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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 60-11

IRON AND TITANIUM IN THE MORIN ANORTHOSITE, QUEBEC

Edward R. Rose

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By

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Illustrations

Figure 1. Map showing main iron and titanium occurrences in the Morin anorthosite massif Ste-Agathe region, Quebec. ..... Enclosed

INTRODUCTION

Scope of Work

Field work on which this report is based was done during parts of the summers of 1958 and 1959. A general survey of the Morin anorthosite was made and geological and dip-needle information collected. Selected areas were mapped on a scale of 200 feet to the inch by plane table, stadia, and alidade.

Microscope studies of thin sections and polished surfaces of field samples yielded information on the mineralogy, texture, and paragenesis of rock and ore minerals. Chemical and spectrographic analyses, mechanical mineral separations, magnetic measurements, and X-ray diffraction mineral identifications were made in laboratories of the Geological Survey of Canada.

Acknowledgments

The writer was assisted in the field by H.L. Lovell in 1958 and by Pierre Migneault and G.F. Rose in 1959. Thanks are due to many residents of the area for permission to search for and examine rock exposures on their land. Much valuable information was obtained from reports of previous investigators, notably F.F. Osborne and the late F.D. Adams. The Crane Company permitted the use of some of the information on the area which was gathered by Mr. Louis Moyd in an unpublished summary report to that company;[1] this was an invaluable aid to the writer. Much information and helpful assistance in the study of the St. Hippolyte-Lac Pin Rouge area, and elsewhere, was given by B.C. Salamis and Guy Lavigne, President and Vice-President respectively, of Laurentian Titanium Mines Limited. Mr. Emile Latremoille, present owner of the Ivry mine, kindly permitted access to the old mine pit which was reopened in 1958-59.

Location and Topography

The Morin anorthosite massif occupies an area of about 1,000 square miles centred about 60 miles north of Montreal in Terrebonne, Joliette, Argenteuil and Montcalm counties, Quebec. It extends from near Shawbridge on the south to St. Donat on the north, and from St. Théodore on the east to St. Faustin on the west (see Fig. 1).

Topographically, the area is characterized by steep rough hills that rise more than 600 feet above their surroundings, in many places reaching elevations of well over 2,000 feet. Bedrock on the

[1]Reports mentioned are listed in the References at the end of this section.

hills is mantled by glacial drift, sand, and gravel, and in the deeper valleys by clay overlain by stratified sand. Much of the area is covered with heavy mixed bush. Spring-fed lakes are abundant, nestled among the hills; most have steep, rough shorelines.

Previous Work

The Morin anorthosite was mapped and named by F.D. Adams for the Geological Survey of Canada in the years 1885 to 1891, and is described in detail in his report of 1896.

In contrast to the earlier-held opinion of Sir William Logan and others, that the anorthosite was part of the sedimentary Laurentian system of gneisses, Adams concluded that the anorthosite was a younger igneous rock, intruded as a batholith into the gneissic rocks that surround it. It thus produced a marked marginal foliation and evidence in many places of intense crushing and shearing in the contact rocks of both systems. The anorthosite was found to contain many large inclusions of country rock and was known to hold occurrences of ilmenite and of titaniferous magnetite that Adams believed to be of possible economic importance. The anorthosite was cut by younger dykes of pegmatite and diabase.

In 1910 a massive ilmenite deposit was found and opened near Ivry, and some mining was done on a titaniferous magnetite deposit near Desgrosbois; both operations were short-lived. From 1912 to 1918, when production terminated, a total of about 16,000 tons of ilmenite ore is reported to have been shipped from the Ivry Mine to the Titanium Alloy Company of Niagara Falls, New York, to be used in the manufacture of ferrotitanium. The results of a vertical magnetometer survey of the Ivry mine by D.A. Keys were published in 1936 by the American Institute of Mining and Metallurgy.

In 1936 F.F. Osborne reported on the Sainte Agathe-Saint Jovite area, covering the west part of the Morin anorthosite and adjacent rocks. This report, published by the Quebec Bureau of Mines, includes descriptions of the deposits at Ivry and Desgrosbois, and a discussion of the results of Keys' magnetic surveys there. Another report by Osborne, published in 1938 by the Quebec Bureau of Mines, deals with the area immediately to the south, including the south rim of the Morin anorthosite. The area was found to be occupied largely by igneous rocks of more acidic composition than anorthosite, ranging from monzonite through syenite to granite, and intrusive into the gneissic series (Trembling Mountain gneiss), but co-magmatic with the anorthosite in what he called "the Morin Series". A few occurrences of ilmenite, titaniferous magnetite and magnetite were noted, and boulders consisting mainly of these minerals were found near the southern edge of the anorthosite, being particularly abundant near the southwest corner of the massif. Geological boundaries in the southwest part of the map (Fig. 1) are taken mainly from Osborne's report.

