THE MINERALOGY OF THE ST. CHARLES PHOSPHATIC TITANIFEROUS MAGNETITE DEPOSITS

by

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INTRODUCTION

The St. Charles titaniferous magnetite deposits lie on the north shore of the Saguenay River, fifteen miles downstream from Lake St. John, on lots 44-48, Bourget township, Chicoutimi County. The location of the area is shown on Fig. 1, and the relation of the apatite-rich body, to the rest of the deposit is shown on Fig. 3. Fig. 4 shows the detail of the apatite-rich bodies from which samples were obtained.

The first published reference to the St. Charles deposits is by Abbe Laflamme[1]. The exposures along the river bank were mapped by Dulieux[2] in 1912, and further examination of the area was done in 1924 by Robinson[3]. In 1942 and 1944 Waddington[4] used a dip needle to show the extension of the deposits. The microtextures and mineralogy were described in 1944 by Osborne[5]. In 1946 Dr. Jolliffe visited the area, and especially examined the

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[1] Laflamme, J. C. K. "Geological Observations in the Saguenay Region". G.S.C. Report of progress 1883

[2] Dulieux, P. E. "Preliminary Report on some Iron Ore Deposits in the Province of Quebec". Dept. Colonization, Mines and Fisheries, Quebec, Mines Branch. pp.52-58 (1915)

[3] Robinson, A. H. A. "Investigations of the Mineral resources and the Mining Industry". Mines Branch, Dept. of Mines, Ottawa. (1926)

[4] Waddington, G. W. "Report of the St. Charles Titaniferous magnetite deposits. Bourget and Tache Townships, Chicoutimi County, Quebec". Dept. of Mines, Quebec. M 1093. 9 p. (1944)

[5] Osborne, F. F. "Special report on the microstructures of certain Quebec Iron Ores". Dept. of Mines, Quebec. P.R. 186 (1944)

apatite-rich portion. Specimens collected at that time from this locality form the basis for this study. The writer was unable to visit the area, and has had to rely largely on published reports and personal communications from Dr. A. W. Jolliffe for information on the geology of the area.

The author wishes to express his most sincere gratitude towards members of the staff of the Geological Department, McGill University for offering many helpful suggestions and constructive criticism. Special thanks are due to Dr. Jolliffe, who supplied the specimens, much of the information, and rendered invaluable service by his helpful advice in the preparation of this manuscript. The writer is indebted to the Department of Mines and Resources, Ottawa, as well as the Department of Mines, Quebec, for supplying analyses and valuable information.

OUTLINE OF REGIONAL GEOLOGY

Dresser and Denis[1] present the following table of formations for the Lake St. John - Saguenay area.

Quaternary and Recent		Alluvial and swamp deposits Stratified clay and boulder clay
Great unconformity		
Palaeozoic	Ordovician Richmond Utica Trenton	Limestone Shale Limestone
Unconformity		
Precambrian	Roberval	Granite, syenite, gneiss
	Intrusive contact	
	Anorthosite series (Morin Series)	Saguenay Intrusives: Anorthosite, gabbro, syenite, granite
	Intrusive contact	
	Laurentian	Gneiss
	Intrusive Contact	
	Grenville	Crystalline limestone sedimentary gneiss

The areal distribution of the formations is shown on Fig. 2.

The oldest rocks in the district are assigned to

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[2] Dresser, J. A. and Dennis, T. C. "Geology of Quebec" Vol. II, p.198 (1944)

the Grenville series and consist of crystalline limestone and paragneiss, and were involved in all the later episodes of intrusion and folding. Granites and granitoid gneisses, generally referred to as Laurentian, are intrusive into the Grenville. The rocks of the Anorthosite series occupy large areas. Normal anorthosite forms but part of the series, since it grades into gabbro, as well as into syenite and granite that seem to be consanguineous with the anorthosite. The St. Charles titaniferous magnetite deposits are in anorthosite belonging to this series. The youngest Precambrian rocks in the area are Roberval granite, syenite and gneiss, which are intrusive into the older formations. Ordovician limestone and shale rest unconformably on the Precambrian, and their preservation is the result of down faulting.

THE GEOLOGY OF THE ST. CHARLES DEPOSITS*

The St. Charles titaniferous-magnetite deposits occur as lenticular bands in anorthosite. They are exposed at intervals in a heavy wooded upland standing 200 to 350 feet above the Saguenay river, which is here 243 feet above the tidewater 13 miles to the east. The descent from the upland to the river is rather abrupt (see Fig. 15). The titaniferous magnetite bands strike north-northwesterly and dip moderately to the west, sensibly parallel to a rather feeble banding in some of the enclosing anorthosite. Other rock types present in the immediate area include diorite and pegmatite dykes. Less than a mile west of the deposit the anorthosite is succeeded by a younger banded norite that strikes northerly and dips steeply west.

The anorthosite is rather variable in composition and texture. Much of it is massive, coarse to fine-grained, and consists almost wholly of feldspar. Elsewhere, lenticles of magnetite or chlorite up to several inches long, or thin discontinuous bands of dark minerals give the rock a rude foliation that strikes north to northwest and dips variably west. Most dips recorded

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* Data from Robinson, A. H. A. "Investigation of the mineral resources and the mining industry" Mines Branch, Dept. of Mines, Ottawa (1926), and from Jolliffe, A. W. - personal communication.

in the field exceed 45°. This may reflect the fact that with flatter dips, the banding (which is poorly developed at best) becomes practically indiscernable on the gently rolling outcrop surfaces. The average dip is probably less than 45°.

The titaniferous magnetite bodies are best exposed in the central parts of lots 46 and 47, and again in the southern parts of lots 44 and 45 (see Fig. 3). Contacts with the enclosing anorthosite are characteristically drift covered, but are shown on the map as 'defined' wherever their positions could be located within 20 feet. At the north end of lot 47 a thin selvage of titaniferous magnetite can be seen in sharp contact with the underlying normal anorthosite. In the southern occurances Robinson[1] states:

> "The contact between titaniferous iron and the gneissoid type of anorthosite is usually characterized by a zone of friable material consisting of grains and lumps of magnetite and rounded fragments of partly decomposed anorthosite embedded in ochreous earthy material such as might result either from the chemical action of surface water percolating through the crushed and porous rock along the contact, or by agents accompanying the magnetite intrusion. At other places, where the titaniferous magnetite abuts against massive (not banded) anorthosite the contact is clean and sharp and no trace of alteration of any kind is visible. Fragments of anorthosite included in the titaniferous iron, also, are as a rule quite fresh looking and unchanged in appearance while the other numerous inclusions of the gneissoid type of anorthosite are always more or less decomposed."

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[1] Robinson, A. H. A. "Investigations of Mineral Resources and the Minding Industry". Mines Branch, Dept. of Min., Ottawa, (1926) p.45

Outcrops of the titaniferous-magnetite bodies are black and are marked by numerous pits commonly less than 5 mm across. In many places the pits are arranged in rows thus giving the rock a banded appearance. Most of the banding is about parallel to the contacts and the foliation of the anorthosite. On outcrop B (see Fig. 3) the banding is contorted.

Diorite dykes are scarce or absent in the vicinity of occurrences A to I (see Fig. 3) but are abundant in the anorthosite farther east. They are medium- to fine-grained, dark weathering and less than 5 feet wide (Fig. 13), they strike northeasterly and dip steeply southeast. Many of the dykes occur in the vicinity of occurrences I to XIII. They...

> "contain in places small fragments of included anorthosite drawn out into lens-shaped masses having their longer axes parallel to the dyke walls. They also carry a considerable quantity of disseminated magnetite which is practically non-titaniferous. A microscopical examination of a thin section of the rock from one of these dyke-like bodies was kindly undertaken by J. B. Mawdsley, of the Geological Survey staff, who found it to contain 40 per cent of monoclinic pyroxene, probably diopside; 40 per cent of acid andesine feldspar; 15 per cent of hornblende; and 5 per cent of accessory minerals, chiefly iron oxides and apatite. It would therefore be called a diopside diorite. It is fairly equigranular in texture, the size of the grains of the three chief constituents, pyroxene, hornblende, and plagioclase, being 0.3 to 2 mm. The colourless pyroxene crystals, which are very irregular in shape and show inclusions of iron oxide and apatite, are altered around their edges to greenish brown hornblende"

It is further stated that

> "The titaniferous magnetite bodies, which also appear to be dyke-like in their nature and also seem to be oriented with their greater dimensions parallel in a general way to the lamination of the country rock, are almost invariably closely associated with these diorite dykes, inclusions of which are of frequent occurrence in the titaniferous magnetite. At nearly all the visible contacts of the titaniferous magnetite with the basic dykes, the magnetite contains numerous fragments of all sizes of the latter. These fragments though often bent and twisted are nevertheless rather sharply angular in outline, and neither they nor the main body of the dyke in the vicinity of the contact show to the naked eye any sign of chemical alteration."

