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GEOLOGICAL REPORT 78

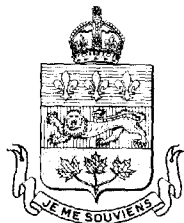
BOURGET AREA

CHICOUTIMI AND JONQUIÈRE - KÉNOGAMI

ELECTORAL DISTRICTS

by

RENÉ-F. JOOSTE



QUEBEC

RÉDEMPTI PARADIS

PRINTER TO HER MAJESTY THE QUEEN

1958

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BOURGET AREA

CHICOUTIMI AND JONQUIERE-KENOGAMI

ELECTORAL DISTRICTS

by René F. Jooste

INTRODUCTION

General Statement

Bourget area lies within the Lake Saint-Jean—Upper Saguenay lowland. It is roughly 15 miles east of lake Saint-Jean, and its southern border coincides in part with Saguenay river.

The consolidated rocks of the area are Precambrian in age and igneous in origin except for two small areas of Ordovician limestone. Anorthosite and related rocks occupy about two-thirds of the area and contain extensive deposits of titaniferous magnetite. The anorthosite group is followed by four successively younger intrusive groups ranging in type from diorite to granite.

Recurring interest in the titaniferous magnetite deposits of the area and the need for further information on the Saint-Charles deposit in particular were the main reasons why the field work leading to this report was undertaken. This work was done for the Quebec Department of Mines during the field season of 1948.

Location and Access

Bourget map-area is bounded by latitudes 48°30'N. and 48°45'N. and longitudes 71°15'W. and 71°30'W. It includes Bourget, most of Bégin and parts of Labrecque, Taché and Kénogami townships, all in Jonquière-Kénogami electoral district, Falardeau township, in Chicoutimi electoral district, and Kénogami township, in Chicoutimi and Jonquière-Kénogami electoral districts. Most of the area is readily accessible by gravelled roads leading from Chicoutimi, Jonquière and Saint-Joseph d'Alma. These towns are on the Quebec-Bagotville line of the Canadian National Railways. Trans Canada Air Lines operates between Quebec and Bagotville. Canada Steamship Lines offers regular service during the summer months between Montreal, Quebec and Chicoutimi via the St. Lawrence and Saguenay rivers.

Settlement and Resources

The chief industry of the area is farming, although the area is not generally suited to agriculture and good farming districts are scattered. This is reflected in the scarcity and small size of the settlements. Saint-Ambroise, with a population of several hundred, is the largest village.

Most of the timber of the area has been destroyed by forest fires or has been cut. The best stands are in the northeastern part of Bégin township, and there is some timber on the steep slopes of the Saguenay.

The potential value of any resources of the area is increased by the geography. This applies particularly to the titaniferous magnetites, the most important of which are in the southern part. Thus, they are close to the hydro-electric power developments and possibilities offered by Saguenay river and its tributaries and to cheap transportation facilities. There is also a potential local market in the several adjacent industrial centres, including Arvida, Kénogami, Chicoutimi and Jonquière, a few miles to the southeast, and Saint-Joseph d'Alma and Riverbend shortly to the west.

Field Work

The area was mapped by pace and compass traverses spaced at intervals of half a mile or less. In addition to the general map of the area, a map of the Saint-Charles titaniferous magnetite deposits was made on a scale of 400 feet to the inch by plane-table methods.

Acknowledgments

The writer was assisted in the field by J. Béland and C. Goddard, who executed their duties admirably. Dr. F. Fitz Osborne visited the party twice in the field and, on these occasions as well as during later discussions, gave valuable assistance. Mr. A. Tait and Dr. W.K. Gummer, both of Arvida, generously advised the author on the general features of the area. Mr. J.-F. Gauthier, of Jonquière, owner of some claims at Saint-Charles, as well as Mr. E. Gauthier of lot 45, range I, Bourget, proved most helpful.

Laboratory work for the report was done at McGill University. The author wishes to express his most sincere thanks to members of the staff of the Geological Department, especially to Dr. A.W. Jolliffe, who supervised the work. Dr. E.H. Kranck guided much of the petrographic work, Dr. T.H. Clark kindly advised the author on palaeontological questions, and Dr. J.E. Gill aided with structural and physiographic problems. Dr. R.P.D. Graham checked the manuscript and suggested numerous revisions.

Previous Work

The geology of the Lake Saint-Jean-Saguenay region has been studied at intervals for more than a hundred years, but areal geological mapping was undertaken only within the last fifty years. A history of geological work is given by Denis (1933)^{*} in a report on the Lake Saint-Jean region.

The eastern part of Bourget area partly overlaps Simard area, which was mapped by Denis (1932) in order to determine the distribution of the Palaeozoic formations.

The index map (see geological map, in pocket) shows the extent of previous geological mapping.

PHYSIOGRAPHY

The Lake Saint-Jean-Upper Saguenay region contains a large area of low relief and low altitude bordered, for the most part, by escarpments. Blanchard (1933) and Dresser (1916) have shown that some of these escarpments mark faults and that the lowland is largely the result of rapid erosion of the relatively soft Palaeozoic sedimentary rocks that were let down along these faults. During a post-glacial marine invasion of the area, thick deposits of clay and sand were laid down and now underlie the valuable farm land of the Lake Saint-Jean region.

Bourget map-area lies within the lowland of the Lake Saint-Jean-Upper Saguenay region. The relief is about 800 feet, the

^{*}See bibliography at end of report for references.

highest points being towards the northeast and the lowest (240 feet) in the southwest along Saguenay river.

Two distinct types of surface are recognizable in the Bourget area. One type, best developed towards the southeast, is practically horizontal except where cut into by streams or interrupted by terraces. The other is hilly. The hills are generally rounded although irregular in plan. The highest are towards the northeast.

Flats underlain by post-glacial marine sediments (clay and sand) extend up stream valleys into the hilly regions. These areas are farmed except where the soils are too sandy or wet. Most of the hills are underlain by Precambrian igneous rocks with an irregular cover of glacial drift. Some of the hills, however, are glacial moraines.

Streams draining the area abound in rapids and lakes in the hilly regions. Where they flow across the plains they are graded, though not continuously, since waterfalls and rapids are formed wherever bedrock or concentrations of boulders occur. In the plains, also, the streams are generally incised well below the surface.

Saguenay river crosses the southwestern corner of the area, and has cut steep banks up to 300 feet high in the bedrock. This part of the stream now resembles a lake as the result of the dams at Shipshaw. The water level here is about 240 feet above sea-level.

The only evidences of the direction of ice movement are roches moutonnées and rare striae. These indicate that the ice moved S.60°E., or nearly parallel to the Saguenay.

GENERAL GEOLOGY

With the exception of two small areas of Palaeozoic limestone, all the consolidated rocks of the area are crystalline igneous rocks of Precambrian age. Anorthosite and related rocks underlie about two-thirds of the area, the rest being underlain by later intrusions of pyroxene diorite, gabbro, and acidic rocks. In the anorthosite group, anorthosite and gabbroic anorthosite are the most common facies. This group is cut by pyroxene diorite and anorthositic troctolite, and these in turn are cut by two or more groups of acidic rocks. Of the latter, there are three main types - syenite-monzonite, quartz syenite and granite.

Palaeozoic rocks occupy only two small areas, and their preservation is the result of down-faulting.

Pleistocene deposits consist of till and glacial outwash, overlain in the lower parts of the area by sediments deposited during a post-glacial marine inundation of the region.

Table of Formations

Cenozoic	Pleistocene	Post-glacial	Marine clay, sand, and gravel
		Glacial	Till and glacial outwash deposits
Unconformity			
Palaeozoic	Ordovician	Trenton	Limestone
Unconformity			
Precambrian	Archaean		Microcline granite and quartz-microcline syenite
			Intrusive Contact
			Syenite- monzonite, quartz syenite
			Intrusive Contact
			Ophitic anorthositic troctolite
			Intrusive Contact
			Pyroxene diorite
			Intrusive Contact
		Anorthosite group: anorthosite, gabbroic anorthosite, troctolite, gabbro, norite	

Precambrian

Anorthosite Group

The anorthosite group is characterized, for the most part, by rocks having a high content of plagioclase feldspar. Anorthosite, the most characteristic rock, is widespread but gabbroic anorthosite has at least as wide a distribution. Commonly, the tenor of dark minerals is sufficient for the rock to be classed as gabbro, norite, or troctolite, depending on whether augite, orthorhombic pyroxene, or olivine is the dominant ferromagnesian mineral.

The rocks of the anorthosite-gabbro group have been classified by Buddington (1939, p. 19) as follows, on the basis of the content of mafic minerals:

Anorthosite:	0-10%
Gabbroic, noritic, or dioritic anorthosite:	10-22 1/2%
Anorthositic or feldspathic gabbro or norite: ...	22 1/2-35%
Gabbro or norite:	35-65%
Mafic gabbro, mafic norite:	65-77 1/2%

This classification is followed here where possible, and representatives of all the types mentioned are recognized. However, in many places the ratio of mafic minerals is so variable, even in a single small exposure, that it is not always possible to assign a rock to any one category. Thus, the writer uses the term "troctolitic" in place of "gabbroic" to designate those rocks with olivine as the principal ferromagnesian mineral.

It is not practicable to designate the various rock types on the accompanying map. No pronounced differences in age could be observed because all the varieties grade into one another or are interlayered. Also, the rocks are composed essentially of the same minerals and differ only in the proportions of plagioclase and dark minerals. And finally, the weathered surface of the plagioclase is characteristically white, so that, as exposed, most of the rocks, except the more mafic varieties, are light coloured.

Anorthosite.- The anorthosites range from very coarse-grained to fine-grained. The most common type is a coarse-grained rock consisting chiefly of plagioclase crystals averaging about half

an inch across, together with finer, irregular grains that appear to have resulted from the breaking of the larger crystals. Thus, the rock is inequigranular in general and, in many places, is porphyroclastic. A common variety contains about 10 per cent plagioclase crystals averaging an inch across (but up to five inches), set in a medium- to fine-grained matrix (Plate V). Smaller porphyroclasts are common in other types. A less common type of anorthosite is a medium- to fine-grained granular rock, not unlike coarse sandstone in appearance, especially where the grains do not cohere very well. In places, this type contains sparsely-scattered large crystals of plagioclase and resembles the deformed anorthosite, except that the groundmass is sugary in texture. Almost every gradation, from comparatively undeformed to completely granulated types, exists.

Thin sections of the anorthosite show that the grain boundaries of the plagioclase are highly irregular, even serrate, jagged, and embayed. Twin laminae are commonly bent and the crystals show wavy extinction. The plagioclase of the granular type, however, does not have irregular grain boundaries, although the crystals show wavy extinction and bent laminae. Inclusions are very abundant in most plagioclase crystals and consist of small opaque rods and dust-like particles. Polished sections suggest that the rods are ilmenite. The plagioclase grains are twinned according to the albite and pericline laws. Carlsbad twinning was not observed. The composition of the plagioclase, determined by refractive indices of cleavage flakes, is from An_{35} to An_{54} , with An_{52} as the most common variety.

