# ANORTHOSITE-ILMENITE-PEGMATITE RELATIONS ON THE WEST BANK OF LA CHALOUPE RIVER, SAGUENAY COUNTY, QUEBEC.

by

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A thesis submitted to the Department of Geological Sciences of McGill University in partial fulfillment of the requirements for the Degree of Master of Science.

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# ANORTHOSITE-ILMENITE-PEGMATITE RELATIONS ON THE WEST BANK OF LA CHALOUPE RIVER, SAGUENAY COUNTY, QUEBEC

## INTRODUCTION

### General Statement

The area which La Chaloupe River drains, as well as the surrounding terrain, was mapped geologically during the four summer months of 1954 by M.A. Klugman. The writer acted as assistant to Mr. Klugman, on a party put in the field by the Quebec Department of Mines.

The system of traversing at half mile intervals employed in reconnaissance mapping, gave only scant opportunity for the examination of a very interesting area at the mouth of La Chaloupe River. Within this area, strongly foliated rocks of anorthositic composition were seen to enclose bands of ilmenite-magnetite, and layers of pyroxene-rich rock. Cutting across the older rocks were found two distinct types of pegmatites, one of which was seen to contain coarse grains of magnetite. Elsewhere during the summer, similar pegmatites were observed, some of which were very highly mineralized (Klugman, 1955, p.36).

The interesting nature of the problem of the relationships of the mineralization to the anorthosite and/or the pegmatites prompted its selection as a subject for study. Near the end of the summer of 1954, twelve days were spent in mapping this area in detail, and the field relations, plus a petrographic and mineralographic study of the rock and ore specimens taken, have provided data for this thesis.

## Acknowledgements

The writer wishes to thank Dr. I.W. Jones, Chief of the Geological Survey Branch of the Quebec Department of Mines, who provided the opportunity for gathering the material used in this thesis. Thanks are due to Dr. E.H. Kranck, who supervised and directed the work. A short visit paid by Dr. Kranck to the thesis area in September of 1954 made possible constructive criticism at first hand.

To the members of the staff of the Department of Geology at McGill University, who at all times were available for consultation, thanks are also due. Dr. Roger Webber was particularly helpful in providing advice in the use of the X-ray Emission Spectrometer.

The writer is indebted to Mr. Mousseau Tremblay for providing the results of a semi-quantitative spectrographic analysis of an ilmenite-magnetite specimen.

Conversation with Mr. M.A. Klugman proved stimulating in the pursuit of the study, as did discussion

with other graduate students of the Department of Geology.

## Location of Map Area

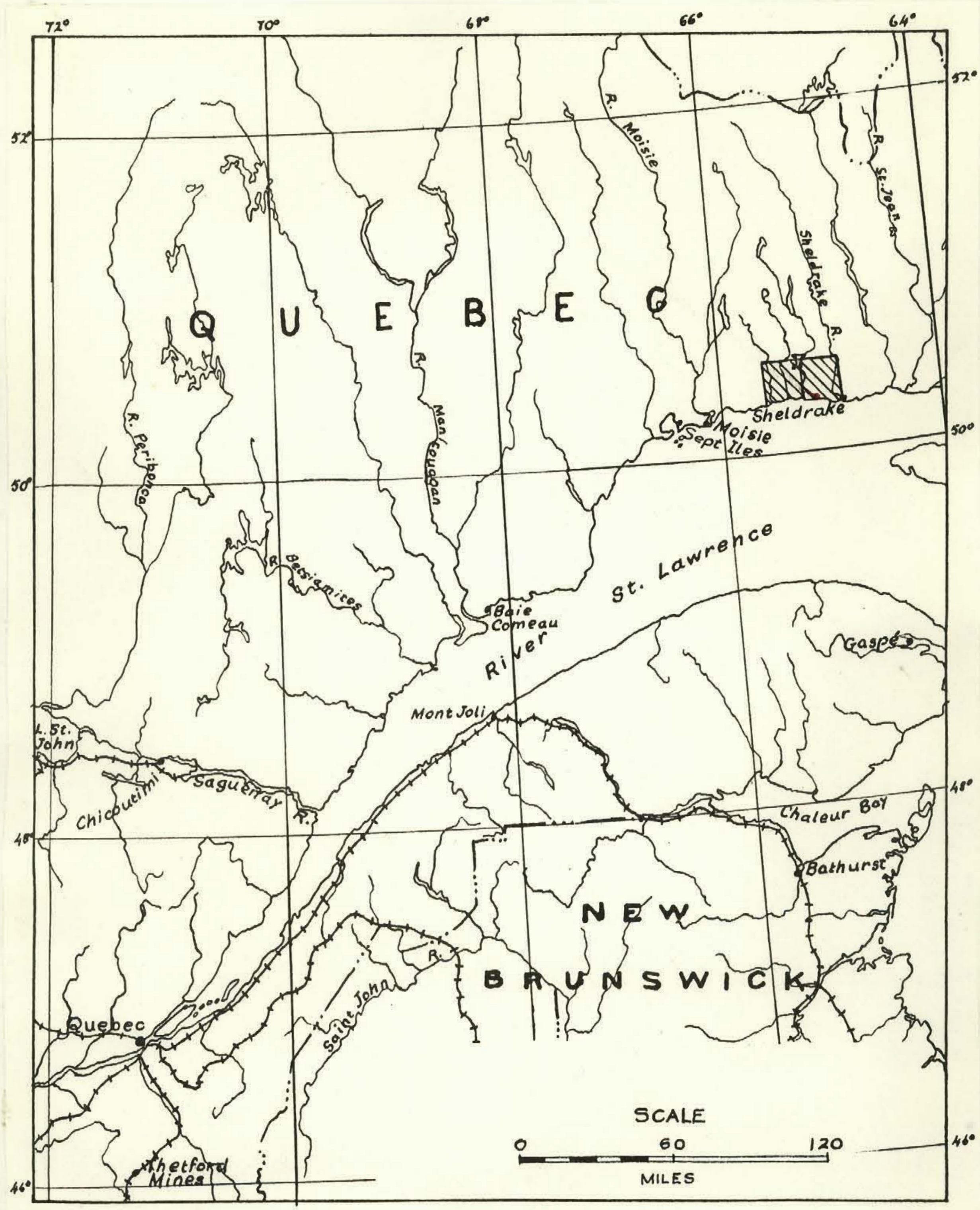
The area mapped in detail includes the west bank of La Chaloupe River, from the junction of that river with the Gulf of St. Lawrence westward for one-quarter of a mile, and northward for one-half of a mile. The village of La Chaloupe (fig. 1), now inhabited by only three families, lies on either side of the river at its confluence with the St. Lawrence. La Chaloupe is approximately fifty-six miles east of Seven Islands, a city on the north shore of the St. Lawrence, 325 miles east of Quebec City.(See Plate 1.)

## Access

The map area may be reached with difficulty by land, by air or by sea. In fine weather a seaplane from the base at Rapide Lake, north of Seven Islands, can land on the Gulf, in the lee of the small islands lying a few hundred feet offshore from the mouth of La Chaloupe River. At high tide, a lightly loaded small seaplane can land in La Chaloupe harbour.

Clarke Steamship Lines makes the village of Rivière-au-Tonnere a regular port of call. La Chaloupe may be reached from that point, or from Sheldrake, a village seven miles to the east, or from Seven Islands, by fishing

Plate No. I




Location of the map area: ....

Fig. 1).
Mouth of La Chaloupe River. Southeastern edge of map area shown at the left.

Fig. 2).
Part of the La Chaloupe map area, view facing east. Note strong development of gneissosity and banding.

boat.

A wide, well kept trail, 9 miles long, joins La Chaloupe to Sheldrake, and this route is the one most independent of weather, and hence the surest means of access to the map area.

## Mapping Procedure

The detail mapping was carried out from a base line laid down across the centre of the point at La Chaloupe, in a direction of 293 degrees. This point was mapped by measured offsets from the base-line. The northern part of the area (i.e., above the bridge) was plotted directly in the field, using a blow-up of an aerial photograph. The geological data were plotted on a base map drawn from an enlargement of as aerial photograph. This map, scaled at one inch equals 260 feet, was then enlarged on the pantograph to the included map (Plate III - in folder) scaling one inch equals 100 feet.

In plotting the narrow dyke rocks, the widths of the dykes has been, in some cases, exaggerated, but other felsic dykes, continuous for several hundred feet but only three inches or so wide, have not been plotted on the map.

## Previous Geological Work

In 1869, J. Richardson(1870) did a rapid reconnaissance survey along the north shore of the St. Lawrence, including the map area in the strip covered. Dulieux(1911) did geological mapping from Moisie Bay to St. John's River in 1911, paying special attention to the titano-magnetite deposits found all along this portion of coast.

Another reconnaissance survey from Chaloupe River to Mingan was carried out by W.W. Longley(1944) in 1944.

In 1954, M.A. Klugman(1955,1955,1956) mapped the Bailloquet area, including La Chaloupe River, for the Quebec Department of Mines.

## REGIONAL GEOLOGY

### General Relationships

The north shore of the St. Lawrence River has been the subject of an intensive geological mapping program carried out by the Quebec Department of Mines for the past several years. A strip fifteen miles wide along the river from Seven Islands to Sheldrake, and also the territory on either side of the Quebec North Shore and Labrador Railroad from Seven Islands to mile 121, have been mapped since 1939, with all but two of the eleven areas involved having been covered since 1951.

The rocks in the North Shore district have been placed in the Grenville lithologic sub-province by most workers, but the reasons for so doing, and whether or not these reasons justify such a placement, lie beyond the scope of this thesis.

A compilation of the geology of the Seven Islands Region has been attempted by Dr. R.A. Blais(1955) of the Quebec Department of Mines, who makes four major subdivisions of the rocks. From oldest to youngest these are: a) Basal Complex of Metasedimentary Rocks and Pegmatites; b) Early Intrusives and Metasomatic Rocks, mainly granite gneiss; c) Basic Intrusives and Associated Rocks, mainly gabbro and anorthosite; d) Late Granite.

The structural relationships among these rocks are complex. In older writings, the rocks of the so-called Grenville Province were admitted to have a northeast trend, but the work done on the North Shore shows that the picture is not this simple. Foliation and gneissosity have been found to vary from north to south, even within a relatively small area (Jenkins, 1956), and the term "general trend" often has little meaning.

## Bailloquet Area

Since this thesis area lies within the Bailloquet Area, a short review of the geology of this area seems desirable.

The geology of the area is not altogether typical of the geology of the North Shore, for 175 of the 220 square miles of it are underlain by a body of anorthositic rocks; other rock types such as paragneiss, granite gneiss and migmatite, and massive granite are correspondingly scarce. Since most of the rock types are represented, however, the difference is merely one of the proportion in which they are present. Other bodies of anorthosite are known in the Seven Islands Region, but none as big has been proven by systematic traversing. (See Plate II, in folder.)

All the consolidated rocks of the area are of Precambrian age, and, listed in the order of their abundance, they are: anorthositic and gabbroic rocks, syenitic rocks, granitic intrusives, such as pegmatites, lamprophyre and diorite dykes. (See Table I.)

## Metamorphosed Sedimentary and Associated Rocks

The metasedimentary rocks of the area are of very limited occurence. The only typical paragneisses occur interbanded with the migmatites in the southwestern portion of the area. Amphibolite, of possible sedimentary origin, is found in thin concordant layers, within the northern syenite-gneiss band.

## Early Intrusive and Metasomatic Rocks

Migmatites occur in the southwest corner of the area, and to the northwest and west of Rivière aux Graines. These rocks are the result of an interjection of biotite granite into the metasedimentary rocks. The granite occurs both as lit-par-lit and discordant bodies in the paragneisses.

Augen gneiss and biotite gneiss crop out in a very small area on either side of the Manitou River, four

Table I.

Table of Formations, Bailloquet Area.'

| | | |
|---|---|---|
| CENOZOIC | Recent and Pleistocene | Sand, gravel, clay and till. |
| | Unconformity | |
| Precambrian | Later intrusives | Diabase dykes (not indicated on map).<br>Lamprophyre dykes (not indicated on map).<br>Pegmatite and aplite dykes (not indicated on map).<br>Pink biotite granite. |
| | Bailloquet igneous complex | Syenite gneiss and monzonite gneiss.<br>Anorthositic and gabbroic rocks, and layered complex. |
| | Early intrusives and metasomatic rocks | Augen gneiss and biotite gneiss.<br>Migmatites. |
| | Metamorphosed sedimentary and associated rocks | Not represented. |

' Modified after Klugman, 1955.

miles from the coast. These rocks are similar in composition, containing feldspar, quartz, biotite, hornblende and garnet. They are both strongly gneissic, medium- to coarse-grained, and pink in colour. The augen gneiss contains well developed augen of microcline, elongated parallel to the gneissic structure.

Bailloquet Igneous Complex

This term is employed by Klugman(1955) to indicate the suspected temporal relationship among the anorthositic and gabbroic rocks, the layered complex and the syenite gneiss. These rocks underlie about seven-eighths of the area, each occupying a distinct part of it, and are believed to be genetically related.

The large massif which occupies three-quarters of the area may be classed as a gabbroic anorthosite body, for the greatest part of it approximates this composition. The colour of the rock is variable from bluish-gray to greenish-black, depending on the mafic content, and the grain size may also vary from fine to coarse. Granulation is common along the western boundary of the body, and the northern contact is characterized by a pronounced cataclastic structure. Foliation parallel to the contact direction is common near the edges of the massif.

The composition of the main body of anorthositic rocks varies from pure anorthosite (less than 10 per cent mafic content) through gabbroic anorthosite (between 10 and 22.5 per cent mafic content) to anorthositic gabbro (between 22.5 and 35 per cent mafic content). The plagioclase which is the chief constituent of these rocks varies in composition from An45 to An60, and is everywhere well twinned. Klugman(1955, p. 25) reports that the predominant mafic mineral is hypersthene. Less abundant mafic minerals are augite, hornblende and biotite, with accessory amounts of epidote, chlorite, sericite, magnetite and ilmenite being noted.

Another body of anorthosite, separated from the north-central body by the layered complex and syenite gneiss, trends northeastward from La Chaloupe to Lac Touzel. This body is strongly gneissic along its southern boundary, but becomes more massive to the north. The rock varies from a white colour on the weathered surface to gray, or mauve-gray, and varies in grain size from coarse to very coarse.

In composition, this rock is quite a pure anorthosite, the plagioclase content varying from 92 to 98 per cent. The composition of the plagioclase varies from An45 to An60. Hypersthene, augite and enstatite are the most common mafic mineral components, with very minor amounts of biotite, hornblende and chlorite also being present.

The southern body of anorthosite becomes more mafic and more strongly gneissic towards the southwest, and at La Chaloupe it merges with the lithologic unit designated "layered complex" by Klugman(1956). This layered complex is essentially a gabbroic anorthosite in composition, but a strong banding is apparent which marks the presence of mafic rich and mineralized (ilmenite-magnetite) bands within an anorthositic major component.

Since this layered complex is the rock unit which crops out in the area under study in this thesis, it will receive further consideration in the following chapters.

The third component of the Bailloquet Igneous Complex, syenite gneiss and monzonite gneiss, occurs in two broad bands, one in the northwest, along the northern boundary of the anorthosite, and the other in the southeast, along the southern boundary of the north-central body of anorthosite. This rock is very strongly foliated, and can, in some localities, easily be mistaken for a feldspathic paragneiss. It is fine- to medium-grained, and greenish-gray to beige colour on the weathered surface within the southern band.

The composition of the rocks of these bands varies from that of a quartz monzonite to that of a quartz syenite. The amount of plagioclase varies from 35 to 20 per cent, but its composition is fairly constant throughout at An33. Microcline, orthoclase and perthitic potassic feldspar comprise from 35 to 45 per cent of the rock. The quartz content of the southern band varies from 2 per cent to 20 per cent, this content increasing towards the contact of the southern band with the biotite granite, but it is more constant at abour 8 per cent in the northern band. Hornblende, hypersthene and biotite are the chief mafic constituents. The extremely quartz-rich, mafic-poor monzonite of the southern band corresponds to the rock termed a hybrid granite by the writer at La Chaloupe.

Later Intrusives

A small body of biotite granite occurs in the southwestern part of the Bailloquet Area. This body trends northeastward from the mouth of Manitou River for a distance of one and one-half miles. A smaller, stock-like body of biotite granite occurs about Lac Vibert in the northeastern part of the area.