Preliminary reports on other parts of the area—one by Pierre E. Côté on the eastern margin, and one by M.A. Klugman on a central area—were published by the Quebec Department of Mines in 1948 and 1957 respectively.

By this time it was generally known that anorthosites are favourable rocks for titanium occurrences, and after 1950 considerable prospecting was done in the Morin anorthosite area. In the period 1951 to 1954, following the discovery of large ilmenite deposits in anorthosite at Allard Lake, the Crane Company of Chicago conducted a program of scientific prospecting for ilmenite in the Morin area. An aeromagnetic survey of the anorthosite area (the results of which were later kindly made available to the Geological Survey of Canada) showed many strong aeromagnetic anomalies in the Morin anorthosite, but no new large deposits of titanium ore were located.

In 1952, Laurentian Titanium Mines Limited, guided by Adams' report and an aeromagnetic map located several ilmenite occurrences in the anorthosite. This company has subsequently conducted an extensive program of magnetic surveying, diamond-drilling, testing, and sampling. The results of these investigations have very kindly been made available and the writer was given free access to the diamond-drill core and plans, thus making possible a thorough study of the nature of the occurrences.

Some independent work has also been done in the area by such private companies as Continental Iron and Titanium Mining Limited, Heavy-Rock Mines Limited, Norvex Mining Company Limited, Pershing Amalgamated Mines Limited, Quebec Smelting and Refining Limited, Tamara Mining Limited and Drummond Copper Corporation and Titanium Development Corporation.

Summary of Conclusions

The Morin anorthosite is believed to be a composite intrusion, emplaced in several stages, accompanied by doming and deformation of the surrounding Grenville-type rocks. One of its main phases is a medium-grained gabbroic anorthosite that is intrusive in places into the anorthosite proper, and apparently gradational elsewhere. Ilmenite and titaniferous magnetite deposits are associated with both types. Titaniferous magnetite deposits seem to be most closely related to the gabbroic anorthosite phase.

Titanomagnetite and ilmenite are important constituents of the titaniferous magnetite deposits, and ilmenite-hematite exsolution members are characteristic of the massive ilmenite deposits. In the Morin anorthosite the latter tend to produce weakly negative magnetic anomalies and the former strongly positive anomalies. Intergrowths of ilmenite and hematite and numerous other factors may scale down anomalies, from positive towards the negative. Thus the strength of the magnetic anomaly does not always indicate the grade or amount of iron-titanium oxide minerals present, but the anomalies serve as guides to relative concentrations of these minerals. Many of the strongly positive aeromagnetic anomalies in the Morin anorthosite body indicate the presence of large disseminated deposits in which titanomagnetite and ilmenite may be potentially valuable constituents as sources of iron and titanium.

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GENERAL GEOLOGY

The general distribution and mutual relationships of bedrock types are shown in Figure 1, in so far as they are known. The oldest rocks in the area are those of the Precambrian Grenville series including gneiss, schist, crystalline limestone, quartzite and metamorphic pyroxenite-amphibolite. These ancient, highly metamorphosed rocks are intruded by igneous bodies of various sizes that range from pyroxenite and gabbro to granite and pegmatite.

The Morin anorthosite and its co-magmatic gabbroic anorthosite, monzonite, syenite, and granite are also intrusive into this older assemblage of country rocks, and are in turn intruded by younger pegmatite and diabase dykes.

Sedimentary rocks of Palaeozoic age, including sandstone (orthoquartzite), dolomite, and limestone overlap the Precambrian rocks in the Ottawa-St. Lawrence Lowland valley to the south where they are intruded in places by the alkaline igneous rocks of the Monteregian suite.

The Morin anorthosite and Palaeozoic rocks are unfortunately not in contact and their relative ages must be inferred from indirect evidence, most of which suggests that the anorthosite there is of late Precambrian age. It should be noted, however, that there is a petrological similarity between the Morin anorthosite series and some of the Monteregian intrusions. This suggests a similarity in origin for these igneous rocks of widely separated ages.

On their maps, both Adams and Osborne indicate outlying bodies of granite, syenite, and porphyry, beyond the borders of the Morin anorthosite, which are also believed to be of Precambrian age, but younger than the anorthosite.