The dark minerals of the anorthosite are: augite, hypersthene, hornblende, biotite, olivine and titanomagnetite. Of these, the pyroxenes are the most abundant. Hornblende and biotite are present in small amounts in nearly all specimens examined. Olivine is rare.

Gabbroic (and Noritic) Anorthosite, Gabbro, Norite.- Gabbroic anorthosite has at least as wide a distribution as anorthosite proper, from which it grades by increase in ferromagnesian minerals. By further increase in dark minerals, the gabbroic anorthosite grades into gabbro and norite.

Typical gabbroic anorthosite is coarse-grained (granularities up to about a half inch), and consists mainly of crushed and uncrushed feldspar as in anorthosite proper. Medium- to fine-grained varieties are rare, and porphyroclasts generally are lacking. Augite is the most abundant dark mineral, but locally hypersthene takes its

place or is present in addition to it. Hornblende and biotite are almost invariably present although not abundant. Ilmenite and magnetite, commonly intergrown, are accessories. The long dimensions of the dark minerals are characteristically aligned so as to suggest foliation. However, here and there the rock is massive and the pyroxenes are interstitial to, or sub-ophitically enclose, plagioclase. The coarsest facies generally are not foliated.

Gabbro and norite occur as bands within, or gradations from, other rock types. The exposures are normally banded, with layers rich in mafic minerals alternating with more feldspathic bands. Augite is the most common mafic mineral in the gabbro and hypersthene in the norite. Hornblende and biotite are normally also present. Ilmenite and magnetite are constant accessories.

Along Shipshaw river in the southeast corner of the area and west of Saint-Ambroise, there are extremely coarse-grained facies consisting of black plagioclase (up to 12 inches long) and pyroxene (up to 8 inches long). The latter mineral encloses plagioclase ophitically, showing that the pyroxene was the later mineral to crystallize. These rocks are so coarse-grained that they may be termed "gabbroic anorthosite pegmatite", or "gabbro pegmatite" where there is sufficient pyroxene present. In some places, these coarse-grained rocks appear to be "segregations" with poorly-defined or gradational boundaries in anorthositic rocks (Plate VI). In other places, they seem to be dykes. The latter is especially true of gabbro pegmatite.

The composition of some of the plagioclase is An_{64} , but most commonly it is about An_{59} . It thus tends to be more calcic than that of the anorthosite proper.

Troctolitic Anorthosite and Troctolite.- Troctolitic anorthosite, locally grading into troctolite, is common along the central and eastern parts of Bourget township, but is also present in other places. Typically, it consists of medium-grained plagioclase of composition An_{59} to An_{63} together with lenticular grains of olivine. The long dimensions of the olivine normally are parallel and the rock, therefore, foliated. Augite, hypersthene, hornblende, ilmenite, and magnetite constitute the other dark minerals.

On weathered outcrops, the olivine can be recognized and distinguished from the other dark minerals by its characteristic rust-coloured surface. Furthermore, the olivine grains are almost

invariably surrounded by a dark green rim. In thin section, the olivine is seen to be partly replaced by serpentine. The optical properties (negative sign with $2V = 78^\circ$) show it to be an iron-rich variety containing about 40 per cent Fe_2SiO_4 . Most olivine grains are surrounded by a two-layer corona consisting of an inner rim of hypersthene, succeeded by cummingtonite (?) with spinel (Plate X-B). The hypersthene layer is formed of small, irregular grains which, for the most part, have their longest dimensions perpendicular to the outline of the olivine grain. This inner zone forms a continuous layer of uniform width around the olivine. The hypersthene is faintly pleochroic, optically negative and has a large axial angle. The zone of cummingtonite (?) succeeds the hypersthene, separating it from the feldspar. Crystals are small and irregular. It is pleochroic from pale green to colourless, has inclined extinction and is optically positive, with $2V$ about 85° . Although the mineral has the appearance of actinolite, the positive sign suggests that it is cummingtonite. Normally, it encloses small grains and vermicular masses of what appear to be spinel.

The coronas around olivine in the Saguenay anorthosite were described by Adams (1893) as corrosion zones. The subject of coronas has recently been reviewed by Shand (1945), who also described a new type of corona from the east side of Lake Napetipe, in Pontchartrain township, Saguenay county, Quebec. This corona is very similar to those found in the Bourget area, except that, in the latter, hypersthene is free from spinel, and the outer zone could not be positively identified as cummingtonite. Shand believes that coronas are probably the result of thermal metamorphism. Other troctolites with coronas have been described from New Glasgow, Quebec, by Osborne (1949).

The troctolitic rocks are characteristically interbanded with anorthosite in layers less than an inch to several tens of feet thick. The differences from layer to layer are chiefly in the content of dark minerals. Individual layers tend to be uniform in composition, although they generally contain lenses and irregular areas with a greater or lesser content of dark minerals.

Textures and Structures

The feldspars of the anorthosite group invariably show features that Adams (1893) has ascribed to granulation; that is, the individual crystals are distorted by deformation of the rocks. In

Bourget area, the granulation is believed to be protoclastic (occurred before complete consolidation) rather than cataclastic (occurred after complete consolidation), for the following reasons:

a) The ferromagnesian minerals that accompany the feldspar are generally undeformed. This is believed to be the result of the ferromagnesian minerals crystallizing later than the feldspar and not of their greater resistance to deformation.

b) Serpentinized olivine shows little evidence of deformation. Serpentine veinlets would offer little resistance to movement during deformation, yet they are seldom, if ever, distorted. The serpentinization is presumably a late magmatic process and the granulation preceded it.

c) Some of the later intrusions are not granulated.

d) All stages, from a completely granulated rock with ophitic ferromagnesian minerals to a completely granulated rock devoid of ferromagnesian minerals, are present. The interstitial material in the latter is believed to have been squeezed out of the magma during crystallization.

The very coarse pegmatitic facies, although common, is not widespread. The pyroxene normally has a sub-ophitic relation to the feldspar, and in certain places, notably along Shipshaw river directly east of Saint-Ambroise, pyroxene crystals two inches or more across completely enclose plagioclase. The ophitic relations show that the feldspar crystallized before the pyroxene. The coarse grain of the rock suggests that volatiles were present, although typical pneumatolytic (or related) minerals were not seen.

The rocks of the anorthosite group are foliated in part. The foliation is obscure in anorthosite proper, whereas in the more mafic facies it is generally plainly shown by an alignment of ferromagnesian minerals, or by compositional layering, or by both. The boundaries between layers are generally gradational, but may be sharp. In places, the foliation is irregular, or only vaguely reflected by local patches of rock rich in dark minerals. Throughout the area, the foliation strikes about north, and steep dips are prevalent, although locally the attitudes show wide variations. Faint indications of foliation striking east and dipping gently to the north may be seen near the range I-II road a mile east of the Saint-Charles prospect. This structure is apparently older than, and obscured by, the north-striking foliation.

Block structure as described by Balk (1931, p. 357) consists of angular blocks of anorthosite surrounded by anorthosite of a slightly different character. In Bourget area, a similar structure was seen in only one place; here a few angular blocks of anorthosite are enclosed in gabbroic anorthosite (Plate VIII).

Mode of Origin of Anorthosite

The anorthosite group includes a wide range of rocks, with anorthosite and gabbroic anorthosite predominant. Thus, any theory of origin must account for anorthosite as well as for other rocks containing a larger proportion of dark minerals.

Logan (1863) included the anorthosites of the Canadian Shield in his Laurentian system and believed them to be of sedimentary origin. Adams (1893), however, demonstrated their igneous origin. Bowen (1917) considers anorthosite to be the result of the settling of plagioclase crystals from a gabbroic magma, after earlier settling of much of the pyroxene. Balk (1931) believes that the Adirondack anorthosite was formed by the aggregation of plagioclase crystals by flowage during injection. Buddington (1939) shows that anorthositic rocks have two contrasting modes of occurrence: large domed masses (e.g., in the Adirondacks); major facies of stratiform sheets (e.g., Bushveld complex). He believes that the domed masses originated as an intrusion of gabbroic anorthosite magma from which some of the mafic minerals had been removed by crystal settling. Ramberg (1948) believes anorthosite results from metamorphism at high temperatures and pressures deep in the earth's crust.

The rocks of the anorthosite group of Bourget area seem to be part of a domed body, and it may be that they have originated in the manner suggested by Buddington for such bodies. The writer believes, however, that much of the anorthosite of the series resulted by filter-pressing of partly crystalline gabbroic anorthosite. Where the rocks are undeformed, the dark minerals appear to have completed their crystallization later than the plagioclase. Continuation of the deformation causing filter-pressing would lead to granulation of the plagioclase. The pressed out gabbroic liquid was injected elsewhere into the consolidated, or partly-consolidated, nearby rocks. Part of the layering may have been caused by such injection.

Age and Correlation

No rocks older than the anorthosite group were recognized in this area. Thus, the age of the group relative to the Grenville and the so-called Laurentian could not be determined. However, as the area is within the Grenville province of the Canadian Shield, the anorthosite group can be taken as the petrographic equivalent of:

- Saguenay formation (Lake Saint-Jean area, Dresser, 1916)
- Anorthosite series (other parts of the Lake Saint-Jean-Upper Saguenay region)
- Buckingham series of the Morin (in the area north of Montreal)
- Anorthosite series of the Adirondacks (Buddington, 1939)

The anorthosite group of the Bourget area does not include acidic members, nor types intermediate between anorthositic and felsic rocks.

Pyroxene Diorite

A narrow body of pyroxene diorite extends north-northeast from Saguenay river in the southwest corner along or near the eastern boundaries of Taché and Labrecque townships, almost to the northern boundary of the area. At Saguenay river it is slightly less than a mile wide. Northward, although it pinches and swells, it is generally less than 1,500 feet wide.

The rock is greenish-grey on fresh surfaces and weathers rust-grey to buff. It consists of feldspar (60 per cent) and dark minerals in grains averaging about one millimeter. Except for some irregular concentrations of dark minerals, there is no suggestion of banding. Foliation in the diorite is vertical or nearly so and is normally parallel to the anorthosite-diorite contact.

In thin section, the rock consists of about 60 per cent plagioclase, 20 per cent pyroxene, together with magnetite, ilmenite, hornblende, biotite, and apatite. The plagioclase occurs in equant grains, generally free from granulation. Its composition is from An_{37} to An_{42} , with An_{41} common. Pyroxenes, the most common dark minerals, occur as subhedral grains or aggregates of grains. Both orthopyroxene and monoclinic pyroxene are present, and many grains seem to show intergrowths of both types. Hypersthene (negative,

2V = 70°) generally predominates, but in some sections it is subordinate to monoclinic pyroxene. There is an abnormal amount (10 to 15 per cent) of magnetite and ilmenite. The magnetite contains the usual ilmenite intergrowth, but ilmenite also occurs as discrete grains. Green hornblende and biotite and rounded grains of apatite are accessory.

