitized, and quartz has been introduced into the crushed material. This is the only outcrop in which pyrite is visible in hand specimen. However, sulphides were noted in thin sections from other parts of the gabbro.

A few of the outcrops near the contact of the uralite gabbro with the unaltered olivine-hypersthene gabbro do not contain remnants of compact hornblende. Sections from these outcrops contain actinolite and a mass, unresolvable at a magnification of 300X, of fibres believed to be actinolite in the early stages of formation. Commonly, some chlorite is present. Magnetite and apatite are common accessory minerals. Quartz is present in small amounts throughout the rock.

The term uralite gabbro is used because it denotes the intrusive origin of the rock and the secondary origin of the amphibole. In a strictly mineralogical sense the name plagioclase amphibolite is applicable. Johannsen's classification is 2312. In some phases of c-238 the rock may be classified as 3312.

Olivine Hypersthene Gabbro and Norite

Distribution and occurrence -- The olivine-hypersthene gabbro and intimately associated olivine norite and norite occur in scattered outcrops along the west edge of the ridge between Myrna Lake and the west shore of Goat Lake. Most of the outcrops are a few feet east of the base line shown on the accompanying map. (Fig. 3) Outcrop c-238-16, south of Goat Lake and separated from the main body of unaltered rock by the quartz uralite gabbro, is also placed in this category.

The rock forms a narrow zone along the western contact of the intrusive. The contact with the microcline granite is hidden in a depression several hundred feet wide. An equal distance separates the gabbro from the nearest outcrop of volcanic rocks to the west of Goat Lake. The eastern boundary is marked, as explained previously, by a rapidly gradational contact with the uralite gabbro phase.

Petrology -- In texture the rock is identical with the uralite gabbro. The feldspar laths attain lengths as much as one inch. As in the uralite gabbro phase the laths are aligned at 140 degrees. The most noteworthy variation in the rock is the feldspar content which ranges from 20 to 60 per cent. The rock weathers light bronzy grey. The feldspar crystal tend to stand out on the weathered surface of the outcrop. On the fresh surface the rock is a dark bronze-grey. In thin section the rock is seen to be composed of plagioclase, hypersthene, augite, olivine, and minor amounts of biotite, hornblende, and magnetite. Zircon and apatite are accessory minerals.

The feldspar is labradorite ($Ab_{32}An_{68}$) which is at the lower end of the compositional range of the feldspars in the uralite gabbro. The crystals are twinned according to the albite law, and are completely free of alterations. As in the uralite gabbro some of the large laths are bent slightly probably due to movement prior to the complete consolidation of the rock.

A Rosiwal analysis of a section of the rock gave 17 per cent olivine, 30 per cent augite, 28 per cent hypersthene, 22 per cent labradorite and 2 per cent magnetite. The percentages of the different ferromagnesian minerals are variable. An increase in the percentage of hypersthene over augite is accompanied by a decrease in olivine. Two thin sections examined, one from C-238-16 and the other from C-241 are norites and contain 4 or 5 per cent augite, 28 per cent hypersthene, and one or two per cent olivine.

The augite crystals are subhedral in outline and many show simple twinning. The mineral has a dusty colour owing to the presence of minute needle-shaped inclusions aligned parallel to the cleavage. These inclusions are believed to be clusters of magnetite crystals. Generally, the augite exhibits better crystal outlines than the hypersthene in the same section. However, where the augite and hypersthene are the only ferromagnesian minerals present, they are equally well developed. The large anhedral olivine grains contain well developed dendritic patterns of magnetite. The olivine gives poor optical figures, but those that were obtained indicated that the mineral is biaxial positive. This suggests that the olivine is an iron-rich variety. Augite and olivine are surrounded by small compact anhedral grains of hypersthene. These hypersthene grains are notably lacking in good cleavage outlines. On the other hand, in the norites in which hypersthene is the predominant mafic mineral, the crystals are subhedral and exhibit good cleavage. The pleochroism of the mineral is exceptionally strong. An incipient green-brown alteration of the pyroxene, identified as hornblende, forms a narrow band about the hypersthene in a few sections. The ferromagnesian minerals occur in triangular shaped interstices between the feldspar laths.

In about half the thin sections examined the ratio of olivine, augite and hypersthene remains constant. The total percentage of ferromagnesian minerals varies widely, ranging from 30 to 80 per cent of the mineral content of the rock. Because the amount of augite and hypersthene are approximately equal, the rock has been called a hypersthene gabbro, rather than a norite, as the latter term implies a decided excess of hypersthene. The term olivine hyperite as used by Johannsen (Vol. III) is also applicable. In Johannsen's system of classification the rock is designated 2312, with some phases which may be designated 3312. As mentioned previously, phases of the rock are true norites that contain only hypersthene and labradorite. Other phases contain a small amount of olivine and are called olivine norites. The two rock types, the olivine hypersthene gabbro and the norite, grade insensibly into one another, and no systematic control of their occurrence was observed.

Associated Dyke Rocks

Anorthosite is the most important dyke rock associated with the basic intrusive. This dyke rock is exposed in outcrop c-227 near the east contact and is present in the core from a diamond drill hole on the east shore of Goat Lake.

Because of the limited exposure at c-227 no determination of the strike or dip of this dyke could be made. The diamond drill core on the east shore of Goat Lake was not in boxes and the logs were not available to the writer, so no interpretation of the core was possible.

The rock weathers grey spotted with minute flecks of green amphibole. On the fresh surface the rock is composed of a fine-grained greenish grey to greenish black matrix which encloses large euhedral phenocrysts of feldspar. In thin section the matrix is found to be a mass of poorly developed actinolite fibres and feldspar crystals. The phenocrysts are labradorite ($Ab_{34}An_{66}$) and are fractured; the matrix has been introduced along these fractures. Local corrosion of the phenocrysts by the groundmass indicates a difference in composition between the feldspars in the groundmass and the phenocrysts.

The gabbro at outcrop c-224 is cut by two small trap dykes, three or four inches wide, that exhibit chilled contacts with the gabbro.

Petrogenesis and Alteration

Petrogenesis -- If it is assumed that the original composition of the uralite gabbro is represented by the composition of the unaltered olivine hypersthene gabbro and associated norites, then the petrogenesis of the body as a whole may be inferred from a study of these unaltered rocks. The variations in composition of the unaltered rocks were probably present to a greater or less extent throughout the body prior to the amphibolitic alteration.

It may therefore be postulated that the Myrna Lake intrusive body solidified as a pyroxene gabbro. The mafic constituents were augite, hypersthene, and olivine. In the unaltered rock the relative percentages of these vary widely from place to place and this variation was probably present throughout the intrusive mass.

The ratio of feldspar to mafic minerals shows considerable local variation. The average feldspar content of the unaltered rock is 55 per cent, which is the same as the average for the body as a whole. The average composition of the feldspar is the same in the altered and unaltered rock if the quartz-bearing phases of the uralite gabbro are not considered. The quartz-bearing phases contain a somewhat more acid feldspar which is attributed to external influences. There is no evidence of a controlled segregation of the constituents, such as that produced by gravitational differention of a partly crystallized magma.

The large euhedral feldspar crystals are one of the striking mineralogical features of the unaltered gabbro. A number of observations indicate that the feldspar was one of the first of the essential constituents to crystallize from the magma. Briefly, these observations are as follows:

(1) The large size of the crystals indicate growth in a fluid medium which would permit the movement of the ions to a few centres of crystallization and consequently reduce the mutual interference of the growing crystals.

(2) The mafic minerals occupy more or less triangular shaped areas between the feldspar laths and do not terminate the feldspar crystals.

(3) The alignment of the feldspars must have been brought about by movement in a reasonably fluid medium or the feldspars would

have suffered fracturing and crushing. Small fractures are present in a few of the crystals, but none completely rupture the crystal in which they occur.

In olivine-rich sections of the unaltered gabbro, the olivine grains are almost invariably surrounded by a narrow border of anhedral hypersthene crystals. It is evident that the hypersthene crystallized after the olivine. Such rims of hypersthene about olivine grains in basic rocks have been noted by many writers. Johannsen (Vol. III, p. 215) states "In some cases the continuation of the crystallization of the magma produced hypersthene instead of more olivine; consequently rims of the latter surround the former".

Dendritic patterns of magnetite occur within the olivine and are believed to be the result of exsolution. Inclusions of magnetite in partly serpentinized olivine have been described and are generally interpreted as by-products of the alteration. However, the olivine in the Myrna Lake gabbro is unaltered, and so it seems unlikely that the magnetite originated in this manner. The olivine is optically positive and is therefore believed to be an iron-rich variety (Rogers and Kerr, p. 296). The writer thinks it probable that the olivine held an excess of iron in solution, and upon cooling the iron that was not taken up in the olivine structure exsolved in the form of magnetite.

Vogt and others have shown that the relative proportions of iron and magnesia in the different ferromagnesian minerals of a given rock are the same for all the minerals. It is to be expected, therefore, that if the olivine is rich in iron the other mafic minerals would also be proportionally rich in iron. This appears to be true in the Myrna Lake gabbro.

The augite is dusty in colour owing to many minute needle-shaped inclusions that are believed to be aggregates of magnetite crystals. As in the case of the olivine the augite is unaltered and it therefore seems improbable that the magnetite formed as the result of alteration. The texture is also interpreted as due to exsolution.

The generally high iron content of the ferromagnesian mineral is also reflected in the strong pleochroism of the hypersthene (Larsen and Berman, p. 241). A comparison of the Myrna Lake hypersthene with the orthorhombic pyroxene in the Lynn Lake body shows that the hypersthene from the Myrna Lake body is considerably more pleochroic.

The augite crystals in the olivine-rich areas of the gabbro are not commonly found in contact with olivine. However, in a few places the augite crystals seem to be terminated by the olivine grains. The general impression given by the three minerals is that the augite and olivine grains lie in a 'matrix' of small anhedral hypersthene grains. The indication is that in the order of crystallization, the augite preceded the hypersthene and was probably partly contemperaneous with, but mostly later, than the olivine.

However, in thin sections of noritic rock that contain predominantly hypersthene with some augite and no olivine, the two pyroxenes are equally well developed. This probably indicates that the order of crystallization was strongly influenced by local conditions. The interstitial nature of the ferromagnesian minerals with respect to the feldspar crystals may have inhibited the free circulation of the ions so that equilibrium was not maintained. The presence of the large feldspar laths may have so interrupted the movement of the ions that 'pockets' of varying composition were set up. In any restricted area the order of crystallization would be governed by the proportions of the minerals present in that particular area of the intrusive. The first mineral to crystallize in any particular area would be the one which was in excess of certain equilibrium proportions. In the norite it is to be expected that hypersthene would crystallize earlier than in the olivine hypersthene gabbro.

In all sections of the unaltered rock a minor amount of green-brown hornblende is present. This hornblende occurs as rims of varying widths about the pyroxene grains. It is not always present on all borders of the grain, but may form a relatively wide band on only one end of the grain. Cracks and cleavage do not appear to exert any particular control upon the hornblende alteration. The contact between the two minerals is marked by an incipient change of colour. In a few crystals the cleavage of the pyroxene is continuous into the amphibole. This hornblende is believed to be of primary origin. However, it is difficult to establish satisfactory criteria for distinguishing between compact hornblende of primary origin and compact hornblende of secondary origin.

The colour of hornblende may be distinctive. Brown hornblende is generally primary whereas green hornblende is secondary. However, Williams (1884) states that green primary hornblende has been noted. Gordon (1904) claims the only incontestable evidence of secondary origin is the presence of hornblende bordering irregular fractures in the pyroxene.

Johannsen (Volume III, p. 228) states ".....instead of a sharp contact line between the two minerals, as in the case of a primary hornblende rim around a pyroxene centre, the line is usually irregular, and the secondary mineral seems to have eaten its way into the older one".

It is evident that no single criterion will suffice.

The writer believes the green-brown, compact hornblende of the Myrna Lake body is of primary origin because:

(1) The rock in which the hornblende occurs does not show evidence of hydrothermal action such as the alteration of the feldspars to kaolin and sericite and the development of chlorite, serpentine and other typical hydrothermal minerals (Schwartz, 1939).

(2) The boundary between the two minerals is sharp and the contact is marked only by an incipient change of colour.

(3) Cleavages and fractures do not exert a controlling influence on the development of the hornblende.

(4) Cleavage of the pyroxene continues uninterrupted from pyroxene to hornblende in a few crystals.