This rock is medium- to coarse-grained, pink in colour, sometimes slightly gneissic, but most commonly massive. Its chief constituents are quartz, microcline, plagioclase (An12 to An32), and biotite, with minor amounts of apatite, pyrite, muscovite, sphene and magnetite. Near Manitou River mouth, the biotite granite is porphyritic, but elsewhere it is an equigranular, hypidiomorphic rock.

Klugman(1955, p.36) notes the occurence of three distinct sets of pegmatites in the Bailloquet Area. The oldest and the youngest of these rocks are of granitic composition, but the second set is of a highly feldspathic composition. Cutting relationships were used to establish the relative ages. The oldest set of pegmatites cuts the anorthosite, but is cut by the syenite gneiss. Klugman notes that this pegmatite is always found in close association with the ilmenite-magnetite mineralization.

Diabase and lamprophyre dykes are widespread throughout the area, and the latter seemed to be later than any of the other rocks in the area. The age relationship between the lamprophyre and the diabase dykes could not be established. The lamprophyres are aphanitic to fine-grained, and consist mainly of plagioclase, hornblende, biotite and quartz. A distinct foliation was noted in some of these rocks. The diabase dykes are medium- to fine-grained, and are composed of intermediate plagioclase, with hornblende, diopside, biotite, magnetite, sphene, apatite and muscovite.

## Pleistocene and Recent

Unconsolidated material covers large sections of the southern part of the map area. This material consists of sand, clay, and some boulders. Well stratified deposits of sand and clay, in which cross bedding was frequently observed, are found several miles inland, along the course of the Manitou, Sheldrake and Chaloupe Rivers. Evidence of glaciation, in the form of glacial erratics, and a north-south set of striae, is abundantly present in this area.

## Structural Geology

The dominant structure of the Bailloquet Area is the domical body of anorthosite which occupies three-quarters of the area (Klugman, 1956, fig. 31). This body has strongly gneissic, and locally granulated, border facies. The gneissosity follows the contacts of the anorthosite, and everywhere dips steeply.

The band of syenite gneiss in the northwest corner strikes northeast, following the anorthosite body, and dips to the southeast at angles of between 30 and 60 degrees. The trend of the rocks to the south of the anorthosite body is N70 degrees E, and these rocks, including the southern anorthosite band, the layered complex, and the syenite gneiss, all dip steeply to the northwest.

Evidence of minor shearing along the coast was noted, but no major fault was indicated by field observations.

Jointing is very prominent throughout the area. The two major joint sets in the northern anorthosite body strike N30 degrees E and N50 degrees W, both sets dipping steeply. The syenite gneiss bands and the layered complex are also strongly jointed in directions parallel to the strike of the gneissic structure, and at right angles to the strike.

## GENERAL GEOLOGY OF THE LA CHALOUPE AREA

### General Relationships

The rocks of the La Chaloupe map area are well exposed throughout the area (fig. 2). Wave action has stripped all the rock along the coast of its cover, glaciation has planed these rocks smooth. The rocks immediately adjacent to La Chaloupe River have also been denuded and smoothed by tide and river action.

The rocks which occur at La Chaloupe are listed in Table II. The second and third columns of this table relate these rocks to the formations of the Bailloquet Area as listed by Klugman(1956).

The most abundant rock type in the area (excluding unconsolidated material) is gabbroic anorthosite. This rock underlies almost the entire point which forms the southern half of the area.

A strongly gneissic rock, herein referred to as hybrid granite, is next to the gabbroic anorthosite in order of abundance, and it underlies the entire west bank of La Chaloupe River above the bridge, within the bounds of the map area.

The other rock types comprise less than 10 per cent of the bedrock. Listed in order of their abundance, the following rock types are found: pyroxene-rich rocks, (including mineralized pyroxene-rich rocks), granite pegmatite dykes, andesinite pegmatite dykes, lamprophyre dykes, and a few, thin, aplitic and felsic dykes which are too small to be shown on the accompanying map (Plate III). The rocks are quite highly altered where they occur close enough to the sea to have been acted upon by the sea waters.

Because of the intimate nature of the interlamination, and the thinness of the individual lamellae,

Table II.

Table of Formations, La Chaloupe Area.

| | | | | |
|---|---|---|---|---|
| Cenozoic | Sand | | | |
| Unconformity | | | | |
| Precambrian | Later intrusives | | Felsic dyke rocks | Aplitic and highly feldspathic dykes (not indicated on map).<br>Granitic pegmatite dykes.<br>Andesinite pegmatite dykes. |
| | | | Lamprophyre dyke rocks | Kersantite<br>Minette |
| | Bailloquet igneous complex | | Hybrid granite | |
| | | Layered complex | Pyroxene-rich rocks | Ilmenite-magnetite bands.<br>Ilmenite-magnetite-pyroxene-rich bands.<br>Pyroxenite bands.<br>Gabbroic bands. |
| | | | Anorthositic rocks | Ilmenite-magnetite-gabbroic anorthosite.<br>Gabbroic anorthosite.<br>Anorthosite. |

difficulty in defining the mappable unit of pyroxene-rich and ilmenite-magnetite-rich rocks was encountered, even on the scale of mapping employed. It was, therefore, arbitrarily decided to define the pyroxene-rich or ilmenite-magnetite-rich rock as any band of rock which was composed of 50 per cent or more pyroxene-rich or ilmenite-magnetite-rich layers across a mappable width (i.e. 10 feet). A pyroxene-rich, or ilmenite-magnetite-rich layer is one which contains 35 per cent of these minerals.

The bands shown on the map, therefore, are strongly layered zones which may contain as little as 18 per cent pyroxene or ilmenite-magnetite. Figures 2 and 5 illustrate the banding at La Chaloupe. Some bands, such as one located 110 feet southwest from the 700 foot mark on the base line, are composed of individual bands of ilmenite-magnetite which measure five feet or more in width, separated from similar or smaller bands by narrow layers of anorthositic rock. For the sake of conveying the scale of the occurrence, such bands would be mapped as a single layer.

The pyroxene-rich rocks and the ilmenite-magnetite-rich bands occur as small concordant bodies within the gabbroic anorthosite. The most extensive pyroxene-rich band measures 260 feet in length and 30 feet across its greatest width. Other pyroxene-rich bands occur which are continuous over almost the entire length of the point, but these are less than one inch wide in most cases, and only occasionally reach a width of one foot. The ilmenite-magnetite-rich bands are closely associated with the pyroxene-rich bands, and are usually found merging into the latter. They have smaller dimensions than the pyroxene-rich bands, and occur less frequently. The largest individual band measures 150 feet by 4 feet, but it pinches and swells over this distance.

The largest of the pegmatite bodies occurs near the southeast tip of the map area. This body measures 160 feet long and reaches 30 feet in width. It is really a composite dyke, for the center of an andesinite dyke has been filled by a granite dyke, and the center of this body is filled with large quartz grains which reach the size of one inch. Other pegmatite dykes are longer than this one, but none is as wide. The widths of most of these pegmatitic bodies have been distorted on the map, for these dykes are, with three exceptions, no wider than 2 feet. The length of these dykes made their mapping desirable. Other felsic dykes, of aplitic or granite composition, have not been placed on the map, however, because their width is no more than 2 inches. Such dykelets are usually continuous to 200 feet or more.

Six lamprophyre dykes are found in the southern portion of the map area. These dykes are usually continuous for no more than 50 feet before being slightly offset, but, as their total length is 150 feet or more in most cases, they have been mapped as continuous bodies.

The widths of the lamprophyre dykes have in three cases been distorted on the accompanying map. The three dykes, located south of the arm of the sea at the west end of this smaller point, are all less than 6 inches wide.

At one point, located 250 feet from the point 10+00 on the base line, in a direction S27 degrees W, a cluster of coarse pyroxene crystals was found along the foliation planes in gabbroic anorthosite. This location is on strike with a shear zone 50 feet to the ENE (fig.3).

Epidote stringers, pervading the anorthositic rocks, are very common in the southern part of the area. Many small inclusions of pyroxene-rich bands are found in the hybrid granite. Only two inclusions, one of a pyroxene-rich layer and the other of gabbroic anorthosite, have been shown on this map. The other bodies are not of mappable size.

## Structural Geology

The most dominant geological feature at La Chaloupe is the exceptionally well developed layering in the rocks of anorthositic composition.(See figs. 2,4,5.) The lack of overburden allows a view of layering which is often continuous for 1200 feet within the map area. This freedom from overburden also permits an unobstructed and close examination of all the structural features of the rocks.

The layering strikes in a direction varying

Fig. 3).
Contortions in interlaminated pyroxene-rich and anorthosite bands.

Fig. 4).
Folding of gabbroic anorthosite and pyroxene-rich bands. Note granite pegmatite cutting across the gneissosity; also fracturing in a mineralized pyroxene-rich band.

Fig. 5).
Jointing along gneissosity planes in interlaminated pyroxene-rich and anorthosite bands. A shear zone can be seen at the extreme left of the picture.

Fig. 6).
Lamprophyre dyke (minette) cutting across gneissic structure of gabbroic anorthosite.

from N65 degrees E to N35 degrees E, and dips vary between 70 degrees SE and 85 degrees SE. The layering continues for an unknown distance on the eastern side of La Chaloupe River, and a conservative estimate of the persistance of some of the individual layers would be one-half mile. The layered appearance of the anorthositic rocks is imparted to it by an interlamination of pyroxene-rich and mineralized bands with a rock of gabbroic anorthosite composition, in which is developed a strong foliation parallel to the banding.

The ilmenite-magnetite-rich bands and the pyroxene -rich bands are quite concordant with the anorthositic rock. Inclusions of gabbroic anorthosite can be found in many of the mineralized bands (figs. 7 & 8). The ilmenite-magnetite bands are apparently sills in the layered rock and are closely associated with the pyroxene-rich bands, being very frequently found occupying these bands. The wider pyroxene-rich bands are, in the great majority of cases, more heavily mineralized than the thin bands. The contorted shapes of some of the country rock inclusions (fig. 8) indicate that the ilmenite-magnetite was emplaced in a plastic country rock.

The gneissic structure of the hybrid granite parallels that of the anorthositic rocks, but here the banding is absent. The hybrid granite includes fragments of the layered rock, but its age relationships to the other rock types of the area are unknown.

Fig. 7).
Fragments of gabbroic anorthosite caught up and included in an ilmenite-magnetite band.

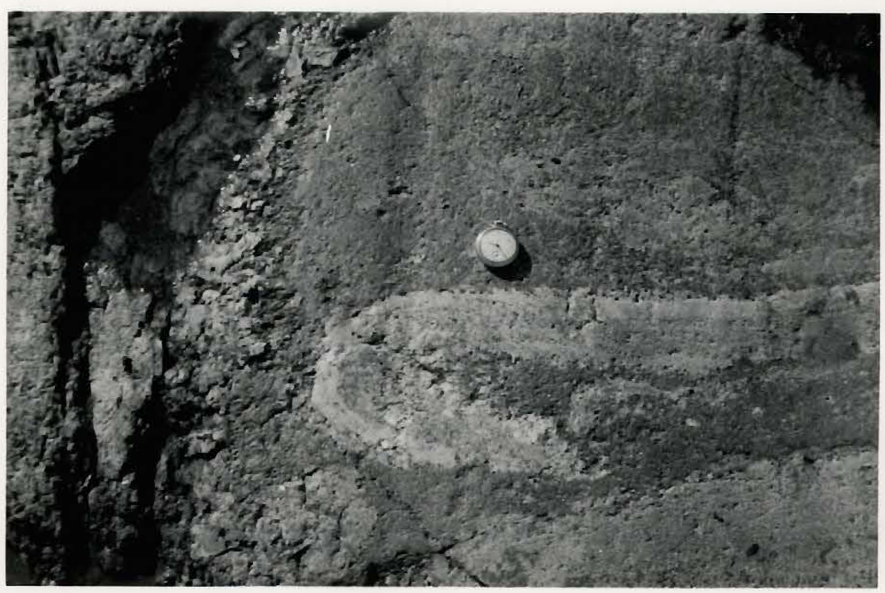


Fig. 8).
Hook-shaped inclusion of gabbroic anorthosite in band of ilmenite-magnetite.

The layered rock (i.e., the pyroxene-rich and mineralized rocks, and the foliated gabbroic anorthosite) is cut by granite and andesinite pegmatites, and a series of lamprophyre dykes. The granite dykes occur in two sets. The most abundantly exposed set strikes from 145 degrees to 198 degrees, with dips varying from 45 degrees W to vertical. The other set, with only one representative, strikes at 35 degrees, dipping 60 degrees SE. Bodies of granite are also found along the northern coast of the point.

The granitic pegmatites are seen to cut the andesinite pegmatites in several places. These latter dykes occur in only one set which strikes from 173 degrees to 198 degrees, with dips fairly constant at about 75 degrees W.

The andesinite dyke is seen to cut a lamprophyre dyke at a point 90 feet, S43 degrees W of point 2+00. The granite bodies on the north coast of the point include and contort fragments of minette. The lamprophyre dykes cut fragments of the layered rock (fig. 6). These dykes strike in various directions, from 13 degrees to 178 degrees, with dip to both east and west. There are two types of lamprophyre dykes in the map area. Their relative age, if a difference does exist, is unknown.

Fine-grained aplitic and highly feldspathic dykelets cut all other rock types. The strikes of these bodies vary between 0 degrees and 180 degrees, and the dip varies from vertical to 45 degrees east or west.

The series of cutting relationships which is well exposed in the rocks at La Chaloupe has allowed the deciphering of the age relationship as given in the table of formations (Table II).

There are abundant signs of shearing in the map area. The shear zones appear as shattered bands in the ilmenite-magnetite ore (fig. 5). In one of these shattered zones, antigorite was extensively developed. The magnitude of the movement is unknown. Further evidence of movement is afforded by granulation, which is common in several of the bands of gabbroic anorthosite. Signs of small-scale faulting were noted. A right hand strike separation of six inches was noted at a point where the granite pegmatite dyke cuts an andesinite dyke. A similar separation was observed where two lamprophyre dykes intersected.

Tight, small-scale folds in the layered rock were frequently observed (fig. 3 & 4). Because of the extreme contortion observed, it is thought that these folds are the result of plastic deformation at an early stage in the cooling of the layered rocks. A shear zone was observed to cut across one of the folds. Measurements made on two tight anticlinal folds indicate that they are plunging at 20 degrees to the ESE.

Several sets of jointing were noted in the layered complex rocks. The most prominent of these sets strikes at 80 degrees, dipping 75 degrees S. The attitudes of other less prominent joint sets are 170 degrees/vertical, 100 degrees/70 degrees N, 140 degrees/45 degrees SW, and 45 degrees/55 degrees NW.

## Economic Geology

Assays made by the Quebec Department of Mines on two specimens from La Chaloupe gave the following results: (Klugman, 1955, p.43-44)

i. Channel sample taken across a four feet wide band of highly mineralized anorthosite assayed, Fe-23.44 per cent, $TiO_2$-5.83 per cent, S-0.35 per cent.

ii. A grab sample from an ilmenite-magnetite layer, Fe-49.52 per cent, $TiO_2$-16.34 per cent, S-0.08 per cent.

The second assay gives encouragingly high iron content, but the high titanium oxide content makes the ore a poor risk. A study of polished sections has shown that a titaniferous hematite is intimately intergrown with the ilmenite. Thus, although the titanium oxide content is almost high enough to make reasonable a consideration of the ilmenite-magnetite as a titanium oxide ore, the intergrowth of hematite would make a separation difficult.

The tonnage of ore at La Chaloupe is roughly estimated at 1500 tons per vertical foot, and this is hardly of economic interest.

A semi-quantitative spectrographic analysis of a specimen of ilmenite-magnetite from La Chaloupe was made by the Quebec Department of Mines laboratories. The results of this analysis were made available by Mr. Mousseau Tremblay, and are as follows:

| | |
|---|---|
| Major Constituents (10 per cent or more) | - Fe and Ti |
| Minor Constituents (1-10 per cent) | - Al, Mg, Si |
| Minor Accessories (0.1-1 per cent) | - Mn |
| Trace Elements (0.01-0.1 per cent) | - Ca, Na, V |
| Weak Trace Elements (0.001-0.01 per cent) | - Co, Ga, Ni. |

# PETROLOGY AND PETROGRAPHY

Forty-seven thin sections were examined under the microscope. Several determinations of optical properties were made on the four-axis universal stage, on the most commonly occuring minerals such as pyroxene and plagioclase. (Turner, 1947.) The technique described by Chayes (1952) for the determination of potassic feldspar by staining with a sodium cobaltinitrate solution was employed in an attempt to determine the effect, if any, of potassium metasomatism in the map area. The results of these tests, and the results of a series of analyses for potassium carried out by X-ray fluorescence, are given at the end of this chapter.