Dykes of diorite cutting anorthosite and inclusions of anorthosite in the diorite clearly show that the pyroxene diorite is younger than the anorthosite.

Ophitic Anorthositic Troctolite

A long narrow body of ophitic anorthositic troctolite extends northeast from near the southwest corner of the area into the northern half. It cuts across the pyroxene diorite in the southwest and then closely parallels that intrusion for about 6 miles before swinging to the east. In the latter course it is cut by granite. Two smaller bodies of the troctolite lie to the north in Bégin township.

The rock is termed ophitic anorthositic troctolite because olivine is the predominant dark mineral. In many places, however, the rock is anorthositic gabbro, or it grades with increase in dark minerals to troctolite and gabbro, or with decrease in dark minerals to troctolitic anorthosite and gabbroic anorthosite. It is essentially similar in mineral composition to the rocks of the anorthosite group, but it differs from these in having a characteristic sub-ophitic texture, with well developed laths of feldspar partially enclosed in olivine, titanomagnetite, or augite.

The feldspar is grey to dark grey, weathering white. Laths, normally about half an inch long, show distinct albite as well as Carlsbad twinning. Dark green, rusty-weathering olivine is usually the principal dark mineral, but in many occurrences titanomagnetite is more abundant. Again, in some facies of the rock, pyroxene or hornblende takes the place of olivine and titanomagnetite.

The following minerals are seen in thin sections: plagioclase, olivine, augite, hornblende, ilmenite, magnetite, spinel, and apatite, as well as the corona minerals, hypersthene and cummingtonite (?). The plagioclase occurs both in large laths and small rounded grains, the laths showing Carlsbad as well as albite and pericline twinning. The laths are markedly zoned and contain relatively

abundant opaque rods, most of which have their long dimension in the zone 100:010. The composition of the feldspar ranges from An₄₄ to An₅₇. Thus, some facies are dioritic. The olivine is partly replaced by serpentine and in most places is surrounded by a double-shelled corona similar to that around olivine in the anorthosite groups. Augite takes the place of olivine in some facies of the rock, but it also occurs with olivine. In a few specimens amphibole, generally green hornblende, is the main dark mineral, but in most specimens it is present only in small amounts. Brown hornblende is rare. Some biotite is present, and is most abundant in the types containing much hornblende. The opaque minerals are ilmenite, and magnetite with intergrown ilmenite. Spinel is normally closely associated with the opaque minerals. Apatite is common and may be up to six per cent.

The anorthositic troctolite is very like some facies of the anorthosite group. However, contact relations, at the few places where the contact is exposed, show the troctolite to be intrusive into the anorthosite. Also, at one place the troctolite cuts across the pyroxene diorite, which in turn intrudes the anorthosite group. Therefore, the troctolite must be separated from the anorthosite as a distinctly later intrusion. The appearance, mineralogy, and age relations of the ophitic anorthositic troctolite resemble those of the metagabbro of the Adirondacks (Buddington, 1939).

Syenite-Monzonite

A massif, ranging in composition from syenite to monzonite, occupies an oval area of some 15 square miles at the junction of Bégin, Bourget, and Falardeau townships. It is closely associated with granite, which almost completely surrounds it and forms masses and dyke-like bodies within it.

The rock is greenish-grey, buff-weathering and normally medium-grained equigranular. Some facies have phenocrysts of plagioclase and are markedly porphyritic. The phenocrysts are light grey, and weather dark grey to black. The equigranular rock contains 60 to 70 per cent feldspar, the rest being dark minerals. The porphyritic facies contain up to 40 per cent plagioclase. They average half an inch across, but some are as much as two inches.

An examination of sections shows the following minerals to be present: microperthite, plagioclase, quartz, pyroxene, horn-

blende, biotite, titanomagnetite, apatite, and titanite. Generally, microperthite is the dominant feldspar, but in some facies it is subordinate to plagioclase. The microperthite consists of potassic feldspar, containing rudely parallel laminae and small irregular areas of plagioclase. The plagioclase grains are normally zoned, contain relatively abundant inclusions, and have the composition of oligoclase-andesine (An_{30}). Phenocrysts have the same composition and general appearance as the plagioclase in the rock. Clear grains of interstitial quartz make up less than five per cent of the rock. Augite forms 20 per cent of some specimens, but is absent in others. Some of the grains of augite seem to contain intergrown orthorhombic pyroxene. Green hornblende normally makes up 10 to 25 per cent of the rock and some biotite is invariably present. The opaque minerals consist of ilmenite, together with magnetite containing intergrown laminae of ilmenite. Apatite constitutes up to 7 per cent of the rock. Small grains of titanite are present here and there.

The syenite-monzonite was nowhere seen in contact with rocks of the anorthosite group. However, in eastern parts of the mass, several inclusions of anorthosite were found within the syenite-monzonite, showing that it is the younger rock. It is intruded by, and hence is older than, the granite to be described below. Age relationships to the other formations could not be determined directly. The syenite-monzonite shows many similarities to the quartz syenite discussed below, and may have the same age relationships.

Quartz Syenite

Quartz syenite occurs over a width of a mile and a half along the northern half of the western side of the area, where it is associated with a younger granite.

The rock is coarse-grained and porphyritic (Plate X-A), with more than 50 per cent pink-weathering phenocrysts of potassic feldspar in a matrix of feldspar, dark minerals, and quartz. The quartz is in rounded grains with a conspicuous bluish opalescence.

Thin-section examination shows the following minerals: microperthite, plagioclase, quartz, pyroxene, hornblende, biotite, ilmenite, magnetite, apatite, titanite and zircon. The phenocrysts, as well as part of the groundmass, consist of potassic feldspar with abundant laminae of plagioclase forming a typical microperthite.

Oligoclase (An_{15}) forms 5 to 10 per cent of the rock. Some of the crystals of plagioclase contain rounded blebs of quartz and are typical myrmekite. Quartz in rounded irregular grains constitutes about 10 per cent of the rock. A small amount of augite, with the same optical properties and general appearance as that in the syenite-monzonite, is present. All the sections examined contain anhedral grains of green hornblende. More commonly, the hornblende is in aggregates of small grains mixed with quartz. Biotite normally accompanies the hornblende and opaque minerals. Apatite, ilmenite, and magnetite with intergrown ilmenite occur in accessory quantities. Titanite is present here and there; in one thin section it forms a complete rim around an opaque grain. Isolated small grains of zircon were seen in one thin section.

Inclusions of anorthosite in the quartz syenite show that the latter is the younger rock. The age of the quartz syenite relative to the other formations (except the younger microcline granite) could not be determined directly. Indirect evidence, however, indicates that the quartz syenite is between the ophitic troctolite and the granite in age.

The quartz syenite and the syenite-monzonite are petrographically similar. In both rocks, microperthite predominates, cross-hatched microcline is absent, and a similar pyroxene is present. The main difference is that the quartz syenite contains abundant phenocrysts of microperthite, whereas the porphyritic facies of the syenite-monzonite has phenocrysts of plagioclase. Also, quartz is more abundant and is uncommonly blue in the quartz syenite. The similarities are sufficient to warrant correlation of the two types. The differences between them may be the result of dissimilar conditions of cooling, or of local assimilation of older rocks, or both. Both rocks are intruded by microcline granite.

Microcline Granite

Two bodies of microcline granite occur in the map-area. The "A" body, located in Bégin, Bourget and Simard townships, has a roughly crescentic outline suggestive of a ring-dyke. It is about a mile wide on the average. The crescent is 4 miles across along a northeast-southwest line. The "B" body, in Labrecque township, is two miles wide along the northern boundary of the area. It extends southward 6 miles, gradually narrowing until it pinches out near the Taché-Labrecque boundary.

Body A occurs as a partial rim around, or as an irregular body within, the syenite-monzonite. The rock is pink, coarse-grained and somewhat inequigranular. It consists of about 55 per cent potash feldspar, 25 per cent plagioclase and dark minerals, and 10 to 20 per cent quartz. In places, the quantity of quartz is sufficiently low for the rock to be termed quartz syenite. Toward the contact with the anorthositic rocks, it becomes more heterogeneous, the content of dark minerals increases, and gneissic structure parallel to the contact becomes distinct.

The following minerals were identified in thin sections: microcline, plagioclase, quartz, hastingsite, biotite, titanite, apatite, ilmenite, and magnetite. Microcline normally constitutes more than half the rock, and much of it contains thin plagioclase laminae to form typical microcline microperthite. The plagioclase (An_{17}) is comparatively fresh and some grains are myrmekitic. Clear, irregular grains of quartz appear to be interstitial to the feldspar. The amphibole seems to be hastingsite (negative, 2V about 30° , X=very dark green, Y= dark green, Z= yellowish-brown). Biotite accompanies the amphibole and opaque minerals. The accessory minerals are ilmenite, magnetite with intergrown ilmenite, apatite, and titanite. The titanite is commonly adjacent to, or rims, grains of ilmenite.

The granite of Body A is clearly intrusive into the anorthosite group, the ophitic anorthositic troctolite, and the syenite-monzonite. The intrusive relationships are shown by abundant inclusions of anorthosite in the granite (Plate IX), by dykes of granite cutting anorthosite, ophitic troctolite, and syenite-monzonite.

Body B is in part adjacent to the quartz syenite and seems to pinch out within it to the south.

The rock is typically pink and coarse-grained. It consists of about 80 per cent feldspar and quartz, together with biotite. Flakes of biotite are in general alignment and impart a vague foliation to the rock. This rock is very similar in mineral composition to that of Body A. The approximate composition is: 50 per cent microcline, 15 per cent plagioclase, 25 per cent quartz, 5 per cent biotite, and the rest apatite, ilmenite, and titanite. It differs from that of Body A in that amphibole is not apparent, microcline perthite is less abundant, and muscovite is present in places. The appearance of the rock in the field is also somewhat different in

that the foliation is uniformly developed and the rock is not gneissic along the borders, as is the case with Body A.

Body B is clearly younger than the anorthosite group and the quartz syenite for both are metamorphosed by and occur as inclusions in the granite. The similarities in mineral composition and time relations of bodies A and B are sufficient to warrant their correlation.

Origin and Correlation of the Felsic Rocks

In most places where anorthositic rocks occur, they are associated with acidic rocks that are, generally, younger than the anorthosite. The younger Roberval granite (Dresser, 1916) is associated with the Saguenay anorthosite.

Many authors believe that the acidic rocks are complementary to the anorthosite. Bowen (1917) postulates that the rest magma from which plagioclase separated to form anorthosite was syenite-granite and that this would crystallize later above the anorthosite. Likewise, Balk (1931) considers the "mother liquor" squeezed out from anorthosite to be syenitic in composition. Buddington (1939), however, does not believe the younger granites and syenites to be complementary to the Adirondack anorthosite. Ramberg (1948) goes so far as to suggest that the acidic rocks as well as the anorthosites are of metamorphic origin.