With regard to the above observations, the association of dykes and titaniferous-magnetite in the occurrences I to XIII seems to be purely fortuitous. The dykes are part of a swarm trending tending north-northeasterly and dip in an opposite direction to the foliation in the anorthosite, and to the contacts of the titaniferous bodies. The observations are important, however, in establishing the fact that the anorthosite was consolidated and intruded by the basic dykes prior to the emplacement of the titaniferous-magnetite bodies.

A very few narrow pegmatite dykes occur cutting the anorthosite and diorite dykes. Their relation with the titaniferous magnetite bodies is unknown.

Robinson, A. H. A. op. cit. p.45

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MINERALOGY

ANORTHOSITE

The anorthosite is light grey, medium grained, and consists of more than 90% plagioclase feldspar. The plagioclase is grey, has good cleavage, and shows closely spaced striations caused by polysynthetic twinning. Titaniferous magnetite occurs in the anorthosite either as small grains less than 2 mm in size, or as lenticles the dimensions of which are about 10 x 5 mm. Where these lenticles are present they are rudely parallel giving the rock a banded appearance. Small areas of dark green chlorite are present in places.

Under the microscope the following minerals are apparent: plagioclase (An_{45}), biotite, hornblende, magnetite, ilmenite, chlorite, and sericite.

Plagioclase

Feldspar constitutes 90% to 97% of the anorthosite. Subhedral grains are up to 15 mm long. In some specimens grains are about equidimensional (0.3 mm), whereas in others large crystals (1.0 mm) have smaller grains (0.2 mm) between them, many such grains have sutured mutual boundaries. The plagioclase is twinned according to the albite and pericline laws. Undulatory extinction is absent and zoning is feeble. The extinction angles are:

Maximum $\perp$ 010 = 25° (An_{45})
$\perp X(Y_{\wedge}010)$ = 24° (An_{42})
$\perp Y(X_{\wedge}010)$ = 12°-15° (An_{42} - An_{44})
$\perp Z(X_{\wedge}001)$ = 6° - 8° (An_{42} - An_{45})
(+) 2V = about 80°.

The composition is therefore taken to be that of Andesine (An_{45}). Much of the andesine contains small, rod-like, opague inclusions less than 0.01 mm wide. These are in places arranged with their longer directions parallel to the albite twinning lamellae. In general the feldspar is free from alteration, but in places it is altered to small flakes of sericite.

<u>Biotite</u>

Dark mica makes up about 2% of the anorthosite. Flakes up to 0.7 mm in diameter are irregularly distributed throughout the rock. The mica has the properties of biotite:

Pleochroism: Z very dark brown
Y dark brown
X pale yellow

Absorption Z>Y>X

Optical Character Biaxial (-)

2V very small

Practically all the biotite occurs in contact with or borders titaniferous magnetite. In places it is partially altered to chlorite.

Hornblende

Less than 1% of hornblende is present. It accompanies biotite and is found in close association with titaniferous magnetite. The optic properties are:

Pleochroism	Z dark green Y green X light green
Absorption	Z>Y>X
Optical Character	biaxial (-)
2V	65° (estimated)
Extinction	$Z \wedge \underline{c}$ 20°

Opaque Minerals

Up to 5% of opaque minerals occur in the anorthosite as lenticular aggregates or as widely scattered grains. Examination under reflected light shows that both ilmenite and magnetite are present, either as discrete grains, or as an intergrowth of both minerals, similar to that found in the titaniferous magnetites.

Chlorite and Sericite

Chlorite is an alteration product of the hornblende and biotite. Examination of the chlorite immersed in oil shows that it has perfect cleavage and is brown green and faintly pleochroic. The negative optic angle is very small. Sericite occurs as widely scattered small flakes, presumably as an alteration product of the plagioclase.

PHOSPHATIC TITANIFEROUS MAGNETITES

Description of the Hand Specimens

In the hand specimens, the phosphatic titaniferous aggregates show considerable variation in grain size, but typically consist of a few crystals of olivine in a black, fine-grained, aggregate of titaniferous-magnetite and apatite. The olivine is brown green in colour, has a waxy lustre, and conchoidal fracture and occurs in grains or aggregates of grains up to two centimeters in diameter. Apatite is present in grains commonly 0.5 mm across but in places up to 5 mm. The apatite is colourless or stained light brown and is normally anhedral. Titaniferous magnetite occurs in black anhedral grains about a millimeter across. Magnetite and ilmenite cannot be differentiated by megascopic examination. Pyroxene can be recognized in a few hand specimens in relatively large, dark green crystals, one of which measures 5 x 7.5 mm.

Description of the Thin and Polished Sections

Examination under the microscope shows the following minerals: magnetite, maghemite (?), ilmenite, hematite, spinel, apatite, olivine, pyroxene, amphibole, biotite, plagioclase, and serpentine.

Magnetite

Magnetite is invariably present and constitutes about 25% of the polished sections examined. It occurs as anhedral grains averaging 0.6 mm in diameter, but grains up to 4 mm are present. It is bright white in colour and isotropic. With the polarizer removed the magnetite can hardly be distinguished from the ilmenite, which is only slightly more brownish. The magnetite shows no etch reaction with 1:1 HNO_3, 20% KNO_3, 20% $FeCl_3$, 40% KOH, or 5% $HgCl_2$. Some of the magnetite is faintly etched after several minutes by 1:1 HCl. Concentrated HCl always etches the magnetite but the rate of etching is variable. Five minutes contact with the acid is adequate to produce a good reaction.

About 50% of the magnetite is in homogeneous grains free from visible laminae of ilmenite, but the rest has ilmenite intergrown with it. Spinel-magnetite intergrowths are rare.

Magnetite also occurs in veinlets 0.005 to 0.02 mm wide. These cut all the non-opaque minerals as well as the magnetite and ilmenite (see fig. 9). Some of them follow the contacts between opaque and non-opaque minerals for short distances. They may represent a by-product of the alteration of the iron-rich olivine to serpentine.

Maghemite (?)

A mineral tentatively identified as maghemite is present in much of the magnetite, characteristically as irregular replacement areas extending out from tiny cracks or veinlets (see fig. 11). It is isotropic and slightly brownish against bluish white magnetite. The maghemite is negative to 1:1 HNO_3, 20% KNO_3, 20% $FeCl_3$, 40% KOH, 5% $HgCl_2$. It is etched somewhat more rapidly than magnetite by concentrated HCl.

Ilmenite

Ilmenite constitutes 20% to 30% of the aggregates. In reflected light it is bright white, but thin laminae appear slightly brownish against the enclosing magnetite. The ilmenite is anisotropic; the polarization colours are yellowish-brown to dark blue. It is negative to 1:1 HCl, 1:1 HNO_3, 20% KCN, 20% $FeCl_3$, 40% KOH, and 5% $HgCl_2$, Concentrated HCl has no effect.

The ilmenite occurs both in discrete grains and in an intimate intergrowth with the magnetite. Individual grains of ilmenite are present in all sections. They are up to 4 mm in diameter but average 0.6 mm and have a rudely tabular habit. Some of the ilmenite grains are crossed by straight bands of a different orientation. These bands are 0.002 to 0.008 mm wide, and are present in as many as three directions in one grain. They may reflect lamellar twinning in the ilmenite (see fig. 7).

Ilmenite intergrown with magnetite is very abundant. It is best shown by etching for five minutes with concentrated HCl. The ilmenite occurs as laminae from less than 0.001 to 0.2 mm in thickness. These are arranged in parallel sets and may be present in as many as three directions in a single crystal of magnetite suggesting that the laminae are parallel to the octahedral faces of the magnetite.

Hematite

Hematite is very rare. It occurs as discrete grains nowhere more than 0.15 mm in diameter, but normally much smaller. It is much brighter than magnetite and ilmenite and is strongly anisotropic with polarization colours dark blue to yellowish brown.

The hematite is negative to 1:1 HCl, 1:1 HNO_3, 20% KCN, 20% $FeCl_3$, 40% KOH, 5% $HgCl_2$ and to concentrated HCl.

Spinel

Spinel is invariably present in the aggregates and is associated with the magnetite. In transmitted light it is dark green and isotropic. The refractive index as measured with oils is about 1.78 suggesting that it is pleonaste $(Mg,Fe)O.Al_2O_3$[1].

The spinel occurs mainly as discrete grains in magnetite and to a lesser extent as an intergrowth with magnetite. The individual grains are anhedral and up to 1.5 mm in size. Spinel inclusions make up about half the area of certain magnetite grains, but show no regular arrangement. A few magnetite grains do show a true intergrowth where the spinel occurs in rods parallel to the ilmenite laminae, both of which presumably mark the octahedral planes of the enclosing magnetite.