(5) The colour of the mineral is typical of primary hornblende as described by many writers (Johannsen, Volume III, p. 227).

The compact green hornblende described in the unique thin section A-78-2 is also believed to be primary. All the criteria listed above, with the exception of (5), are noted in this section.

The question arises as to why primary hornblende in different parts of the same intrusive body should be different in colour. Two possibilities are suggested:

(1) Local conditions within the body were such that in one place the primary hornblende formed was green-brown in colour, whereas in another place green hornblende formed.

(2) The colour of the green hornblende is due to secondary causes, and the hornblende as originally formed was the same colour throughout the body.

In view of the arguments already presented, to show that local conditions influenced the order of crystallization, it is conceivable that local conditions may also have governed the colour of the hornblende formed in any particular area. However, the writer favours the idea that the green colour of the hornblende is due to secondary causes.

In summary, the Myrna Lake intrusive body consolidated as a rock composed of labradorite, olivine, augite, hypersthene, and minor compact green-brown hornblende. The large labradorite crystals were the first crystals formed, followed by olivine, augite, and hypersthene. The sequence of the last two minerals was governed by the relative proportions of each present in local areas of the intrusive, so that in noritic zones the order was partly reversed. A relatively small amount of feldspar was the last mineral to crystallize, and filled the interstices between the other minerals.

In considering the origin of a rock of the composition outlined in the preceding paragraphs two possibilities arise:

(1) The magma from which the rock consolidated was of the same composition as the original magma, and the molten material has simply been moved from the original magma chamber to its present position.

(2) The magma from which the rock consolidated was a partial magma derived from an original magma of different composition by some process of segregation.

The writer prefers (2) as an explanation for the origin of the

Myrna Lake gabbro, although the first possibility is one which cannot be directly disproved.

Three features of the Myrna Lake intrusive body that are unique and were not observed in any of the other basic intrusive bodies examined by the writer, suggest that the body is a differentiate of a more basic igneous mass. These features are as follows:

(1) The rock is generally feldspathic; the feldspar content ranges from 55 to 80 per cent in the sections examined, and is in general from 15 to 20 per cent higher than in the other basic bodies of the Lynn-Barrington Lakes Area.

(2) The texture of the feldspars is idiomorphic and there is evidence to suggest a partial reversal of the normal Rosenbusch order of crystallization.

(3) Anorthositic dykes are associated with the body.

The anorthosite dykes associated with the Myrna Lake gabbro certainly suggest that differentiation did take place to a certain extent. The majority of writers agree that anorthosites are one of the end products of the differentiation of a magma, although not all of them agree upon the actual mechanics of the process or the composition of the original magma.

Early writers believed that the process was simply one of liquid segregation into 'salic and mafic poles'. However, the field evidence has shown, from the effects of anorthosite upon inclusions, that the actual temperature of the anorthosite was far below that required to maintain such a monomineral rock in a molten condition. To overcome this difficulty, some writers have postulated that the anorthosite was so rich in mineralizers that it was able to remain molten at unnaturally low temperatures. This theory is also contradicted by the field evidence which shows that the rock into which anorthosite has been intruded does not show the hydrothermal effects that would be expected if the anorthosite was rich in mineralizing fluids.

Bowen (1917) attributed anorthosites to the segregation of plagioclase crystals from a gabbroic solution. He believed that the marked tendency for the plagioclase in plagioclase-rich melts to be labradorite rather anorthite is due to the similarity in density between the crystals of plagioclase and the magma. The crystals thus remained suspended in the melt as the temperature fell, and equilibrium was maintained between the melt and the crystals so that their composition approached that of the original magma. Meanwhile the mafic constituents settled out, leaving the residual material much more salic. As a consequence of the reduction of the specific gravity of the residual fluid, owing to the subtraction of some of the mafic constituents, the feldspar crystals begin to settle out and form in the extreme case a band of anorthositic material.

Balk (1930) assumed, that from an original dioritic magma, fractional crystallization produced labradorite and ferromagnesian minerals. These crystals did not sink, but were swept along through narrowing channels, so that motion of the crystals was retarded and the syenitic residual liquid advanced past them. As fresh material was brought up, more crystals were added to those already arrested in their movement, so that three rock types were formed, gabbro, anorthosite, and syenite.

Alling (1932) agrees in general with Balk's explanation of the

Adirondack anorthosites. Johannsen (Volume III) states that although he believes Balk's picture of the process is the best so far presented, he would regard the original magma as being granodioritic rather than dioritic as Balk proposed. Despite the disagreement as to the composition of the original magma and the mechanics of the process, most writers agree that anorthosite is the result of the extreme differentiation of a polymineralic magma.

If we assume that the Myrna Lake gabbro formed from a partial magma, of less basic composition than the original magma, it is possible to account for the texture of the intrusive body and for the associated anorthosites by the process of differentiation. In the first stage of differentiation of the parental magma the growing mafic minerals would begin to settle out. At a certain stage in this process the equilibrium would be so shifted that feldspar crystals would begin to form. The subtraction of the mafic constituents would result in a lowering of the specific gravity of the liquid, and eventually the feldspar crystals would begin to segregate. This would occur very slowly so that chemical equilibrium between crystals and liquid is maintained, resulting in feldspar of intermediate composition rather than the basic crystals first formed. The accumulation of these crystals and a small amount of interstitial material would form an anorthositic phase.

The residual crystal and liquid mixture from which some of the mafic constituents and to a lesser extent plagioclase crystals have been subtracted would eventually attain the composition of the unaltered gabbro. If this material was then moved from the lower levels at which differentiation occurred to its present position, the feldspar crystals would tend to align themselves with their long axes parallel with the direction of flow. The lineation of the Myrna Lake body strikes S 40° E and dips vertically indicating that the intrusive mass rose vertically towards the southeast or northwest.

The small amount of anorthosite associated with the Myrna Lake gabbro and the moderately feldspathic nature of the basic intrusive rock would only require a moderate amount of segregation. It would not be expected that striking differences in the composition of the feldspar of the gabbro and that of the anorthosite would occur. The feldspars are, practically speaking, identical.

Gradually, as the molten material reached the upper levels it cooled sufficiently to form the minerals described previously. The anorthositic material, probably following the same channels, was injected into the gabbro. This probably occurred at a time when the gabbro was sufficiently warm to permit the penetration of the anorthosite to considerable distances, before consolidation of the interstitial fluid of the anorthosite was complete. However, the gabbro was sufficiently cool that the interstitial fluid was chilled to form a relatively fine-grained matrix of feldspar and minor ferromagnesian minerals.

Balk (1930) by means of the constrictional flowage theory was able to account for the extreme crushing and fracturing of the feldspar crystals in the Adirondack anorthosite masses. This crushing and fracturing he attributed to the repeated shoving about of the masses of accumulated crystals by successive influxes of new material. To the writer, this seems an inescapable consequence of this method of accumulation of the feldspar crystals.

The Myrna Lake gabbro and anorthosite show no such extensive fracturing. In fact, they seem to have been emplaced rather gently, for although there is a moderate amount of distortion of the crystals, only rarely are crystals completely ruptured. The writer therefore favors a segregation at depth rather than constrictional flowage theory to account for the origin of the Myrna Lake gabbro and associated anorthosites.

<u>Alteration</u> -- In the description of the uralite gabbro of the Myrna Lake intrusive body the sequence of the formation of the secondary minerals was established. This sequence will be reviewed at this point for the sake of convenience.

The first change to occur was the partial conversion of the pyroxene to compact green hornblende. At a second stage in the alteration the compact green hornblende was partly converted to actinolite, and much of the pyroxene was changed to antigorite. As the alteration continued, minor amounts of the compact hornblende and actinolite were converted to antigorite also. A blue-green rim around the actinolite fibres is believed to be the same mineral as the blue-green actinolite in the northeast part of the intrusive. If this is so, then the blue-green actinolite represents the last stage in the amphibole alteration, for where it is present none of the other minerals, actinolite, antigorite, or compact hornblende are present. Biotite is a fairly extensive alteration product of the blue-green amphibole and is therefore the final mineral formed.

Reference has been made to the unique thin section A-78-2. It was stated previously that the writer believed the green hornblende in this section to be of primary origin, but that the green colour was a secondary effect. This inference is drawn from the intermediate nature of the colour and birefringence of the mineral. The birefringence is low and in that respect the mineral resembles the compact green-brown primary hornblende. The colour, although green, is not as dark as that of the hornblende in more highly altered sections.

The writer suggests that as the rock cooled it reached a point at which hornblende became stable and green-brown hornblende began to form rather than pyroxene. However, before much of this mineral was produced the rock consolidated. According to Bowen (1922 and 1928) such a rock is in a metastable state. If at a somewhat later time, the temperature of the rock is raised sufficiently the reaction thus begun will go to completion. That is to say, the pyroxene will again begin to invert to the lower temperature hornblende.

The first stage in this process in the Myrna Lake gabbro would probably be the conversion of the green-brown hornblende to green hornblende. A-78-2 may represent this initial stage, and as the process continued it is inferred that the colour of the hornblende darkened and the birefringence increased. This equilibrium adjustment continued, and more and more pyroxene was converted to hornblende. Before the conversion of the pyroxene was complete, the equilibrium conditions changed so that actinolite and antigorite began to form as described previously.

At this point, it is necessary to arrive at some conclusion in regard to the cause of the mineralogical changes previously described. In general, the agencies that cause uralitization can be broadly classified into two groups:

(1) Deuteric

(2) Metamorphic

The term 'deuteric alteration' will be used here in a broad sense to include not only those mineralogical changes that are attributable to the reaction of the crystals with the residual liquid of the consolidating magma, but also those mineralogical changes that are wrought in the consolidated or partly consolidated outer portion of an intrusive mass by gases and fluids emanating from the molten interior of the body.

The term 'metamorphic alteration' will be used to denote mineralogical changes induced in a consolidated body of rock by external influences not directly related to the genesis of the body.

Colony (1931) describes the deuteric effects on the norites of the Maskwa River area in Manitoba and the Sudbury basin as resulting in the conversion of the pyroxenes to actinolite and biotite. The feldspars have in some places been albitized, and in places the rock has been saturated with end-stage quartz and heavily mineralized. In these examples there was presumably considerable residual fluid which was to a large extent injected into the nearby consolidated portions of the rock, producing changes not only in the pyroxene but also in the plagioclase, indicating a fairly aqueous fluid. Wandke and Hoffman (1924) also attributed the alteration of the norite of Sudbury, Ontario to the action of deuteric agencies. In such extreme cases, where there is an injection of residual liquids, fractures produced in the semi-solid rock would probably be injected with material, giving rise to textures which would be difficult to distinguish from those formed by hydrothermal alteration.

Other writers have described basic intrusive bodies in which the effects of the residual liquid were not so striking. Dennen (1943) in a study of the norite near Dracut, Massechusettes describes the development of chlorite rims that "....surround hypersthene grains but are entirely separate from each other and show no relation to fractures and therefore there could have been no introduction of material". This is an example of a limited amount of residual liquid and one in which the nature of the alteration is clearly shown.

If the uralitization of the Myrna Lake gabbro is to be explained as a deuteric effect, then the nature of the deuteric agent must be such as to account for the following features of the rock.

(1) The rock shows no evidence of having bean saturated with residual liquid. The amount of interstitial quartz is negligible except in the quartz uralite phases which have previously been attributed to the assimilation of quartz from nearby granitic rocks.

(2) The anhedral grains of interstitial feldspar which was one of the last minerals formed show no evidence of reaction with earlier formed minerals.

(3) The feldspars are only slightly altered to kaolin and sericite. The strongest alteration is in the northeast part of the intrusive body. Albitization and zoning are absent except along the contacts of the body.

(4) A few fractures filled with amphibole are present and are most abundant along the contacts of the body, particularly in the northeast.

Oliver (1949) has shown that the process of uralitization of the Sudbury norite has not apparently affected the chemical analyses. That is to say, the conclusions based upon analyses of rock which contained uralite would be equally valid if interpreted in terms of unaltered rock. He proposed that the uralitization process was carried out by a residual liquid of aqueous character carrying small amounts of Si, Al, and possibly F.

Insofar as the mineralogical changes are concerned a residual fluid of the type postulated by Oliver could account for the alteration of the Myrna Lake gabbro. However, such a theory fails to account for two important features:

(1) The mineralogical similarity of the alteration of all the basic rocks of the area, both extrusive and intrusive.