In Bourget area the only evidence that the acidic rocks are comagmatic with the anorthosite group is that they are closely associated with that group in space. Transitional rocks, intermediate in composition between anorthosite and granite, were not observed. Therefore, it is believed that the acidic rocks represent distinctly later intrusions that may not be related to the anorthosite group. The syenitic and granitic rocks were probably derived from a common parent.

The acidic rocks of Bourget area comprise two distinct groups, the earlier being syenitic in composition, the later granitic. They may be included in the Roberval type. They also have petrographic similarities to the Pine Hill series which is intrusive into the Morin anorthositic massif. It may be noted that the sequence of intrusions is very similar to that of the Adirondacks (Buddington, 1939), where anorthosite is followed by quartz syenite and this in turn by granite.

Dykes

Dykes observed within Bourget area are of rock types directly related to pyroxene diorite, quartz syenite, granite and pegmatite, as well as others (gabbro-diorite and diorite porphyry) that are not so obviously related to the major intrusions.

Diorite dykes related to the north-trending pyroxene diorite body in the western part of the area are very common near the contact of the diorite with the anorthosite and are obviously off-shoots from the main mass. Quartz syenite dykes are rare, but a few were observed cutting anorthosite in the northwest part of the area. Granite dykes are very common in the anorthosite, especially in the vicinity of Body A. These dykes are as much as a quarter of a mile wide and a mile or more long, but most of them are 5 feet wide or less. They are composed of the same minerals as the granite mass; in one, hastingsite constitutes the main ferromagnesian mineral.

Pegmatites are very common throughout the area, occurring as dykes commonly about two feet wide. Most of them consist of coarse, pink microcline-perthite and quartz. The latter is commonly graphically intergrown with microcline, but it also appears within the dykes as irregular masses. White plagioclase (An_{15}) is present in some of the dykes; in a few of them, books of muscovite and (more rarely) of biotite are found. Most of the pegmatites appear to be late magmatic derivatives of the microcline granite, as they have a similar mineralogical composition and cut all the Precambrian rocks, including the microcline granite. In the western part of the area, however, there are some pegmatites that contain quartz with a bluish opalescence, suggesting that they were derived from the quartz syenite mass.

Dykes that are apparently not related to the plutonic masses include gabbro-diorite and diorite porphyry.

Gabbro-diorite dykes are common in the anorthosite and locally are abundant. Normally, they are two feet thick or less, dip vertically and trend north, cutting across the foliation of the anorthosite at a small angle. The rock is dark grey, fine-grained and massive. In thin section, it consists of about 55 per cent andesine (An_{48}), 30 per cent augite, 10 per cent hornblende and 5 per cent opaque grains. The hornblende normally forms complete reaction rims around opaque grains. Augite is partly surrounded by a pale-green fringe similar to that forming the outer rim of the coronas around

the olivine of the troctolites and, hence, is considered to be actinolite or cummingtonite. These dykes are younger than the anorthosite group, but older than the Saint-Charles titaniferous magnetite deposits.

A few small dykes of black diorite porphyry, most of which are less than a foot thick, cut both anorthosite and diorite just west of the Saint-Charles deposits. The rock consists of dark phenocrysts of plagioclase (An_{42}), averaging 3 millimeters across, set in an aphanitic groundmass. The groundmass consists of plagioclase laths about a millimeter long embedded in a very fine-grained aggregate of biotite, feldspar, opaque minerals, and hornblende (?). In one thin section, the groundmass is so fine-grained that the minerals cannot be distinguished.

Palaeozoic

Ordovician-Trenton

Fine-grained, well-bedded, buff-grey, fossiliferous limestone of Trenton age is present in two places. One occurrence is at the eastern border of the area in southwest Bégin township. The other is in east-central Labrecque township. The former was mapped by Denis (1932), who described it (p. 66) as follows:

"The limestone lies near the foot, on the southeast side, of a range of low hills ... The limestone band is between three hundred and four hundred feet in length and one hundred feet wide. Between this outcrop and the falls at Chute aux Galets, no outcrops rise above the level of the plain."

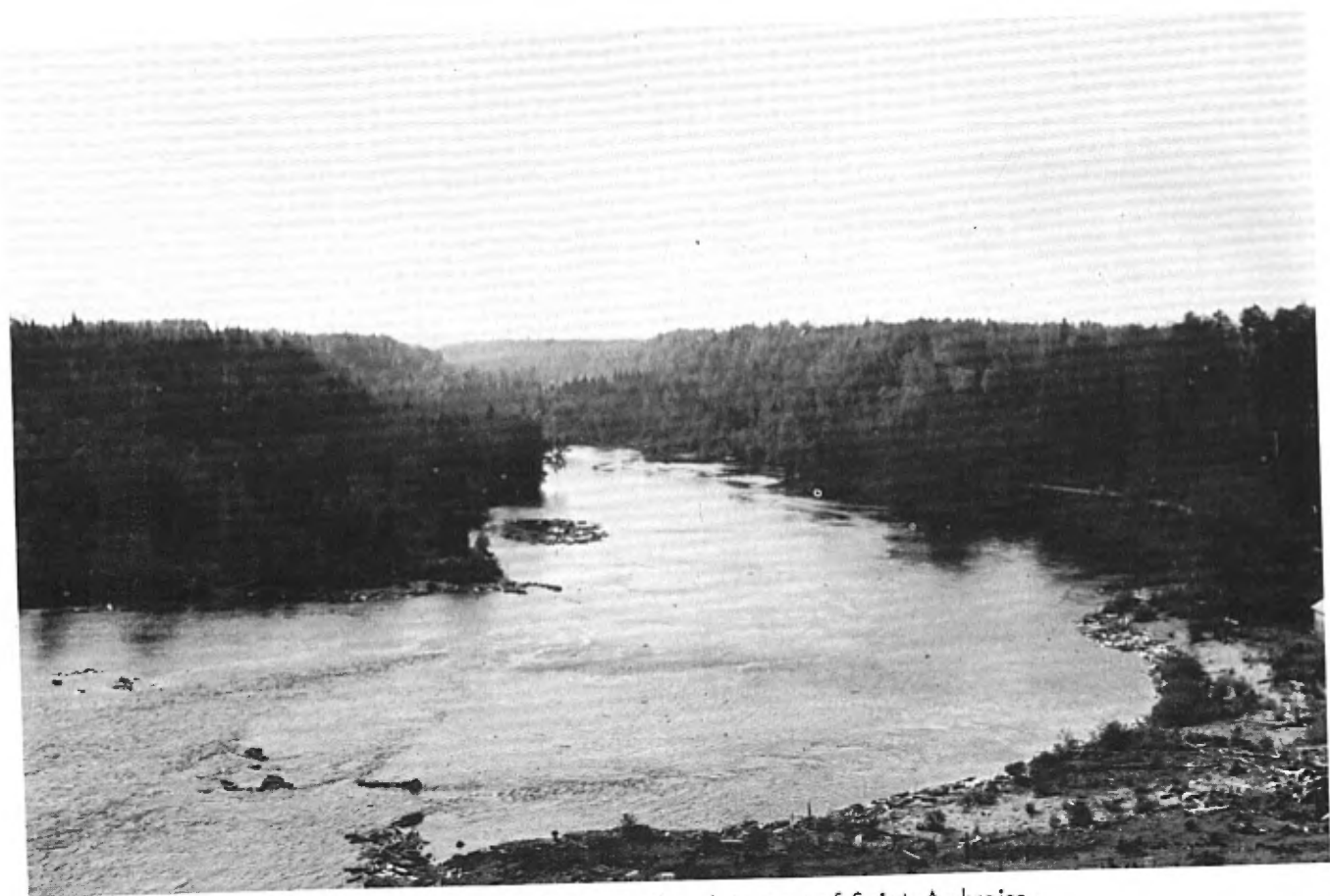
The limestone is lower than the adjacent escarpment of Precambrian rocks. This escarpment, although low, is remarkably straight for a mile and a half. It probably marks a fault along which the limestone was downthrown. Fossils^{*} from this locality are:

Actinoceras sp.
Streptelasma corniculum Hall
Rhynchotrema increbescens Hall
Receptaculites cf. oweni Hall
Hormotoma gracilis (Hall)
Platystrophia trentonensis McEwan

^{*}Identified with the assistance of T.H. Clark, J. Béland, and R. Bureau.



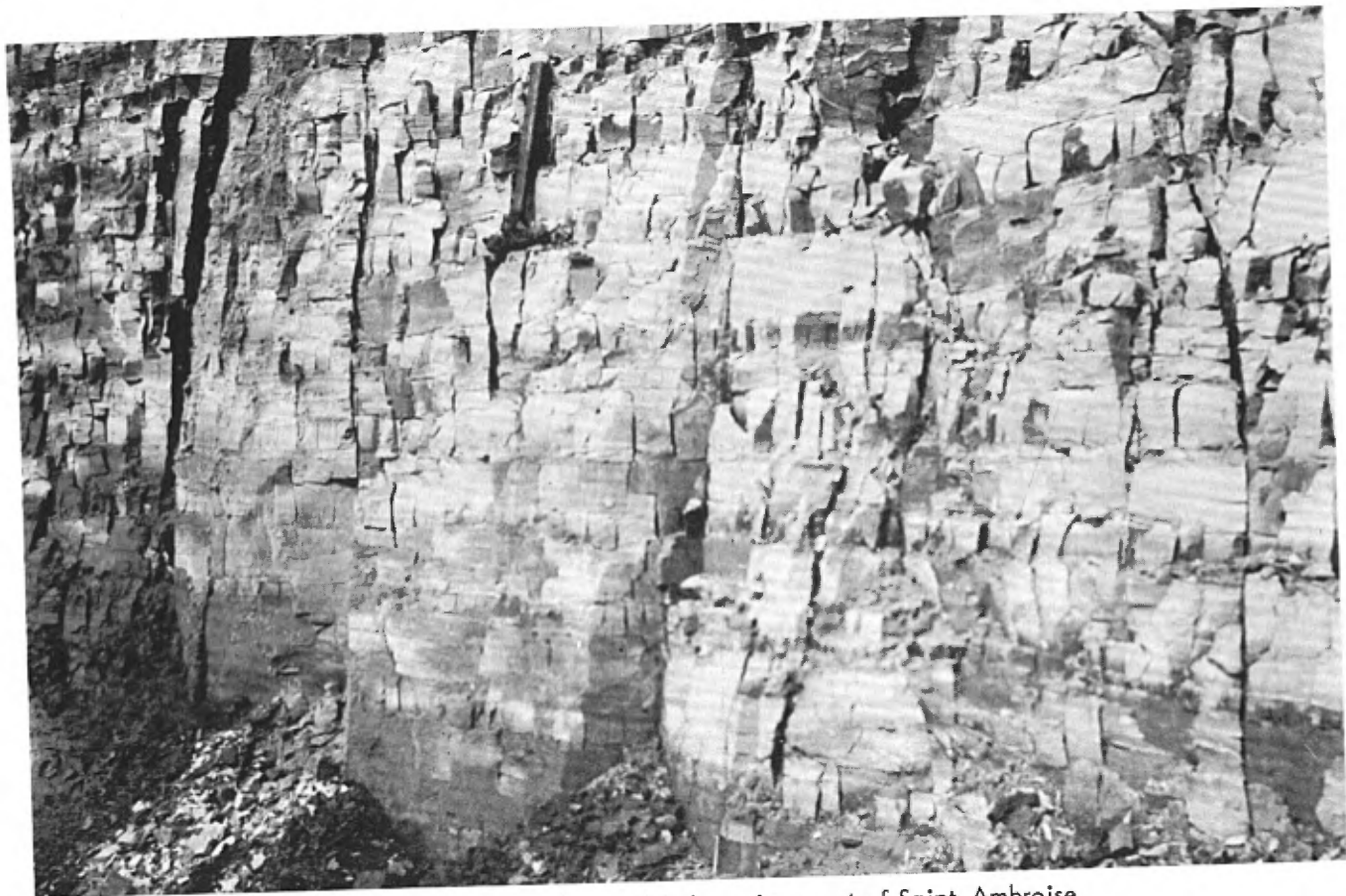
Plain north of Canton Bégin with hilly country in foreground and background.