Apatite

Apatite is present in all the specimens examined. It occurs in colourless, anhedral grains, generally with a somewhat rounded outline, varying in size from 0.02 to 2.5 mm and averaging about 0.6 mm. It is uniaxial negative, and its refractive indices lie between 1.63 and 1.64, indicating that it is fluor-apatite.

Inclusions in the apatite are of two types: 1) rounded grains of magnetite averaging 0.02 mm, and 2) opaque rods less than 0.01 mm thick and about 0.04 mm long. The rods are invariably parallel with the c crystallographic axis of the apatite. In places they are so abundant as to give the apatite a clouded appearance.

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[1] Larson, E. S. and Bermann "The microscopic determination of non-opaque minerals" U.S.G.S. Bull 848 p.247 ~~(1934)~~

Where the apatite occurs with olivine it is commonly along the intergrain boundaries, particularly at the intersection of the 010 and 021 crystal faces of the Olivine.

Olivine

Most of the sections show olivine either as individual isolated grains or as aggregates. The average size of the olivine grains is about a millimeter but grains up to 8 mm occur. The outlines of the isolated grains are commonly irregular, whereas many grains in the aggregates are subhedral.

The olivine is pale green, non-pleocroic and shows poorly-developed cleavage in places.

The optical data are:

Indices	X 1.715 Y 1.735 Z 1.75
Optical Character	biaxial (-)
2V	80° (estimated)
Optic plane	normal to <u>010</u>

These properties suggest the olivine to be a ferriferous chrysolite containing about 40% of the fayalite molecule[1]

Alteration to serpentine is more extensive in

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[1] Winchell, A. N. "Elements of optical mineralogy" Part II p.191 (1945)

the isolated olivine grains than in the aggregates.

Pyroxene

Pyroxene is present only in two thin sections, J12-1 and J13. It occurs as subhedral grains of varying size, but averaging a millimeter in diameter.

The optical data are:

Indices	X 1.70 Y 1.712 Z 1.725
Optical Character	biaxial (+)
2V	55° (estimated)
Pleochroism	Z very pale pink Y very pale pink X very pale green

These properties approximate those of an intermediate member of the Diopside-Hedenburgite series[1]

The pyroxene contains rounded inclusions of plagioclase 0.1 mm in diameter as well as rods of ilmenite. The latter occur in two sets one of which is made up of thinner rods parallel to the prismatic cleavage; the other set is inclined at 60° to this. The pyroxene is free from alteration but some of the crystals are surrounded by reaction rims of hornblende.

Hornblende

Hornblende is present in only three sections:

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[1] Winchell op. cit. p.226

J11-4, J12-1 and J13. It occurs in subhedral grains averaging 0.4 mm across, almost invariably near or along the contact of olivine, pyroxene or magnetite with feldspar. Most of the hornblende is brown but there may be a gradual transition to a green variety towards the periphery of grains, especially where the hornblende is in contact with plagioclase.

The optic properties of the brown hornblende are:

Pleochroism	Z dark brown Y brown X pale brownish yellow
Absorption	$Z>Y>X$
Optical character	biaxial (-)
2V	70° (estimated)
Extinction	$Z \wedge \underline{c}$ 17°

The relatively large extinction angle indicates that the mineral is normal and not basaltic hornblende. The mode of occurrence suggests that it is a reaction product.

Biotite

Biotite is present in most specimens but in minor amounts only. It occurs as small flakes in magnetite or as rims around magnetite or hornblende in plagioclase.

The optic data are:

Pleochroism	Z dark brown Y brown X pale yellowish brown
Absorption	Z>Y>X
Optical character	biaxial (-)
2V	very small

Plagioclase

Feldspar occurs in sections J11-4, J13 and J17-2 only. In two of these (J13 and J17-2) the plagioclase is in small grains up to 0.2 mm in diameter, as inclusions in the pyroxene and at the intergrain boundaries. The optic properties, and composition of these small grains could not be determined. The remaining section contains about 10% feldspar in an aggregate of crystals with anhedral outlines, twinned according to the albite and pericline laws, and having refractive indices higher than that of balsam.

The extinction angles are:

$$\text{Maximum} \perp 010 = 14^\circ \ (An_{32})$$
$$\perp X,(Y \wedge 010) = 14^\circ \ (An_{30})$$

The negative optic angle is close to 90°. The composition is taken to be andesine[1].

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[1] From charts prepared by F. F. Osborne.

Serpentine

The serpentine is in all cases an alteration product of olivine. Commonly it occurs as veinlets cutting the olivine, or around the periphery, but some aggregates represent completely replaced olivine. Most of the serpentine is green brown, and non-pleochroic. Some aggregates representing completely changed olivine show a light green serpentine core grading into a dark brown periphery. The refractive index ranges from 1.53 (measured against balsam) to about 1.6 (measured in oil) the light green portions having the lower refractive index. In all cases where suitable optic figures could be obtained the serpentine had a positive optic angle of 10° to 20°. These properties agree more or less with those of chrysotile[1]. However, it has been shown by Selfridge[2] that chrysotile is not a distinct mineral, but only a flexible fibrous form of serpentine. Most of the serpentines investigated by him were biaxial negative, but a few showed biaxial positive figures; accordingly the alteration product of the St. Charles olivene is called serpentine.

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[1] Winchell, A. N. Op. cit. p.260

[2] Selfridge, G. E. "An X-ray and Optic Investigation of the Serpentine Group of Minerals" Am. Min., 21, pp.463-502 (1936)

DISCUSSION OF THE MINERAL ASSOCIATIONS

Maghemite

An iron oxide intermediate in composition and properties between magnetite and hematite has been called maghemite by Wagner[1]. Twenhovel[2] showed that an intermediate compound between magnetite and hematite is possible, and is formed by the oxidation of magnetite. Newhouse and Callahan[3] found that brownish magnetite (maghemite) replaces bluish magnetite and is formed by the oxidation of the latter. Osborne[4] in the course of an extensive examination of iron ores found no such alteration. Hickock[5] noted brown and blue "magnetite" but was unable to decide which mineral was the replacing one. However, in the St. Charles sections brownish

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[1] Wagner, P. A. "Changes in the Oxidation of Iron in Magnetite" Econ. Geol., 22 pp.846 (1927)

[2] Twenhovel, L. H. "Changes in the Oxidation of Iron in Magnetite". Econ. Geol., 22, pp.180-188 (1927)

[3] Newhouse and Callahan, W. H. "Two Kinds of Magnetite". Econ. Geol. 22., pp.629-632 (1927)

[4] Osborne, F. F. "Certain Magmatic Titaniferous Magnetite Deposits and their Origin". Econ. Geol., 23 pp.724-761 and 895-922 (1928)

[5] Hickock, W. O. "Iron deposits of Cornwall Pennsylvania" Econ. Geol., 28, pp.193-265 (1933)

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[5] Hickock, W. O. "Iron deposits of Cornwall Pennsylvania" Econ. Geol., 28, pp.193-265 (1933)

magnetite (maghemite) invariably replaces the bluish magnetite, and is considered to be due to oxidation of the latter.

Ilmenite-magnetite Intergrowths

Ilmenite laminae in magnetite have been described many times, notably by Singenwald[1], Warren[2] and Osborne[3]. The latter author supports Ramdohr[4](who was able to homogenize the intergrowth by heating) in believing that the intergrowth is the result of unmixing of magnetite-ilmenite solid-solution. It seems, therefore, that at the temperature of formation of the ore minerals a considerable amount of ilmenite is soluble in magnetite. With cooling the solubility decreases, so that the ilmenite separates out in laminae parallel to the octahedral faces of the magnetite.

Magnetite-Spinel intergrowths

Regularly orientated rods of spinel in magnetite are rare. In one polished section rods of spinel in magnetite are parallel to, and, in places, continuous with, ilmenite laminae, indicating that the rods are parallel

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[1] Singenwald, J. T. "The Microstructure of Titaniferous magnetites". Econ. Geol. 8, pp.207-214 (1913)

[2] Warren, C. H. "On the Microstructure of Certain Titanic Iron Ores" Econ. Geol. 13, pp.412-446 (1918)

[3] Osborne, F. F. op. cit. p.909

[4] Ramdohr, P. Beobachtungen an Magnetit, Ilmenite Etc. Neues. Jahrb. f. Min. Beil. Bd 54 pp.320-379 (1926)

with the octahedral faces of the magnetite. Some of the magnetite, however, contains abundant rounded inclusions of spinel, not arranged in any regular pattern. These inclusions may be so abundant as to equal the area of the enclosing magnetite.

Osborne[1] considers the magnetite-spinel intergrowths to be due to unmixing of a solid solution of those two minerals, and that the resultant spinel rods are generally parallel to the cube faces of the magnetite. In the St. Charles aggregates, however, some of the spinel rods are parallel to the octahedral directions. The irregularly arranged inclusions in some of the magnetite indicate that, if the intergrowth is due to unmixing, the spinel need not necessarily have separated along definite crystal directions.