(2) The aerial association of certain alteration minerals of these basic rocks with granitic intrusives.

The similarity of the mineral percentages, mineral properties, and sequence of alteration of the extrusive and intrusive rocks of the area cannot be overlooked in considering the alteration of the intrusive bodies. Although few of the pyroxene remnants remain in the volcanics, some were noted. As in the uralite gabbro these were enclosed in a compact green hornblende. The hornblende was partly altered to actinolite, and both minerals have undergone partial alteration to antigorite. The same sequence has been noted in the diorites of the area.

In both the extrusive and intrusive rocks the feldspars are only slightly to moderately kaolinized, and in both rocks there is a definite increase of plagioclase alteration in the proximity of the granitic rocks. It is true that completely altered volcanics are noted in certain outcrops such as at c-242 west of the gabbro, but one also observes mylonitized and granitized diorites and gabbros, and in the experience of the writer these always mark the contact with a granitic intrusive. Furthermore, it is to be expected that schistose rocks such as the volcanic flows and tuffs would be more permeable and therefore more highly altered at an equal distance from a source of aqueo-igneous emanations. It is not surprising, therefore that areas of unaltered rock are noted within the intrusive masses but are rarely if ever found in the flows.

It would be expected, from the apparent areal extent of the granitic rocks, that large amounts of volatile constituents capable of producing hydrothermal alteration would be present at the time of the granitic intrusion. However, field evidence shows that except in fractured and crushed rocks hydrothermal effects had a very limited range. Inclusions of volcanic rocks of moderate size do not show extensive development of the typical hydrothermal minerals such as kaolin, sericite, chlorite, and epidote.

It is worthwhile to note, that geological maps on the scale of 1/2 mile to 1 inch or even 1/4 mile to 1 inch do not give an accurate picture of the actual volume of granitic rock present in any given area. So confused are the outcrop patterns that an accurate picture of the distribution of the rocks is impossible. In some of the areas mapped as granite, the actual true granitic material probably does not exceed half the area shown on the map. The remainder is composed of included areas of foreign rock, granitized rock, and slightly assimilated inclusions. This may in part account for the seeming lack of volume of hydrothermal emanations.

If emanations from the granitic masses did penetrate the rocks, they must have been similar chemically to the deuteric fluid described by Oliver. The writer believes that the chief cause of the uralitization of the Myrna Lake gabbro was the thermal metamorphism produced by the intrusion of the granitic bodies. This was possibly aided in part by the regional disturbance which preceded the emplacement of the granitic rocks.

It is believed that the thermal gradient of the rock was raised to a point where the pyroxene began to invert to hornblende. At a somewhat later stage in the process, a change in the physico-chemical conditions caused the hornblende to invert in part to actinolite, and the pyroxene to antigorite. An interchange of ions between the minerals maintained chemical equilibrium as nearly as possible.

The second point that a theory of deuteric origin of the uralite fails to explain is the distribution of the blue-green actinolite and biotite. These minerals are best developed in the northeast part of the intrusive where a large biotite-quartz diorite dyke intrudes the gabbro. They are also found in minor amounts along the 'granite'-gabbro contact, and commonly throughout the intrusive. Blue-green amphiboles in the volcanic flows and diorites show a similar association with the contacts of the acid rocks. It is evident that the development of this amphibole is related to the granitic rocks. A similar blue-green amphibole in the Sudbury norite has been described by Wandke and Hoffman (1924) who attributed the colour to the addition of sodium. The association of blue-green amphibole with the acid intrusive contacts was noted by Bateman (1942) in the McVeigh Lake Area.

The biotite, which is an alteration product of the blue green amphibole in the northeast part of the intrusive, commonly begins to form about a grain of magnetite. This association suggests that in part the hornblende and magnetite combined to form biotite.

Age Relationships

The volcanics are the oldest rocks in the area. Inclusions of these rocks are present in quartz-hornblende diorite, gabbro, and microcline granite.

The conclusion that the quartz-hornblende diorite is older than the gabbro is based upon two facts:

(1) In the contact zone south of Goat Lake, the diorite is cut by two small dykes which are similar to the gabbro.

(2) The gabbro along the contact with the diroite is finer-grained than it is away from the contact. The fine-grained phase is interpreted as a chilled border.

An inclusion of the quartz monzonite is found within the gabbro south of Goat Lake. It is a block about 2 square feet in area and is fractured and intruded by stringers of the basic rock. This inclusion shows that the quartz monzonite is older than the gabbro. The sequence between the quartz monzonite and the quartz-hornblende diorite is unknown.

In considering the age of the microcline granite mention must be made of certain bodies of granitic-appearing rock that occur within the gabbro south of Goat Lake, and in the fine-grained zone along the east contact. South of Goat Lake, the outcrops are separated by intervals of overburden, but the continuity of the strike of the granitic areas suggests a dyke. The largest of these exposures is about 30 feet wide by 150 feet long. The pinkish white weathered surface of these rocks which are spotted with milky blue quartz 'eyes' resembles the blue quartz phase of the microcline granite. On the fresh surface the rock grades from pinkish grey to dark grey towards the contact with the gabbro. This change of colour corresponds to a change in the mineralogical composition from untwinned feldspar (oligoclase and some orthoclase) quartz, and biotite, to albite-twinned andesine, quartz, and hornblende. The increasing basicity of the acid rock towards the contact suggests contamination by the gabbro. Further evidence of an interchange of material is the presence of blue quartz 'eyes' in the gabbro over a limited area near the contact.

The presence of myrmikitic and perthitic intergrowths in the blue quartz phase of the microcline granite has been noted previously. Such evidence of deuteric action is not found in the dyke rock. The same sutured mineral borders as seen in the blue quartz phase are present in the lighter parts of the dyke, although these are not seen in the more contaminated zones. The lack of these textures may be due to:

(1) An original difference, between the dyke and the blue quartz phase, in the quality and quantity of those elements that form the residual fluids of the consolidating magma.

(2) The interaction of the dyke and the wall rock as suggested previously.

Another indication of the reaction of the granite and the gabbro is found at station C-237 along the east contact. C-237 lies between the gabbro and the granite outcrops which are within a few hundred feet of one another at this point. The rock is a hybrid type composed of 10% albite-twinned oligoclase, 70% untwinned feldspar, 10% quartz and 10% ferromagnesian minerals.

The untwinned feldspar is optically positive and has an index of refraction greater than that of balsam, indicating that the mineral is either albite or untwinned acid oligoclase. The twinned feldspar is enclosed in the untwinned variety and is apparently corroded by the untwinned variety.

The ferromagnesian minerals are a mixture of actinolitic amphibole, biotite, antigorite, and an unidentified pyroxene.

In hand specimen the rock is medium coarse-grained and weathers light greyish bronze. The fresh surface is a darker greyish bronze. In the gabbro near C-237 quartz 'eyes' similar to those in the gabbro south of Goat Lake are present. The quartz is erratic in distrubution but generally decreases in amount towards the west side of the ridge.

The presence of the quartz 'eyes' over a limited area near the granite-gabbro contact and the decrease in the percentage of these 'eyes' as the distance from the contact increases suggests that these 'eyes' represent introduced quartz associated with the granite. The untwinned feldspar rim about a more basic core is interpreted as indicating albitization. Such changes would be expected if a basic rock had been subjected to the action of hydrothermal agencies associated with the granite.

Between c-213 which is a fine-grained gabbro and c-212 which is microcline granite an outcrop of blue quartz rock, similar to that south of Goat Lake, occurs.

C-210 is an outcrop of uralite gabbro which is cut by stringers of granitic rock. It is impossible to tell if this outcrop is an inclusion in the granite or if it is directly connected to the main gabbro body.

In summary, it may be stated that the following observations suggest that the microcline granite is younger than the gabbro:

(1) The presence of blue quartz dykes (in the gabbro) that are similar in appearance to the blue quartz phase of the microcline granite.

(2) The hybrid rock at C-237 supports the idea of reaction between the two rocks. The presence of quartz in the gabbro near C-237 indicates that this reaction is in part due to emanations from the granite.

(3) The gabbro at C-210 is cut by stringers of granite and may be an inclusion in the granite.

The nature of the contact between the microcline granite and the biotite quartz diorite is unknown because it lies beneath a muskeg-filled depression. Although not conclusive, two facts suggest that the diorite is younger than the granite.

(1) The biotite quartz-diorite is entirely free of alteration either dynamic, thermal or hydrothermal.

(2) In contrast to the diorite, the microcline granite has been slightly altered, as shown by the kaolinization of the plagioclase, and has been subjected to crushing. This crushing is most pronounced near the diorite and is absent in the outcrops south and east of the gabbro.

(1) and (2) imply that either the crushing is related to the

diorite, probably caused by the emplacement of that body, or the granite was crushed before the diorite was emplaced.

The writer examined samples of the microcline granite of the Sickle Lake Area collected by Dr. A. P. Fawley, and these cannot be distinguished from rocks collected in the Myrna Lake Area. Dr. Fawley (1949) has noted that ".....the microcline granite, in general, is fresh and massive, however crushing is shown in a few localities by mortar structure and/or by strain shadows in the quartz".

The crushing is therefore due to local causes and the writer considers it probable that in the Myrna Lake Area the crushing shown by the granite is due to the emplacement of the diorite.

On the basis of the arguments presented the following sequence seems the most probable:

	Biotite quartz diorite
Post-Sickle	Microcline granite
	Myrna Lake gabbro
	Quartz monzonite, Quartz-hornblende diorite
Wasekwan	Volcanics

The sequence is unknown between the quartz monzonite and quartz hornblende diorite.

Conclusions

1. The age relationships of the different rocks of the area are as follows:

	Biotite-quartz diorite
Post Sickle	Microcline granite
	Myrna Lake gabbro
	Quartz monzonite, Quartz-hornblende diorite.
Wasekwan	Volcanics

The sequence between the quartz monzonite and the quartz hornblende diorite could not be determined.

2. The following sequence of events in the history of the body is inferred:

(a) A more basic magma was partly differentiated at depth to yield an anorthositic phase, and a magma of the composition of the gabbro.

(b) The magma was intruded into its present position. Consequent upon the movement of the magma, the feldspar laths became aligned parallel to the direction of flow, indicating that the body rose vertically toward the northwest or southeast.

(c) The consolidation of the magma yielded a rock of the average composition of an olivine-hypersthene gabbro and composed predominantly of plagioclase, olivine augite, hypersthene, and minor amounts of primary hornblende.

3. The evidence shows that the uralitization of the gabbro was caused by thermal metamorphism aided by hydrothermal emanations. The sources of the heat and hydrothermal materials were the granitic intrusives of the area. Three stages of the alteration representing successive metamorphic stages are recognized:

(a) Inversion of the pyroxene to compact hornblende

(b) Development of actinolite and antigorite

(c) Development of blue-green actinolite and biotite

The inversion of the pyroxene to compact hornblende is believed to represent a response to predominantly thermal metamorphism. As the acid intrusives were emplaced, increased hydrothermal activity resulted in the partial conversion of the compact hornblende and pyroxene remnants to actinolite and antigorite. The blue-green actinolite that more or less completely replaces the actinolite and antigorite along the contact of the gabbro with the acid bodies is believed to represent the highest grade of metamorphism. The development of this mineral is attributed to the higher temperatures attained in these zones, and the introduction of sodium bearing solutions from the nearby granitic intrusive masses. The local development of biotite may be due to retrograde metamorphism as the temperature of the gabbro decreased during the cooling of the granitic rocks.

LEGEND

PROBABLY POST-SICKLE

5 Quartz monzonite

4 Gabbro

3 Diorite (Sequence with number 4 unknown)

WASEKWAN

2 Quartzites (Granitized equivalents)

1 Volcanics

Symbols

Strike (Dip vertical, inclined, unknown)..........

Schistosity (Dip vertical, inclined, unknown)......

Flow lineation (Dip vertical, inclined, unknown)...

Geological boundary (Observed, approximate)........

Outcrop..

Swamp..