Shipshaw river, incised into the plain east of Saint-Ambroise.

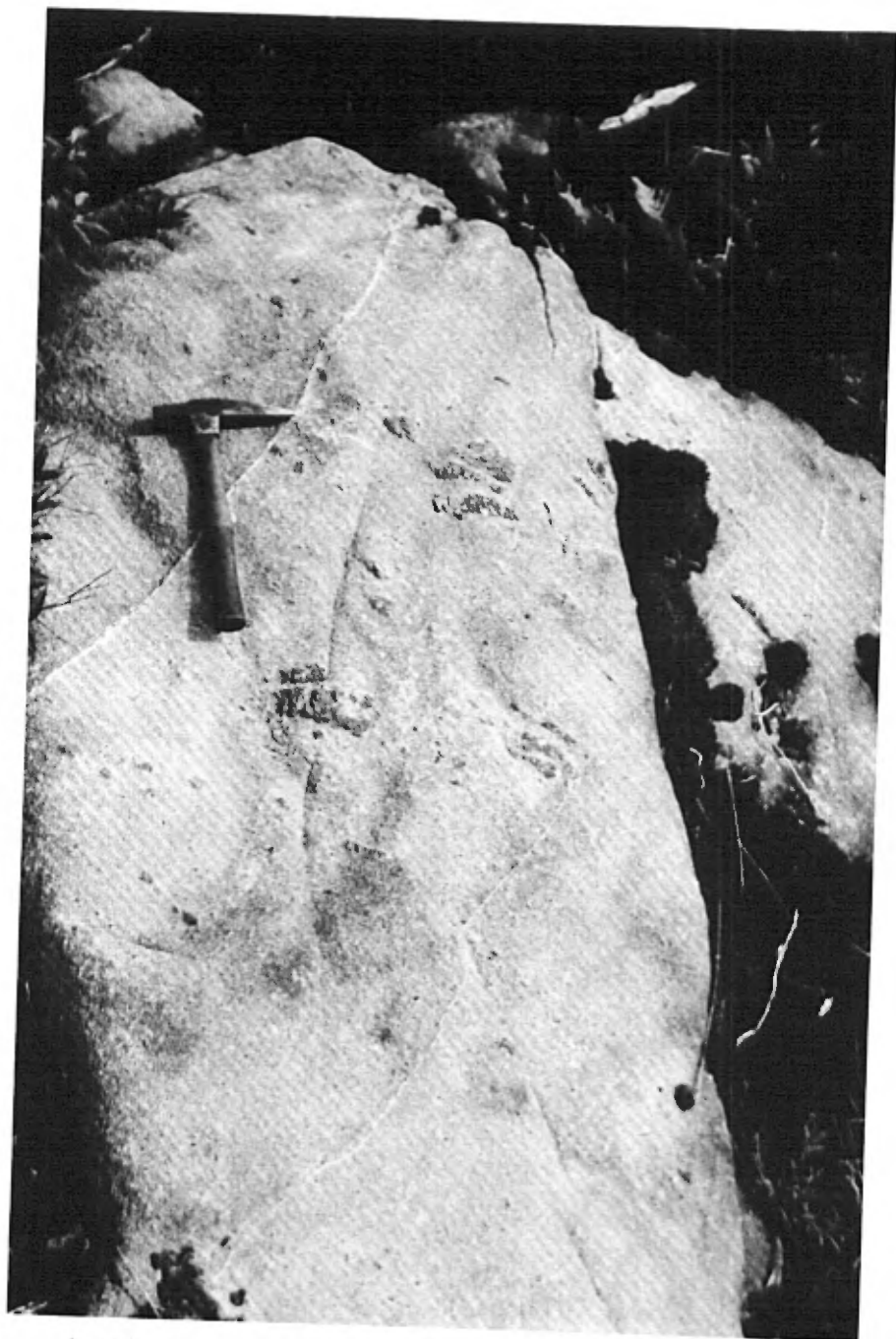


Saguenay river, above the Saint-Charles deposits.



Bedded post-glacial clay on Shipshaw river east of Saint-Ambroise.

Plate V

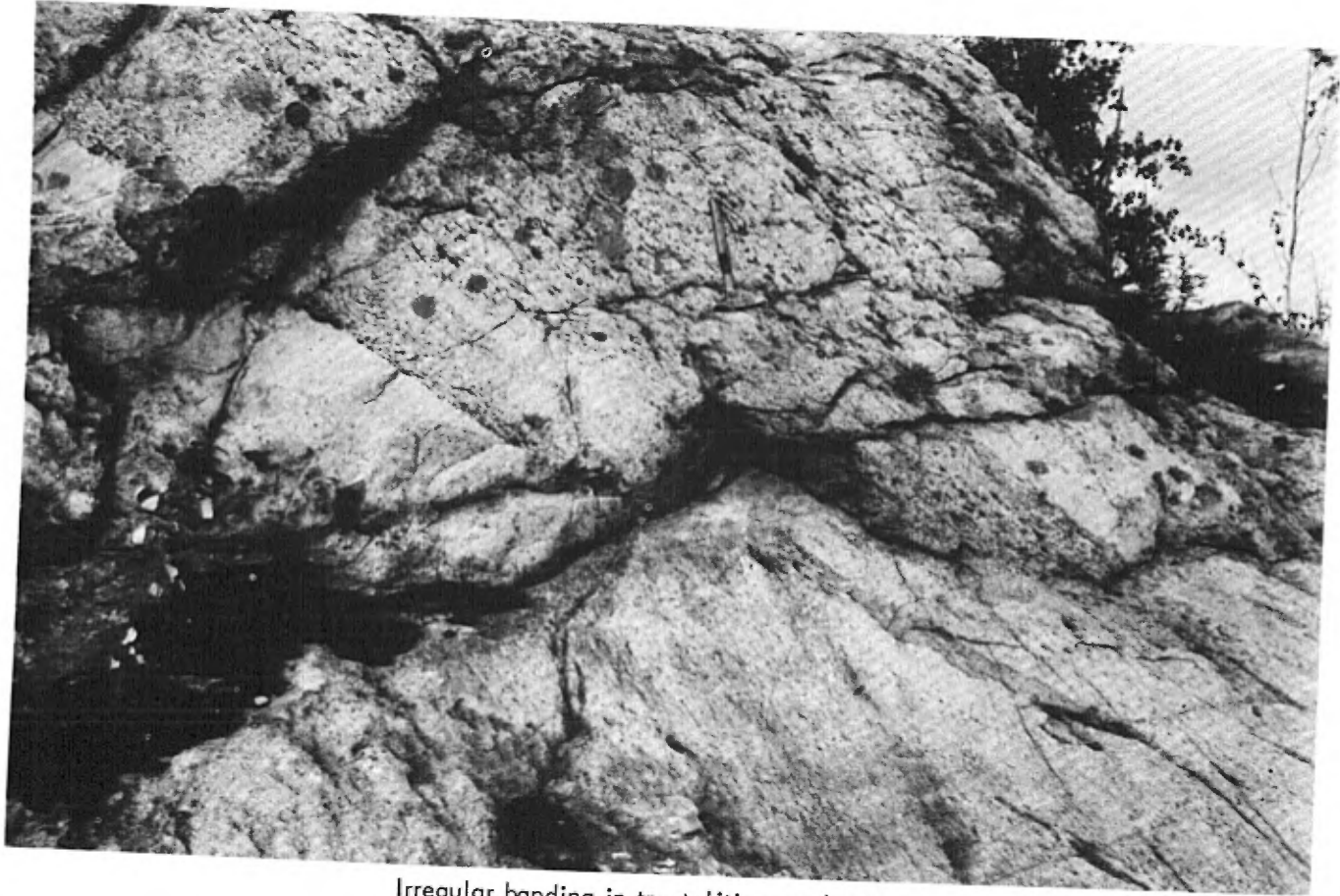


Anorthosite: large crystals of plagioclase in a matrix of medium-grained feldspar.

Plate VI



Gabbroic anorthosite pegmatite in gabbroic anorthosite .



Irregular banding in troctolitic anorthosite .

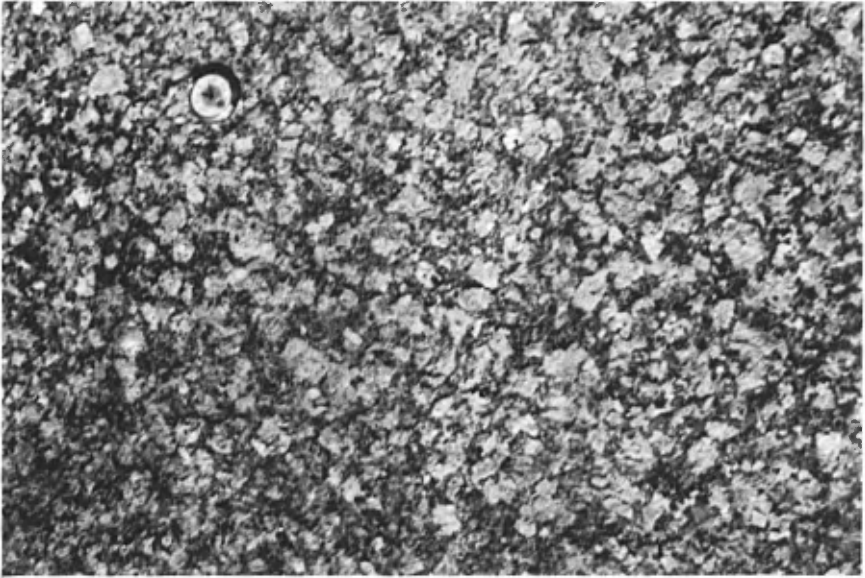


Block structure . Rounded block of granular anorthosite surrounded by gabbroic anorthosite .