Mineral Relations

No inclusions of olivine in apatite, nor apatite in olivine occur. Where these minerals are associated the apatite is commonly between individual grains in the olivine aggregates.

Magnetite and ilmenite are normally moulded on and around olivine, and do not penetrate individual olivine crystals.

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[1] Osborne, F. F. "Certain Magmatic Titaniferous Iron Ores and their origen". Econ. Geol. 23, p.906 (1928)

Apatite and ore occur in rounded grains of about the same order of size (average 0.6 mm) and shape. In a few places tongues of ore penetrate apatite but no veinlets cutting completely across apatite are apparent, although a few thin veins of ore follow the contact between apatite grains of different orientation. In places spinel completely encloses apatite. Since spinel appears to have crystallized with the ores the latter presumably formed later than the apatite.

COMPOSITION OF THE PHOSPHATIC-TITANIFEROUS MAGNETITES

From the description of the minerals it is apparent that the normal constituents of the phosphatic titaniferous magnetite aggregates are magnetite, ilmenite, spinel, olivine and apatite. The other minerals occur in minor amounts or are only locally developed.

The accompanying table shows a partial analysis of the ore. From a knowledge of the mineralogy the mineral composition deduced from the analysis is:

21% apatite
25% ilmenite
30% magnetite
24% olivine spinel and other minerals.

Although there is a considerable variation in the proportions of minerals in different specimens, the

TABLE 1

PARTIAL ANALYSES OF THE PHOSPHATIC TITANIFEROUS AGGREGATES

Sample No	Fe	TiO_2	P_2O_5	V_2O_5
J3	37.18	16.04	10.90	0.15
J4	35.10	12.67	9.35	0.15
J5	34.06	14.00	9.59	0.13
J6	33.02	10.00	10.59	0.11
J8	36.14	14.30	8.29	0.15
J9	37.44	14.41	9.12	0.17
J10	34.58	13.60	10.69	0.13
J11	36.66	15.70	10.34	0.15
J12	28.60	10.00	5.70	0.13
J13	25.48	12.70	4.41	0.15
J14	35.36	14.00	10.76	0.18
J16	35.62	12.50	6.90	0.15
J17	35.10	10.61	10.17	0.17
J18	34.58	11.10	10.35	0.15
Average	34.21	12.98	9.08	0.15
Composite Sample	34.84	12.76	9.65	0.14

Analyses by: Ore Dressing and Metallurgical Laboratories, Dept. of Mines and Resources, Ottawa.

analysis of the larger samples is remarkably uniform, individual assays not differing greatly from the average. Two notable exceptions to this are J12 and J13, both of which have lower values of Fe, TiO_2, P_2O_5 than the rest of the samples. These lower values are caused by the presence of a considerable amount of silicates, mostly pyroxene, in the samples. Samples J11 and J17 have hornblende and feldspar in addition to the normal constituents. The content of these samples is similar to that of the rest showing that these minerals are present in such small amounts that they do not dilute the aggregates to any extent. The assays and mineral composition of the smaller bands to the east of the main band are similar to those of the main band, except for a lower P_2O_5 content in J16.

UTILIZATION OF THE PHOSPHATIC TITANIFEROUS-MAGNETITES

Geological mapping and dip needle surveys show that the titaniferous-magnetite bodies occur within an area 1200 feet wide and 7000 feet long. The high phosphorous band particularly investigated (see map No. 3) outcrops almost continuously for a length of about 900 feet and a width of 250 to 400 feet, giving an area of about 300,000 square feet.

In calculating the tonnage available the aggregate is taken to have a specific gravity of 4. With this specific gravity, and for an area of 300,000 square feet, 37,000 tons is present for every vertical foot.

The average content of the main band is: 35.5% Fe, 13.87% TiO_2, 9.96% P_2O_5 corresponding to an approximate mineral content of:

23% apatite
26% ilmenite
32% magnetite

The extraction of iron, titanium and phosphorous from these bodies can be considered.

Iron

Analyses show that the bodies contain on the average 35.5% Fe. The iron is to a large extent in the form of magnetite, but considerable quantities of it are combined with ilmenite, (37% Fe) olivine (25% Fe) as well as with the spinel and silicates. Much of the magnetite is intergrown with ilmenite, in laminae that are so thin (down to less than 0.001 mm) that very fine grinding would be necessary to separate these two minerals.

Bourgoin[1] conducted tests on these ores and found that the high phosphorous type of ore can be reduced in a blast furnace, to produce a phosphorous rich pig iron, that can be converted into steel by the Bessemer process.

Compared with workable iron ores the iron content of this body is low (35% Fe). So much of the iron is combined with silicates and spinel that the amount of iron available for reduction in the blast furnace is considerably less than the analyses indicate. The ilmenite is so finely intergrown with the magnetite that the magnetic separation of these two minerals does not seem feasible. Even if separation could be effected the magnetite content is so low (estimated 32%) that it is unlikely that it could be

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[1] Bourgoin, L. "Special report on the Utilization of Titaniferous Magnetites of St. Charles, Bourget Township, Quebec. Dept. of Mines P.R.179 (1943)

worked profitably for the extraction of iron alone.

Titanium

The average TiO_2 content of the main deposit is 13.87%, corresponding to 26% ilmenite. The ilmenite is in discrete grains and as a fine regular intergrowth with the magnetite. Many of the laminae are so thin (less than 0.001 mm) that very fine grinding seems necessary if these minerals are to be separated mechanically. Magnetic separation is probably not feasible. Tests by the United States Bureau of Mines[1] on ores from Roseland, Nelson County, Va., showed that 80% of the TiO_2 could be recovered from ore containing 32.5% TiO_2 by tabling, but it is not stated whether magnetite-ilmenite intergrowths are present in those ores. Smelting tests on the St. Charles material by Bourgoin[2] showed that it is possible to obtain a slag yielding 36% to 40% TiO_2 from ore having 17% to 21% TiO_2. However, the pigment industry requires ore containing more than 48% TiO_2, so that the 13% TiO_2 ore would not be expected to yield slag that is rich enough to be utilized by the pigment industry.

Phosphorous

The western part of the St. Charles deposits

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[1] U.S. Bur. Min. Report of investigations. R.I.3328 (1937)

[2] Bourgoin, L. op. cit. p.9

TABLE 2

VARIATION IN PHOSPHOROUS CONTENT OF THE ST CHARLES DEPOSITS

WEST					EAST
G 4.34%[1]		F 3.35%	B 3.12%		A 0.03%
		J16[1] 3.01%	C 2.06%		
			D 3.19%		
H 4.43%	I 4.54%			E 1.31%	

	VIII	VII 2.10%[2]	J 1.00%		VI
	IX		V 0.95%[2]	IV 0.00%	
	X 0.13%[2]	XI		III 0.00%	
XIII 0.02%	XII 0.03%			II 0.00%	
				I 0.03%	

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[1] Samples collected by A. W. Jolliffe, 1946, and analysed by Dept. of Mines and Resources, Ottawa.

[2] 600-lb bulk samples, Quebec Department of Mines, 1942 all other data from Waddington, op. cit. pp.8, 9.