FRASER-LYNN LAKES AREA

SCALE: 1/2 MILE TO ONE INCH

MILES 0 1/4 1/2 1 1 1/2 2 MILES

FIGURE 4

CHAPTER IV

GEOLOGY OF THE FRASER-LYNN LAKES AREA

Location and Character of the Area

The Fraser Lake and Lynn Lake basic intrusive bodies are located in the southeast corner of the Lynn Lake sheet which lies between longitudes 101° and 101° 15' west and between latitudes 56° 45' and 57° north. These intrusive bodies are shown on the accompanying map (Fig. 4, p. 53) which covers an area 6 miles long by 4 3/4 miles wide. Outcrops are generally confined to the ridges which are separated by areas of low ground and swamp. Glacial deposits of sand and gravel form large ridges in parts of the area, notably near Lynn Lake.

In plan view, the Lynn Lake intrusive body is a pear-shaped body, the long axis of which trends north. The body is 2 miles long and has a maximum width of 1 1/4 miles. Most of the western contact of the body lies beneath Lynn Lake. The Fraser Lake gabbro, an irregular shaped body of gabbro similar to the Lynn Lake body, lies 1 1/2 miles south of Lynn Lake. A geophysical survey and a limited amount of diamond drilling have been done on the Fraser Lake body, but no positive results have been reported. Both the Fraser Lake and Lynn Lake intrusive bodies were staked by Sherritt Gordon Mines Limited.

Country Rocks

General Statement

The country rocks which surround these basic intrusive bodies consist of the Wasekwan quartzite and volcanics, and post-Sickle granitic intrusive rock. A brief description of these rocks follows.

Volcanic Rocks

<u>Distribution and occurrence</u> -- Wasekwan volcanic rocks lie on the east and north sides of the Lynn Lake gabbro and on the south side of the Fraser Lake gabbro. The volcanic rocks form large steep-sided ridges in contrast to the rounded outcrops of the granite and quartzites.

<u>Petrology</u> -- Allan (1946, p. 1) gives the following summary of the lithology of the volcanic rocks of the area.

> "They (the volcanic rocks) are chiefly basic lavas and greenstone, typically massive and fine-grained with small needles of hornblende. A common phase is fine-grained with phenocrysts of altered feldspar which stand out on the weathered surface. Metamorphism of various degrees has produced hornblende feldspar gneisses and hornblendite some of which are very coarse grained......... Pillow structures are discernable in the sheared volcanics north of Berge Lake.........Volcanic breccia is well exposed on the prominent ridge along the east side of Ralph Lake".

Allan (1946, p. 2) says of the volcanic rocks south of Fraser Lake:

> "In these bands the breccia is less clearly defined, and the breccia, flow, and tuff appear to be about equally

represented and cannot easily be mapped separately. Hornblendite is found in most of the volcanic series. Some is probably metamorphosed flow, but some is undoubtedly intrusive in origin.

Tuffs occur in all units. They are generally fine-grained grey to green and thin bedded. In some beds considerable recrystallization has taken place. At some places the tuffs are extensive and can be mapped as a group but at most places they are only a minor rock type in the map unit".

Inclusions of volcanic rocks were noted within the gabbro and the granite. In the gabbro the inclusions are either hornblende schists or porphyroblastic hornblende schists, whereas in the granite they have been altered to biotite-hornblende schist or plagioclase amphibolite.

Thin sections of the fine-grained massive volcanic flows of the area show the rock to be composed of equal amounts of plagioclase feldspar and hornblende. Minor amounts of biotite, magnetite, and epidote are present. The hornblende is blue-green in colour and occurs as compact grains and as poorly developed acicular or feathery fibres. In a few places biotite replaces the hornblende. The hornblende crystals are enclosed in a 'matrix' of plagioclase feldspar. The plagioclase crystals are anhedral and show indistinct, poorly developed twins. A few crystals are subhedral in outline and polysynthetic albite twins can be recognized in these crystals. The composition of the plagioclase could not be determined accurately from the thin sections.

Magnetite is enclosed within both the hornblende and feldspar. Epidote is present as small grains within a few of the feldspar crystals, which suggests that it has formed by alteration of the plagioclase.

The volcanic rocks in the area near the Fraser Lake gabbro are in general more sheared and recrystallized than the massive flows described in the preceding paragraphs. This is especially true of volcanic inclusions in the quartz monzonite zone and within the gabbro body. An outcrop of volcanic rock in the quartz monzonite zone east of the gabbro body is composed of approximately 80 per cent mafic minerals and 20 per cent plagioclase and minor epidote.

The mafic minerals consist of an intimate mixture of chlorite, hornblende, and actinolite with antigorite as the predominant mineral. In polarized light the boundary between the antigorite and the hornblende is marked by an incipient change of birefringence, from the first order yellow of the antigorite to the second order yellow of the hornblende. In non-polarized light the contact between the two minerals cannot be distinguished. Near the boundary between the two minerals small irregular patches, which have the same birefringence as the hornblende, occur within the antigorite. These are evidently remnants of unreplaced hornblende. Further evidence of replacement of the hornblende by antigorite is that the antigorite retains the outline of the hornblende and thus forms compact psuedomorphs. Actinolite is not particularly abundant but it exhibits the same gradational contacts with the antigorite as the hornblende. The antigorite tends to retain the fibrous outline of the replaced actinolite.

In only one place were the hornblende and actinolite found to have a well defined relationship. The actinolite fibres penetrate the hornblende and surround irregular patches of that mineral suggesting that actinolite has in part replaced the hornblende. The writer infers that the hornblende was partly replaced by actinolite and that subsequently both amphiboles were partly converted to antigorite.

The plagioclase is andesine ($Ab_{52}An_{48}$). The crystals are subhedral to anhedral and generally show poorly developed albite twins. The plagioclase crystals occupy the interstices between the mafic minerals and many are spotted with epidote. In many places patches of epidote occupy the interstices between the mafic minerals and suggest that the feldspar has been completely converted to epidote.

This rock has been designated a plagioclase amphibolite. It is typical of many volcanic rocks that are closely associated with the granitic intrusives.

In thin section the porphyroblastic plagioclase amphibolites that occur as inclusions within the gabbro and along the contact of the gabbro are seen to be composed of a matrix of feathery medium green actinolite fibres in which anhedral porphyroblasts of compact hornblende occur. Many of these porphyroblasts are almost opaque because of the large amount of magnetite within the crystal. However, in many of the crystals only a few spots of magnetite are present, possibly owing to the gradual chemical absorption of the iron by the hornblende as the crystal developed. Feldspar is not present in most of these rocks.

Quartzites

<u>Distribution and occurrence</u> -- Quartzites lie along the east boundary of the Lynn Lake intrusive body and are separated from the

north and west contacts of the Fraser Lake gabbro by a narrow zone of granitic rock. The quartzite has a general trend of 55 degrees, but between Bay and Jay Lakes the strike is locally 70 degrees.

The quartzites form large rounded outcrops and are best exposed east of Francis Lake and south of Bay Lake. These sediments have an exposed thickness of over 5,000 feet. At the bottom and top of the series they are intercalated with volcanic flows.

Petrology -- The quartzites are uniform in appearance across the entire width of their exposure. They are fine-grained rocks and weather grey white to light brown. The weathered surface is streaked with lenses of biotite which give the rock a gneissic texture. The fresh surface of the rock is dark grey to pinkish grey in colour. Quartz is the principal constituent, but some biotite and feldspar are present.

Hunter (1950) who studied thin sections of these sediments in connection with his work on the Lynn Lake gabbro says that thin sections show quartz 70 to 75 per cent, feldspar 10 to 15 per cent, biotite 10 to 15 per cent, muscovite 5 to 10 per cent, and minor amounts of andalusite and garnet. The texture is granoblastic. Feldspar is intergrown with fine-grained anhedral quartz. Large grains of quartz show strain shadows. Bands and lenses of biotite and muscovite lie between the fine-grained quartz, and small flakes are scattered throughout the sections. Small shreds and grains of andalusite occur in some sections.

These rocks represent metamorphosed impure sandstones and feldspathic sediments.

Quartz Monzonite

Distribution and occurrence -- With the exception of the south contact, the Fraser Lake gabbro is bounded by quartz monzonite and associated hybrid rocks.

The quartz monzonite generally occurs in low rounded outcrops. Between the west contact of the Fraser Lake gabbro and the quartzites, the quartz monzonite is uncontaminated except for a few inclusions of volcanics.

From the east contact of the gabbro to Eldon Lake outcrops of quartz monzonite are intimately associated with a few outcrops of diorite, volcanics and sediments. Most of this area is composed of transitional hybrid rocks which exhibit too many gradations in composition to permit classification as separate units.

Petrology -- The average composition of the quartz monzonite as estimated from hand specimen is 75 per cent feldspar, 10 per cent biotite and 15 per cent quartz. The rock has a coarse-grained granitic texture. The feldspar grains are pink and grey on the fresh surface, but on the weathered surface they are a uniform pink colour. Aligned biotite flakes give the rock a slight gneissosity.

A Rosiwal analysis of a selected thin section of the quartz monzonite indicated 43 per cent orthoclase, 29 per cent plagioclase, 24 per cent quartz, 3 per cent biotite and minor magnetite, apatite, sericite, and kaolin.

The orthoclase forms anhedral to subhedral crystals which generally show carlsbad twins. A few of the crystals contain one or two irregularly shaped patches of feldspar which have a slightly higher index of refraction than the surrounding orthoclase. The contact between the two feldspars is indistinct in ordinary light. In polarized light they have a random orientation with respect to each other and with respect to the enclosing orthoclase. They are probably small crystals of a slightly more basic feldspar which were enclosed in the orthoclase during the growth of the crystal. Crushed zones are common along the contacts between feldspar and quartz grains. Occasionally, crushed zones are present between two feldspar grains.

The plagioclase is oligoclase which has the composition ($Ab_{72}An_{38}$). All the oligoclase crystals show thin albite twin lamellae and the crystals are better developed than those of orthoclase. Both the plagioclase and orthoclase are moderately altered to sericite and slightly altered to kaolin. Quartz occurs in the interstices between the feldspar grains. The grains are anhedral, and most of them show distinct strain shadows. Yellowish brown biotite occurs in irregular patches throughout the rock. For the most part, the mineral is in minute shreds but a few large flakes are present. Commonly, these larger flakes have been slightly bent. Because of lack of evidence to the contrary the biotite is assumed to be primary. Magnetite and apatite are minor accessory minerals in the rock.

The amount of uncontaminated quartz monzonite exposed east of the Fraser Lake gabbro is comparitively small. Outcrops of quartz monzonite are intimately associated with outcrops of volcanic flows, diorite, and quartzite, and with outcrops of hybrid rocks formed by the action of the quartz monzonite on the other rock types.

The interaction of acid and basic rocks is illustrated in several outcrops. One of the best exposures is at C-97 along the contact of the gabbro. The east edge of this outcrop is a coarse-grained granitic rock. The weathered surface shows white or pinkish white feldspar quartz and biotite. The fresh surface shows 50 per cent grey feldspar, 30 per cent biotite, and 20 per cent quartz. The west edge of outcrop C-97 is coarse-grained rock which has a spotted green and white weathered surface. The mafic mineral content has increased to 50 per cent. Both hornblende and biotite are present, and are much darker than on the weathered east side of the outcrop. The feldspar content has decreased to 30 per cent; quartz content is approximately the same. There is a gradation between these two rock types.

Thin sections from the west edge of the outcrop contain approximately 25 per cent hornblende, 30 per cent biotite, 10 per cent quartz, 3 per cent calcite, and minor magnetite, epidote, sericite, and apatite. The plagioclase is andesine ($Ab_{62}An_{38}$). The crystals are subhedral and show albite twins. Prismatic sections of the hornblende show a preferred orientation of the long axis of the sections.

In biotite-rich zones in the rock, vein-like masses of calcite cut the rock parallel to the alignment of the feldspar grains. The calcite embays the feldspar in places where the two minerals are in contact, suggesting that the plagioclase is replaced by the calcite. The dark-brown biotite forms an incipient growth along the boundaries and cleavages of the hornblende grains.

On the east side of the outcrop the rock is composed of 72 per cent plagioclase, 15 per cent quartz, 3 per cent biotite, 1 per cent hornblende, and minor kaolin, sericite and epidote. The plagioclase does not have a preferred orientation and the crystals do not have an elongate habit as in the rock on the other side of the outcrop. About 25 per cent of the plagioclase is andesine ($Ab_{62}An_{38}$). The crystals are subhedral and show distinct albite twins. The remaining feldspar is untwinned oligoclase with a few crystals of orthoclase. The latter mineral always exhibits carlsbad twins. These rocks are believed to represent a transition between the quartz monzonite on the one hand and the diorite on the other.