The field classification which is given in the fourth column of Table II may be further subdivided after petrographic study. A nearly complete list of rock types occuring in the La Chaloupe map area can be found in the last column of Table II. A petrological and petrographic description of each of these rock types will now be given.

## Anorthositic Rocks

Anorthositic rocks underlie the entire southern half of the map area, and almost half of the thin sections studied were of anorthositic rocks. Three varieties of anorthositic rocks were distinguished: anorthosite, gabbroic anorthosite and ilmenite-magnetite gabbroic anorthosite.

Anorthosite

This rock occurs in a few thick bands between other bands of gabbroic anorthosite. It weathers a gray-yellow colour, but its fresh surface is a very light gray to purplish gray. The grain size is medium, and the rock appears to be less granulated then the gabbroic anorthosite. A few green specks of epidote can be seen on a fresh surface.

Five thin sections of the anorthosite were studied. Plagioclase composed 90 per cent or more of this rock. Only a trace of pyroxene (augite) was found in one specimen. In none of these sections did opaque minerals compose more than one per cent of the slide. Epidote and chlorite were present in all sections in amounts less than one per cent. Four of the five sections studied were highly altered to saussurite-zoisite, sericite and epidote being identified as being present in this aggregate. The composition of the plagioclase varied between An46 and An54. The extreme values of An content were checked on the universal stage and found to agree with the values determined by use of Michel-Levy's curves. (Winchell, 1951, p.262.) Sodic labradorite (An51) was the plagioclase most commonly identified.

The anorthosite exhibited a hypidiomorphic-granular texture, with grain size varying from 1.5-0.8 mm. The plagioclase crystals are all well twinned, except in grains which have been highly saussuritized. Fracturing of the grains is very evident, but no granulation was observed.

Gabbroic Anorthosite

Gabbroic Anorthosite is the most abundant rock type of the area. It usually, but not always, occurs as lamellae of pure anorthosite interlaminated with very thin pyroxene and biotite layers. These lamellae vary in width from 1/4 to 1/32 of an inch. Interlamination of layers wider than this place the rock either in the group of pyroxene-rich rocks or in the banded pyroxene-anorthositic rock group which bridges the gap between the anorthositic rocks and the pyroxene-rich rocks. In some localities the gabbroic anorthosite is massive within the limits of a band. This rock weathers a dark greenish-gray and has a mottled black and gray fresh surface. The laminated variety of gabbroic anorthosite weathers the same colour, but with an obvious lamellation, and its fresh surface shows an alternation of black and white lamellae. The grain size of both varieties of gabbroic anorthosite varies from about 0.2 mm. to 1.2 mm. Ten thin sections of this rock were studied.

Plagioclase, with a composition varying from An42 to An58 was found in all sections, and comprised from 75 to 88 per cent of the section. Augite occured in 7 of the sections, composing from one to 10 per cent of the rock, and hypersthene was found in three sections in amounts up to 2 per cent. Hornblende made up from 3 to 22 per cent of the rock in the 7 sections studied. Opaque minerals occured in all the sections in amounts up to 8 per cent. Biotite and chlorite (pennine or prochlorite) were also found in most of the rocks, composing up to 5 per cent of them. Orthoclase was identified in one section studied. Tremolite, epidote, pleonaste, rutile, sericite, saussurite, zoisite and quartz were other minor minerals identified. The identities of augite and tremolite were checked on the universal stage, as were the compositions of the extreme varieties of plagioclase.

Hornblende and tremolite were most often found replacing pyroxene, sometimes having completely replaced it, (fig. 9.).

In one specimen, several grains of magnetite were observed to be altering to chlorite and zoisite. (fig. 11). Another section showed grains of magnetite altering to biotite and clinozoisite (fig. 12.)

The most common texture of this rock is hypidiomorphic-granular. In every section studied, unless present in distinct lamellae, the pyroxene and hornblende crystals were interstitial, indicating a later crystallization of these minerals.

Some degree of granulation was observed in a few specimens. In these granulated varieties the plagioclase often lacked twinning. Quartz occured in the most highly granulated rock. Its interstitial texture may indicate either an introduction off SiO2, or a release of SiO2 upon granulation. The specimen in which orthoclase was found was taken from a point close to a two-feet wide granite

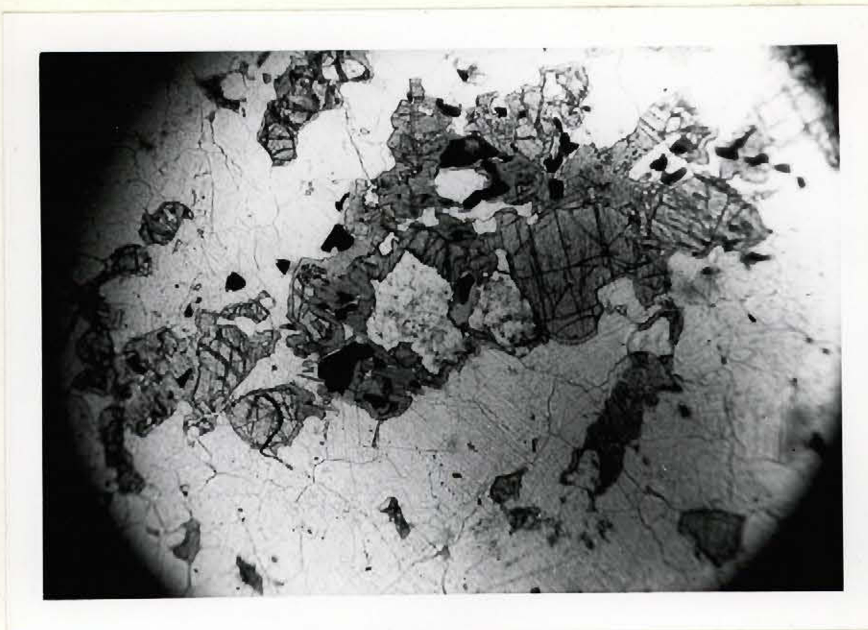


Fig.9). Plane Light; Diameter of Field, 4.85 mm.
Thin pyroxene-rich band in gabbroic anorthosite. Hornblende rims augite and hypersthene.

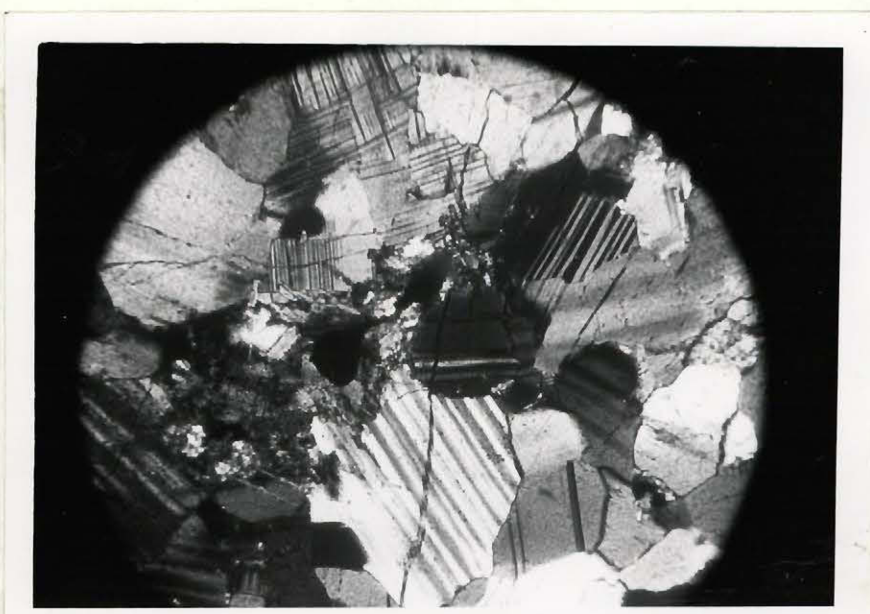


Fig.10). Crossed nichols, diameter of field, 1.55 mm.
Typical Gabbroic Anorthosite; Clinozoisite, plagioclase, biotite and magnetite present.

pegmatite dyke from which several stringers ran off. Because of this proximity, the orthoclase is considered to be introduced.

Ilmenite-Magnetite-Gabbroic Anorthosite

This rock has the appearance of a foliated gabbroic anorthosite, but instead of pyroxenes, amphiboles and micas, the dark component is an opaque mineral(s). The rock has the same appearance on the weathered and fresh surfaces as has the gabbroic anorthosite, and is also fine-grained to medium-grained.

Two thin sections of this rock type were studied, and in one the opaque content is 25 per cent, and in the other it is 10 per cent. Plagioclase makes up 60 and 72 per cent of these specimens respectively, and it has a composition of $An_{38}$ and $An_{55}$. In the specimens containing $An_{38}$, the opaque mineral is altering to biotite and clinozoisite. Chlorite veins cut across the section, and sericite is extensively developed in the feldspar. The plagioclase is fractured and in many grains the polysynthetic twinning is not apparent. The opaque mineral in this rock forms an interlocking texture with the plagioclase, and appears to have crystallized simultaneously with the plagioclase.

The rock containing plagioclase ($An_{55}$) and 25 per cent opaques contains 4 per cent hypersthene, 10 per cent biotite, and a little pleonaste. The opaque minerals and the pleonaste are here seen to be cutting and including the silicates. (fig. 13.) Furthermore, the opaque minerals are seen

Fig. 11). Plane light; Diameter of field, 1.55 mm. Magnetite altering to chlorite and zoisite in gabbroic anorthosite.

Fig. 12). Plane light; Diameter of field, 1.55 mm. Magnetite altering to biotite and clinozoisite in gabbroic anorthosite.

to be concentrated along planes in which the hypersthene is contained. This indicates that the ilmenite magnetite is preferentially emplaced along pyroxene-rich bands even on a microscopic scale.

## Pyroxene-Rich Rocks

Pyroxene-rich rocks, including anorthositic-gabbros, gabbros, pyroxenites, ilmenite-magnetite-pyroxene-rich rocks, and ilmenite-magnetite bands, are found as concordant bodies in the anorthositic rocks as has been described. The definition of these bands has been given elsewhere in this thesis. Where interbanding with rocks of anorthositic composition occurs, only a description of the pyroxene-rich component will be given. The ore bands have been included with the pyroxene-rich rocks because of their obvious field association with these rocks.

### Gabbroic Bands

The gabbroic bands include rocks of from anorthositic gabbroic to gabbroic composition. The rocks are a dark greenish-gray to black colour on both the weathered and fresh surfaces. The grain size varies from 0.5 mm. to 1.25 mm. The strong foliation is imparted to these rocks by the arrangement of biotite parallel to the banding.

Seven thin sections of the gabbroic bands were studied, and besides plagioclase, biotite and opaque minerals are present in all the sections. The biotite content varies from 3 to 15 per cent, and the opaque content varies from 2 to 20 per cent. Plagioclase, of composition An38 to An56, composes from 50 to 70 per cent of the thin sections studied. Hornblende is present in 5 of the sections, composing from 5 to 22 per cent of the section. It usually occurs surrounding a center of augite, but sometimes has completely replaced the augite. In one section augite comprised 25 per cent of the slide, but usually it comprises less than 2 per cent of the rock. Tremolite, hypersthene, sericite, epidote, pleonaste, apatite, rutile, quartz, and orthoclase occur in minor quantities in a few of the sections. Pennine is present in all of the sections studied in amounts up to 20 per cent. The two specimens in which quartz and orthoclase were noted came from points very close to the granite pegmatites, and so these minerals are presumed to have been introduced.

In one thin section several grains of magnetite were seen to be altering to chlorite (clinochlore) and biotite (fig. 14). These grains were located in more anorthositic portions of the gabbroic bands, and are interpreted as being pyrogenic minerals, and not introduced. A few very tiny, grains of a mineral with an extreme birefringence were noted near the grains of altered magnetite. This mineral is probably rutile, although positive identification could not be made because of the small grain size.

Plagioclase and mafic minerals are usually present in an interlocking equigranular texture, but in two of the thin sections studied, pyroxene grains, altering to hornblende

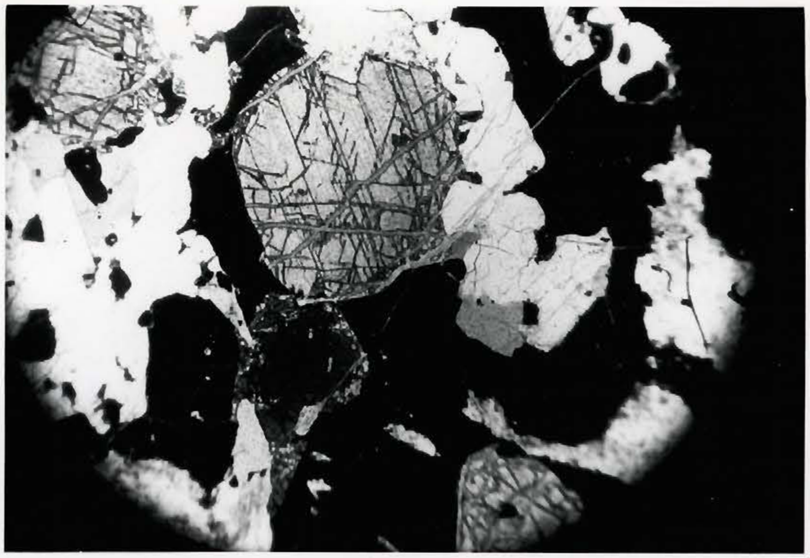


Fig. 13). Plane light; Diameter of field, 4.8 mm.
Ilmenite-magnetite cutting and engulfing hyersthene plagiodlase and biotite in gabbroic anorthosite.

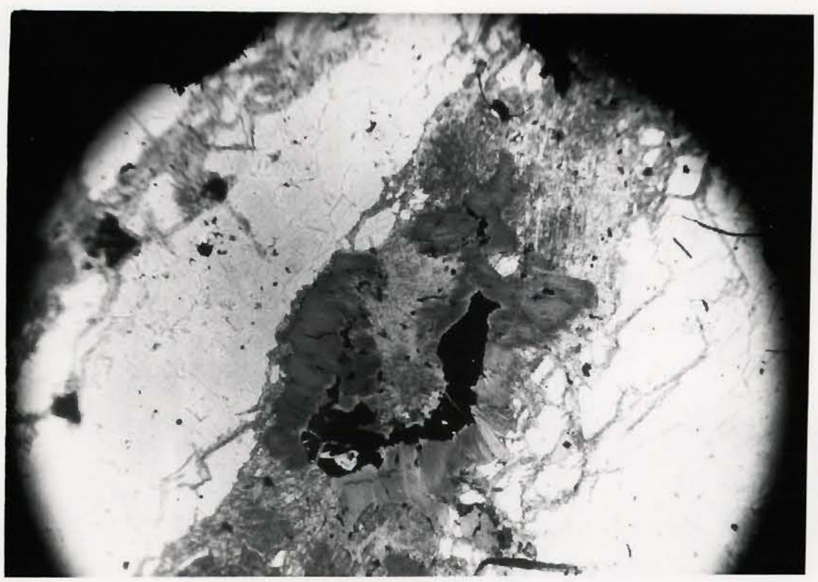


Fig. 14). Plane light; Diameter of field, 4.8 mm.
Ilmenite-magnetite altering to chlorite and biotite.
A typical thin mafic band in the gabbroic anorthosite.

are interstitial to plagioclase crystals. This may indicate the relatively early crystallization of plagioclase, even in gabbroic bands.

Pyroxenite Bands

The pyroxenite bands observed in the field were very few, and were all under three inches in width. These bands were composed of fine-grained crystals, from 0.2 - 0.8 mm in length, which were lineated in the plane of the banding. The weathered surface of the pyroxenite is brown, and the fresh surface a black colour.

Only one thin section of pyroxenite band was cut. This showed the rock to be composed of augite 88 per cent, hypersthene 5 per cent, biotite 2 per cent, opaques 3 per cent, and biotite and plagioclase 1 per cent each. The composition of the plagioclase is An36. The biotite and plagioclase were seen to be interstitial between the pyroxene grains, indicating a late crystallization for plagioclase, and possibly a secondary origin for the biotite (fig. 15).

The texture of the pyroxenite is hypidiomorphic-granular. Fracturing was noted in these rocks, but there was no sign of granulation.

Ilmenite-Magnetite-Pyroxene-Rich Bands

The rock which occurs in these bands shows the effects of the introduction of ilmenite-magnetite mineralization, for grains of pyroxene and fragments of anorthositic rocks are present in the ilmenite-magnetite. The rock is greenish-black on its weathered surface, and black with a dull metallic luster on the fresh surface. Grain size is from coarse to fine. Stringers of epidote are seen to cut the rock.