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FORM 200

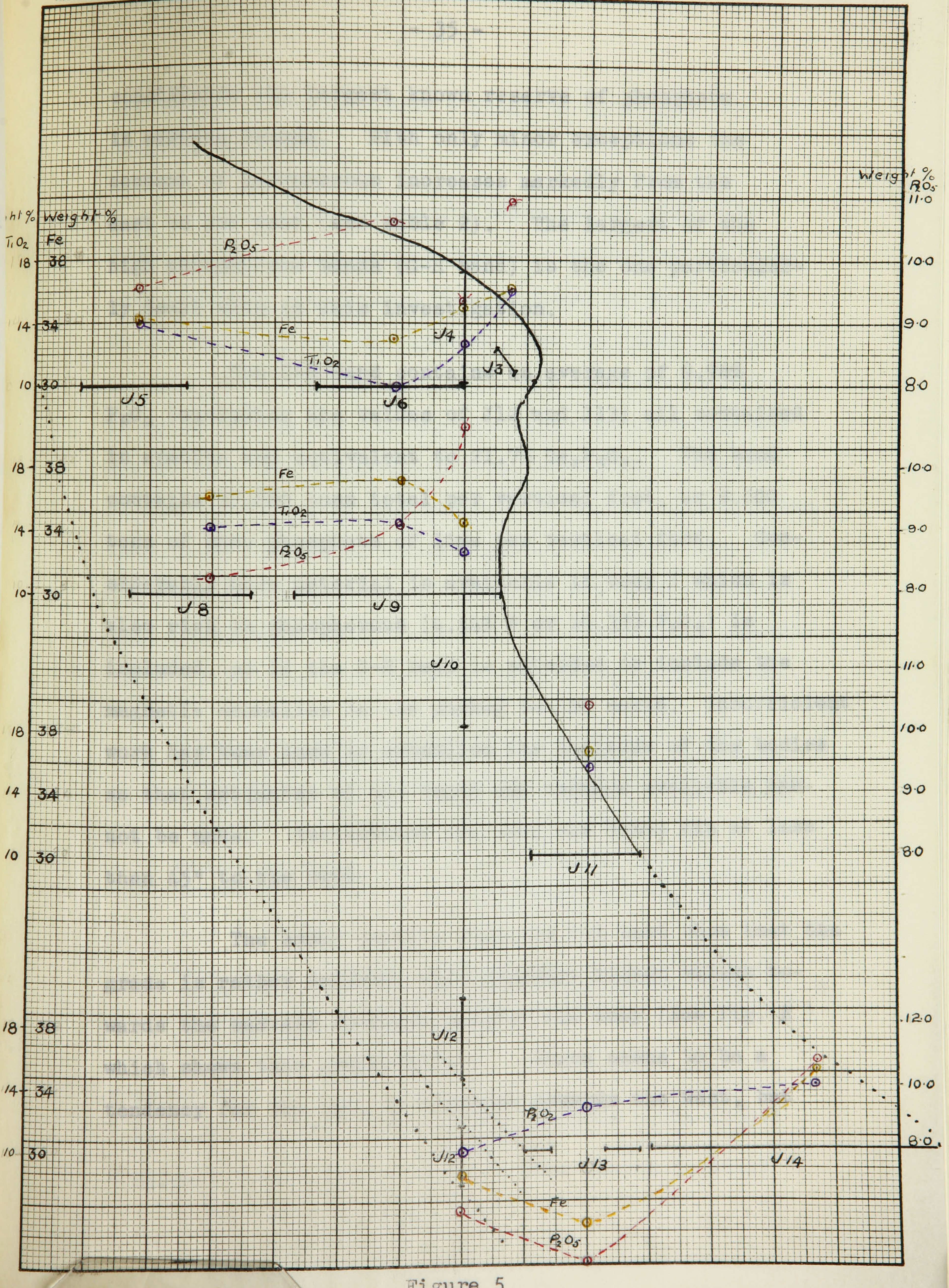

Figure 5

constitutes the largest known reserve of phosphate in eastern Canada. With only minor exceptions the content of phosphorous increases markedly from the east to the west (see table 2). The largest of the high phosphorous bands (G-H band) is the one particularly dealt with in this investigation.

The G-H band contains an average of 9.96% P_2O_5 (excluding the values of J12 and J13) all contained in apatite and equivalent to 21.7% $Ca_3P_2O_5$. The band contains 37,000 tons total per vertical foot, or 8,000 tons of bone phosphate of lime per vertical foot. Considerably more material is available if body I which is also rich in phosphorous (4.54% P or 10.33% P_2O_5) is included, or if the G-H band is extended to include the magnetic anomalies in the muskeg to the north. Insufficient work has been done to establish the attitude of the bodies so that estimates of the depth and tonnage available cannot be made. Indications are that the bands dip at less than 45° to the west.

The assay results from the G-H band show that the grade is rather uniform, with somewhat higher values towards the eastern boundary (base) of the body (see fig. ~~2~~ 5 which shows this graphically). There seems to be a tendency for the P_2O_5 to decrease towards the west, but the samples cover too wide a range to establish the tendency as a fact.

Apatite is commonly recovered by flotation. Tests by the United States Bureau of Mines[1] on ore from near Franklin, Williamson County, Tenn. showed that 80% to 85% recovery can be expected from ore assaying 60% to 65% Bone Phosphate of Lime. The ore from Franklin is quite unlike the St. Charles Titaniferous-magnetites except that the phosphate mineral recovered is apatite. Preliminary tests by the Division of Mineral Dressing and Metallurgy, Bureau of Mines, Ottawa, on 11,000 lbs of St. Charles samples chiefly from the G-H band indicated that the separation of magnetite and ilmenite is unsatisfactory, but that the recovery of apatite is promising.

> "Magnetic concentration will not produce a magnetite concentrate free from ilmenite. Our best results in this regard gave a magnetic concentrate assaying 54.5% Fe, 12.4% TiO_2 and 2.9% P_2O_5, when the ore was ground to minus 48 mesh".
>
> "Table concentration of the combined ilmenite and magnetite, without prior magnetic concentration, gave a concentrate assaying 52.4% Fe, 19.1% TiO_2 and 2.3% P_2O_5".
>
> "Flotation of these table tails (after desliming) gave an apatite concentrate assaying 39% P_2O_5, 3.1% Fe and 1.1% TiO_2 with an overall recovery of 75% of the P_2O_5".*

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[1] U.S. Bur. of Min. Rept. of Inv. No.3328 p.114 (1937)

* Extract from a letter by H. L. Beer (March 5, 1947)

The 39% P_2O_5 is equivalent to 85% bone phosphate of lime. Further work is being done at the flotation of the apatite as a primary operation. It is expected that this will yield a higher recovery of the phosphate.

The deposits are conveniently situated as regards transportation (less than 20 miles from tidewater) and hydro-electric power is available from transmission lines which pass within half-a-mile of the G-H band. A large market for phosphates already exists in eastern Canada, presently supplied almost wholly by imports.

ORIGIN

The origin of titaniferous magnetites has received much attention, since they are present at numerous localities all over the world. If the problem of smelting iron from them can be solved, these masses, which are in many cases very extensive, will constitute large reserves of iron ore. Many of these deposits are closely related in time and space to anorthositic and gabbroidal rocks. Since titaniferous magnetite is a common accessory mineral in basic igneous rocks, the conception arose that these bodies are segregations; that is the pyrogenic accessories accumulated to form the deposits. Various explanations have been given to account for the segregation. Sinking of crystals has been especially attractive since the ore minerals were formerly regarded as early crystallization products and are more dense than the common constituents of the associated igneous rocks. Other methods of segregation suggested are liquid immiscibility, gaseous transfer, gaseous tension, and refusion of sunken crystals.

However, Osborne[1] cites many instances where the ore minerals are interstitial to the common rock

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[1] Osborne, F. F. "Certain Titaniferous Magnetites and their Origin" Econ. Geol. 23 pp.727-761; 895-922 (1928)

forming minerals and Newhouse[1] presents much evidence that the iron oxides are among the last minerals to crystallize in basic igneous rocks. The titaniferous magnetites are therefore unlikely to have accumulated by the sinking of crystals.

As the result of a study of certain titaniferous magnetites occurring in the Adirondacks, Quebec and Ontario, Osborne[2] concluded that the deposits associated with anorthosite were formed by filtration differentiation by which the residual liquid remaining after considerable crystallization, is pressed out to solidify elsewhere as titaniferous magnetite bodies. Broderick[3] considers it possible that some of the irregular and some of the dyke-like bodies of titaniferous magnetite associated with the Duluth gabbro are contact metamorphosed phases of the Gunflint iron formation enriched in titanium by the gabbro. Dunn[4] suggests that the gabbroidal rocks associated with the titaniferous magnetites near Kumbardubi, India, may

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[1] Newhouse, W. H. "Opaque Oxides and Sulphides in common Igneous Rocks" Bull. Geol. Sic. Am. 47 pp.1-52 (1936)

[2] Osborne, F. F. op. cit.

[3] Broderick, T. M. "The relation of Titaniferous magnetites of Northern Minnesota to the Duluth Gabbro" Econ. Geol. 12 pp.663-697 (1917)

[4] Dunn, J. A. "The mineral deposits of the Singhbaum and surrounding areas. Geo. Sur. India. Mem.69 pp.1-279 (1937)

have absorbed some of the ferruginous material which occurs in the vicinity, enriching the basic rocks in iron. A hydrothermal origin has been invoked for the ilmentite deposits near St. Urbain by Gillson[1]. Ross[2] ascribed the titanium deposits at Nelson Virginia, to replacement. These two deposits are not exactly similar to the titaniferous magnetites in that they have much rutile, and hydrothermal minerals are associated with them. In his study of the titaniferous deposits of Lake Sanford, New York, Stephenson[3] concluded that these deposits are magmatic segregations in gabbro and magmatic injections and replacements in anorthosite and considers that

> "...it seems likely that replacement was the dominant process for the introduction of ore into the anorthosite"

In the G-H band of the St. Charles deposit the invariable constituents are magnetite, ilmenite, apatite and olivine. It seems unlikely that the bodies were produced by crystal accumulation caused by gravity separation. Even if the magnetite, ilmenite and apatite crystallized early, the difference in specific gravity is so

---

[1] Gillson, J. L. "Genesis of the Ilmenite deposits of St. Urbain County, Charleroix, Que." Econ. Geol. 27 pp.554-577 (1932)

[2] Ross, C. S. "Titanium Deposits of Nelson and Amherst Counties, Virginia" U.S.G.S. P.P 198 (1941)