Diorites and Quartz Diorites

Distribution and occurrence -- Surrounding Jay Lake and extending east to Wheatcroft Lake is a zone of mixed rock in which outcrops of basic rock are intimately associated with outcrops of granitic rocks. The contacts of the diorite bodies as shown on the map are indicative of zones which are predominantly of basic rock. No sharp boundary exists between the granitic rocks and the basic rocks.

Petrology -- The basic rocks are a mixture of diorite and quartz diorite similar to some of the contact phases of the Fraser Lake gabbro. A minor amount of gabbro is associated with the diorite.

The diorite is a medium-grained spotted green and white weathering rock. In hand specimen the rock appears to be composed of 50 per cent feldspar and 50 per cent green-black amphibole. The feldspar is anhedral and interstitial with respect to the mafic minerals. In many places quartz is visible on the weathered surface of the outcrop.

A Rosiwal analysis of a thin section of the diorite indicated 68 per cent plagioclase, 11 per cent antigorite, 18 per cent hornblende, and minor magnetite, and quartz. The plagioclase is andesine ($Ab_{56}An_{44}$) and occurs as subhedral crystals that show albite twins. The hornblende is medium-green in colour and is replaced in part by antigorite. For the most part the contact between the two minerals is sharp and smooth. In a few places irregular patches of hornblende were noted within the antigorite which is psuedomorphic after the replaced hornblende.

The diorite grades into minor quartz diorite phases. At J-106 along the west shore of Wheatcroft Lake there is a good exposure of the quartz diorite. In outcrop the weathered surface of the rock is spotted green and grey and is porphyritic in appearance. Some of the feldspar is slightly pink. The amphiboles are green-black in colour.

A Rosiwal analysis of a typical thin section indicated 27 per cent plagioclase, 34 per cent blue-green actinolite, 16 per cent biotite, 13 per cent quartz and minor magnetite and apatite. The plagioclase is andesine ($Ab_{57}An_{43}$). The crystals are subhedral in outline and show albite twins. Blebs of quartz occur within the feldspar grains and the plagioclase is deeply embayed by quartz. The manner in which the quartz replaces the feldspar, and the lack of strain shadows and fractures in the quartz grains, suggests that the quartz was introduced subsequent to the shearing.

The well developed fibres of blue-green actinolite are replaced by biotite. The first stage of the alteration is the appearance of an incipient brown colour along the borders of the fibres and along fractures within the amphibole fibres. The biotite flakes are a deep red-brown colour.

At outcrop A-25-1 the rock is darker than the diorite or quartz diorite and contains from 10 to 15 per cent more mafic minerals. In thin section, the rock is estimated to be composed of 18 per cent plagioclase, 7 per cent hornblende, 61 per cent actinolite, 12 per cent antigorite, and minor quartz, sericite, biotite, and magnetite. The crystals of plagioclase are subhedral to anhedral in outline and show more distinct albite twins than the feldspar crystals in the diorite. The composition of the plagioclase is labradorite ($Ab_{48}An_{52}$) and on this basis the rock is called gabbro.

The light-green acicular fibres of actinolite and the medium-green compact grains of hornblende are replaced by antigorite which is commonly psuedomorphic after the replaced mineral. Remnants of both minerals occur within the antigorite. Brown rims are found on some of the amphibole grains, suggesting alteration to biotite. Chlorite occurs along fractures in the feldspar crystals and penetrates the crystals along their borders.

Gabbroic rock similar to that just described occurs in minor amounts throughout the dioritic rock along the east shore of Jay Lake, and is similar to the normal uralite gabbro of the Fraser Lake body. The diorite resembles many of the contact phases of the Fraser Lake body. The similarity of these rocks to the Fraser Lake gabbro suggests that prior to the intrusion of the granite they may have formed one continuous body. A small gabbro body, designated the 'El' orebody by the Sherritt Gordon mining company, which lies several hundred feet northeast of the Jay Lake diorite may also have been part of this larger intrusive mass. The 'El' orebody , within the 'El' gabbro, may therefore be genetically related to the Fraser Lake gabbro.

Mylonitized Quartz Diorite

<u>Distribution and occurrence</u> -- The mylonitized quartz diorite has a limited exposure along the west shore of Wheatcroft Lake south of the mouth of the Fraser River. Outcrops of diorite are intimately associated with outcrops of acid intrusive rocks related to the quartz monzonite.

<u>Petrology</u> -- The weathered surface of the quartz diorite appears porphyritic. Pinkish brown feldspar crystals are enclosed in a matrix of biotite and fine-grained quartz. The fresh surface of the rock is greyish white and gneissic as shown by the alignment of the biotite flakes.

In thin section the mylonitized quartz diorite is composed of irregular crystals of plagioclase enclosed in a matrix of crushed quartz, plagioclase, and biotite. The rock has a cataclastic mortar texture and is pseudoporphyritic rather than porphyritic. The feldspar 'phenocrysts' are actually remnants which resisted the crushing to which the rock was subjected.

The plagioclase crystals have an irregular central core in which the albite twins are much more uniform and distinct than they are in the enclosing rim. A slight difference in crystallographic orientation of the twins in the two parts of the crystal is shown by the different extinction angles. An accurate determination of the composition of the plagioclase was not possible because of the replacement zoning. The best determination indicated a composition in the andesine range.

Much of the quartz of the matrix occur in lense-shaped areas composed of many small grains of quartz. All these small grains show strain shadows which are attributed to the crushing of a large quartz grain into a number of smaller grains. Many plagioclase crystals are cut by veins of quartz which is somewhat less strained than the quartz in the matrix.

The zoned nature of the feldspar and the evidence of introduced quartz suggest that the rock has been subjected not only to cataclastic action but also to some chemical action. These effects are attributed to the local influence of the nearby granitic intrusive body. It is probable that the rock was originally a quartz diorite similar to those found farther north along the shore of Wheatcroft Lake and near Jay Lake.

The Fraser Lake Gabbro

General Statement

The body of basic rock designated the Fraser Lake gabbro body is not homogeneous and may be divided into two phases:

(1) Normal uralite gabbro phase

(2) Contact phase of the uralite gabbro

The normal uralite gabbro phase comprises the rocks of comparatively uniform composition in the central portion of the intrusive body. The contact phase comprises a number of local variations of the uralite gabbro associated with the contact of the gabbro with granite. These two phases will be discussed under separate headings.

Normal Uralite Gabbro Phase

Distribution and occurrence -- The normal uralite gabbro occupies the central portion of the gabbro body. It occurs in outcrop as large rounded ridges separated by areas of muskeg or swamp. As in the Myrna Lake area, the best exposures of rock are found on the north ends of the ridges.

Petrology -- In hand specimen the normal uralite gabbro is a medium-grained to medium coarse-grained rock composed of 50 to 70 per cent green-black amphibole and 30 to 50 per cent grey to blue-grey feldspar. Where the percentage of amphibole and feldspar are about equal the rock weathers spotted green and grey, and where amphibole is the predominant mineral the weathering-out of the feldspar produces a rough 'scoria-like' weathered surface of green amphibole. On the fresh surface the feldspar crystals appear to be poorly developed and to fill the interstices between ferromagnesian minerals. In a few outcrops the feldspar crystals do approach euhedral outlines but such development is rare.

The primary lineation of the Fraser Lake gabbro body is confined to a narrow zone parallel to the contact with the volcanic flows and locally trends parallel to the borders of the volcanic inclusions. The only other significant lineation was produced by the post-consolidation shearing along the contact with the quartz monzonite.

In thin section the normal uralite gabbro is seen to be composed of actinolite, actinolitic hornblende, antigorite, plagioclase, and minor amounts of hornblende, chlorite, and magnetite. A Rosiwal analysis of a typical thin section gave the following results: 38 per cent plagioclase; 3 per cent hornblende; 17 per cent actinolitic hornblende; 20 per cent antigorite; 20 per cent actinolite, and minor magnetite and chlorite.

The plagioclase forms anhedral to subhedral crystals which show albite twinning; but the polysynthetic nature of the twinning is not well developed. Commonly, only three or four lamellae are present in a crystal. The more nearly euhedral the crystal the better is the development of the albite twinning. More rarely pericline twinning is combined with the Carlsbad twinning in some crystals. The plagioclase is labradorite and ranges from ($Ab_{42}An_{58}$) to ($Ab_{46}An_{54}$).

The actinolite occurs as pale-green to colourless acicular or feathery fibres. In many places irregular patches of green-brown hornblende are present within the masses of actinolite fibres. The actinolite fibres penetrate these patches and replace the hornblende. A few nearly euhedral crystals of hornblende can be seen, but most of the hornblende is present as minute spots within the actinolite. The actinolite is associated with a compact amphibole of the same colour. This mineral has the following properties: slightly pleochroic from light green to colourless; length slow; optically negative; 2V approximately $60^{\circ} - 70^{\circ}$.

Antigorite replaces the actinolite, actinolitic hornblende, and hornblende. Remnants of all three minerals are found within the antigorite. Commonly, the antigorite is pseudomorphic after the replaced mineral. Chlorite occurs as feathery fibres along fractures in the feldspar crystals and also penetrates the crystals along their borders. In the uralite gabbro north of the Fraser River chlorite is only a minor constituent. In one or two places minute grains of a colourless mineral, possibly a pyroxene, are present within the hornblende. The mineral has parallel extinction and a birefringence of second order yellow. Because of the small size of the grain no optic figure could be obtained. An unresolvable rim of some fibrous mineral is present along the border of the colourless mineral.

South of the Fraser River on both side of the granite 'finger' and in a small area immediately north of Fraser Lake the uralite gabbro differs considerably in appearance from the rock previously described. In this area the rock weathers light green in contrast to the medium-green or dark-green weathered surface of the rocks north of the river. The weathered surface is invariably of the 'scoria-like' type. The fresh surface shows 40 to 50 per cent 'anhydrite-blue' feldspar. In hand specimen the feldspar grains are anhedral and occupy the interstices between the mafic mineral. In several outcrops this rock grades insensibly into the darker-variety of gabbro. Because of this gradation and the lack of outcrops the exact areal extent of the rock type is difficult to define.

In thin section this phase of the uralite gabbro is seen to be composed predominantly of plagioclase, antigorite, actinolite, and minor sericite and chlorite. A Rosiwal analysis of a typical thin section indicated 45 per cent plagioclase, 32 per cent antigorite, 20 per cent actinolite, 1 per cent chlorite and 2 per cent sericite.

The plagioclase is labradorite ($Ab_{45}An_{55}$). The crystals are anhedral to subhedral and show albite twinning which in rare crystals is combined with pericline twinning. Alteration to sericite is extensive in a few crystals and to some extent is seen in all crystals. The predominant mafic minerals are actinolite and antigorite. The actinolite occur as pale-green acicular fibres which are commonly intimately associated with antigorite. In a few places the antigorite, which is pseudomorphic after the actinolite, contains remnants of the replaced actinolite fibres. The percentage of antigorite in the light green weathering phase is higher than that in the dark green phase. The difference in antigorite content is the only noteworthy difference between the two phases. The yellow-green colour of the mafic minerals is probably due to the high antigorite content. A minor amount of chlorite replaces the feldspar along cracks in the grains or along the grain boundaries.

Contact Phases of the Gabbro

Distribution and occurrence -- Along the contact of the basic body with the granitic rocks the outcrops of gabbro exhibit many local variations in composition and texture. It is these variations of the gabbro associated with the gabbro-granite contact that will be discussed in this section.

Petrology -- The different rock types found along the contact are best described by reference to specific outcrops.

At outcrop C-5 along the northwest contact the gabbro is in contact with a granitic rock which is megascopically similar to the quartz monzonite. The contact between the two rock types is generally smooth, but in a few places the granite forms small apophyses in the gabbro. The granite dips under the gabbro at an angle of approximately 20 degrees. On the southeast edge of the outcrop the gabbro is entirely surrounded by granite. The gabbro in the outcrop is more coarse grained than the normal uralite gabbro, and the grain size increases towards the contact. The feldspar grains are grey-white and commonly are up to one quarter inch wide. The amphibole is medium- to dark-green in colour and forms well-developed fibres as much as one quarter inch long.

From thin sections the gabbro is estimated to be composed of 35 per cent plagioclase, 63 per cent blue-green actinolite, and minor orthoclase and quartz; it has been termed mylonitized uralite gabbro. The feldspar crystals are so crushed that an accurate determination of the composition of the plagioclase is impossible. Fractures filled with quartz cut across the plagioclase crystals and are surrounded by zones of crushed feldspar and quartz. The veins of quartz terminate at the amphibole fibres.