Two thin sections taken from bands containing ilmenite-magnetite were examined petrographically, and each showed a total absence of plagioclase, and an almost complete absence of pyroxene. Biotite was seen to replace hornblende grains, which had cores of a less strongly anisotropic, and non-pleochroic mineral determined to be augite. The composition of this rock as determined from study of these slides is; opaque minerals 60 per cent, biotite 5 per cent, hornblende plus augite 1 per cent, saussurite 34 per cent.

The opaque minerals are veining and including the silicates (fig. 16), and at the same time these silicates have been completely altered by the heat and solutions attendant upon the injection.

Although no pyroxene crystals were positively identified in the thin sections studied, their presence can be proven megascopically. Hence these bands are termed ilmenite-magnetite-pyroxene-rich bands, and not simply ore bands. The relations of pyroxene to opaque minerals cannot be positively stated from the examination of the thin sections, but the inference is drawn that the alteration to biotite of the pyroxene is due to the injection of ore, and is not simply a secondary alteration of a pyroxene introduced with the ore. Textures indicate that the ilmenite-magnetite is cutting silicate grains, now highly altered, of which pyroxene (now biotite)

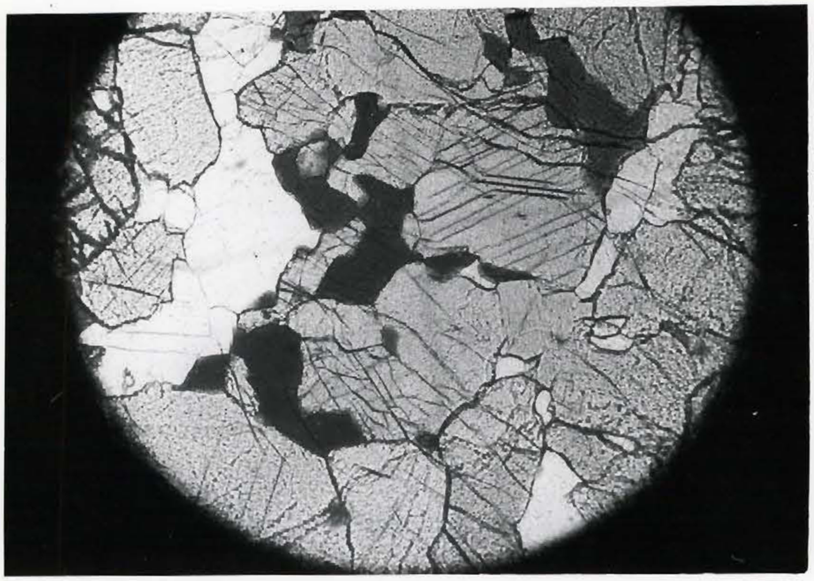


Fig. 15). Plane light; Diameter of field, 1.55 mm. Pyroxene-rich band showing plagioclase interstitial to augite, biotite, and hornblende.

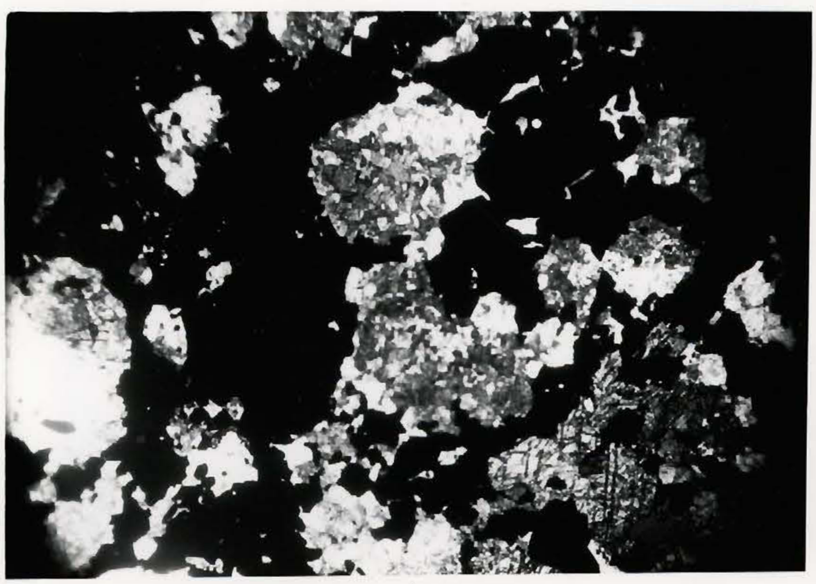


Fig. 16). Plane light; Diameter of field, 4.8 mm. Ilmenite-magnetite engulfing a completely saussuritized pyroxene-plagioclase rock.

once formed a part.

## Ilmenite-Magnetite Bands

These bands are the most metallic-rich portions of the ilmenite-magnetite-pyroxene-rich bands. They are composed almost completely of ilmenite-magnetite, and no pyroxene crystals could be made out in them megascopically.

No thin sections of this rock type were studied, but polished sections showed that the metallics cut and include fragments of the silicates. The silicates, identified by use of a binocular microscope, are pyroxene and biotite. It can be stated with fair certainty that the metallic minerals of these bands are injected into the pyroxene-rich bands in preference to the anorthositic rocks.

## Anorthositic-Pyroxene-Rich Bands

An earlier section has dealt with the scale of lamination in these rocks, and the definition used in this thesis to distinguish a pyroxene-rich or ilmenite-magnetite-rich band from an anorthositic rock. In several cases, however, these pyroxene-rich or mineralized bands occur in the anorthositic rocks in such a way as to fit neither pigeon-hole (pyroxene-rich or anorthositic) in the classification. Such is the case when pyroxene-rich or mineralized bands fail to comprise 50 per cent of a mappable unit, and yet are obviously sufficiently abundant to be distinguished. Although no provision for such a unit was made on the map (Plate III), three thin sections were cut which exhibited the fine scale banding to the degree where half of the slide would be classified as pyroxenite, and the other half as anorthosite. These sections proved most interesting for they showed that the contact between these rock types was perfectly sharp and straight, and unmarked by a chill zone or granulation (figs. 17 & 18). The mineral components on either side of this contact were the same, but present in very different proportions.

In one section, plagioclase An36, comprised 98 per cent of the felsic portion of the slide, with accessory amounts of opaques (1.09 per cent), biotite (0.7 per cent), and leucaugite (0.02 per cent). On the other side of the contact, the composition was: plagioclase (An36) 1 per cent, opaque 3 per cent, biotite 2 per cent, leucaugite 88 per cent, hypersthene 5 per cent, and hornblende 1 per cent. The analysis of this slide was done by Rosiwal method, first using the universal stage to determine the minerals present. Analyses of the other two slides gave comparable results.

The explanation proposed for the described fabric is that this banding is, at least in part, the result of a rhythmic magmatic crystallization process, whereby the effects of gravity settling, and the fluctuation of temperature, pressure, or water content for relatively short periods has caused the settling out of pyroxene crystals from a melt from which was crystallizing the anorthositic rocks (Klugman, 1956, p. 133-158).

Fig. 17). Plane light; Diameter of field, 4.8 mm. Sharp contact between pyroxene-rich band and anorthosite band. Pyroxenes are hypersthene and augite, and plagioclase is andesine, An36.

Fig. 18). Crossed nichols; Diameter of field, 4.8 mm. Same contact.

The strong foliation exhibited by the thinly laminated anorthositic rocks, and the granulose textures in the thin sections studied, indicate that the original magmatic banding has probably been accentuated by deforming forces which caused a differential movement in the semi-crystalline rocks. The granulation is interpreted as being protoclastic rather than cataclastic.

## Hybrid Granite

North of the bridge is found a body of rock designated hybrid granite on the map. This rock is very strongly foliated, but banding was only apparent within two included bodies, one of gabbroic anorthosite and the other of gabbro. The rock has the appearance of a strongly gneissic granite, with paper-thin lamellae of biotite imparting the foliated aspect to it. The brownish-red weathered surface usually displays the foliation well, but it is even more apparent on the pinkish-white fresh surface. The rock is fine-grained, with a few very small (1 mm.) augen of white feldspar developed parallel to the foliation planes. Abundant quartz, pink feldspar and a little biotite can be distinguished megascopically, and so this rock was mapped in the field as a gneissic granite.

Two thin sections were cut of this rock, and the mineralogical composition was found to be: quartz 24 and 40 per cent, microcline 16 per cent and orthoclase 16 per cent, antiperthite 18 and 7 per cent, plagioclase 38 and 35 per cent, biotite 1 and 1 per cent. Epidote, allanite, sericite, spinel and another opaque mineral were identified in one or both of the sections. Under high power magnification, tiny rod-like inclusions of an opaque mineral (possibly ilmenite) were noted aligned along regular planes (probably cleavage planes) in the larger, faintly twinned grains of plagioclase. Cote (1948, p. 36), among others, has noted similar inclusions in the plagioclase of the Ashton facies of the Morin anorthosite massif of the Laurentians, and he has discussed their composition. He notes that in the strongly sheared Chertsey facies, these inclusions are found only in the larger grains of plagioclase occurring in a granulated groundmass. None of these inclusions were noted in the plagioclase of the layered complex rocks.

The composition of the plagioclase was determined to be An34 in one of the sections studied, but the other contained very little twinned plagioclase and no grains which were oriented normal to (010), hence no determination of its composition was made.

The texture of the rock was slightly porphyroblastic, with small porphyroblasts of antiperthite set in a granulated groundmass of microcline and orthoclase, quartz, and largely untwinned plagioclase (fig. 19 & 26). Rounded inclusions of untwinned feldspar with a relatively high relief often occur in potassic feldspars.

The composition of this rock makes difficult any attempt to classify it. Klugman (1956) has included it in his quartz-monzonite subdivision of the Bailloquet igneous complex, and this placement is as accurate as can be made in ordinary igneous classification. The composition would place the rock in the quartz-leucomonzonite class of Johannsen (1939, vol. 1), but even then the extreme paucity of mafic minerals (3 and 4 per cent in the rocks studied) makes this placement questionable.

This rock is interpreted as being the result of the forceful injection of a syenitic or granitic magma into rocks of anorthositic composition. The granulation is interpreted as a protoclastic fabric. In this interpretation the injected syenitic or granitic body was contaminated by the anorthositic rocks, yielding a final product with a high plagioclase content of intermediate calcicity. Since this rock has the field aspect of a granite, and except for the composition of the plagioclase, the composition of a granite, and since it is interpreted as being the result of contamination of a normal magma, it has been called a hybrid granite in this thesis.

Two mappable bands of pyroxene-rich and anorthositic rocks, and several smaller ones were noted in the hybrid granite, parallel to the foliation. Stringers of pink feldspar, as well as isolated crystals of this mineral, were noted cutting across foliation planes within these bands. These bands are interpreted as being undigested remnant of blocks of country rock engulfed by the emplaced magma.

Fig. 19). Crossed nichols; diameter of field, 4.8 mm. Granulation in hybrid granite. Antiperthite porphyroblasts in a fine-grained groundmass of quartz, orthoclase, plagioclase, magnetite and biotite.

Fig. 20). Crossed nichols; Diameter of field 1.55 mm. Antiperthite in hybrid granite, with groundmass of quartz, plagioclase and orthoclase.

## Lamprophyre Dyke Rocks

In the field, several sets of lamprophyre dykes were seen to cut the rocks of the layered complex (fig. 6). Upon petrographic examination, it was found that two types of lamprophyres were represented. These are minette and kersantite. All the minette dykes are now schistose, and can be termed mica schists.

### Minette

This rock is the most commonly occurring type of lamprophyre in the map area. It is a dark brownish green-gray on the weathered surface, and a lighter greenish-gray on the fresh surface. It is dense, aphanitic to fine-grained, and is always schistose, some specimens more strongly so than others. Mica and chlorite were the minerals which could be distinguished with the naked eye, and a few small phenocrysts or porphyroblasts of pink feldspar were also noted.

Five thin sections of this rock were cut, and two subtypes were distinguished, one in which the chief dark mineral was biotite, and the other in which the chief dark mineral was chlorite. The chlorite variety of minette was found included in and cut by large granitic pegmatite bodies, while the biotite variety came from dykes which cut the layered complex rocks.

The composition of the chlorite variety is as follows: chlorite (pennine) 28 per cent, quartz 15 to 20 per cent, orthoclase 40 to 45 per cent, opaque minerals 0 to 10 per cent, biotite 0 to 1 per cent, apatite 1 to 5 per cent, sphene 2 to 5 per cent, plagioclase 3 per cent.

The composition of the biotite variety is as follows: chlorite 0 per cent, quartz 10 per cent, orthoclase 35 to 42 per cent, opaque minerals 5 to 15 per cent, biotite 25 to 30 per cent, hornblende 2 to 4 per cent, apatite 4 per cent, sphene 3 to 5 per cent, and plagioclase 2 per cent.

The chlorite variety is considered to be an alteration of the biotite lamprophyre, having had its biotite and hornblende completely altered to chlorite, with some quartz being added from the pegmatite.

A few phenocrysts of orthoclase are found in this rock, but the texture is pandiomorphic-granular rather than porphyritic. Biotite and pennine, opaque grains (probably magnetite), apatite and sphene are all euhedral.

Kersantite

A dyke approximating this composition is found being cut by an andesinite dyke. Another thin body of almost similar composition is found as a sill in the layered complex. These rocks are dark gray to greenish-black on the weathered surface and black on the fresh surface. They are less apparently schistose and more dense than the minette in the hand specimen, and also finer-grained (aphanitic).

Two thin sections of these rocks were examined under the microscope, and they showed the following mineralogical composition: a) plagioclase (An38) 60 per cent, biotite 11 per cent, hornblende 16 per cent, quartz 6 per cent, opaques

5 per cent, apatite 2 per cent, b) Plagioclase (An42) 32 per cent, biotite 25 per cent, quartz 10 per cent, clinochlore 14 per cent, orthoclase 10 per cent, magnetite 3 per cent, apatite 5 per cent, clinozoisite 1 per cent.

The hand specimen from which this second section was cut shows stringers of potassic feldspar cutting across it, and pink feldspar porphyroblasts throughout, and so the orthoclase and higher content of quartz are assumed to be introduced.

A few phenocrysts of plagioclase were found in thin section (a), and orthoclase forms small augen in thin section (b). Biotite, apatite and plagioclase often form euhedral crystals, and the texture is best described as pandiomorphic granular, and not porphyritic (fig. 21). Thin section (a) showed several grains of plagioclase which contained tiny inclusions of pyroxene, biotite, and an opaque mineral. These inclusions are arranged along parallel planes, or are found rimming eliptical shaped grains of plagioclase (figs. 21 & 22). No explanation of this phenomenon can be given.

These rocks are aphanitic, having a grain size of from .1 to .3 mm. A distinct foliation is apparent in thin sections, although on account of its fine grain size the rock does not have a pronounced schistosity in the hand specimens.

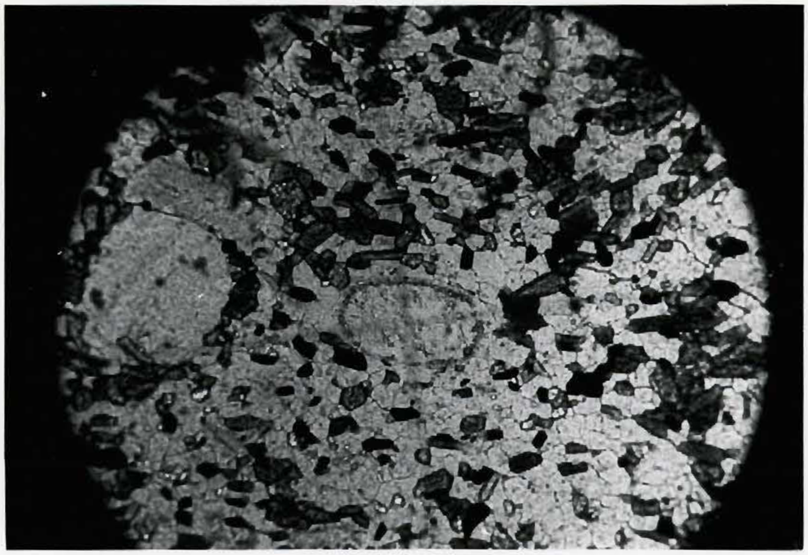


Fig. 21). Plane light; diameter of field, 1.55 mm. Lamprophyre dyke (Kersantite). Note two phenocrysts of plagioclase, one of which is outlined by minute crystals of pyroxene, biotite, and an opaque mineral, set in a groundmass of biotite, plagioclase and hornblende.