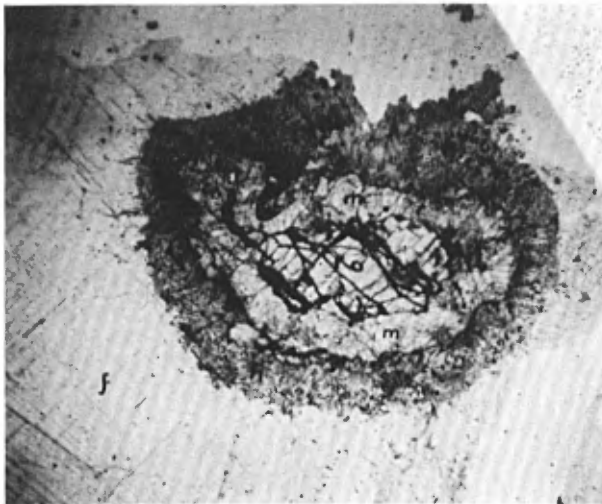


Inclusions of anorthosite in local quartz syenite facies of microcline granite of body A.

Plate X



A.-Typical quartz syenite . Phenocrysts are micropertthite .



B.-Photomicrograph showing corona around olivine in anorthosite:
o=serpentinized olivine; m=hypersthene; h=amphibole and spinel; f=plagioclase . Plane polarized light x15.

Plate XI



A.-Photomicrograph of phosphorus-rich titaniferous magnetite:
a=apatite; o=serpentinized olivine. Plane polarized light. x20.

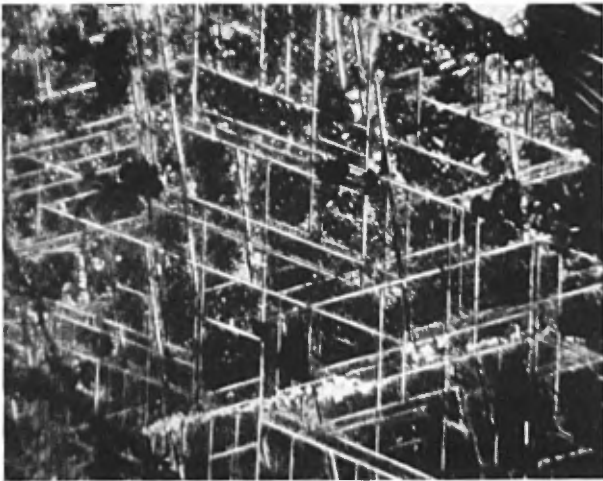


B.-Photomicrograph of ilmenite along grain boundaries of magnetite. White is ilmenite; rest is magnetite. Reflected light. x40.

Plate XII



A.-Photomicrograph of titaniferous magnetite. Broad and fine laminae of ilmenite (white) in magnetite (dark). Etched with HCl. Reflected light. x 35



B.-Photomicrograph of magnetite-ilmenite intergrowth. Ilmenite (white) along octahedral planes of magnetite. Etched with HCl. Reflected light. x 100.

In the Labrecque locality, there are several exposures of limestone in a shallow valley between ridges of Precambrian rock. One of the exposures of limestone is separated from granite by a vein of coarsely-crystalline calcite containing fragments of limestone and granite. The vein probably occupies a fault along which the limestone was let down. The fossils* from this locality include:

Streptelasma sp.

Actinoceras sp.

Halysites sp.

The limestone presumably rests on Precambrian rocks and its preservation is probably the result of down-faulting. The fossils indicate the limestone to be of Trenton age.

Cenozoic

Pleistocene and Recent

Till and glacial outwash deposits are present in most of the hilly parts of the area. The former consists of bouldery moraine that generally forms a superficial covering. The latter are coarse-bedded gravels that are particularly abundant in the vicinity of lake Nazaire (Lac des Isles) and Bégin lake on the northeastern part of the area.

The till and glacial outwash were probably deposited during the Wisconsin stage. Legget (1945) and Radforth (1945) have presented some evidence for the presence of inter-glacial deposits near Shipshaw, but no evidence for such deposits was seen in the Bourget region.

In the low flat country, the unconsolidated deposits are stratified clay and sand deposited in part at least in an arm of the post-glacial Champlain Sea. The clay is fine-grained, bedded but not varved, and poorly consolidated (Plate IV). It is best exposed along streams that have cut into the plain, but in places it lies at the surface, forming an excellent soil. An extensive search in the clays yielded only one fragment of a fossil which could be Saxicava.

*Identified by T.H. Clark.

Coarse, cross-bedded sands with numerous gravelly patches overlie the clay, and make up the surface of much of the flat country.

The stratified clays and sands are probably mostly marine in origin, as is suggested by their widespread distribution and uniform character, and by the one fossil (Saxicava?) found in the clay. The marine character of the sand and clay in the Lake Saint-Jean lowland has been established by previous investigators on the basis of fossils (Saxicava rugosa), long and regular terraces, and by the uniform stratification.

ECONOMIC GEOLOGY

The titaniferous magnetites are the only known deposits of metallic minerals in Bourget area. Of these, the Saint-Charles deposits are by far the largest. Non-metallic deposits include mica and calcite. Building stone, sand, and gravel are utilized and clay is potentially economic.

Titaniferous Magnetite Deposits

The known exposures of titaniferous magnetites are shown on the accompanying map. With one exception, all those not included in the Saint-Charles deposits are small, generally less than three feet wide, and appear to be dykes cutting anorthosite. It is possible that there are other occurrences in the vicinity of the band of ophitic anorthositic troctolite.

The exception noted above is a small outcrop south of the Saguenay. This is similar to the Saint-Charles deposits, consisting of a coarse-grained aggregate of titaniferous magnetite and olivine with little or no apatite. More deposits may be present on strike farther south.

Saint-Charles Deposits

General.-

The Saint-Charles titaniferous magnetite deposits lie north of Saguenay river, 15 miles downstream from lake Saint-Jean, on lots 44 to 48, range I, Bourget township. The deposits take their name from the village of Saint-Charles Borromée, 3 miles distant

downstream or east and 5 miles by road. Although the name was originally applied to the occurrences on the immediate shore of the Saguenay, it now includes those within a mile to the north.

The first published reference to the deposits was made by Laflamme (1884). Adams (1893) recognized the presence of olivine in them. The exposures on the south end of lot 44 were mapped by Dulieux (1912) and a further examination was made of the southern part of the deposits by Robinson (1926). In the files of the Quebec Department of Mines there is a compilation of the many assay results of samples taken from these deposits by P.-E. Bourret in 1941 and 1942. A dip-needle survey was made on the northern parts of the deposits by Waddington (1944). Osborne (1944) described the mineralogy of some of the occurrences. A report, map, and the results of numerous analyses, were kindly made available to the writer by A.W. Jolliffe, who examined the deposits in 1946. American Metals Company generously furnished the author with the results of some analyses made by them in 1948.

In the summer of 1948, the writer made a detailed geological study of the deposits, the mapping being done by plane table on the scale of 400 feet equal to one inch (see map in pocket). A transit survey of a bush road extending south on lot 45 from the main road between ranges I and II of Bourget township was used as a base. The main road gives access to the area from Chicoutimi, Jonquière, and Arvida.

The greater part of the area mapped around the Saint-Charles deposits is heavily covered by second-growth bush, and outcrops are largely covered by moss. However, toward the north, a considerable part has been cleared for farming purposes. The northern two-thirds is about 500 feet above sea level, has a relatively low relief, and is characterized by rock protruding through the clay covering. The southern third is on the steep north slope of the Saguenay valley, the river here, now held up by a dam, being at an altitude of 243 feet.

The Saint-Charles titaniferous magnetite bodies occur as irregular masses in rocks of the anorthosite group. The sequence of formations is shown in the following table:

Granitic pegmatite dykes ? Granodiorite dykes
Intrusive contact
Titaniferous magnetite bodies
Intrusive contact ?
Gabbro-diorite dykes
Intrusive contact
Anorthosite series: anorthosite, gabbroic anorthosite, etc.

The anorthosite group is cut by numerous thin dykes of gabbro-diorite. The magnetite was emplaced after the intrusion of these dykes, as is shown by inclusions of gabbro-diorite within the ore. There are several granitic pegmatites in the area, one of which cuts across a body of titaniferous magnetite. Granodiorite dykes were seen intruding only anorthosite, but the structure in adjacent parts suggests that they were earlier than the pegmatite dykes.

The rock types of the anorthosite group are similar to those already described. Around the deposits, anorthosite predominates, and troctolitic anorthosite and gabbroic rocks are only locally developed for the most part as poorly defined layers in more feldspar-rich rocks.

In general, the anorthosite has scattered porphyroclasts about two centimeters across embedded in a medium-grained, granulated groundmass. In some places, the porphyroclasts are absent and locally the rock is relatively coarse-grained, but typical coarse-grained anorthosite is nowhere developed. In thin section, the plagioclase shows highly irregular grain boundaries, wavy extinction, bent twin laminae and a marked diversity in grain size that is believed to be the result of granulation. The feldspar is from An_{44} to An_{47} - a distinctly lower anorthite content than in the anorthosite elsewhere. The dark minerals are green hornblende, biotite, magnetite with inter-

grown ilmenite, and ilmenite. Calcite is present in a few places and a grain of titanite was seen in one of the sections examined.

Large areas of troctolitic and gabbroic anorthosite occur to the east and north of the deposits, but these rocks are present in very small amount in the area under discussion, being practically confined to the northeast and easternmost portions of the Saint-Charles map-area. The distribution of dark minerals in these rocks is highly variable, even within a small area.

Gabbro-diorite dykes are numerous in the northeastern part of the Saint-Charles deposits. They average about two feet wide, generally strike N.20°E., and consist of about 55 per cent plagioclase (An_{48}), 30 per cent pyroxene, 10 per cent hornblende, and 5 per cent opaque grains. They are clearly younger than the anorthosite, for they cut across the foliation, but they are older than the titaniferous magnetite, which, as was noted by Robinson (1926, p. 45), contains inclusions of gabbro-diorite.

Granodiorite dykes are few and scattered in the area of the Saint-Charles deposits. The rock is pinkish and medium-grained granular. It consists of about 70 per cent feldspar, together with biotite arranged in parallel flakes so as to impart a foliation to the rock. A thin section showed about 40 per cent microcline, 35 per cent plagioclase (oligoclase An_{27}), 10 per cent quartz, 15 per cent biotite, with magnetite and apatite as well as a little calcite as accessory minerals.

Pegmatite dykes are present in several places in the anorthosite. One cuts a body of titaniferous magnetite. These dykes are commonly about two feet wide and consist chiefly of pink feldspar (microcline perthite), but some contain quartz (partly in graphic intergrowth with feldspar) as well as a small amount of biotite. Thus, both syenite and granite pegmatites are present.