The granitic rock with which the mylonitized gabbro is in contact is a quartz diorite composed of 70 to 75 per cent plagioclase, 15 to 20 per cent quartz, 2 per cent hornblende, 3 per cent biotite and minor orthoclase, sericite, kaolin, magnetite, and apatite. The plagioclase is an acid andesine ($Ab_{69}An_{31}$) and occurs in subhedral crystals that show albite twinning. The hornblende is a medium-green compact variety. Dark brown biotite replaces the amphibole along crystal boundaries. Some of the lighter biotite may be primary.

In the outcrop a decided increase of hornblende was noted in the granite near the contact with the gabbro.

Rocks similar to the two described above are in contact at C-31 along the northern contact of the intrusive. In this outcrop, a stringer of the acid rock approximately 2 inches wide and originating at the contact cuts through the gabbro. This stringer shows chilled borders. Along the contact with the granite northwest of Fraser Lake the gabbro is the same composition and texture as that at C-5 and C-31.

At outcrop C-34 in the extreme northeast projection of the gabbro body, about a quarter of a mile west of Jay Lake the gabbro shows strong lineation of fine rod-shaped amphibole grains. The trend of the alignment is south 65 degrees east. The feldspar crystals are anhedral and have a bluish white colour similar to that of anhydrite. Knots of biotite, ranging from 1/8 to 1/2 inch in diameter, are sporadically distributed throughout the rock.

From thin sections, the rock is estimated to be composed of 55 per cent plagioclase, 25 per cent hornblende, 15 per cent biotite, 1 per cent magnetite, and minor quartz, orthoclase, kaolin, sericite, and epidote. Most of the plagioclase crystals are zoned in a peculiar manner. An irregular rim of andesine feldspar ($Ab_{58}An_{42}$ in one crystal) encloses an inner core of more basic feldspar commonly of labradorite composition. The cores are generally slightly altered to sericite, but the outer rim is unaltered. The feldspar crystals show a tendency to lie with their long dimensions parallel to the alignment of the amphibole needles. The amphibole is blue-green actinolite. An incipient brown colour along the borders and cleavage of the amphibole is common, and represents the first stage in the alteration of the actinolite to biotite. The biotite flakes tend to develop with their cleavage parallel to the long dimension of the amphibole fibres. Epidote and magnetite are associated with the biotite, and may be a bi-product of the formation of the biotite from the amphibole, or they may be an alteration product of the biotite. Minor quartz is present in the interstices between the feldspar and amphibole grains. A few crystals of orthoclase showing simple Carlsbad twinning were observed.

Outcrop C-32, a few hundred feet south of C-34, shows the same 'anhydrite-blue' feldspar. The rock contains from 10 to 20 per cent more amphibole than C-34. The feldspar crystals are andesine ($Ab_{64}An_{36}$) and are not zoned. Otherwise, thin sections of the rock show the same minerals and mineral relationships as those observed in the thin sections from C-34.

Near C-31 and at C-42-7 along the southwest contact the gabbro has been markedly sheared. In thin section the rock is seen to be composed mainly of mylonitized quartz and feldspar, blue-green actinolite, and biotite. At C-42-7 numerous dykes similar in appearance to the quartz monzonite have been injected along the shears. These dykes range in width from 6 inches to 2 feet. This gabbro is more extensively crushed than that at C-5, but they are essentially the same rock.

At C-89 about 1,500 feet southwest of C-31 the normal grey-white feldspar of the gabbro grades into a pink feldspar. A hand specimen was selected that showed both pink and colourless feldspar, and thin sections were cut from both parts. The thin section cut from the unpinked rock, was composed of plagioclase, blue-green amphibole, sericite, epidote, and quartz. The plagioclase crystals are subhedral and show faint albite twins, but are too extensively altered to sericite to permit the reliable determination of their compositions. Quartz replaces the plagioclase, and in several places, only small remnants of the feldspar crystal remain. The feldspar crystals appear to be enclosed in a matrix of quartz in parts of the slide. The quartz shows no strain shadows and is believed to have been introduced into the gabbro. In the pink coloured gabbro the feldspar has been replaced by a mixture of kaolin and an unresolvable matte of material, that is brown in colour by transmitted light and red-brown by reflected light. It is thought that this material is an iron oxide. The blue-green amphibole remains unaltered. Pink alteration also occurs at J-11 along the southwest contact of the gabbro. The writer noted this phenomenon along the granite-gabbro contacts of several other intrusive bodies in the area.

The following general points may be noted about the gabbro near the contact of the basic body with the granite rocks:

(1) Blue-green actinolite is the only amphibole present.

(2) Biotite alteration of the amphibole is commonly extensive.

(3) Mylonitization is common, with evidence of the introduction of quartz.

(4) Lineation produced by the parallel growth of fibrous amphibole and by shearing is common parallel to the contact.

(5) 'Pinking' of the feldspars is well developed in a few areas.

(6) Stringers and dykes of granitic material commonly cut the outcrops of gabbro.

(7) The feldspar grains are more acid in the border phases than in the central part of the intrusive body.

Petrogenesis and Alteration

Petrogenesis -- One difficulty in determining the genesis of the Fraser Lake gabbro body is the lack of evidence of the original composition of the body. No completely unaltered thin sections were obtained. In one thin section a small remnant of pyroxene enclosed within a compact green hornblende grain was observed. The type of pyroxene could not be determined because of the small size of the crystal. Excluding the contact phases the feldspar throughout the intrusive body is relatively uniform in composition. No significant distribution of the slight variations in composition is present. The relationship of the feldspar to the amphibole crystals suggests that in the original pyroxene rock the feldspar crystallized after the mafic minerals. Minute remnants of green-brown hornblende that occur within the actinolite in many places suggest that a compact primary hornblende stage was present in the original rock. The amphibole content of the normal uralite gabbro ranges from 50 to 80 per cent. The rock grades from one extreme to the other in any individual outcrop. No regular distribution of the segregation is present. Another difficulty in postulating the mode of emplacement of the body is the lack of a significant lineation. The only primary lineation in the body is that along the southeast contact with the volcanics.

The facts suggest that the Fraser Lake gabbro was intruded as a body of more or less uniform composition. The lack of significant lineation may be due to the homogeneity of the magma or to slow emplacement of the gabbro by some method such as stoping. The fact that both the Lynn Lake and Fraser Lake intrusive bodies lie in the volcanics next to the quartzites suggests that the quartzites may have exerted a controlling influence on the position of the gabbro bodies. If during the tectonic disturbance that preceded the intrusion of the gabbro local shearing developed in the volcanic rock because of the incompetence of these rocks relative to the quartzites, the shearing may have produced a zone of weakness that controlled the intrusion of the gabbro bodies.

Alteration -- The alteration of the Fraser Lake gabbro has produced the same minerals in the same order of sequence as those in the Myrna Lake body. Mention has already been made of minute remnants of green-brown hornblende in the actinolite, and it has been suggested that these represent a primary hornblende stage. Green compact hornblende partly altered to actinolite was observed in several thin sections, but for the most part the normal uralite gabbro is composed of plagioclase, actinolite, actinolitic hornblende, and antigorite. The mafic minerals show the same sequence of alteration as those in the Myrna Lake gabbro, that is, compact hornblende altered to actinolite, and finally antigorite that is pseudomorphic after both minerals. As in the Myrna Lake body, the plagioclase is altered to sericite to a moderate extent, and chlorite replaces the feldspar in some sections.

Towards the contact of the body, the colour of the amphiboles deepens somewhat. Along the contact with the quartz monzonite blue-green amphibole and biotite are the only mafic minerals. The contact phases are believed to represent a higher grade of metamorphism. These rocks have been subjected to local fracturing and mylonitization and the action of aqueo-igneous materials. The introduction of this material has resulted in:

(1) Quartz veinlets that cut across the mylonitized rocks.

(2) Albitization of the feldspars forming andesine rims around an inner core of labradorite.

(3) Pink alteration of the feldspar, and the introduction of quartz into the 'pinked' rock.

The development of the blue-green amphibole and biotite are analogous to the development of these minerals in the Myrna Lake gabbro.

It is inferred that the alteration of the Fraser Lake gabbro was brought about by the same agencies that caused the alteration of the Myrna Lake gabbro. The contact phases represent the highest grade of metamorphism, and the grade decreases towards the center of the body. The volcanic rocks of the Lynn-Barrington Lakes area confirm the relationship between the alteration of the extrusive and intrusive basic rocks of the area, and the granitic rocks.

A thin section of the fine-grained massive flows described under "Volcanic Rocks" was chosen from the central part of the flows at a considerable distance from the granitic rocks. As described, this section contains only plagioclase, compact hornblende and minor actinolitic hornblende. This is believed to represent a thermal alteration in the first stage of the metamorphism. Other sections taken from the vicinity of the gabbro-quartz monzonite contact show the development of blue-green actinolite. Intermediate stages between these two extremes show actinolite and antigorite.

The evidence as seen in the Fraser Lake gabbro and surrounding volcanics therefore tends to confirm the conclusion reached concerning the Myrna Lake area, that the alteration of the basic rocks is related to the intrusion of the granitic rocks.

Age Relationships of the Rocks

The Wasekwan volcanics and quartzites are older than the acidic and basic intrusives of the area. Inclusions of the volcanics are common in both the granite and the gabbro. The gabbro, as has been stated previously, shows a local trend parallel to the contacts of the inclusions and has a chilled border in many phases.

The relative ages of the gabbro and granitic rocks was one of the important field problems in the mapping of the area. The writer concluded that the quartz monzonite is the younger of the two intrusive masses. The reasons for this conclusion may be summarized as follows:

(1) Certain mineralogical changes exhibited by the contact phase of the gabbro body are best explained as the result of the action of the heat and emanations accompanying the intrusion of the quartz monzonite. These changes are:

(a) The development of blue-green amphibole and the replacement of the amphibole by biotite. (In the Myrna Lake body these minerals were shown to be associated with the biotite-quartz diorite, which is demonstrably younger than the gabbro).

(b) The development of acidic rims on the plagioclase crystals, and the generally higher albite content of the feldspar of the contact phase may be attributed to albitization produced by emanations from the quartz monzonite.

(c) The pink alteration of the feldspars of the gabbro and the large amount of quartz in these specimens indicates that material has been introduced. The close association of 'pinked' gabbro outcrops with outcrops of quartz monzonite suggests that the introduced material came from the quartz monzonite.

(2) The evidence of local shearing and mylonitization of the gabbro along the quartz monzonite contact and the introduction of quartz into the mylonitized zones may be attributed to the emplacement of the quartz monzonite.

(3) Granitic stringers and dykes cut the gabbro in outcrops C-32, C-31, C-42-7, and A-27. These are similar in appearance and composition to the quartz monzonite.

(4) Southwest of Fraser Lake a breccia of amphibolitic fragments in a granitic matrix was observed. These fragments may have been derived from the gabbro body.

(5) Tongues of quartz monzonite apparently project into the northern and southern borders of the gabbro body, as shown on the map. This also suggests the granitic rock is the younger of the two.

A noteworthy phenomenon observed at C-31 and C-41 is the presence of volcanic outcrops between the gabbro and quartz monzonite. These outcrops seem to indicate that the quartz monzonite intrusion followed along the original volcanic-gabbro contact quite closely, and that these volcanics are remnants of the original border left between the two intrusive rocks.

A few small areas of gabbro near the border of the intrusive are finer grained than the rest of the gabbro. These fine-grained zones might be interpreted as borders of the gabbro that chilled against the quartz monzonite. However, in view of the evidence that the quartz monzonite is the younger of the two rocks another interpretation is required. If, as suggested in the previous paragraph, the quartz monzonite followed closely along the gabbro-volcanic contact, then these fine-grained zones in the gabbro may represent remnants of the original border of the gabbro that chilled against the volcanics.

The similarity between the Jay Lake diorite and associated gabbro, and the normal uralite gabbro and contact phases of the Fraser Lake intrusive body has been noted previously. These rocks may be of the same age, but there is no evidence to indicate otherwise.

The quartz monzonite is younger than these diorites, because they are cut by numerous dykes and stringers related to the quartz monzonite.

The established sequence is:

Probably	(Quartz monzonite
Post-Sickle	(Gabbro (Possibly Jay Lake diorite and gabbro)
Wasekwan	(Volcanics and quartzites.