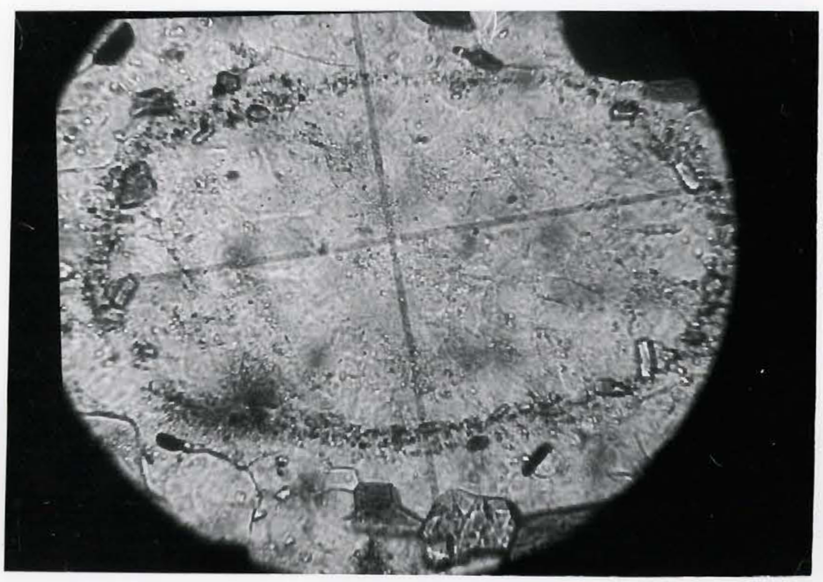


Fig. 22). Plane light; Diameter of field 0.35 mm. Plagioclase phenocryst, rimmed by minute crystals of pyroxene, biotite, and an opaque mineral, in a kersantite dyke.

## Felsic Dyke Rocks

Several ages of felsic dykes can be made out in the La Chaloupe map area. From oldest to youngest they are: andesinite dykes, granitic dykes, feldspathic and aplitic dykes.

### Andesinite Pegmatite Dykes

This rock type occurs as dykes from 4 inches to 15 feet wide. It is coarse-grained, and a mottled black and rusty-brown on its weathered surface. The fresh surface is a mottled pinkish-brown and green-gray colour, and in places is almost white where the feldspar has been highly saussuritized. Coarse leaves of mica, up to 2 inches long, are set in a mass of twinned plagioclase crystals which reach 2 inches in length. Grains of a magnetic metallic mineral, assumed to be magnetite, were noted, as well as a few medium-sized grains of pyroxenes and quartz. A megascopic estimate of the composition of this rock is given as follows: plagioclase 85 per cent, biotite 10 per cent, pyroxene plus quartz plus magnetite 5 per cent. Some of the biotite appears to be chloritized.

Three thin sections of the andesinite dyke were cut, but these served little purpose except to determine the composition of the plagioclase, for almost the whole of the slides in two of the sections cut were made up of a single plagioclase crystal. Universal stage determinations showed the composition of the plagioclase to be An30 and An34. The plagioclase crystals are quite highly altered to sericite, and the biotite is partially altered to pennine. Smaller grains of plagioclase show only faint twinning, and in one of the sections studied, micro-faults cut the large plagioclase crystals. An opaque mineral (identified as magnetite from polished sections studied) and a little quartz were noted in each of the two sections studied.

In the third thin section examined, a microscopic stringer of quartz and orthoclase cut across the plagioclase crystal, and comprised 85 per cent of the section. The composition of the plagioclase is An30.

The contacts of the andesinite dykes and the layered complex rocks are often heavily mineralized, and sometimes the mineralization extends into the andesinite dykes. A sample of the mineralization from this contact was taken and crushed. Most of the crushed metallic grains were attracted by a magnet, but some were not. These latter were identified as ilmenite. Since no ilmenite was found in the polished or thin sections studied, the heavy concentrations of ilmenite-magnetite are interpreted as being the result of a remobilization and localization of the andesinite.

## Granitic Pegmatite Dykes

Many of these dykes cut across the rocks of the layered complex, and also the andesinite pegmatites. They vary in grain size from fine to coarse, and are a whitish-pink colour on both the fresh and weathered surfaces. The texture is usually sugary, and several coarse leaves of mica are found as phenocrysts in the rock. Minerals identified in the hand specimen are pink feldspar, quartz, biotite, magnetite, and a little hornblende. Feldspar was estimated to compose 70 per cent of the rock, and the quartz 20 per cent. A common feature of these granitic pegmatite dykes is the gradation from coarse- to fine-grain size from the edges of the dyke to the center. This gradation probably reflects a loss of volatiles during the crystallization of the pegmatite.

Four thin sections of these dykes were examined, and the composition varied as follows: microcline 20 to 50 per cent, orthoclase 20 to 50 per cent, quartz 20 to 35 per cent, plagioclase 0 to 5 per cent. Biotite altering to chlorite, hornblende, and a little magnetite were found in all sections in very minor amounts. Myrmekite was noted in one section. Allanite, zircon, apatite, and pleonaste were other minerals identified in one or more of the sections studied. The composition of the plagioclase was determined by use of a univeral stage as An30.

The texture of these rocks is sugary, with few crystal faces being developed.

A concentration of ilmenite-magnetite along the borders of granitic pegmatic dykes similar to the concentration along the edges of andesinite dykes was noted. The same explanation of remobilization and localization is offered for these concentrations. The occurrence of similar mineralization adjacent to dykes of different ages and compositions adds strength to the view that these dykes were important in relocalizing the metallics, but not in introducing them.

Feldspathic and Aplitic Dykes

Dykelets composed entirely of pink potassic feldspar are very abundant in the map area, and cut all the other rock types of the area. These dykes are less than 3 inches wide usually, and are composed of potassic feldspar crystals which vary in grain size from fine to coarse. No thin sections of these rocks were examined.

Aplitic veins cut the rocks of the layered complex in many places. This rock is a brick red colour both on the weathered and fresh surfaces, and is very fine-grained, almost aphanitic. Stringers of epidote are very common in the aplite.

One thin section of an aplitic dyke was studied. Quartz, orthoclase and myrmekite composed 85 per cent of the rock, and these minerals occurred intergrown in a very irregular, fragmental manner. Epidote composed 8 per cent of the rock, and a reddish dust was very abundant in the thin section. This dust could be an iron oxide, or more probably a potassic feldspar dust produced in preparation of the section.

Porphyroblasts and Antigorite

It has been noted that in one location a cluster of coarse pyroxene crystals occured along foliation planes in gabbroic anorthosite (fig. 23). These crystals also cut across the foliation planes. They are very coarse-grained, and black with a sub-metallic luster. A thin section of one of these crystals was examined, and it was found that the pyroxene was hypersthene (fig. 24). This orthopyroxene occurred as porphyroblasts in a hypidiomorphic groundmass of hypersthene. Plagio-

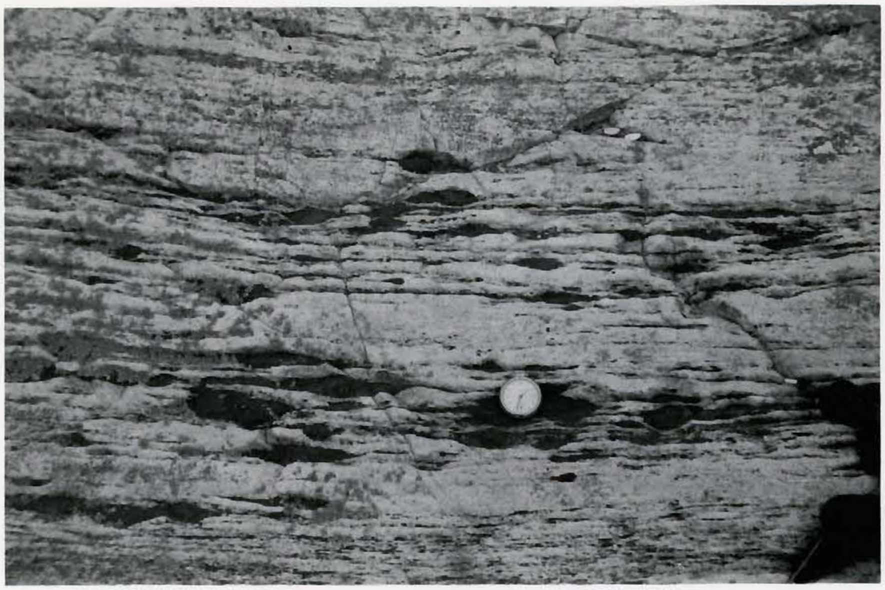


Fig. 23).
Cluster of hypersthene crystals along foliation planes in gabbroic anorthosite.

Fig. 24). Plane light; Diameter of field, 1.55 mm.
Schiller structure in hypersthene.

clase of composition An48 is present in the slide, but only in one thin lamellae which appears to be cut by the hypersthene. An opaque mineral made up 25 per cent of the slide, and formed an equigranular texture with the pyroxene.

These hypersthene crystals are interpreted as porphyroblasts introduced into the gabbroic anorthosite at a later stage in the consolidation of the rock. No definite statement can be made on the relationship of the porphyroblasts to the metallic minerals on the data available, but examination of the one thin section indicates that the hypersthene porphyroblasts may have been introduced slightly before the ilmenite-magnetite.

One thin section cut from the rock occurring along a contact between an anorthositic band and a pyroxene-rich band contained 60 per cent antigorite. This mineral rims and almost completely replaces augite. Magnetite 10 per cent, pleonaste 8 per cent, and chlorite 15 per cent, were other minerals present. The presence of a serpentine mineral along this zone indicates that shearing has taken place.

## Cobaltinitrate Staining and X-Ray Fluorescence

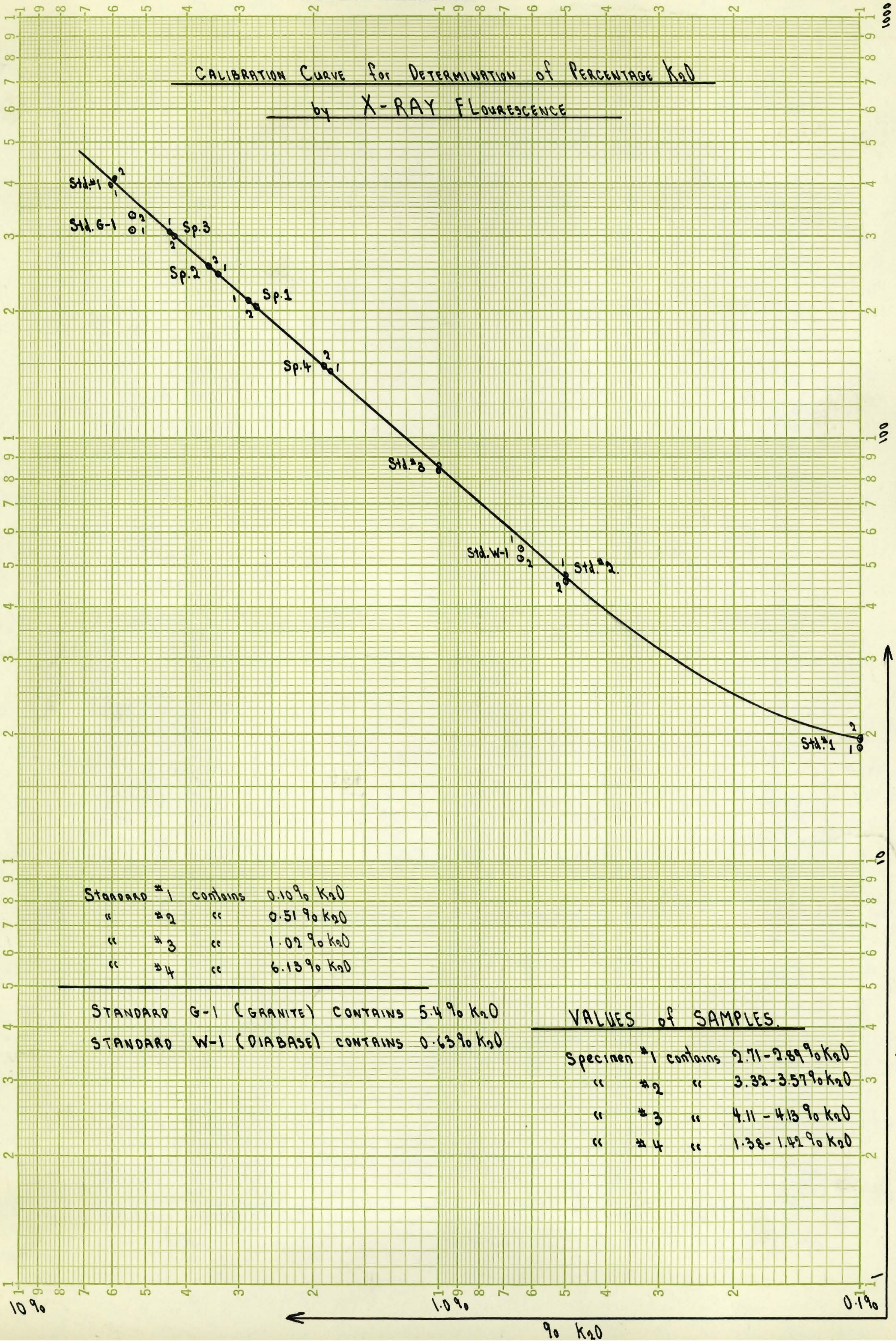
In the course of studying the relationship of the body of hybrid granite to the rocks of the layered complex, the possibility of a metasomatic introduction of material from the hybrid granite into the anorthositic rocks was considered. Since much of the plagioclase of the anorthositic rocks was untwinned, and therefore distinguishable from potassic feldspars only with difficulty, the staining procedure outlined by Chayes (1952) was employed to determine the potassic feldspar content of the rocks. It was decided to stain not the thin sections, but cut and polished slices of rocks, and to this end 22 rock slices were prepared. The HF etch and sodium cobaltinitrate stain were then carried out, rigidly following the method outlined by Chayes. The polished surfaces of the rock slices were then studied under a mineralogical microscope. It was found that only one of the slices showed any appreciable sign of a stain, and yet it was known that at least two of the rocks stained contained potassic feldspar.

In order to check the accuracy of the results of the staining procedure, four of the rock were analyzed for potassium by X-rey fluorescence, using a helium chamber in order to provide an inert atmosphere for the experiment, and so to minimize the factor of air absorption. In analyzing by X-ray fluorescence, standard samples were carefully prepared, containing known amounts of $K_2O$. These standards were mixed with equal weights of lead nitrate, as were the samples to be analyzed. The purpose of adding the lead nitrate was to attempt to equalize the matrix effects, that is to add a weight of material which would minimize, by overshadowing, the absorption effects of other components in the different matrixes. A calibration curve was obtained (Plate IV), and its accuracy was established by analysing standard specimens of diabese(W-1) and granite(G-1) prepared by the United States

# PLATE IV



## Calibration Curve for Determination of Percentage $K_2O$ by X-Ray Flourescence




| | | | |
|---|---|---|---|
| Standard #1 | contains | 0.10 % $K_2O$ |
| " #2 | " | 0.51 % $K_2O$ |
| " #3 | " | 1.02 % $K_2O$ |
| " #4 | " | 6.13 % $K_2O$ |

Standard G-1 (Granite) contains 5.4 % $K_2O$

Standard W-1 (Diabase) contains 0.63 % $K_2O$

### Values of Samples.

| | | |
|---|---|---|
| Specimen #1 | contains | 2.71-2.89 % $K_2O$ |
| " #2 | " | 3.32-3.57 % $K_2O$ |
| " #3 | " | 4.11 - 4.13 % $K_2O$ |
| " #4 | " | 1.38- 1.42 % $K_2O$ |

Bureau of Standards, and plotting the values obtained on the curve. The points so obtained fell very close to the curve determined experimentally, and thus established that the order of magnitude of obtained results would be fairly correct.

The four rocks were than analyzed, and the results obtained were markedly different from those obtained by staining. Rosiwal analyses of the thin sectionscut from the rocks stained were then carried out, and by using relative relief as a basis for distinguishing potash feldspar from quartz, the potassic feldspar content, as well as the content of other potassic minerals, of each slide was determined. These results agreed more nearly with those obtained by X-ray fluorescence than those obtained by staining. A comparison of the results obtained by these methods is shown in Table III. In this table, the percentages of $K_2O$ shown in columns 2 and 3 have been calculated from the content of potassic feldspar as shown by staining (column 3), or from the content of all the potassium-bearing minerals in the thin section, such as, potassic feldspar, sericite, perthite or biotite (column 2).