[3] Stephenson, R. C. "Titaniferous Magnetite Deposits of the Lake Sanford Area, New York. New York State Museum Bull. No.340 (1945)

PLATE I

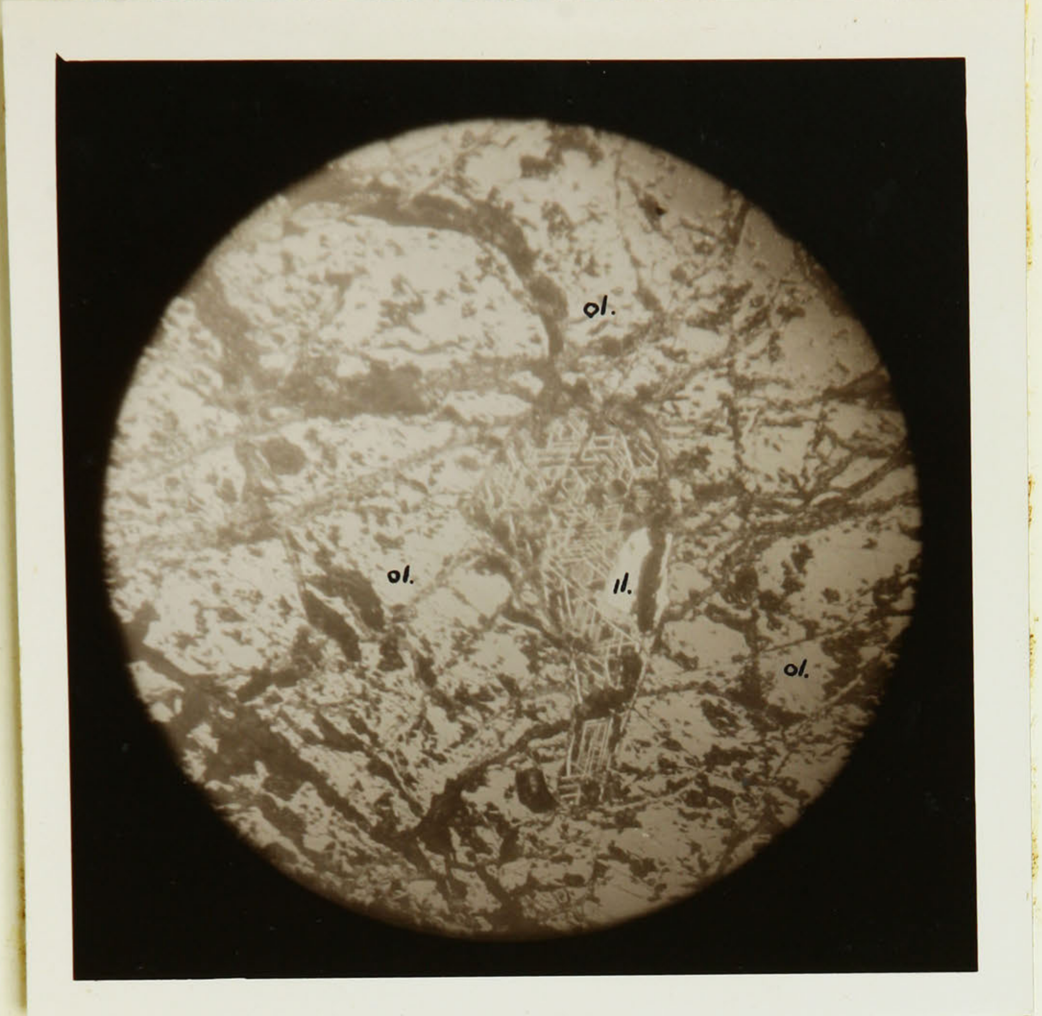


Figure 6

Ilmenite in laminae and as a discrete grain in magnetite.
il.=ilmenite; ol.=olivine. Etched 5 minutes by conc. HCl. (x50)

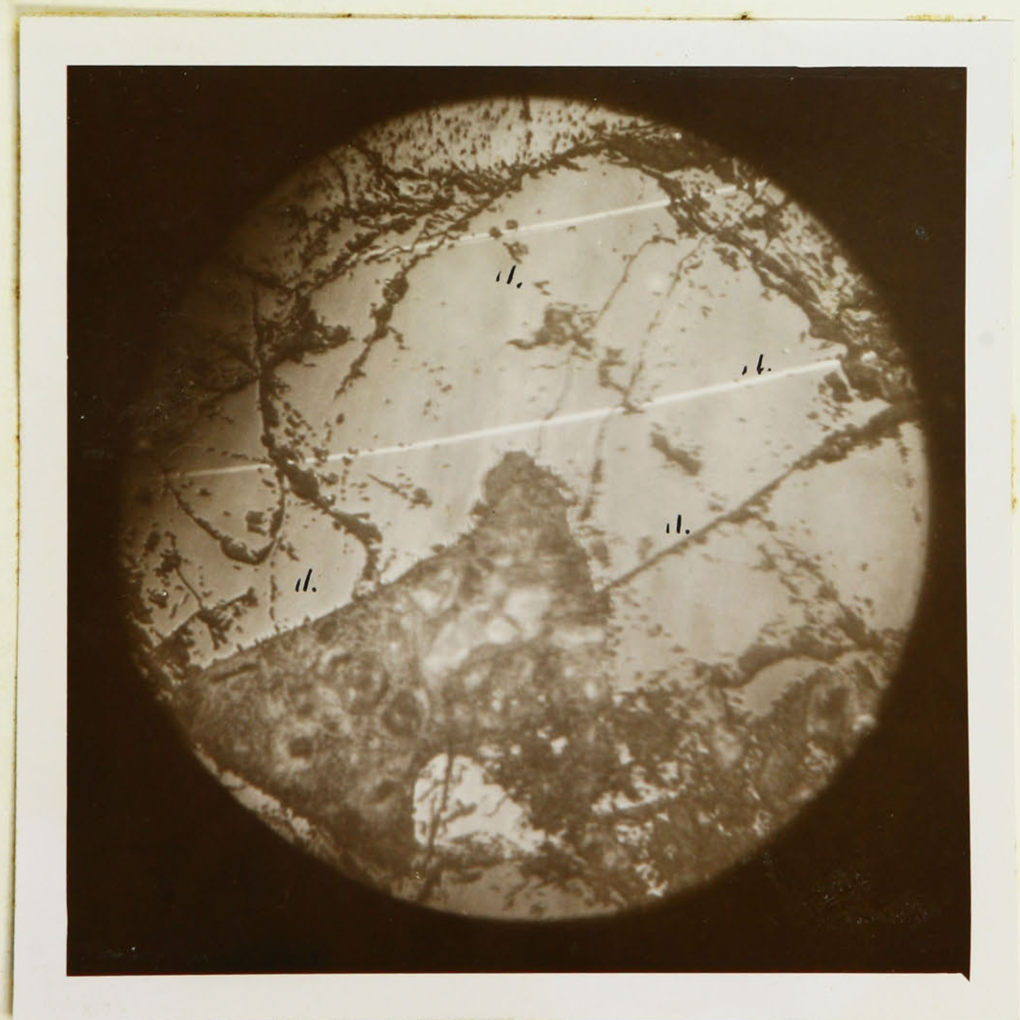


Figure 7

Twin lamellae in an ilmenite grain.
il.=ilmenite. Crossed nicols.(x50)

PLATE II

Figure 8

Magnetite surrounding rounded non-opaque minerals mostly apatite. mt.=magnetite. (x50)