Petrography of the Morin Anorthosite

The Morin anorthosite body varies considerably throughout its 1,000-square-mile area. It varies from typical anorthosite to gabbro; in colour, from light grey through green and mauve-brown to black; and in texture, from very coarse to fine grained. In some places it weathers light and in others dark and rusty. It is massive in places and foliated in others, and is commonly intersected by several sets of joints. It is also commonly brecciated and cut by several penecontemporaneous dykes and dykelets of similar composition, colour, and texture to the main mass. In places it contains large inclusions of country rock, including quartzite and gneiss. It is cut by late-stage quartz veins and pegmatite dykes, and by even younger diabase dykes.

The contacts of the anorthosite and the surrounding rocks are not well exposed, but the relationships of the two are apparently complex. A 3-foot-wide, sill-like dyke of anorthosite penetrates quartzite of Grenville type near the main contact north of St. Donat. East of Oureau River, near Lake George, a swarm of black pyroxenite dykes, rich in fine-grained titanomagnetite and ilmenite, cuts grey gneiss and is in turn cut by small anorthositic dykelets. Nearby, the rock, presumably anorthosite, is badly altered to an incoherent friable aggregate of kaolinized grains seamed with pink zeolites. Near the main anorthosite contact the gneiss and quartzite are twisted, contorted, drawn out, and perhaps altered in places beyond the regional grade of metamorphism. Foliation and banding in the rocks intruded by the anorthosite massif generally parallel the borders of the intrusion for several miles away from the contact. This is believed to be the result of doming by the forceful intrusion of the anorthosite.

The irregular brecciated nature of the anorthosite, together with the intrusion of various phases of gabbroic anorthosite and anorthosite, suggest that the massif is a multiple intrusion emplaced in a series of magmatic surges. Generally, a fine-grained gabbroic

anorthosite phase that commonly contains more titanomagnetite than ilmenite, invaded an earlier-formed anorthosite that carried disseminated ilmenite in places. There are, however, reversals of this sequence, indicating periods of differentiation and renewed activity from a deep-seated magmatic source.

Anorthosite and gabbroic anorthosite are gradational in places. They consist essentially of labradorite, hypersthene, and augite, with members of the ilmenite-titanomagnetite series in various proportions. The iron-titanium oxide minerals, particularly titanomagnetite, are commonly more abundant in the gabbroic phases, but in places they occur also in the anorthosite. This is especially true of ilmenite which occurs free of titanomagnetite in massive, vein-like deposits that cut sharply through otherwise barren, coarse-grained anorthosite. Titanomagnetite essentially free of ilmenite also occurs in veins in gabbroic anorthosite and in places replaces anorthosite bands marginally.

Exsolution textures characterize both the iron-titanium oxide minerals in these rocks and the feldspars, which show microscopic antiperthitic intergrowths in plagioclase. The plagioclase is commonly twinned, approaching labradorite in composition, and in many places holds swarms of microscopic inclusions too small for ready identification. In a few places the plagioclase shows an opalescent play of blue colours on cleavage surfaces. The pyroxene is commonly hypersthene, but augite is also present. Pink garnet is locally abundant, and amphibole, brown mica, pyrite, pyrrhotite, chalcopyrite, apatite, zircon, and rutile(?) also occur as accessory minerals in small amounts. Chlorite, epidote, zoisite, goethite, limonite, leucoxene, carbonates, and zeolites may also be found, generally in minor amounts, as alteration products. In places, pink garnet is developed at the contacts of feldspar and either iron-titanium oxides or pyroxene, and is apparently a metamorphic product. Dark green spinel is sporadically disseminated through the ilmenite at Ivry.

Geochemistry

The association of iron and titanium with anorthositic and gabbroic rocks is now well established in many parts of the world, and nowhere is there a better example than in the Morin anorthosite. The average iron content in rocks of the earth's crust, 5.1 per cent, is about ten times that of titanium, which is about 0.5 per cent. The true anorthosite is generally lower in both iron and titanium than the average igneous rock, but in places it may be higher depending mainly on its ilmenite and titanomagnetite content. The gabbroic anorthosite associated with it is generally much higher in both iron and titanium than the average igneous rock, but it too has phases that are relatively iron and titanium poor. As a whole, the Morin anorthosite body is probably above the crustal average in both of these elements.

Iron and titanium in these rocks is combined chiefly with oxygen, forming a solid solution series of iron-titanium oxide minerals which may be dispersed or concentrated in the parent rock, or, in some cases, carried into adjacent rocks or into other parts of the

consolidated magma. The principal iron-titanium oxide minerals thus formed are ilmenite, titanomagnetite and magnetite, with ulvö-spinel, hematite, rutile, anatase, brookite, pseudobrookite, titanite (sphene) and perovskite normally in smaller amounts.