The results of these experiments show that, in this particular case, the staining method was not effective. It should be stressed that the outlined procedure was rigidly followed. An explanation of this failure cannot be given, but it is suggested that the reason for the lack of success lies in the concentration of the HF used in the etching, for this concentration is the only item not definitly specified. Another possible explanation is that a considerable amount of $K_2O$ is in solid solution in the plagioclase.

## MINERALOGRAPHY

W.W. Longley(1944) collected a suite of iron-titanium mineral specimens from the North Shore, and Osborne(1944) has studied polished sections of these specimens. He reports that they consist predominantly of ilmenite, with low gangue content. Spinel was observed in all sections studied.

A specimen from Magnet Point (i.e., Cap Rond - see Plate II) was studied and is reported to contain separate grains of ilmenite and magnetite, the proportions being two to one, ilmenite to magnetite.

Klugman(1956) has also studied a polished section from Cap Rond, and reports the presence of pyrrhotite. No specimen taken from a point closer to the thesis area has been reported.

Dulieux(1911) made astute observations on the "titano-magnetite" bodies at La Chaloupe and Cap Rond, but no mineralogical study of the specimens was made.

### Mineralized Pyroxene-Rich Bands

Nine polished sections prepared from the mineralized pyroxene-rich bands were examined under the reflecting microscope. The metallic minerals identified, in order of abundance, are ilmenite, maghemite, magnetite, titanhematite, spinel and pyrite. The gangue minerals, determined by use of a binocular microscope, were pyroxene, amphibole and biotite predominantly. Ilmenite grains make up approximately 60 per cent of the opaque minerals in the sections studied.

Ramdohr(1953) has stated that ulvospinel, $Fe_2TiO_4$, is a mineral frequently found in iron ore, but this mineral was not identified in any of the polished sections of the iron ore at La Chaloupe.

## Ilmenite

Ilmenite, $FeTiO_3$, occurs as discreet anhedral grains and also forms laths in magnetite grains. It is harder than magnetite, but slightly softer than hematite. The colour of ilmenite seen next to magnetite is violet gray; next to titanhematite, pinkish-gray; next to maghemite, a distinct pink gray. It is strongly anisotropic from greenish-gray to brownish-gray and gives a negative reaction to all standard reagents. When treated with HF, ilmenite readily etches and tarnishes brown. In three of the sections studied the ilmenite encloses very small lenticular bodies of titanhematite, which are exsolving along planes parallel to (0001) (Uytenbogaardt, p.184). Spinel also occurs in ilmenite as thin tablets, arranged parallel to the base and at right angles to it. All sections studied showed spinel present in ilmenite, but this mineral could only be detected under crossed nichols.

## Maghemite

Maghemite, (the unstable form of magnetite- $\gamma Fe_2O_3$), is a distinctly bluish-gray colour when seen in contact with either magnetite or ilmenite. It is harder than magnetite, and completely isotropic. It gives no reaction with any of the standard reagents. Maghemite is only known to form as an oxidation product of magnetite, and it is found in all the sections from the mineralized bands. Characteristically, maghemite is found as a cloud-like material in the magnetite, and all the magnetite is altered in some degree to maghemite. The contacts between maghemite and magnetite are very hazy and seem to be gradational even when observed under high power magnification. The ilmenite lamellae occupying the octahedral parting planes in magnetite are unaltered in maghemite (Uytenbogaardt, p. 174).

## Magnetite

Magnetite, $Fe_3O_4$, is various shades of light gray. Next to ilmenite it appears whitish-pink, and next to maghemite it has a brownish-gray colour. This mineral is found in discreet anhedral grains, and in most cases is at least partially altered to maghemite. Magnetite sometimes exhibits a very weak anomolous anisotropism from dark gray to lighter gray, but most grains are isotropic. Octahedral partings were seen to be filled by ilmenite laths. Tiny inclusions and thin laths of spinel were also noted in several grains. Magnetite did not react with concentrated HCl, but hot concentrated HCl blackened the mineral rapidly (Uytenbogaardt, p. 175 and Short, 1940).

Titanhematite

Titanhematite, or White Ilmenite, is the term proposed by Edwards(1938) for ilmenite which carries up to 6 per cent of $Fe_2O_3$, or hematite which carries up to 10 per cent of $TiO_2$ in solid solution. If more than 6 per cent of $Fe_2O_3$ is present in ilmenite, or if more than 10 per cent of $TiO_2$ is present in titanhematite, the excess forms exsolution laths in the major component(Edwards, 1938, p.40). Titanhematite shows only weak anisotropism, light to dark gray, and no internal reflection. When tested with HF, the ilmenite reacted, but the titanhematite did not. As seen next to ilmenite, this mineral appeared a cream colour. Titanhematite was distinguished from magnetite by its slight anisotropism, and its failure to react with hot or cold concentrated HCl or aqua regia.

Spinel

This mineral, a form of $Al_2O_3$, has a very low reflectivity, about the same as that of a gangue mineral. It is harder than any of the opaque minerals, and it is not affected by any of the standard reagents. This spinel has been identified as pleonaste from thin section study. It occurs as very small inclusions in magnetite, as lamellae

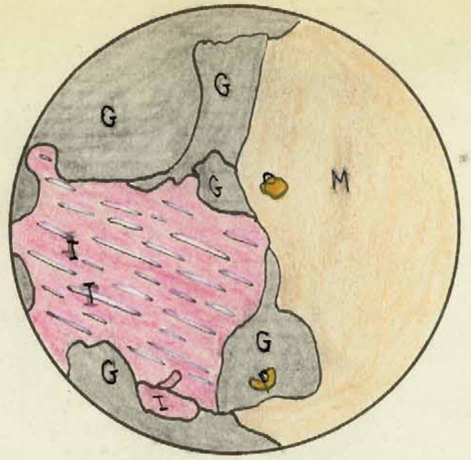



Fig.25). Plane light; Diameter of field, 3mm. Camera lucida drawing of magnetite-ilmenite-titanhematite relationships. Note exsolution laths of titanhematite in ilmenite. M-Magnetite, I-Ilmenite, T-Titanhematite, P-Pyrite, G-Gangue.

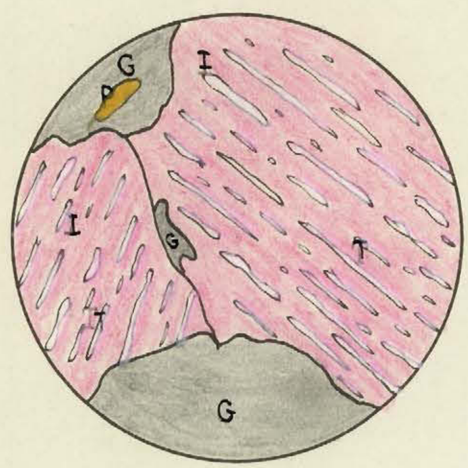



Fig. 26). Plane light; Diameter of field, 1.07mm. Camera lucida drawing of titanhematite exsolution laths in ilmenite. T-Titanhematite, I-Ilmenite, P-Pyrite, G-Gangue.

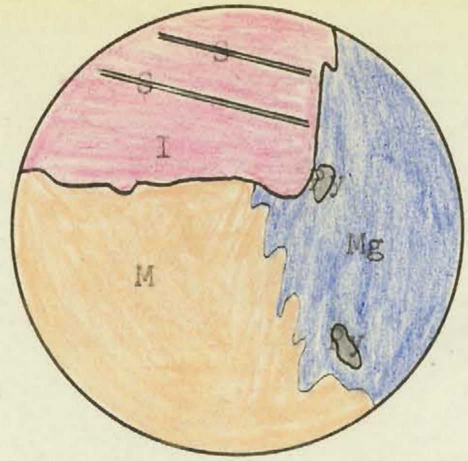



Fig.27). Plane light; Diameter of field, 1.07mm. Camera lucida drawing showing alteration of magnetite to maghemite. Note granular relationship of ilmenite and magnetite. M-Magnetite, I-Ilmenite, Mg-Maghemite, Py-Pyroxene, S-Spinel.


Fig.28). Plane light; Diameter of field, 3mm. Camera lucida drawing showing metallic minerals cutting gangue. M-Magnetite, I-Ilmenite, Mg-Maghemite, S-Spinel, G-Gangue.

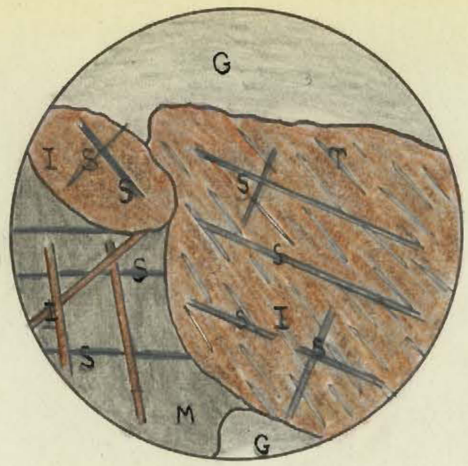



Fig.29). Crossed nichols; Diameter of field, 3mm. Camera lucida drawing showing spinel laths in both ilmenite and magnetite, ilmenite laths in magnetite, and blebs of titanhematite in ilmenite. M-Magnetite, I-Ilmenite, T-Titanhematite, S-Spinel, G-Gangue.

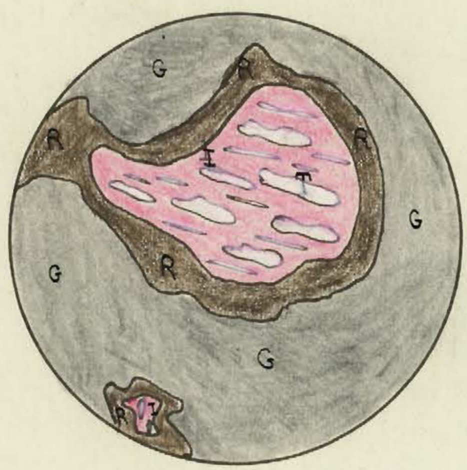



Fig.30). Plane light; Diameter of field, 1.07mm. Camera lucida drawing showing rutile rimming grains of ilmenite containing two distinct sizes of titanhematite blebs. I-Ilmenite, T-Titanhematite, R-Rutile.

in magnetite and ilmenite, and also as discreet grains about the edges of clusters of the metallic minerals. Spinel never comprises more than 5 per cent of the opaque minerals in the sections studied(Uytenbogaardt, p. 175).

Pyrite

A few minute grains of pyrite are found scattered throughout the sections examined. This yellowish-white mineral never makes up more than 1 per cent of any section, and rarely that. It occurs as discreet anhedral grains in both the metallic and gangue minerals (Uytenbogaardt, p. 200).

Textures and their Interpretations

The most characteristic texture in the mineralized pyroxene-rich bands is a granular, allotriomorphic relationship between ilmenite and magnetite grains (figs. 27, 28, 29). Exsolution textures of titanhematite-ilmenite, ilmenite-magnetite, spinel-magnetite, and spinel-ilmenite, a replacement texture of maghemite for magnetite, and the peculiar occurrence of ilmenite-titanhematite and magnetite in the same specimen, have all been noted, and are further described below.

i. Titanhematite-ilmenite: No discreet grains of hematite were found in any of the sections studied. Titanhematite, a titanium-bearing hematite, was found intergrown in ilmenite. In these intergrowths ilmenite forms the host material, and titanhematite forms lens-like discontinuous exsolution bodies in the ilmenite (figs. 25 & 26). These bodies are generally elongated, and parallel the (0001) direction of the ilmenite. Osborne(1928, 2, p. 911) and Edwards(1938, p.43) have both described two sets of titan-hematite lamellae, one large and one small, but only the tiny exsolution lamellae were noted in the La Chaloupe sections. The nature of these exsolution laths formed the main basis for identification of this mineral as ti-tanhematite, for the mineral is less anisotropic than the described properties indicated it should be. Another pos-sibility was that the mineral was magnetite, but exsolu-tion of magnetite from ilmenite is a very uncommon tex-ture (Osborne, 1944, p.33) and should form much more reg-ular bodies than those noted in the examined sections.

Ramdohr(1926) and Posnjak and Barth(1934) have done experiments showing the existence of a solid solu-tion of ilmenite-hematite at temperatures above 700-800 degrees C. Below this temperature, exsolution of titan-hematite from ilmenite will take place provided the $Fe_2O_3$ content of ilmenite is greater than 5.6 per cent (Edwards, 1938, p.49). Ramdohr considers that the exsolution will take place in two stages, one at 700 degrees C., and the second at 500-600 degrees C. His basis for this postu-late is the disappearance of the larger lamellae of hema-tite at the higher temperature, while the small blebs of hematite disappear at the lower temperature, upon exper-imental heating of specimens showing both these lamellae sets. He does not consider the temperature of exsolution of specimens with only the finer intergrowth. Grieg (1932) has questioned this interpretation, and Edwards, too, doubts its validity. The presence of only the smaller bodies of titanhematite has been interpreted by Edwards as indicating merely a lesser amount of hematite remaining in solid solution in the ilmenite (Edwards, 1938, p. 44). It would seem that the temperature of exsolution in the La Chaloupe specimens can lie between 800 degrees C. and 500 degrees C., and that the $Fe_2O_3$ content in ilmenite was small.

ii. Magnetite-ilmenite: In a few instances in the sections studied, ilmenite was seen to be present as thin laths in the magnetite (fig. 29). Three sets of laths are found in the magnetite, but one of these sets was found to be composed of spinel. These laths are interpreted as exsolution bodies of ilmenite, and the temperature for unmixing which Ramdohr proposes is between 700 degrees C. and 800 degrees C.(Ramdohr, 1926, p.374). Above this temperature, the mutual solubility of the magnetite and ilmenite is great. It is probable that this exsolution takes place at a higher temperature than that of ilmenite and hematite, according to Edwards(1938, p.49).

When the cooling is slow, the ilmenite-magnetite solid solution can completely unmix (Edwards, p. 48, and Osborne, 1928, p. 911). The occurrence of discreet grains of ilmenite and magnetite, and the paucity of ilmenite laths in magnetite indicate that the cooling of the solid solution of magnetite and ilmenite was sufficiently slow to allow almost complete unmixing, producing the granular intergrowth of ilmenite and magnetite typical of the La Chaloupe polished sections.(figs. 27 & 29). This granular, allotriomorphic texture is the most characteristic texture of the sections studied.

<u>iii</u>. Magnetite-ilmenite-titanhematite: Although many descriptions of the ilmenite-hematite and the magnetite-ilmenite textures can be found, a magnetite-ilmenite-titanhematite texture is seemingly rare, for only one description of an occurence similar to that at La Chaloupe could be found (Bray,1939), and here no attempt at explanation is made. As has been described, however, in the map-area, ilmenite grains, which are in sharp contact with magnetite grains, contain exsolved bodies of titanhematite.(fig. 25).

It thus appears that as well as an exsolution of ilmenite from magnetite, there was a roughly contemporaneous separation of hematite from ilmenite. In order to produce this texture, it is necessary to postulate that the melt from which the magnetite-ilmenite-titanhematite formed was unusually rich in ferric ions. According to Shand(1947, p.635), who based his calculations on Clarke and Washington's figures for average igneous rocks, FeO molecules outnumber Fe2O3 molecules by a three to one ratio in deep-seated magmas. Hence, in most cases FeO would so predominate in an iron ore melt, that all ferric ions would immediatly be taken up to form magnetite ($FeO.Fe_2O_3$). In the La Chaloupe ore bands, however, ferric ions must locally have reached a concentration which was sufficient to allow $Fe_2O_3$ to be present in solid solution with ilmenite, as well as to satisfy the requirements of the FeO to form magnetite. This surplus amount of $Fe_2O_3$ was just great enough to allow laths of titanhematite to form in the ilmenite upon the slow cooling of the melt, but not great enough to allow discreet grains of hematite to form, or even to form a larger set of titanhematite lamellae in the ilmenite. The excess $Fe_2O_3$ must then have amounted to just over 6 per cent of the ilmenite-hematite solid solution.

Magnetite lamellae could not have been oxidized to hematite under atmospheric conditions to produce the magnetite-ilmenite-titanhematite texture, for besides the absence of the regularity in the lamellae which characterizes the rare texture of magnetite exsolution laths in ilmenite, the abundant grains of magnetite in the sections studied show no complete alteration to hematite. The unstable form of hematite, maghemite, is found as an alteration product of magnetite, but this mineral is readily distinguished from the mineral forming exsolution laths in the ilmenite.