<u>Conclusions</u>

(1) The sequence of intrusion of the various rocks of the area has been shown to be as follows:

Probably	(Quartz monzonite
Post-Sickle	(Gabbro (Possibly Jay Lake diorite and gabbro)
Wasekwan	(Volcanics and quartzites

(2) The writer suggests that considering the similarity of the Jay Lake diorite and gabbro to the contact phases and normal uralite gabbro of the Fraser Lake body respectively, the 'El' gabbro body may have been connected to the Fraser Lake gabbro prior to the intrusion of the quartz monzonite.

(3) The lack of thin sections of unaltered rock makes it impossible to accurately infer the original composition of the Fraser Lake gabbro. It is suggested that the body contained monoclinic pyroxene and possibly orthorhombic pyroxene. In the final stages of consolidation some compact hornblende was formed.

(4) The lack of a significant lineation reflects the general homogeneity of the body and may also indicate that the body was intruded gently, perhaps by stoping.

(5) It is possible that during the tectonic disturbance

that preceded the intrusion of the gabbro bodies there occurred shearing of the relatively incompetent volcanics. This shearing may have controlled the emplacement of the gabbro bodies.

(6) The alteration of the Fraser Lake gabbro was produced by thermal metamorphism aided by hydrothermal agencies directly attributable to the nearby granitic rocks. The body shows increasing metamorphic grade towards the contact with the quartz monzonite. The contact phases represent the highest grade of metamorphism.

The Lynn Lake Intrusive Body

General Statement

The description of the Lynn Lake basic body which is given in this section is based upon the work of Hunter (1950) who carried out detailed mapping of the Lynn Lake intrusive body for Sherritt Gordon Mines Limited during the summer of 1949. At that time the writer had the opportunity of accompanying Mr. Hunter on several traverses.

Hunter divides the rocks of the Lynn Lake intrusive body into three phases:

(1) "Uralite gabbro phase 'A'"

(2) "Uralite gabbro phase 'B'"

(3) "Uralite gabbro phase 'C'"

The Phase 'A' and 'B' Gabbro

Distribution and occurrence -- The phase 'A' gabbro is defined as extending from the west contact to the ridge along the east shore of Lynn Lake. It extends slightly north of the 'C' orebody and south to a position opposite the river joining West Lynn and Lynn Lakes.

The phase 'B' gabbro lies in a belt bordering the phase 'A' gabbro to the east, south, and possibly to the north.

The approximate positions of both phases are shown on the accompanying map (Fig. 4, p. 53).

Petrology -- The phase 'A' gabbro is described as being medium-grained, dark-green to greyish green, more or less massive, and is composed chiefly of amphibole and feldspar. Where visible the feldspar weathers greyish white. In many outcrops of this area, the amphibole grains are arranged roughly in parallel rows. The fresh surface of the gabbro is medium-grained, dark yellowish green, and appears to be composed entirely of amphibole because of the greenish white colour of the feldspar.

The rock is composed of 25 to 30 per cent labradorite ranging in composition from ($Ab_{40}An_{60}$) to ($Ab_{45}An_{55}$), 65 to 70 per cent pale green actinolite and minor pale green hornblende, 5 to 7 per cent antigorite, and 3 to 5 per cent chlorite, minor sulphides and small remnants of brownish green hornblende.

Hunter noted the occurrence of orthorhombic and monoclinic pyroxene in two small areas of the phase 'A' gabbro and described them as augite and "enstatite with iron content approaching the hypersthene composition". He believes that the amphiboles of the phase 'A' and 'B' gabbros were derived from rocks approaching the composition of these norites and enstatite norites, and outlines the following sequence of events:

(1) Crystallization of the ferromagnesium minerals, pyroxene and possibly some magmatic hornblende.

(2) Crystallization of feldspar, later than or contemporaneous with the ferromagnesian minerals.

(3) Slight movement of the rock after consolidation of the main silicates, causing fractures in the feldspar and to a lesser extent in the mafic minerals.

(4) Uralitization of the ferromagnesian minerals and development of chlorite from feldspar.

(5) Alteration of some of the remaining enstatite to talc, and the formation of antigorite from actinolite.

The division between the phase 'A' and phase 'B' gabbro is based upon an arbitrary value of "65 per cent mafic minerals" for the phase 'A' and to a "lesser extent upon grain size".

Hunter describes "a more or less parallel arrangement of alternate narrow bands of amphibole-rich and feldspar-rich material". He believes this banding was produced by the segregation of feldspar-rich and amphibole-rich areas in the magma. The more strongly lineated portions were intruded after crystallization had begun, whereas portions lacking the lineation were intruded in a more molten state.

The Phase 'C' Gabbro

<u>Distribution and occurrence</u> -- The phase 'C' gabbro makes up a wedge shaped portion on the northeast extremity of the intrusive.

<u>Petrology</u> -- The phase 'C' gabbro is composed of 45 per cent

labradorite ranging in composition from Ab_{45} - Ab_{50}, 45 per cent blue-green amphibole, 8 per cent antigorite, 2 per cent chlorite and minor amounts of sulphide and oxides. The feldspars are slightly fractured and amphibole, chlorite, and epidote fill these fractures. The feldspars contain poickilitic inclusions of quartz. The amphibole is pleochroic from bluish green to yellow-green, and some grains have darker rims about a lighter central core.

Petrogenesis and Alteration

Petrogenesis -- Hunter outlines the following stages in the history of the body. A body of basic magma, in a magma chamber below the present location of the basic body, underwent differentiation into three zones. The zones are represented by the phase 'A', 'B', and 'C' gabbro in the intrusive body.

The phase 'A', 'B', and 'C' represent the basic, intermediate and most acid phases of the magma. The 'A' and 'B' phases were intruded "possibly contemporaneously". The phase 'A' gabbro shows lineation of pyroxene crystals, whereas the phase 'B' gabbro shows slight lineation only owing to its fluidity.

The phase 'C' gabbro was intruded after the phase 'A' and 'B' gabbro, possibly after consolidation of these rock types.

The dykes of fine-grained material that intrude the phase 'A' and 'B' gabbro, are believed by Hunter to be related to the phase 'C' gabbro.

Alteration -- Hunter attributes the uralitization of the Lynn Lake gabbro to thermal metamorphism accompanied by hydrothermal activity.

The metamorphism as represented by the uralitization of the pyroxene, forms three zones of increasing alteration from west to east across the intrusive.

The bluish green amphibole represents a higher degree of metamorphism than the pale-green actinolite.

Hunter therefore postulates that the source of the heat and hydrothermal solutions responsible for the uralitization of the Lynn Lake gabbro is the granite intrusive bodies north and east of the gabbro.

The talc in the phase 'A' gabbro is attributed to the acid intrusive bodies near the west contact of the gabbro.

Ore Genesis

Hunter postulates that consequent upon the differentiation of the magma in a chamber below the present level the sulphides were concentrated as a liquid melt in pools in the bottom of the magma chamber with the crystallized ferromagnesian minerals. When the phases 'A' and 'B' gabbro were emplaced the concentrated sulphides were carried up along with the gabbro and "intruded more or less concordantly along the contact between the Wasekwan volcanics and sediments". It is stated by Hunter that "the more viscous phase 'A' gabbro became strongly lineated, whereas the more fluid phase 'B' gabbro was only slightly lineated". After solidification of the main silicates, slight movement caused fractures in the feldspar, and a portion of the massive sulphides was intruded into the surrounding zone of disseminated sulphides. All but a portion of the sulphides rich in mineralizers solidified at this stage. The 'C' gabbro was emplaced and dykes of phase 'C' gabbro cut the 'A' and 'B' phases.

Dykes of pegmatite and felsite were intruded at this time and were followed by considerable movement within the intrusive body causing faults and brecciation of the gabbro. The mineralizer-rich portion of the sulphides was intruded into the fractures and brecciated zones. Complex faulting offset the ore and caused the development of extensive shear zones.

The thermal and hydrothermal alteration, caused by the intrusion of the granite bodies to the north and east of the gabbro caused uralization of the ferromagnesian minerals and redistributed the sulphides. This redistribution resulted in the dissemination of the sulphides along the cleavage planes of the amphibole forming a replacement texture. At this time sulphides were introduced into fractures in the basic and acid dykes.

Allan (1948) noted this replacement texture in his study of the Lynn Lake ores and concluded that the development of secondary amphibole from pyroxene took place before ore deposition, and that the basic and acid dykes were emplaced before ore deposition. The actinolite associated with the disseminated ore was interpreted by him as evidence that hydrothermal activity was closely associated with ore deposition. He stated that the temperature of deposition was sufficiently high that actinolite rather than talc, sericite, or chlorite was the stable mineral, but that the temperature of deposition was not sufficiently high to cause the development of pyroxene.

Hunter points out that at the time Allan's study of the ores was made no specimens of pyroxene bearing rock had been obtained.

From a study of such specimens Hunter concludes that the sulphides occur interstitially as an original component of the rock and that redistribution occurred at a later stage during uralitization, forming the replacement type of texture of sulphides in amphibole.

During the last stage of igneous activity in the area bodies of feldspar porphyry and granite intruded "the basic body in the vicinity of the west contact, and extended north beyond the gabbro body". This intrusion post-dated uralitization of the gabbro and resulted in the alteration of some of the remaining enstatite to talc.

Finally, erosion reduced the land surface to its present level.

CHAPTER V

HEAVY MINERAL STUDIES

Introduction

Heavy mineral studies were carried out on the Fraser and Myrna Lakes intrusive bodies as a complimentary study to that of Dornian (1950) on the Lynn Lake body.

The work was originally suggested by the pioneer study of Newhouse (1936). Newhouse examined the primary oxides and sulphides from many different types of igneous rocks and concluded that these minerals varied in amount, grain size, habit, species, and position in the crystallization sequence in rocks of different composition and texture.

It was hoped that there might exist certain significant similarities or differences in the heavy mineral assemblages that would be of aid in correlation of the intrusive masses.

Method of Separation

From the Myrna Lake gabbro five samples were chosen, two from the olivine hypersthene gabbro, three from the uralite gabbro, and one from the quartz uralite gabbro. From the Fraser Lake body four samples were selected, two from the blue-green amphibole contact phases, and two from the normal uralite gabbro.

The procedure for separating the heavy minerals was carried out in five major steps:

(1) Crushing and pulverizing

(2) Panning

(3) Bromoform separation

(4) Magnetic separation

(5) Clerici separation

Crushing and pulverizing -- The samples were crushed and pulverized by mechanical means. In pulverizing the material was reduced to 80 mesh.

Panning -- The samples were panned with water to remove rock flour. Water was added repeatedly until the run-off was clear. The samples were then dried in an oven.

Bromoform separation -- The dried samples were separated into heavy and light fraction by means of bromoform. A small amount of each sample was poured into a glass funnel containing bromoform and the mixture stirred vigorously. After the heavy portion had settled to the bottom it was run-off into a filter paper and washed with alcohol. The light portion was similarly collected and washed.

The heavy fraction was composed of mafic minerals and heavy accessories, whereas the light portion was chiefly quartz and feldspar.

Magnetic separation -- The heavy portion from the bromoform separation, after drying, was separated magnetically into four portions:

(1) Strongly magnetic

(2) Weakly magnetic

(3) Very weakly magnetic

(4) Non-magnetic

The strongly magnetic fraction was separated by passing a permanent magnet (with the poles covered by a piece of paper) over the sample.

The separation of the weakly and very weakly magnetic portions was accomplished by changing the strength of the field of the electromagnet by varying the distance between the poles.

<u>Clerici Separation</u> -- The weakly magnetic and non-magnetic fractions from the magnetic separation were again subdivided into a heavy and a light fraction by clerici solution with a specific gravity of 3.4 - 3.6. This density assured that only silicates of high specific gravity and the oxides would settle out. The method used is the same as that described in detail by Caldwell (1950).

Mounting

The stongly magnetic fraction and the weakly magnetic heavy fraction from the clerici solution were mounted in bakelite as polished sections. The non-magnetic heavy minerals were mounted on slides with Canada balsam.

Microscopic Study

The polished sections of the strongly magnetic and weakly magnetic heavy fractions were traversed by means of a dual axis stage mounted on an ore microscope. The grains were studied and a tabulation of the features shown by each grain was made.