In this report, rocks consisting predominantly of magnetite and ilmenite are referred to as titaniferous magnetite, although olivine, apatite and other minerals may constitute up to 50 per cent of the rock.

The titaniferous magnetite forms irregular, lenticular bodies in the surrounding anorthosite, many of which seem to be elongated towards the north, at a small angle to the regional foliation.

The exact shapes and attitudes of most of the bodies could not be determined for but few contacts are exposed. However, the foliation within the bodies for the most part strikes north. The dip of the foliation is steep in some exposures and moderate in others. In one place (occurrence B, see map), an apparent fold structure is present.

The areas of abundant exposures fall into two groups: a northern group in the central part of lot 46 and overlapping into lots 45 and 47; and a southern group, in the southern parts of lots 44 and 45, partly on the steep slope of the Saguenay valley.

The contact of titaniferous magnetite with anorthosite is very rarely exposed but, where seen, it is sharp. This relation is well shown in occurrence B, where dyke-like offshoots cut anorthosite cleanly with no gradation and no alteration along the contact. In the southern part of the deposits, Robinson (1926, p. 45), although also remarking on the rarity of exposed contacts of these rocks, found that the contact with gabbroic, gneissose anorthosite is characterized by a zone of friable material, probably the result of weathering, whereas the contact with massive anorthosite is clean and sharp, without visible traces of alteration.

Robinson (1926) and Waddington (1944) used numbers and letters, respectively, to designate separate bodies. On the accompanying map, their designations are used as far as possible.

On the basis of mineralogy, the titaniferous magnetite bodies can be divided as phosphatic or phosphorus-poor, the former containing 5 to 30 per cent apatite by volume and the latter containing less than 5 per cent apatite. Waddington (1944) made a distinction between these two types on the basis of chemical analysis. This division is purely arbitrary, as one kind may grade directly into the other by an increase or decrease in apatite content. There does not seem to be any genetic difference between these two types.

The phosphatic titaniferous magnetites are restricted to the northern group of deposits with the exception of occurrences VII and J. The phosphorus-poor types are restricted to the southern group with the exception of occurrence A. In the latter, there are local areas containing more than 5 per cent apatite. Deposits J, E, and VII, although belonging to the phosphatic type, contain only 5 to 10 per cent apatite.

Mineralogy.-

The titaniferous magnetites vary considerably in grain size and proportions of minerals.

The phosphatic titaniferous magnetite is typically made up of medium-grained aggregates of magnetite and apatite surrounding larger crystals or masses of olivine. The olivine is brown-green in colour and has a waxy lustre and conchoidal fracture. Grains average about half an inch across, but in places, as at deposit I, aggregates of olivine up to a foot across are present. Apatite is in rounded grains generally 0.5 mm. in diameter; in deposit B, there are grains up to 7.5 mm. The apatite may be colourless, very pale green, or stained light brown. Titaniferous magnetite occurs in black anhedral grains about a millimeter across and normally constitutes more than 50 per cent of the rock. Pyroxene as relatively large dark green crystals with good cleavage is present in a few places.

The phosphorus-poor titaniferous magnetite is like the phosphatic type, except that apatite is scarce or absent, and the granularity is coarser. Thus, the rock typically consists of masses and crystals of olivine embedded in coarse-grained titaniferous magnetite.

Examination of thin and polished sections shows the following minerals to be present: magnetite, ilmenite, hematite (?), spinel, apatite, olivine, serpentine, pyroxene, amphibole, biotite, and plagioclase.

Magnetite is in anhedral grains up to 5 mm. in diameter. About half the magnetite has intergrown ilmenite, and in places, intergrown spinel.

Ilmenite constitutes 20 to 40 per cent of the titaniferous magnetite and is distinguished from the magnetite proper by its anisotropism and negative etch reaction with concentrated hydrochloric acid. It occurs both as discrete grains and intergrown magnetite. The discrete grains occur in rounded or rudely tabular crystals up to 4 mm. across. Ilmenite intergrown with magnetite is very abundant. The widths of laminae are widely variable from place to place, although there is some consistency within a single polished section. In places, the laminae are thin (0.001-0.1 mm.), regular, with orientation in three directions which are parallel to the octahedral planes of the

magnetite. In other places, the laminae are up to 0.3 mm., and such thicker laminae commonly form only one parallel set and are irregular in distribution within a single grain. In some grains, the ilmenite laminae are confined to the borders of magnetite grains. The intergrowth of magnetite and ilmenite has been described many times, and it is generally agreed that it is the result of unmixing.

Very rare, small, discrete grains, nowhere more than 0.15 mm. in diameter, may be hematite; but these are so small that the mineral could not be definitely identified.

Spinel is invariably present, and constitutes 5 to 10 per cent of the titaniferous magnetite. The spinel is dark green and isotropic; the refractive index of 1.78 suggests that it is pleonaste $(\text{MgFe})\text{Al}_2\text{O}_4$. The spinel occurs mainly as discrete grains, and to a lesser extent as an intergrowth with magnetite. Individual grains are up to 2 mm. in diameter and are normally anhedral. The intergrowth consists of parallel laminae or irregular inclusions in magnetite, and is probably the result of unmixing.

Apatite constitutes up to 30 per cent of the phosphatic titaniferous magnetite, whereas it is scarce or absent in the phosphorus-poor types. It occurs in colourless, anhedral, normally somewhat rounded grains ranging in size from 0.2 to 7.5 mm., and averaging about 0.6 mm. Refractive indices between 1.63 and 1.64 indicate that it is fluorapatite. Inclusions in the apatite consist of magnetite in rounded grains averaging 0.02 mm. in size, and in opaque rods 0.01 mm. thick that are invariably parallel to the c crystallographic axis. These rods are so abundant in places that the apatite is clouded.

Olivine is characteristic and occurs as isolated grains or as aggregates that give the rock a porphyritic appearance. The optical data ($X=1.715$, $Y=1.735$, $Z=1.75$, negative, $2V\ 80^\circ$, estimated) suggest that the olivine is a ferriferous chrysolite containing about 40 per cent Fe_2SiO_4 . Serpentine replaces olivine along veins and around the periphery of grains.

Pyroxene occurs rarely in the phosphatic titaniferous magnetite, as subhedral grains averaging about a millimeter across. The monoclinic pyroxene contains small, thin rods of ilmenite arranged in two directions.

Hornblende is generally present, although in very small amounts, near the contacts of magnetite with feldspar, pyroxene, or

olivine. The hornblende is brown, grading toward the margins of some grains to green. Most of the amphibole seems to have developed from plagioclase, since this mineral is everywhere separated from the enclosing magnetite by a zone of brown hornblende.

Biotite is commonly present, but in minor amounts only; it occurs as small flakes associated with brown hornblende, or completely enclosed in magnetite, and is most common adjacent to hornblende and feldspar.

Plagioclase is rare and in accessory amounts. At several places, especially in the southern group of deposits, masses of plagioclase that probably represent inclusions of anorthosite are present. In thin section, the plagioclase shows mainly as aggregates of deformed grains with irregular boundaries and markedly irregular extinction. Single crystals of plagioclase enclosed in magnetite, and small grains included in pyroxene, are also present. Brown hornblende almost invariably separates the feldspar from the enclosing magnetite. The plagioclase normally contains abundant, small, angular, green inclusions that appear to be amphibole or spinel. The composition of the feldspar ranges from An_{30} to An_{40} , and thus has a lower anorthite content than the plagioclase of the adjacent anorthosite. The anorthite content probably was lowered by the reaction with magnetite to produce brown hornblende.

Mineral Relations.-

The texture of the titaniferous magnetite resembles that of a basic igneous rock, and so suggests that the magnetite crystallized from a melt. The textures further suggest that the crystallization of olivine and apatite preceded that of the magnetite, ilmenite and spinel. The feldspars, however, probably are inclusions from the wall-rock, and hornblende and biotite reaction products of magnetite with feldspar. The serpentine presumably is of late magmatic origin. The unmixing of ilmenite and spinel from magnetite took place as the temperature declined.

Inclusions.-

The titaniferous magnetite contains inclusions of anorthosite and of gabbro-diorite. Thus, the magnetite was introduced after the anorthosite was consolidated and intruded by gabbro-diorite.

Anorthosite inclusions are found in occurrences D and J in the northern group of deposits and in I and a few other places in the southern group. The inclusions are small, angular, and generally less than 3 inches in diameter. Two thin sections of such inclusions contain feldspar exactly similar to that in the titaniferous magnetites. Especially noteworthy is the development of brown hornblende at the contact of feldspar and magnetite. This lends further support to the conclusion presented above that most, if not all, of the feldspar in the titaniferous magnetite represents inclusions that were detached from the adjacent anorthosite.

Inclusions of gabbro-diorite, identical with dykes cutting anorthosite, are more common than anorthosite in the titaniferous magnetite. Most of these inclusions are sub-angular and less than a foot in diameter. A thin section taken from across the contact of titaniferous magnetite and a gabbro-diorite inclusion shows that olivine, serpentine, and spinel become more abundant toward the contact with the titaniferous magnetite. The zone immediately adjacent to the titaniferous magnetite is a fibrous mass of serpentine, but farther away there is unreplaced olivine. At about 2 mm. from the contact much olivine is present and feldspar appears. Feldspar becomes more abundant away from the contact and the number of olivine and spinel grains decrease until the mineral content approaches that of normal gabbro-diorite. However, brown hornblende is more common in the inclusions than in unaltered gabbro-diorite.

Composition of the Titaniferous Magnetites

The deposits were sampled by Bourret in 1942, Waddington in 1944, Jolliffe in 1946, and American Metals Company in 1948. No new analyses were made for the present report. The accompanying table (p. 32) contains a compilation of analyses of the various occurrences. It will be noted that analyses from samples taken by different investigators agree closely, considering the nature of the deposit. The analyses confirm the field observations as regards phosphorus content, the phosphatic type showing visible grains of apatite.

The phosphorus is contained in apatite; the titanium oxide, in ilmenite; and most of the iron, in magnetite and ilmenite although there is some in olivine and spinel. Spinel accounts for most of the Al_2O_3 , olivine for the SiO_2 and MgO , and apatite for the CaO , fluorine, and chlorine. Vanadium and manganese are probably in solid solution in the magnetite. The sulphur cannot be accounted for, as no sulphides were observed.