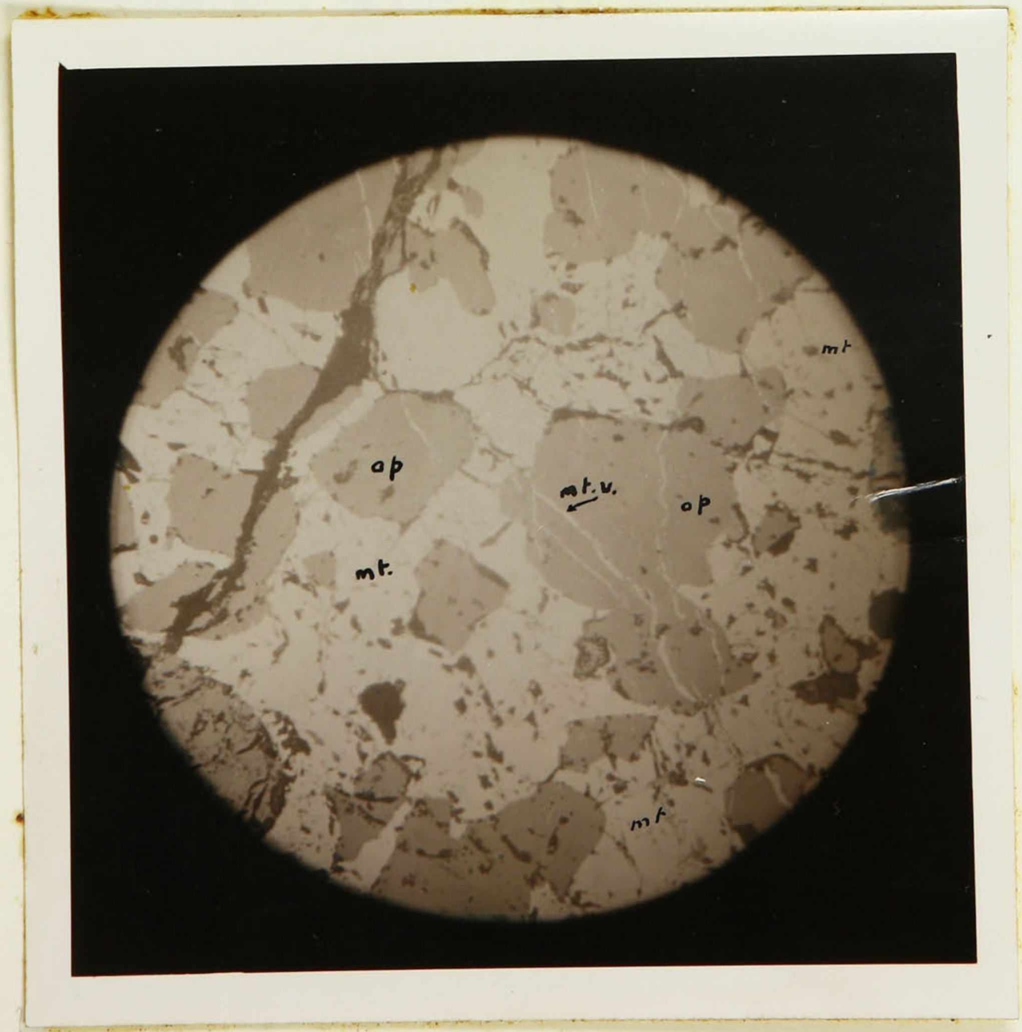


Figure 9

Secondary magnetite veinlets cutting non opaques; mt.=magnetite ap.=apatite, mt.v.=secondary magnetite veinlets. (x50)

PLATE III

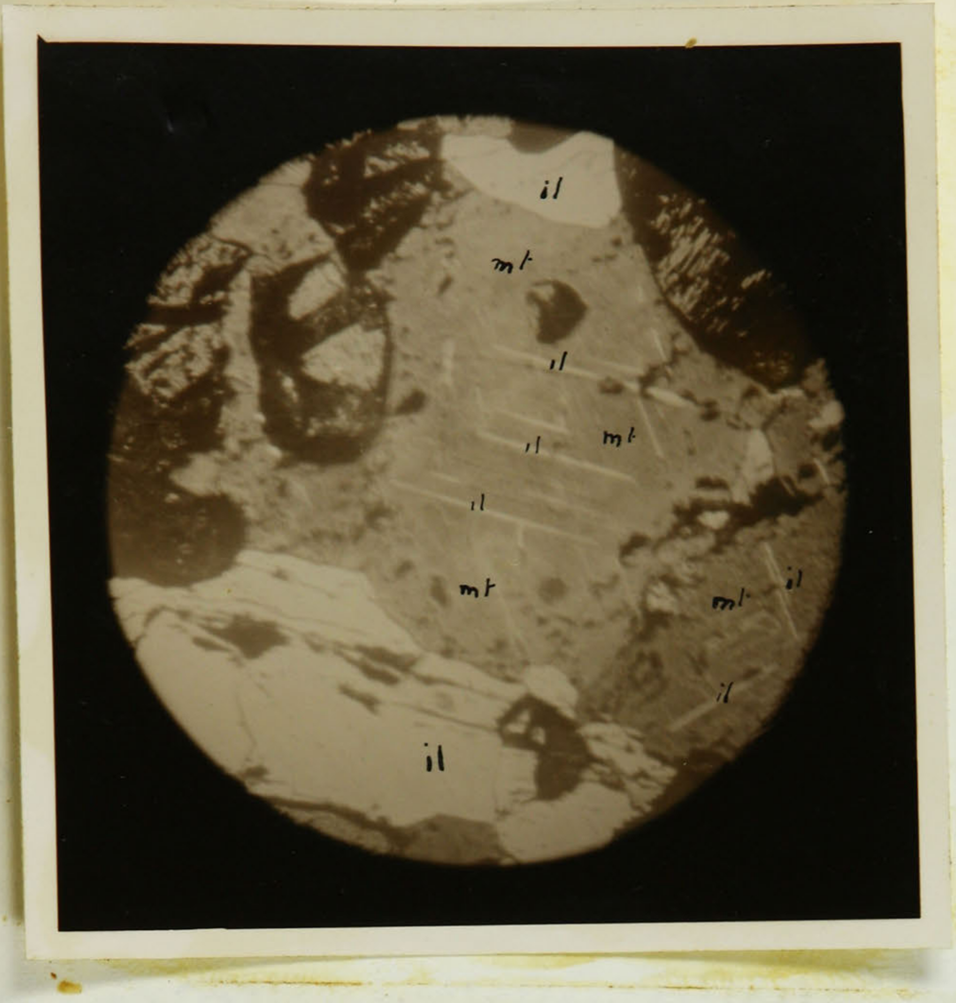


Figure 10

Ilmenite and magnetite-ilmenite intergrowths; il= ilmenite mt= magnetite. Etched 5 minutes with conc. HCl. (x50)

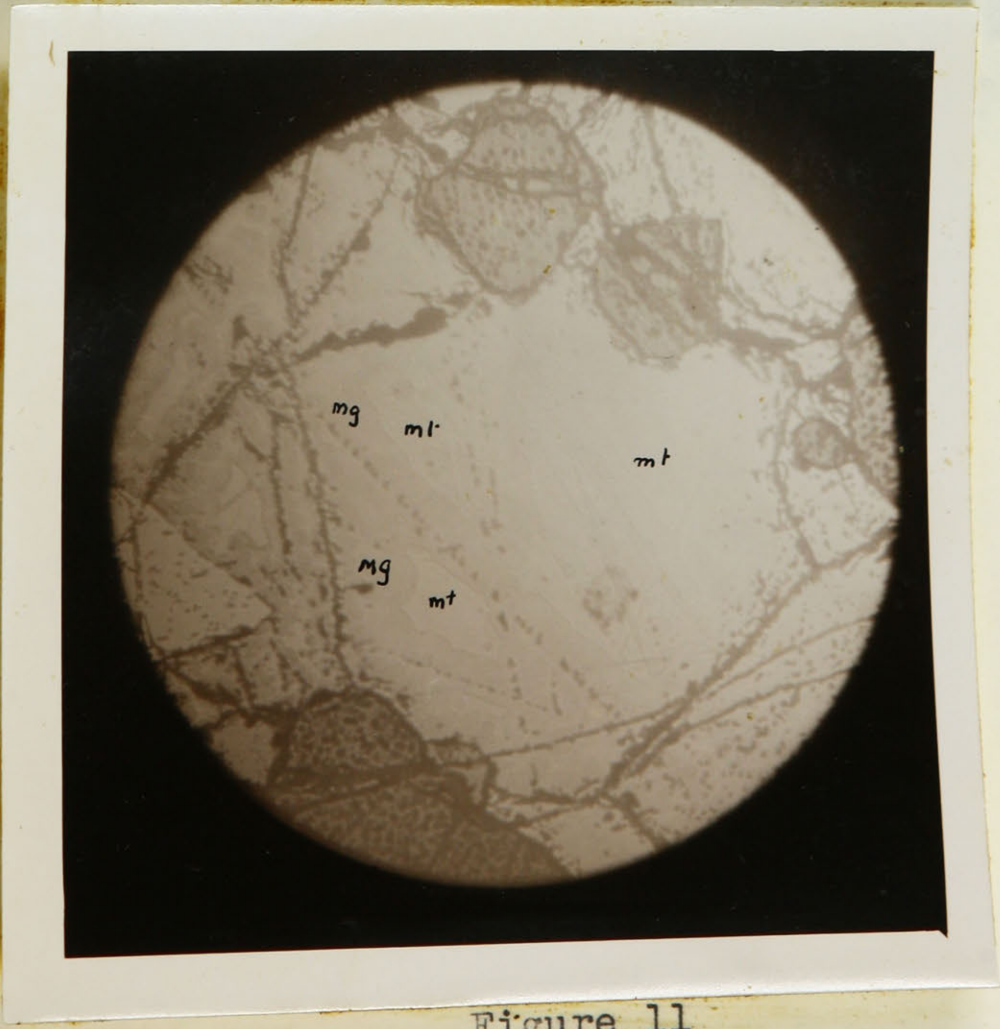


Figure 11

Magnemite (?) in magnetite
magnemite; mt=magnetite. (x50)