Conclusions

(1) There are no qualitative features that would serve to distinguish the oxides of the Fraser and Myrna Lakes basic intrusive bodies.

(2) The amount of heavy silicate minerals present in the non-magnetic heavy fraction is insufficient to warrant any conclusions.

(3) Dornian (1950) found no qualitative features in the oxides of the Lynn Lake body and concluded that the only feature of value for correlation was the relative amount of ilmenite and magnetite present. He states further that the amount of non-magnetic heavy fraction obtained was insufficient to warrant any conclusions.

(4) Because the methods used in the separation of the oxides from the Myrna and Fraser Lakes bodies were different from those used by Dornian in his study of the Lynn Lake rocks, no comparison on a quantitative basis is possible.

CHAPTER VI

SUMMARY DISCUSSION AND CONCLUSION

Summary Discussion -- The origin of nickel sulphide bodies has been the subject of much controversy in geological literature. Some writers believe that they are the result of magmatic segregations, whereas others maintain they are formed by hydrothermal replacement. Much of the literature on these ores concerns the deposits of the Sudbury basin. The evidence from these deposits has been interpreted to support both the above theories. To reconcile these opposed views several writers have introduced modified magmatic and modified hydrothermal theories. Phemister (1925, p. 49) gives an excellent summary of the theories of origin of these deposits. The theories may be briefly stated as follows:

(1) The sulphides have formed by the settling of an immiscible sulphide melt from the norite.

(2) After solidification of the norite the sulphides have been injected in a molten condition, the separation into sulphide and norite having taken place in a magma chamber, presumably not far beneath the present site of the norite micropegmatite.

(3) The sulphides are hydrothermal replacements of the country rock, and the solutions came either from the norite or from the same deep-seated reservoir which was the source of the post-Sudburian igneous rocks of the district.

(4) Sulphide crystallized from magmas which form independent members in the series of magmatic injections.

Although the deposits at Lynn Lake have not been known for very long, there is already some controversy as to their origin, Allan (1948, p.115) states:

> "The ore deposits are post-magmatic; prior to the introduction of the sulphides, the gabbro had solidified and secondary amphibole (uralite) had replaced pyroxene in a large part of the gabbro stock. Also, in parts of the stock, apparently associated with the ore, a large amount of actinolite had replaced the silicates. This development of actinolite, and the development of antigorite, chlorite, epidote, sericite, and talc away from the massive sulphides, probably represents the results of hydrothermal solutions associated with the ore, as may also the earlier development of uralite".

On p. 113 he says, "Further development will show whether or not a study of the quantitative development of actinolite in the host rock will be of use in indicating the presence of ore deposits."

Allan believed that the ore has some genetic relationship to the gabbro, probably ".....through a common magma source at depth". He further suggests, p. 113 - p. 114, that the intrusion of the granite later than the basic intrusives ".....may have opened up channels or provided the energy which caused the sulphide to be moved from the original magma chamber to their present position".

On the other hand, Hunter (1950) believes that the ores formed by magmatic segregation in a lower magma chamber, and that they were intruded along with the gabbro. The alteration of the gabbro he attributes, as outlined previously, to the heat and emanations accompanying the intrusion of the younger granite masses.

Hunter's conclusion regarding the alteration of the gabbro is confirmed by the present study which has shown that all the basic rocks of the area tend to have a common mineral assemblage. It is concluded that this alteration is related to the younger acid intrusives. It follows, if this conclusion is correct, that the extent of alteration of the basic intrusive bodies has no significance with respect to possible ore deposits.

If these ores are hydrothermal replacement of the country rock, the question arises as to why the country rock of the nickel deposits should always be the basic intrusive bodies. It would appear from the chemical and structural viewpoints that the basic volcanic flows would be equally favourable as a host rock. These rocks are mineralogically similar to the gabbro, and as has been shown they are even more permeable to hydrothermal agencies. Large tabular bodies of pyrrhotite occur within the Wasekwan volcanic flows north of Arbour Lake. However, no nickel-bearing pyrrhotite deposits have been reported except those in the gabbro bodies.

If the tabular bodies of pyrrhotite in the volcanics and those deposits in the gabbro have a common igneous source, it is difficult to explain the lack of nickel in the former. However, the two bodies may have no genetic relationship.

If it is assumed that both pyrrhotite deposits were derived from a common source and were emplaced by hydrothermal agencies there is no apparent reason why the two bodies should be markedly different in any respect. A similar argument would seem to hold for pyrrhotite derived from a common source by a process of magmatic segregation. However, on the basis of work done by Vogt (1923) it is possible to postulate a mechanism by which this could occur. Vogt has suggested that the relationship between the magmatic silicate compound and the sulphide compound is illustrated by the following reaction:

$$FeS + \text{Ni-cation in silicate compound} \rightleftharpoons NiS + \text{Fe-cation in the silicate compound.}$$

The system represented above is an equilibrium reaction. If it is assumed that high temperature would shift the equilibrium to the left, whereas lowering temperature would tend to shift it to the right, then, the first sulphide formed at high temperature would be rich in iron and relatively poor in nickel forming a barren pyrrhotite. As the temperature fell the sulphides would become increasingly rich in nickel and eventually pentlandite would begin to replace the pyrrhotite. The textures of pentlandite replacing pyrrhotite noted by Allan (1948) in the Lynn Lake ore could have formed in this manner. If the first iron-rich pyrrhotite formed was segregated from the magma and later injected it would form a barren pyrrhotite body. Those sulphides which remained associated with the silicates as cooling proceeded would become enriched with nickel and would be injected along with the silicates, forming ore deposits.

The arguments presented, plus an examination of some of Hunter's thin sections of the ore, lead the writer to believe that the Lynn Lake nickel deposits are of magmatic origin. He agrees with Hunter's conclusion that the ores are the result of magmatic segregation. The writer does not rule out the possibility of some hydrothermal deposition, for as Lindgren (1933, p. 807) points out there is in places a gradation between the two processes.

At this point it should be mentioned that the three gabbro bodies examined by the writer during the summer of 1949 are presumably of the same age. All are older than the granitic rocks, but younger than the other rocks of the area. This suggests that they were intruded about the same time and probably were derived from a common igneous source.

Extending the principle of magmatic segregation to this larger igneous source it is not difficult to conceive of this parental magma giving rise to a number of differentiates which vary considerably in composition. This segregation might take place in either or both of two ways:

(1) Segregation in the original magma chamber, either due to gravitational differentiation, liquid immiscibility, or to local movement.

(2) Segregation of the different parts of the magma during their movement from the original magma chamber to their present site, possibly by gravitational differentiation or by constrictional flowage or both.

Vogt has shown that there is a definite relationship between the MgO of the rocks and the nickel of the sulphides, and he states that the cause of this relation must be that the percentage of nickel in the resulting partial magma was one of the main factors in the further concentration of the nickel in the sulphides during their final magmatic segregation. Therefore, we would expect the nickel to be associated with those partial magmas which were rich in magnesia.

If the barren pyrrhotite represents higher temperature segregations from the same igneous source as the ore-bearing pyrrhotites we may picture this segregation as having taken place at or near the original magma chamber. The barren pyrrhotite was then injected along zones of weakness in the same manner as the gabbroic partial magmas. Other sulphides which were carried up with some of the gabbroic partial magmas to cooler regions became enriched with nickel from the silicates before and during their partial segregation from the silicates.

The gabbroic partial magmas were emplaced along zones of weakness, commonly as roughly lense-shaped masses parallel to the strike of the volcanic flows. The Myrna, Lynn, and Fraser Lakes bodies represent three of these partial magmas. The Myrna Lake body has been shown to be relatively poor in mafic minerals and to contain a high percentage of iron in the mafic constituents. According to Vogt's work these conditions would imply a corresponding decrease in the amount of magnesium and nickel. The interpretation of the body as the result of partial differentiation of a more basic magma implies the possible loss of any associated sulphides in the segregation of the more basic phase.

On the other hand, the enstatite or norite of the Lynn Lake body is relatively rich in mafic minerals (especially the basic segregations with which the ore is associated) and these constituents contain less iron than the Myrna Lake gabbro. Such a magma would be correspondingly richer in magnesium and nickel.

The normal uralite gabbro of the Fraser Lake body is comparable in percentage of feldspar to the phase 'A' and 'B' gabbros of the Lynn Lake body. It may be assumed, therefore, that the ratio of pyroxene to feldspar in the unaltered rock was approximately the same.

However, nothing is known regarding the nature of these pyroxenes. The only apparent difference between the two bodies is the lack of definite basic segregations and significant lineation in the Fraser Lake body. This may indicate that the body was emplaced so slowly that the associated sulphides settled out to great depth and were, for all practical purposes, lost. The possibility that the 'El' ore-body may be related to this intrusive mass must be borne in mind.

Conclusions -- (1) The gabbro bodies of the Lynn-Barrington Lakes area are all of the same age and are believed to represent partial magmas from a common igneous source.

(2) The sulphides were most strongly concentrated with those partial magmas that contained a high percentage of magnesium-rich mafic minerals. Ore deposits might be expected to occur within the more basic portions of gabbroic rocks formed from such a magma.

(3) Alteration of the original rock to uralite gabbro was caused by the thermal and hydrothermal metamorphism that accompanied the intrusion of the younger granitic bodies. The alteration is believed to have no significance with respect to ore deposits.

(4) A study of the opaque oxides reveals no qualitative features that would serve to correlate the bodies. The lack of such features may be a reflection of the common origin of all the bodies, but is not very convincing evidence. A quantitative treatment, on a weight basis, of the ratio of magnetite to ilmenite might prove of value in this respect.

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PLATE I

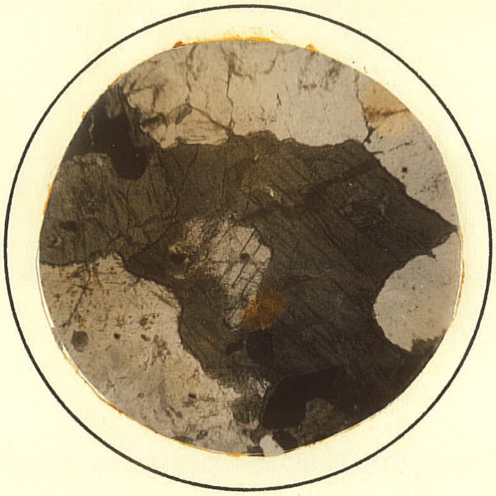
A. Secondary compact hornblende (dark) enclosing pyroxene remnant (light).

B. Small actinolite fibres (light) embaying secondary compact hornblende (dark). Vein-like replacement of hornblende by actinolite along a fracture in the hornblende crystal.

C. Antigorite (light) replacing pyroxene remnants enclosed within compact hornblende (dark).

D. Hypersthene rims (H) about olivine grain (O). Dendritic pattern of magnetite (M) within the olivine grain.

PLATE I



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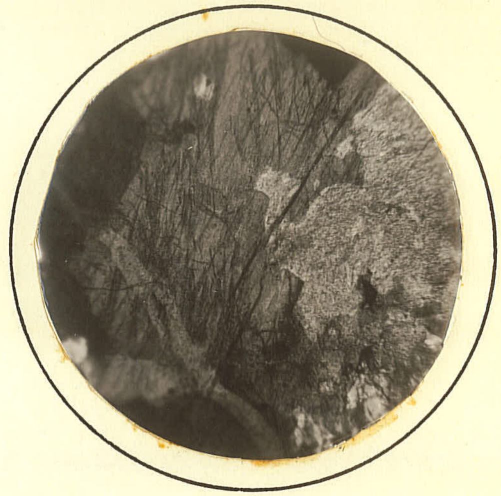

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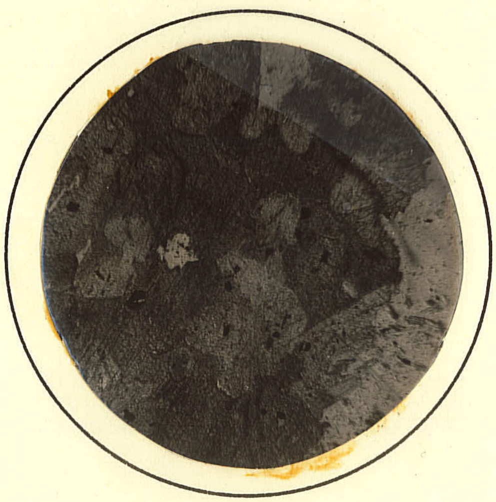

C

D