<u>iv</u>. Maghemite-magnetite: Wagner(1927) has proposed the term maghemite for an oxidation product of magnetite which has properties intermediate between those of magnetite and hematite. This mineral is found in typical fashion as cloudy material intimately ingrown with the magnetite, producing pinkish grains befogged with bluish patches. Contacts between

the maghemite and magnetite are very hazy, but are discernable under high power magnification.(fig. 27).

The pervasive nature of this association, both in mineralized bands and in magnetite grains in anorthositic and pegmatitic rocks, indicates that the texture was produced by atmospheric oxidation.

v. Spinel-magnetite, spinal-ilmenite: Thin lamellae of spinel occur as regularly arranged laths in both magnetite and ilmenite(fig. 29). Osborne has noted as a generality that the tablets of spinel included in ilmenite are not as continuous or regular as those in magnetite, but this does not hold true for the La Chaloupe sections. The ilmenite grains contain continuous laths of spinel oriented in directions parallel to the base and at right angles to it, while the magnetite contains only one set of spinel lamellae, arranged parallel to the face of the cube. These lamellae in magnetite are more rare than those occuring in ilmenite.

Spinel also occurs in very small blebs in the magnetite. These regularly arranged blebs were found in grains of magnetite which contained no lamellae of spinel, but not in those grains which contained spinel lamellae.

In all sections studied, spinel was found as discreet grains near the margins of clusters of metallic minerals(fig. 28).

Ramdohr(1926, p.371) has performed experiments on the solution of spinel in magnetite, and the temperatures of unmixing, and has concluded that above 800 degrees C., spinel exists in solid solution in magnetite, but that unmixing takes place below that temperature.

It is thought that the slow cooling of the titanium-iron melt produced nearly complete exsolution of spinel from magnetite. The texture of dots and dashes of spinel along regular planes in magnetite is interpreted as an intermediate step in the exsolution sequence from lamellae to discreet grains. The relatively small number of spinel laths in magnetite can be explained by the presence of discreet grains of spinel on the assumption of a nearly complete exsolution. The temperature of exsolution was probably around 800 degrees C.

vi. Pyrite: Pyrite occurs in very small quantities as minute rounded grains in ilmenite, magnetite and gangue. The relationship between this mineral and the other metallics could not be made out in the sections studied.

vii. Gangue-metallics: In most of the polished sections studied, the textures between the gangue material and the metallic minerals were indeterminate. Mutual boundaries textures were most common, and contradictory textures of gangue cutting metallics, and metallics cutting gangue were noted. In two sections, however, the ilmenite-magnetite-maghemite-spinel assemblage was seen to definitly cut, and to include fragments of the gangue(fig. 28). In several thin sections studied, an opaque mineral(s) is seen to cut and include the pyroxene and hornblende of the mineralized band (figs. 13 & 16).

From these relations, it is concluded that the metallic minerals formed at a later stage than the gangue minerals. The textures indicate that although the difference in age of formation between the gangue and the metallic minerals may not be great, there is a distinct separation in time. The difference in age is to be distinguished from one which represents an order of crystallization difference.

## Paragenesis

The textures occuring in the sections studied indicate that the metallic minerals crystallized slightly later than the silicate gangue minerals. The cooling process was slow, and the temperature at which the introduction was effected was well above 800 degrees C. The melt cooled to produce a solid solution of ilmenite and spinel in magnetite. Exsolution began below 800 degrees C., and slow cooling allowed the almost complete unmixing of ilmenite from magnetite, and spinel from magnetite to form discreet grains. An excess of $Fe2O3$ molecules over the amount necessary to form magnetite in the melt allowed hematite to be taken into solid solution in the ilmenite. At a temperature somewhere between 800 degrees C. and 500 degrees C. exsolution of $Fe2O3$ from ilmenite, in the form of small blebs of titanhematite, took place. Spinel continued to unmix from ilmenite and magnetite during this period. Atmospheric conditions produced a partial oxidation of magnetite to maghemite as the final stage in the history. The position of pyrite in this paragenitic sequence is uncertain.

## Gabbroic Anorthosite

Two polished sections were prepared from the banded gabbroic anorthosite which forms the country rock for the heavily mineralized bands. The opaque minerals identified were, in order of their abundance, ilmenite, magnetite, titan-hematite, maghemite, titaniferous magnetite, spinel, rutile, pyrite and chromite. In one of the polished sections, one lamellae of biotite and metallic minerals one-eighth of one inch thick, contained 80 per cent of the opaque minerals present in the section. The foliated anorthositic portion of the section contained less than 5 per cent metallic minerals. The metallic content of the rocks studied was less than 5 per cent.

### Metallic Minerals and their Textures

Pyrite, ilmenite, magnetite, maghemite and titan-hematite have been described in a previous section, and, since there is no change in their properties, no further description is necessary. The textures among these minerals are also similar to those previously described, that is, exsolution bodies of titanhematite in ilmenite were noted, as well as discreet grains of ilmenite and magnetite producing a granular allotriomorphic texture.

No exsolution laths of ilmenite from magnetite were noted in these sections, nor was spinel seen to exsolve from magnetite or ilmenite. This would seem to indicate a long cooling period, allowing complete unmining of the ilmenite from magnetite and spinel from both ilmenite and magnetite. Oxidation of magnetite to maghemite was not as pronounced in these sections as in those from the mineralized pyroxene-rich bands.

i. Spinel: Spinel occurs more abundantly in the gabbroic anorthositic rocks than in the heavily mineralized bands. In one of the polished sections of the anorthositic rocks, spinel comprised 50 per cent of the opaque minerals. The properties of spinel were similar to those of the spinel found in the ore bands, (i.e. it is isotropic and very hard, has a low reflectivity and a slight internal reflection, and is unaffected by all standard reagents).

Spinel occurs as discreet grains around the edges of clusters of metallic minerals. In one narrow band of metallics and biotite one-eighth of one inch thick, spinel and rutile occured as a graphic intergrowth comprising about 60 per cent of the opaque minerals of the band. It was in this same band that three small anhedral grains of chromite occured. In this texture, the rutile appeared to be indented by and contained in the spinel.

ii. Rutile and titaniferous magnetite: Rutile was identified in both of the sections from the gabbroic anorthosite. This mineral, $TiO_2$, is a little softer than spinel but harder than ilmenite and magnetite. It is a dark grey colour, with a slightly higher reflectivity than spinel, and shows strong anisotropism from yellow grey to black (four positions of extinction). A brown-orange internal reflection was noted and the mineral was unaffected by all standard reagents.

In one of the sections examined, rutile formed worm-like laths of irregular shape and width in a pinkish brown, magnetic, weakly anisotropic mineral (fig. 32). This texture is exactly similar to that exhibited by titan-hematite laths in ilmenite. Rutile occurring in this fashion was seen in no other polished section of the entire suite. Tests showed that the mineral in which the rutile occurred is neither ilmenite nor magnetite, but has properties midway between these minerals. It is pinkish brown, negative to all reagents, weakly anisotropic (dark gray to light brown), harder than rutile, and quite strongly magnetic. This mineral was identified as titaniferous magnetite. Edwards(1938, p.50) quotes the results of experiments performed by Ramdohr and others, which show how rutile and titaniferous magnetite can be produced from the heating of an ilmenite-hematite intergrowth. This reaction takes place according to the equation

$$Fe_2O_3 + FeO.TiO_2 \longrightarrow TiO_2 + FeO.Fe_2O_3.$$

In these experiments, ilmenite-titanhematite intergrowths were heated to temperatures of 950 degrees C. and then cooled down to and quenched at various temperatures. One specimen was allowed to cool slowly. In some specimens the amount of rutile was considerably less than the amount of ilmenite in the original specimen, while the amount of titaniferous magnetite was considerably greater than the original amount of titanhematite. In one more slowly cooled specimen, more rutile and less titaniferous magnetite was

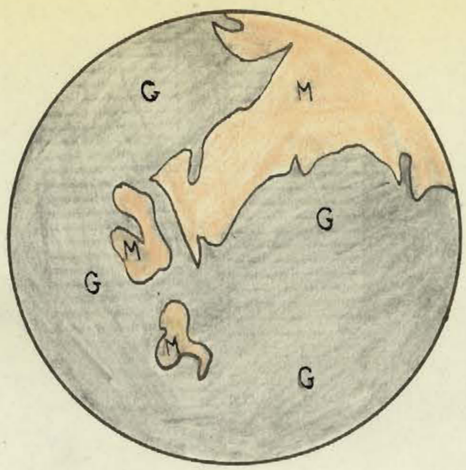



Fig.31). Plane light; Diameter of field, 3mm.
Camera lucida drawing showing magnetite being cut by gangue minerals. M-Magnetite, G-Gangue.

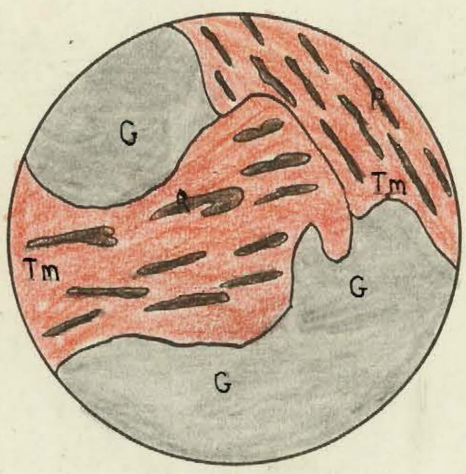



Fig.32). Plane light; Diameter of field, 1.07mm.
Camera lucida drawing showing rutile blebs in titaniferous magnetite. R-Rutile, Tm-Titaniferous magnetite.

present than in the more quickly chilled specimens. This phenomenon can be explained by a process of exsolution proceeding to a more advanced stage for a longer period of cooling.

The polished section in which this titaniferous magnetite-rutile texture occurred was cut from a rock occurring immediately adjacent to a heavily mineralized band, one and one-half inches thick. With this information, the interpretation of the texture can be made as follows. A pyregenic titanhematite-ilmenite intergrowth crystallized, and was in the process of unmixing, near a zone of weakness along which an iron-oxide melt was injected. The heat attendant upon the injection raised the temperature of the immediately adjacent rocks to at least 900 degrees C. bringing about the conversion of titanhematite-ilmenite to rutile-titaniferous magnetite. With a dissipation of heat into relatively cool surrounding rocks, cooling was relatively rapid, but not so rapid as to be equated with quenching. Enough time was available to allow a partial exsolution, at least.

Another texture involving rutile is common in a polished section prepared from a specimen of gabbroic anorthosite taken at a point 4 inches from the contact of the anorthositic rock with a three-feet wide heavily mineralized band. In this specimen, several grains of ilmenite containing exsolution laths of titanhematite were completely enclosed by rims composed of rutile grains (fig. 30). Under high power magnification, small dots and dashes, arranged along regular planes (probably cleavage directions) were observed, and these were equivocally identified as rutile grains. Edwards (1938, p.54) has experimented with an ilmenite-titan-hematite-rutile intergrowth and found that, when he heated this intergrowth to a temperature above 950 degrees C. titan-hematite was converted to titaniferous magnetite, in which the rutile dissolved. He infers that upon the reversal of this process, rutile will crystallize first, until the remaining melt is greatly enriched in $Fe_2O_3$. This residual liquid will then solidify as a homogenous solution, from which, upon slow cooling, will unmix any remaining rutile and the titanhematite-ilmenite solid solution. From this latter solid solution, continued slow cooling will produce exsolution laths of titanhematite in an ilmenite base.

The heat for accomplishing this process is supplied by the injected body of ore, which, on account of its relatively great thickness, cooled slowly, and so maintained a high temperature in the country rock for a relatively long period of time. The presence of rutile in the gabbroic anorthosite, while it is not found in the mineralized bands, and the fact that the proportions of ilmenite to magnetite remain roughly the same in these rocks, indicates that rutile probably was present as a pyrogenic mineral in the gabbroic anorthosite. Hence, an intergrowth of ilmenite-titanhematite-rutile could have been available to produce the texture described by the proposed mechanism. Grains of ilmenite from which laths of titanhematite are exsolving were observed in a very roughly polished section prepared from a specimen taken four feet away from the closest mineralized band. Gashes in the ilmenite were filled by a dark gray material,but it could not be determined if this mineral was rutile; even if it had proven to be rutile, the distance from an injected body at which the heat of injection would be sufficient to produce the described process is entirely unknown.

iii. Rutile and spinel: It has been mentioned earlier that in one thin biotite and opaque-rich band, rutile and spinel occur together as a graphic intergrowth. It is probable that both spinel and rutile crystallized from the original magma. Whether these oxides were present as discreet grains, or in solid solution with the iron oxides, is unknown. Three explanations are proposed for graphic intergrowth textures. These are a), the components crystallized from a eutectic solution; b), the texture is the result of unmixing from a solid solution; c), it is a replacement texture. No description of a rutile-spinel relationship could be found in the literature, and, as it is not known whether rutile can be replaced by spinel, no explanation of this texture can be made with any certainty.

iv. Chromite: Three small grains of a mineral identified as chromite were found in one thin, biotite-rich band. This mineral is dark brownish-gray in reflected light, completely isotropic, and has an orange internal reflection. It is harder than rutile, with which it is in contact, and is unaffected by all standard reagents. Chromite was found only in this one section. It is regarded as an early pyrogenic mineral in the gabbroic anorthosite.

v. Gangue-metallics: A study of the polished sections prepared from gabbroic anorthosite did not shed much light on the question of relative ages of gangue and opaque minerals. The textures between the gangue and the metallic minerals most often yielded no evidence of a difference in age. One grain of magnetite, however, was seen to be cut by, or replaced by, the silicates(fig. 31). The thin sections show that the metallic minerals are now altering to chlorite, biotite, and zoisite, but this alteration is probably a secondary phenomenon, although it may be deuteric. It seems safe to conclude that the metallic oxides were deposited at least simultaneously with the silicates, and probably slightly before them in a normal magmatic crystallization sequence. It is possible that the alteration of the metallics was at least initiated, if not totally effected, by the injection of the sills of iron ore.

The important point established is that the metallic minerals are no younger than the silicates.

## Paragenesis

The textures observed in the gabbroic anorthosite indicate that the silicates and the oxides precipitated from a melt in normal crystallization sequence (if, following Rosenbusch, we admit a "normal" order of crystallization). Thus, the chromite, ilmenite, magnetite, spinel and probably rutile formed first, followed by the silicate minerals. Titanhematite exsolved from ilmenite, ilmenite from magnetite, spinel from ilmenite and magnetite, and rutile from ilmenite as the temperature was slowly lowered. At some later stage, probably before the rock was completely solidified, and while a primary foliation was being developed, concordant bodies of iron ore were emplaced. The heat of this injection raised the temperature of the enclosing rock to the point when the ilmenite-titanhematite-rutile and the titanhematite-ilmenite intergrowths returned to a solid solution state. With the cooling of the injected body, the solid solutions began to unmix and yielded rutile-titaniferous magnetite and rutile-rimmed, ilmenite-titanhematite intergrowths.

## Pegmatites

Two polished sections were prepared from dykes which cut across the foliation of the banded rocks. One was cut from an andesinite dyke, while the other was cut from a granitic dyke. These specimens are typical representatives of two main types of felsic dykes occurring in the map area. A study of the polished sections showed the presence of a few small grains of magnetite, which is somewhat altered to maghemite, in both rocks. In the andesinite dyke, the magnetite contained exsolution laths of ilmenite, arranged along regular planes parallel to the octahedral faces of the magnetite. No ilmenite was found in the granitic dyke rock. A very few, small grains of pyrite are found scattered throughout both polished sections. Mutual boundaries textures indicate a roughly simultaneous deposition of silicate and metallic minerals. The metallic mineral content does not exceed one per cent in either section.

The absence of titanhematite, spinel, rutile and abundant ilmenite point out the difference in metallic mineralogical character between the dyke and the rocks which they cut. This difference makes improbable the theory that the pegmatites were the source of the mineralization in the layered complex.

## GENESIS OF THE ILMENITE-MAGNETITE BANDS

It is thought that in the La Chaloupe area, the bands of ilmenite-magnetite have been injected into the layered rocks, but this injection took place while the rocks were still not perfectly consolidated. The inclusions of rounded fragments of anorthositic rocks in the ore bands prove the intrusion of these bodies into the anorthositic rocks, but the occurrence of the metallic minerals predominantly in the pyroxene-rich rocks requires further consideration.

Osborne(1928, p.898) has indicated that in the concordant titaniferous iron ore bodies studied by him, the gabbro, norite, pyroxenite, ilmenite and websterite which are found as sill-like bodies have all formed by the same process. Hence he considers these bodies to be injected, along with the metallic minerals.