Phosphatic Titaniferous Magnetite.- Most occurrences of the phosphatic type are confined to the northern group. Some of these, as E in the northern group and J and VII in the southern group are relatively low in phosphorus (1.31, 1.01, 1.45 per cent P respectively), although of the phosphatic type. For B, C, D and F, the range in average composition is:

P	2.70- 3.52%
Fe	37.61-39.31%
TiO ₂	16.12-17.39%

Occurrences G, H, and I may be parts of one body. The G-H-I zone contains an average of 36.19 per cent Fe, 13.98 per cent TiO₂, and 4.26 per cent P, corresponding to a mineral composition of:

Apatite	21%
Ilmenite	26%
Magnetite (estimated)	30%
Olivine, spinel, and other minerals (estimated)	24%

Although there is considerable variation in the proportion of the several minerals from place to place, individual analyses do not differ greatly from the average. Low percentages of iron and titanium oxide can be readily attributed to the presence of silicates, especially pyroxene, in the samples.

Phosphorus-poor Titaniferous Magnetite.- Most of the phosphorus-poor occurrences are in the southern group of deposits, but they also include occurrence A, the most northern major occurrence. The phosphorus content does not exceed 0.13 per cent. The Fe is from 39.81 to 52.17 per cent (average 46.24) and TiO₂ from 13.35 to 22.04 per cent (average 19.08).

From the analyses and a study of the deposits, the mineral composition is estimated to be:

Ilmenite	36%
Magnetite	44%
Olivine, spinel, and other minerals	20%

The analyses are fairly uniform, with the exception of those from occurrence IV which has considerably less Fe and TiO₂ than the rest. Undue weight must not be placed on this since the analyses represent but one grab sample.

Table 1

Analyses of St. Charles Titaniferous Magnetites (Phosphatic)

Local-ity	Fe	TiO ₂	SiO ₂	Al ₂ O ₃	CaO	MgO	P	S	V	F	Cl	Ref.
B	38.40	17.14	1.91	10.25	7.65	2.35	3.12	0.07	0.10	0.32	0.04	(1)
B	40.22	17.65					3.90					(2)
B	39.31	17.39					3.51					Average
C	33.32	13.38	15.11	7.56	6.71	6.84	2.06	0.04	0.09	0.16	0.03	...(1)
C	41.90	18.95					3.35					...(2)
C	37.61	16.16					2.70					Average
D	37.60	16.29	5.15	6.14	7.55	4.48	3.19	0.07	0.09	0.29	0.01	...(1)
D	38.20	16.27					3.85					...(2)
D	37.90	16.28					3.52					Average
E	45.43	20.72	2.11	4.60	3.39	4.73	1.31	0.07	0.14	0.00	0.02	...(1)
E	46.05	20.23					1.32					...(2)
E	45.74	20.47					1.31					Average
F	37.15	15.19	6.80	2.52	9.51	7.15	3.35	0.11	0.09	0.19	0.04	...(1)
F	40.45	17.05					3.32					...(2)
F	38.80	16.12					3.33					Average
G	35.38	14.40	4.27	4.40	13.31	5.24	4.45	0.18	0.08	0.33	0.04	...(1)
G	36.52	14.65					4.96					...(2)
G	35.49	13.57					3.81		0.11			(3)(a)
G	35.80	14.21					4.41					Average
H	33.27	12.30	7.19	4.67	13.76	6.88	4.43	0.08	0.06	0.46	0.02	...(1)
H	39.60	15.95					3.57					...(2)
H	36.43	14.12					4.00					Average
G-H	36.11	14.16					4.20		0.07			Average from above
G-H	33.97	13.40					3.59		0.13			(3)(b)
G-H	35.04	13.78					3.89					Average
I	35.30	12.29	6.31	5.32	12.14	5.59	4.54	0.06	0.07	0.37	0.04	...(1)
I	37.70	14.70					4.05					...(2)
I	36.50	13.49					4.29					Average
G-H-I	36.19	13.98					4.26					Average from above
J(V)	45.59	18.74					1.01		0.05			(4)(c)
J(V)	45.22						0.95		0.09			(4)(d)
J(V)	43.94	18.74	4.88	7.03	3.23	4.07	1.00	0.03	0.03			(1)(a)
VII	33.95	11.94					1.45		0.23			...(4)

Table 2

Analyses of St. Charles Titaniferous Magnetites (Phosphorus-poor)

Local-ity	Fe	TiO ₂	SiO ₂	Al ₂ O ₃	CaO	MgO	P	S	V	F	Cl	Ref.
A	40.23	13.35	13.06	6.37	0.21	11.35	0.03	0.05	0.11			(1)(e)
I	46.75	17.95					0.03		0.24			(4)(f)
I	44.16						0.01		0.01			(4)(d)
II	47.20	18.57					0.00		0.22			(4)(g)
III	52.17	21.87					0.00		0.25			...(4)
IV	39.81	13.35					0.00		0.27			...(4)
VIII	41.29	17.92					0.00		0.25			...(4)
X	47.45	20.90					0.02		0.26			...(4)
X	49.37		2.12	5.91	0.16	3.26	0.13		0.22			(4)(d)
XII	48.13	20.04					0.005		0.25			(4)(h)
XII	44.71						0.06		0.09			(4)(d)
XIII	47.57	22.04					0.09		0.25			...(4)

References, Table 1 and Table 2:

1. Waddington, 1944
 - (a) average of 6 samples
 - (b) average of 11 samples across
2. American Metals, 1948
 - (c) average of 6 samples (MnO = 0.42)
 - (d) bulk sample (600 lbs.)
3. Jolliffe, 1946
 - (e) average of 16 samples
 - (f) average of 11 samples
4. Bourret, 1941, 1942
 - (g) average of 4 samples
 - (h) average of 2 samples

Uses.-

The Saint-Charles deposits have received the attention of many mining concerns, but active development has not been attempted as yet. The deposits may be considered as a possible source of iron, titanium and phosphorus. Compared to the deposits at Allard lake, exploitation of which began in 1950, the Saint-Charles deposits average higher in iron and lower in titanium oxide.

The possibility of commercial extraction of phosphorus from apatite in the Saint-Charles deposits was first suggested by Osborne (1944), and later was considered by Jolliffe^A. The latter submitted a bulk sample (1,100 pounds) to the Mineral Dressing and Metallurgical Laboratories, Department of Mines, Ottawa, for testing. The results of these tests are given in Reports No. 2213 and 2213a issued by that Department. The sample contained 9.65 per cent P_2O_5 (22.8 per cent apatite), 34.84 per cent Fe, and 12.76 per cent TiO_2 . The tests showed that from this material magnetic separation, followed by flotation, could be recovered 76.7 per cent of the apatite, as well as a magnetic concentrate containing 61.0 per cent Fe and 11.1 per cent TiO_2 .

Origin.-

In a general way, the Saint-Charles titaniferous magnetites are like many such deposits contained in anorthosite in various parts of the world, but differ from most other occurrences in that olivine is generally abundant and apatite locally abundant.

A number of theories have been advanced to explain the formation of bodies of titaniferous magnetite. They have been interpreted as segregations, replacements, or injections. The Saint-Charles material cannot be regarded as a segregation because it does not grade into gabbro; in fact, the containing rock generally is anorthosite and this appears to have a sharp contact with the titaniferous magnetite. There is little evidence for replacement, either in the constituent minerals or in the adjacent rocks. Furthermore, minerals normally suggestive of hydrothermal origin are not present. We are left, therefore, with the theory that the Saint-Charles deposits represent injections, and that the original magma was able to remain

^APersonal communication.

liquid at a relatively low temperature as the result of the abundant admixed silicates and apatite.

If the titaniferous magnetites are to be regarded as magmatic injections, the parent liquid may have been derived by filter-press differentiation of one or another of the adjacent rocks, as suggested by Osborne (1928). The adjacent anorthosite seems the most obvious, but probably was not the actual source of the deposits. The reasons are, first, that although the anorthosite contains olivine it is almost lacking in apatite, and, second, that the anorthosite seems to have been largely consolidated prior to the introduction of the titaniferous magnetite. On the other hand, the band of ophitic anorthositic troctolite contains much olivine as well as titaniferous magnetite, both of which have an ophitic relation to the plagioclase (showing that the feldspar crystallized earlier). In addition, apatite is particularly abundant in most parts of this rock.

Therefore, it is concluded that the Saint-Charles titaniferous magnetites were formed by the injection of a residual magma that was kept liquid by its unusual composition and was derived by filter-pressing of partly consolidated ophitic anorthositic troctolite.

Calcite

Several calcite veins are exposed in the northern parts of lots 9, 10, and 11, range VI, Labrecque township, adjacent to the Range VI-VII road. Records of the deposits are to be found in the files of the Quebec Department of Mines.

The veins occur close to the contact of limestone and granite. The largest, in lot 9 about 300 feet south of the road and 200 feet east of the west boundary of the lot, is 80 feet long as exposed and about five feet wide. It strikes about east and seems to dip steeply. The calcite is white, coarsely-crystalline, and contains inclusions of fossiliferous limestone. Analysis by the Quebec Department of Mines Laboratories (P.-E. Bourret, 1943; 1955) of material from this locality gave the following result:

CaO	48.03%
MgO	0.82%
Insoluble material	10.33%

Material from some of the other exposures had as much as 55.88 per cent CaO.

The veins have been explored by trenching and by diamond drilling two holes. They were probably emplaced during the faulting which brought down the Trenton limestone now found south of the veins.

Mica

Granite and syenite pegmatites are very common throughout the area. They contain mica at a few places, as described below.

(1) Lot 30, range IV, Bégin township (one-half mile east of the village of Canton-Bégin) at the south end of the lot, about 30 feet north of the abandoned Range III-IV road. The pegmatite cuts anorthosite and averages one foot wide over a length of 35 feet. It consists of quartz, pink microcline perthite, and white plagioclase (An_{15}), with scattered books of white mica (muscovite) and black mica (biotite). The muscovite constitutes about 3 per cent of the pegmatite; the books average about three-eighths of an inch thick and one and one-half inches across. A little blasting has been done and some mica extracted.

(2) Lots 30 and 31, range V, Bégin township (two miles north-northeast of the village of Canton Bégin). This pegmatite occurs along the north ends of the lots, about a mile from the nearest gravelled road. The dyke is exposed, partly by trenching, for 230 feet, and has an average width of 3 feet. It strikes $N.70^{\circ}W.$, and dips vertically. The pegmatite consists of quartz and feldspar, with scattered books of muscovite averaging one to two inches across and generally less than one and one-half inches thick. As a whole, the pegmatite contains less than 5 per cent muscovite. Some mica has been extracted.

(3) Other occurrences. Small pegmatite dykes containing a little mica occur in lot 34, range IV, Bégin township, lot 46, range VII, Bourget township, and at a few other places.

Miscellaneous Products

A considerable amount of building stone is quarried in the Lake Saint-Jean region (see Osborne, 1933), but, in the Bourget area, no quarries have been opened. Parts of the anorthosite, especially that immediately east of the village of Saint-Ambroise, and some of the granite might be suitable for building or monument stone.

The bedded clays are not utilized at present, but large quantities of them are readily available, especially where streams are incised below the level of the plain. They may be suitable for brick or tile. The best soils are developed where these clays form the surface of the land.

Sand and gravel are found throughout the area and are extensively used for road construction and maintenance.

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