PLATE IV

Figure 12

View northwest over outcrop at I

PLATE V

Figure 13

Diorite dyke cutting anorthosite. North end of lot 45

PLATE VI

Figure 14

Trench at occurrence J

PLATE VII

Figure 15

View east from occurrence II, showing abrupt drop to the Saguenay river

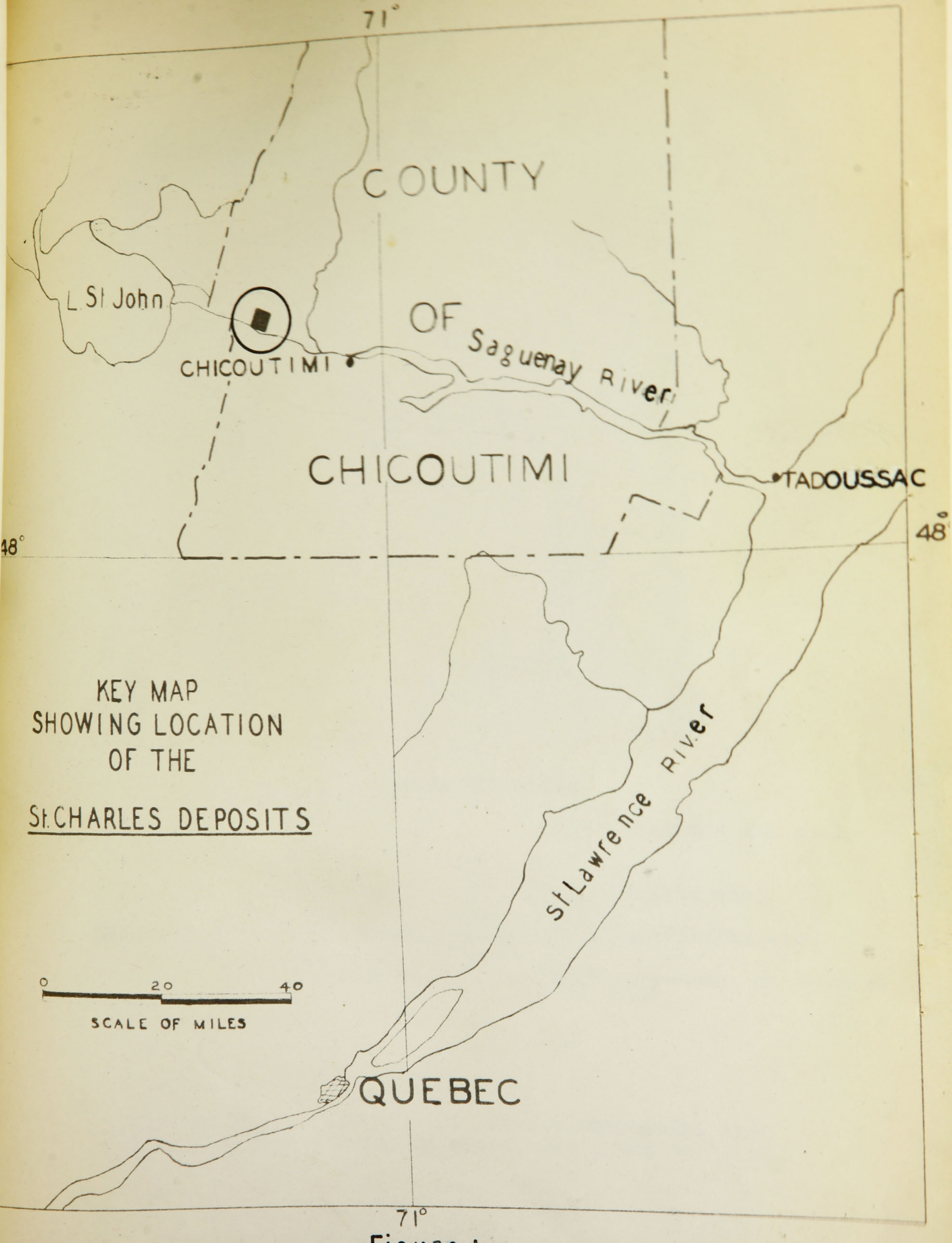
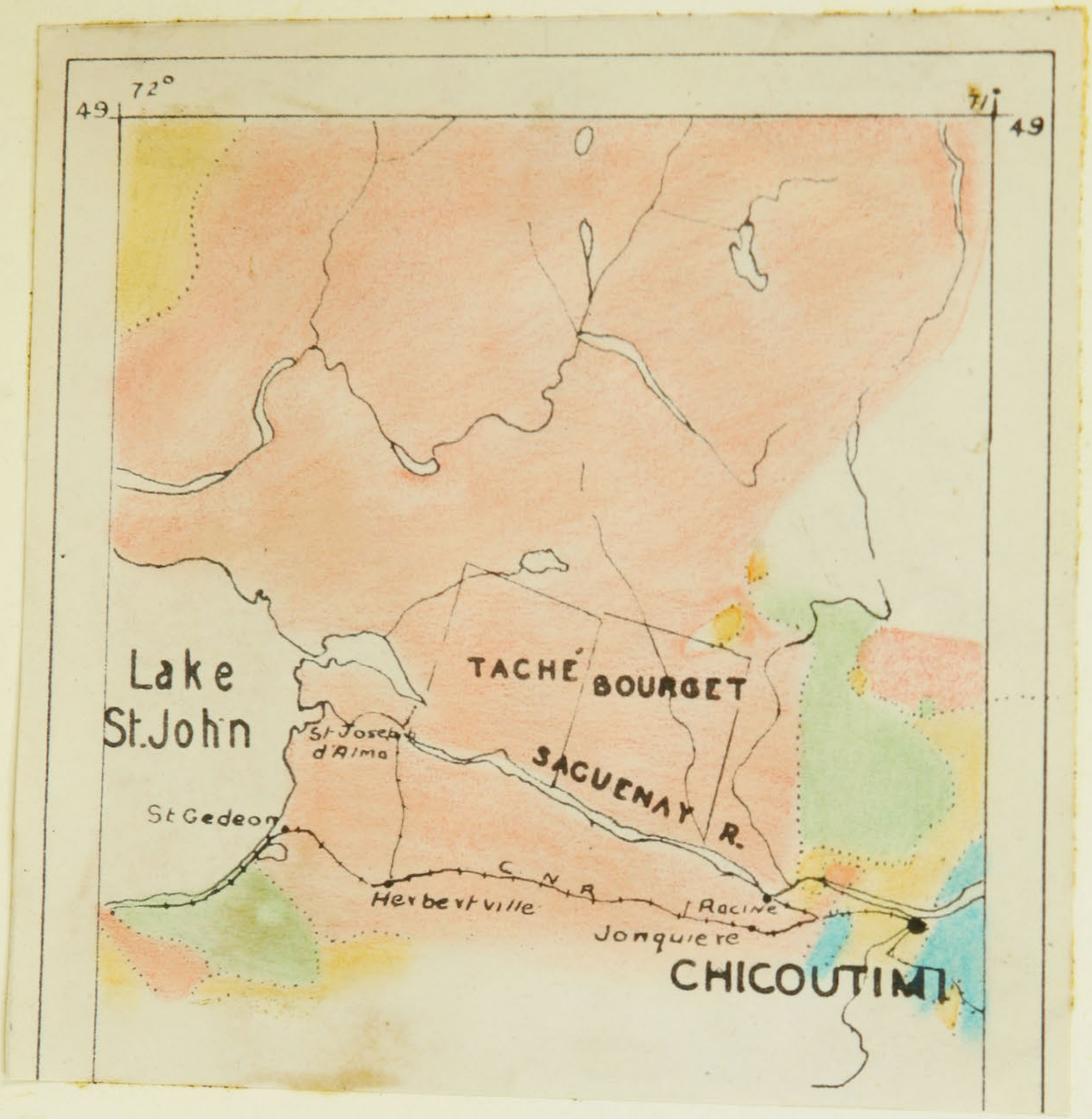

71°
COUNTY
OF
CHICOUTIMI
L. St John
CHICOUTIMI
Saguenay River
TADOUSSAC
48°
48°
KEY MAP
SHOWING LOCATION
OF THE
St. CHARLES DEPOSITS
0
20
40
SCALE OF MILES
St. Lawrence River
QUEBEC
71°

Figure I



Scale: 1 inch to 12 miles

PALEOZOIC	Ordovician	🟩	Limestone and shale
PRECAMBRIAN	Roberval	🟨	Granite etc.
	Anorthosite series	🟥	Anorthosite etc.
	Grenville	🟦	Limestone, paragneiss etc.

Figure 2

The Geology of the Lake St. John - Chicoutimi Area
Modified from: Dept. of Mines, Que., Map No. 704A