At La Chaloupe, the evidence supports the view that the metallics were injected into the pyroxene-rich bands in preference to the anorthositic rocks.

Typical igneous contacts are not found between the ilmenite-magnetite-rich rocks and the pyroxene-rich rocks, and indeed the letallics and pyroxene are often intergrown in the hand specimen, and so seem to support Osborne's conclusions. The textures observed in both thin section and polished section studies, however, indicate that the metallics have crystallized later than the pyroxene gangue minerals.

If the pyroxene had been introduced with the metallics, the reverse order of crystallization would be expected.

It was noted in the field that the larger bands of metallic minerals were found in the ticker pyroxene-rich bands. This observation supports the view that the pyroxene bands were preferred as loci for emplacement, and that a larger body of gabbro or pyroxenite would be preferred to a smaller one. The reasons for this are not clear, but the explanation of it may lie in the relative degree of consolidation of pyroxene-rich bands and anorthositic rocks at the time of emplacement.

Klugman(1956, pp. 131-151) has given a good summary of current views on the banding in anorthosite rocks, and it need only be stated here that the writer's observations confirm Klugman's contention that crystal settling by gravity action, accentuated by a fluctuation of temperature, pressure or water content, has assumed the dominant role in producing the banding in these rocks. In a melt from which pyroxene and andesine are crystallizing to produce a massive anorthositic body, plagioclase should crystallize first. This order of crystallization differs from the normal one, in which mafic minerals would crystallize before the feldspars, because of the relatively low concentration of mafic minerals in such a magma. It is not known whether a pyroxenite layer would reach a completely crystalline state before an anorthositic layer in a rock produced by rhythmic magmatic crystallization.

If it may be assumed that such is the case, the preference expressed by the concordant bodies of ilmenite-magnetite for the pyroxene-rich bands could be explained by requiring a shearing force acting upon the semi-consolidated rock to produce fractures in the consolidated pyroxene-rich layers, and flowage, plastic deformation, and local granulation in anorthositic layers. That a plastic deformation has occurred in the anorthositic layers is quite evident in the field(fig. 3). The metallic minerals could then have been injected along these fractures to produce the ore bands.

Thin section examination has shown that local granulation of the anorthositic layers has been produced, but granulation is not found in all layers of the anorthositic rock. While it is difficult to determine whether a dimensional orientation exists in rock composed of equidimensional crystals, certain thin biotitic layers in the layered complex do exhibit such an orientation. Since well twinned crystals of plagioclase, showing little signs of deformation, are found in the same sections which exhibit the dimensional orientation of biotite flakes, it is thought that this foliation could have been produced by flowage in a semi-consolidated magma.

Textures between gangue and metallic minerals are most commonly indeterminate and the determination of the older age of the gangue could only be made in a few polished sections. The textures usually indicate a simultaneous crystallization. This too can be explained by assuming injection into semi-consolidated rocks, for the temperature of injection, (which may be as high as 900 degrees C. if the exsolution of rutile from titaniferous magnetite in the gabbroic anorthosite has been correctly interpreted), would have been sufficient to produce local re-melting. Klugman (1956, p.181) has estimated the upper temperature of crystallization of the anorthositic rocks to be 1000 degrees C., based on experiments carried out by Yoder(1955), and so the heat attendant upon the injection could very well have produced local re-melting.

Bowen has pointed out the high temperature of crystallization of magnetite and ilmenite, and this high temperature has always been a stumbling block in the path of the proponents of the theory of an injection of magnetite-ilmenite deposits. Shand(1947, p.131), however, has proposed a mechanism by which these minerals can be formed at relatively low temperatures by a process of self-oxidation from the ferrous hydroxide hydrosol state.

The possibility that the ilmenite-magnetite bands are magmatic segregations "in situ" was not considered, for the evidence of forceful injection of these bodies was too strong to be ignored, (i.e., included blocks of anorthosite). Polished sections studies have also shown that at La Chaloupe the minerals of the ilmenite-magnetite bodies are of a different character then the opaque minerals found in the gabbroic anorthosite, and hence these minerals are probably of different ages. The occurence of chlorite in the gabbroic anorthosite rocks indicates that the opaque minerals in that rock are pyrogenic minerals. Wilson(1953, p.379) has stated that we should expect the magmatic oxides crystallizing with the first formed most basic rocks to have a high trivalent Al and Cr content, and divalent Mg content. The absence of chromite, but high Mg content of the ilmenite-magnetite band, as indicated by spectographic analysis, may point to an early segregation of the oxides occurring in the bands, taking place during crystallization of the layered complex rocks, with subsequent injection. The writer, however, prefers to think of these ilmenite-magnetite bodies as belonging to Bateman's (1950, p.77) late magmatic residual liquid injection class.

De Vore(1953) has discussed the possibility of deriving titaniferous magnetite deposits from Ti and Fe contained in the plagioclase of anorthosites. This theory is an interesting one, but it is felt that no such complicated mechanism need be invoked to explain the ilmenite-magnetite bands at La Chaloupe.

## SUMMARY AND CONCLUSIONS

The rock underlying the La Chaloupe map area is predominantly a gneissic gabbroic anorthosite, with bands of pyroxene-rich and ilmenite-magnetite-rich rocks occurring as concordant bodies within the gabbroic anorthosite. Two types of pegmatite dykes cut these rocks, and both of these contain grains of magnetite. A strongly gneissic hybrid granite occurs in the northern half of the area. No connection between this rock and the ilmenite-magnetite mineralization can be made out. Two varieties of lamprophyre dykes cut the gabbroic anorthosite, and are cut by both types of pegmatites. No relationship with the mineralization can be established for these lamprophyres.

The variation in the composition of plagioclase is considerable in the anorthositic rocks (from An42 to An58), but this same range is found in the pyroxene-rich rocks.

Petrographic study shows that the same minerals are present in both the anorthositic rocks and the pyroxene-rich bands, but that the proportions of these minerals are quite different in the two rock types. A study of the features of the contacts between pyroxene-rich and anorthositic layers leads to the conclusion that these layers have formed by crystal settling from a magma. Opaque minerals occur in both rocks, but in the gabbroic anorthosite these minerals are undergoing alteration to biotite, chlorite and zoisite, whereas in the pyroxene-rich bands the metallic minerals are replacing the silicates. A study of the textures between the metallic minerals and the silicates supports the view that the silicates are being cut by the metallics.

The occurrence of chromite in the gabbroic anorthosite, but not in the mineralized pyroxene-rich bands suggests that the metallic oxides of the rocks are of different ages.

The textures and minerals found in the polished sections of heavily mineralized pyroxene-rich bands indicate that a slow cooling of an iron-titanium melt unusually rich in ferric ions took place. Exsolution of titanhematite from ilmenite suggests that this cooling took place from a temperature of above 800 degrees C.

A mineralographical study of specimens taken from gabbroic anorthosite showed that an exsolution of rutile from titaniferous magnetite had taken place. This texture, not found in the mineralized pyroxene-rich band specimens, is probably the result of the reheating of pyrogenic metallic oxides. As determined experimentally, the temperature necessary for producing this texture lies above 950 degrees C. It is postulated that the rise in temperature was the result of the emplacement of the ilmenite-magnetite bands into the semi-consolidated, differentiated, gabbroic anorthosite.

There is statistical proof that the metallic mineral bands were preferentially emplaced along the widest pyroxene-rich layers at La Chaloupe. It is thought that this emplacement was made possible by the opening up of fractures in the more highly consolidated pyroxene-rich layers, during a period in which differential movement in the semi-consolidated magma was causing plastic deformation of the less highly consolidated anorthositic layers. Evidence of plastic deformation is plentiful at La Chaloupe, where the anorthositic lamellae are highly contorted. Contorted fragments of anorthositic rocks in the mineralized bands again suggest the plastic character of the anorthositic rock during the emplacement of the bands. Granulation is found locally in the gabbroic anorthosite, but not throughout this rock.

Although the pegmatites contain grains of primary magnetite, ilmenite is not present except as exsolution laths in magnetite. The difference in the metallic mineralogy of the mineralized pyroxene-rich bands and the pegmatites is strong evidence that the pegmatites could not have been the source of the ilmenite-magnetite of the mineralized pyroxene-rich bands.

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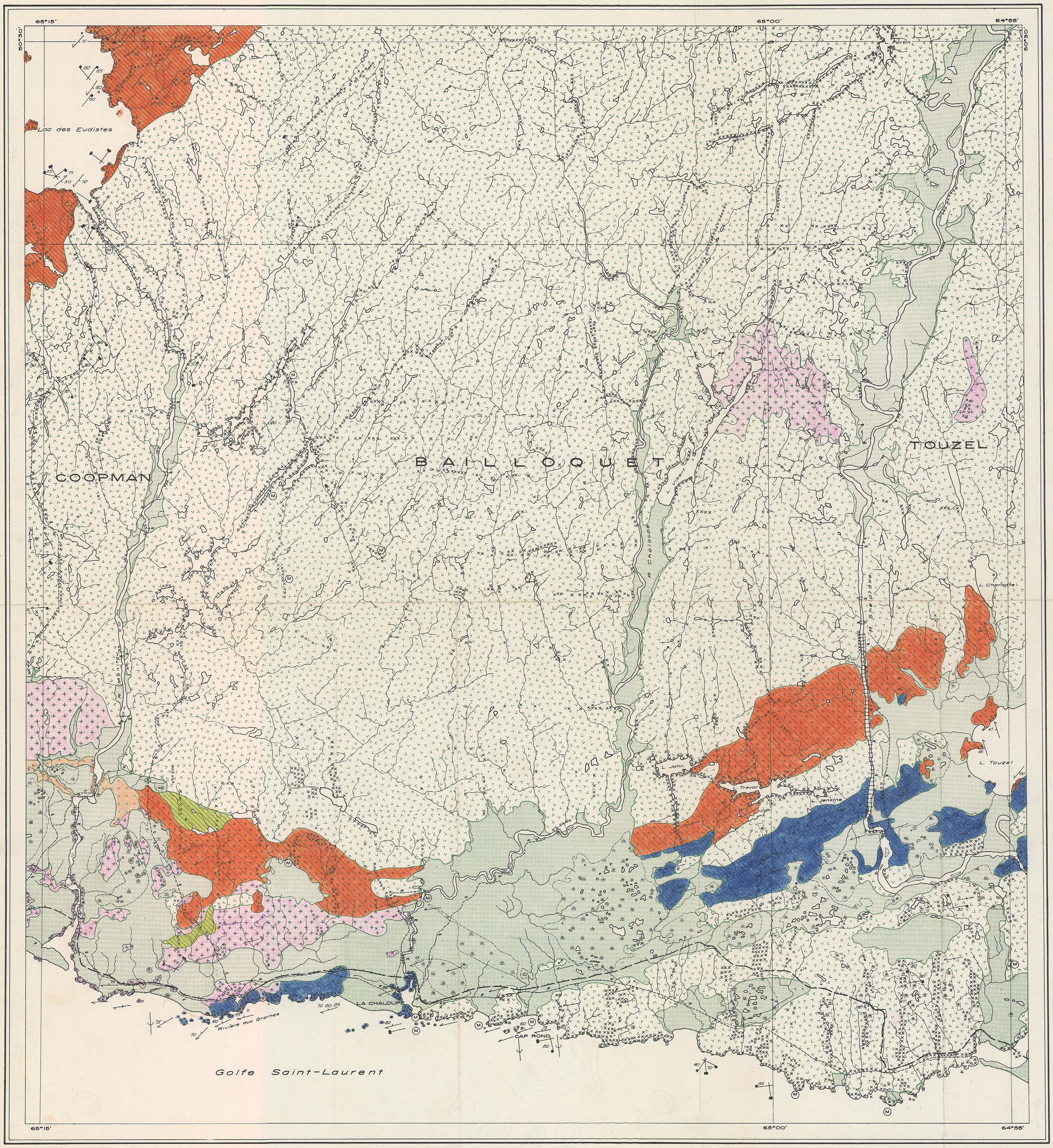
PLATE II




LEGEND — LÉGENDE

CENOZOIC - CÉNOZOÏQUE

Sand, gravel, clay, till
*Sable, gravier, argile, till*

PRECAMBRIAN - PRÉCAMBRIEN

Pink biotite granite
*Granite rose à biotite*

Syenite gneiss
*Gneiss syénitique*

**Layered complex**
Anorthositic and gabbroic rocks
*Roches anorthosiques et gabbroïques*

Augen and biotite gneisses
*Gneiss oeillés et à biotite*

Sedimentary gneisses and schists, migmatites
*Gneiss et schistes sédimentaires, migmatites*

SYMBOLS - SYMBOLES

Observed outcrop
*Affleurement relevé*

Strike and dip of schistosity and gneissic structure (a) inclined, (b) vertical, (c) dip not determined
*Direction et pendage de la schistosité et de la structure gneissique (a) inclinées, (b) verticales (c) pendage non déterminé*

Strike and dip of joints: (a) inclined, (b) vertical
*Direction et pendage des joints (a) inclinés, (b) verticaux*

Glacial striae
*Stries glaciaires*

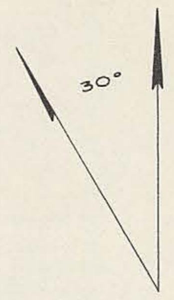
Portage
*Portage*

Telegraph line
*Ligne télégraphique*

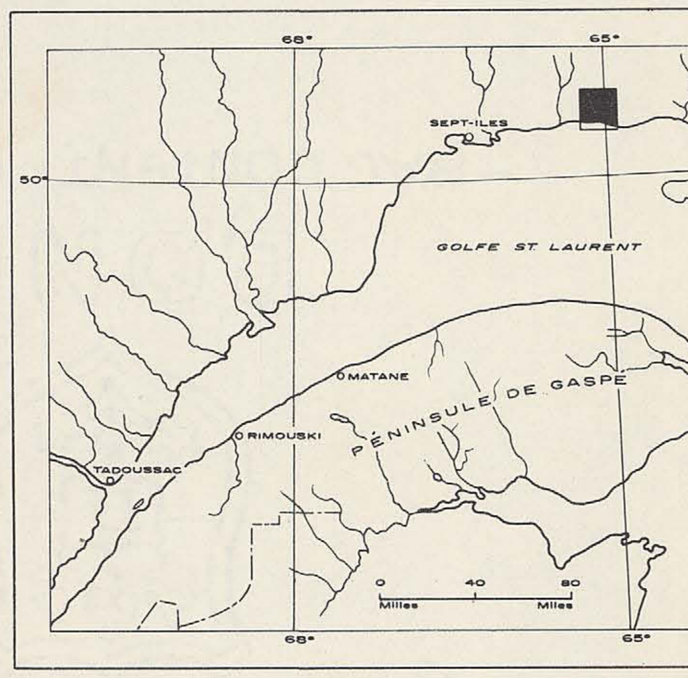
Rapids and falls
*Rapides et chutes*

Swamp
*Marécage*

Ilmenite-magnetite mineralization
*Minéralisation ilménite-magnétite*








GEOLOGY BY: / GÉOLOGIE PAR: M. A. Klugman, 1954

Ministère des Mines, Québec, 1955, R. P. No. 313

CARTE PRÉLIMINAIRE No. 1072 PRELIMINARY MAP

Department of Mines, Quebec, 1955, P. R. No. 313

## RÉGION DE BAILLOQUET
COMTÉ DE SAGUENAY

## BAILLOQUET AREA
SAGUENAY COUNTY


PLATE III
GEOLOGICAL MAP
of the
WEST BANK of
LA CHALOUPE RIVER
SAGUENAY COUNTY
QUEBEC
LEGEND
CENOZOIC
7 Sand
PRECAMBRIAN
6b Granite pegmatite dyke
6a Andesinite pegmatite dyke
5 Hybrid granite
4 Altered lamprophyre dyke
3 Ilmenite-magnetite rich band
2 Pyroxene rich band
1 Anorthosite and gabbroic anorthosite
SYMBOLS
Geological boundary
Shearing
Folding
Foliation and banding
Jointing
Base line
Bridge
Building
Channel marker
GEOLOGY BY J.T. JENKINS
1954
SCALE 1" = 100 FEET
0 100 200
Location Map
Eastern Quebec Province
Gulf of St. Lawrence
La Chaloupe River
GULF of ST. LAWRENCE
65°07'30"
50°17'10"
N
30°
12+00 11+00 10+00 9+00 8+00 7+00 6+00 5+00 4+00 3+00 2+00 1+00 0+00