The iron-titanium oxide minerals tend to be much more strongly disseminated in the gabbroic (noritic) phase of the Morin anorthosite than in the true anorthosite, and the iron/titanium ratio is generally higher in the former. Thus the titaniferous magnetite deposits are most commonly found in gabbroic rocks and ilmenite deposits in anorthosite. If the differentiation process is carried further we may expect to find magnetite with low titanium content in the country rocks intruded by gabbroic anorthosite. A low titanium magnetite occurrence in quartz monzonite and gneiss about 2 miles west of St. Jerome may be of this nature.

Interpretation of Magnetic Anomalies

The Crane Company's aeromagnetic compilation map shows a large, partly broken ring of strong positive magnetic anomalies, occupying, somewhat discontinuously, the border zones of the Morin anorthosite body. In addition, irregular and linear zones of anomalies occur in the central part of the body, and a few occur outside its borders. Within the anorthosite body much of the area, covered by anomalous zones was found to be underlain by gabbroic anorthosite carrying disseminated titaniferous magnetite. The gabbroic anorthosite occupies the margin and irregular central zones in the anorthosite. It is commonly gradational to anorthosite by dimunition in the amount of pyroxenes and opaque minerals, but it intrudes the anorthosite in many places in the form of dykes, poorly defined masses, and in breccia zones.

In detail, the Morin anorthosite area was found to show more than 30 aeromagnetic anomalies, most of which are strongly positive but a few of which are weakly negative. Field intensities of more than 6,000 gammas are abundant, a few reaching more than 10,000 gammas, but values of the order of the 3,000 gammas below the regional magnetic level were not indicated, as in the case of the Allard Lake ilmenite deposit. A concerted effort to determine the cause of anomalies was made by Louis Moyd, consulting geologist, who under-took ground surveys, trenching, sampling, diamond-drilling, and various laboratory investigations. He concluded that, in general, most of the magnetic anomalies were caused by disseminations of titaniferous magnetite in localized patches of fine- to medium-grained noritic anorthosite. Some anomalies are associated with disseminations of titaniferous magnetite in altered anorthosite, or of magnetite or ilmenite in typical coarse-grained purplish brown anorthosite. Moyd concluded that, although most of the known occurrences of appreciable size are indicated by aeromagnetic anomalies, the intensity of the anomalies is not directly proportional to the size or concentration of the ore mass. Rather, it appears to be controlled by the mineralogy and texture of the ore. Some true negative anomalies (pole inversions) are associated with ilmenite-hematite intergrowths, but others are

associated with magnetite-ilmenite intergrowths. Some anomalies were found to be associated with minor disseminations of magnetite in large masses of Grenville gneiss within the anorthosite, and in the Lac Oureau area, a series of low-intensity magnetic anomalies was associated with sparse disseminations of ilmenite in medium-grained, foliated granite.

A pronounced magnetic depression between two strong positive aeromagnetic anomalies at Lac Pin Rouge is apparently related to the underlying ilmenite deposit with its characteristic exsolution texture of hematite blades in ilmenite. The deposit grades into a titanomagnetite-rich belt of gabbroic anorthosite to which the strong positive aeromagnetic anomalies mentioned above are related. Dip-needle readings over the titanomagnetite-rich belt are generally strongly positive, and over the ilmenite-rich part they are commonly negative, thus indicating a true negative anomaly or pole inversion.

An oriented specimen collected from the ilmenite-rich part of the deposit was submitted to A. Larochelle for remanent magnetism and magnetic-stability measurements. Even though the magnetic susceptibility of the surrounding rocks is very high, it appears that remanent polarization is mainly responsible for the magnetic depression in this area. In fact, the oriented specimen collected from the ilmenite deposit was found to be polarized in a direction almost opposite to that of the present earth's field, i.e. almost parallel with the near-vertical foliation and banding in the host rock there. On the other hand, two oriented specimens from the central and western parts of the anorthosite and one from the gneissic hornblende syenite on the west contact of the anorthosite body were all found to be unstably positively polarized downward with different angles of declination.

Thus, indirectly the mineralogical composition of the rocks dealt with appears to govern the polarity of the anomalies over the area and, to a lesser extent, the intensity of these anomalies. The latter is also tied with the magnetic susceptibility of the rocks (which is only partly dependent upon the mineralogical composition), with the mass, depth, and attitude of the magnetic bodies, as well as with the scatter index in the polarization directions throughout the bodies.

A strong belt of aeromagnetic anomalies is also found on the southwest margin of the Morin anorthosite extending southerly from near St. Faustin through Wolfe township, Terrebonne county, into Howard and Montcalm townships, Argenteuil county. No information on these is available from drill cores, but surface examination by the writer indicates that there also, many of the anomalies are caused by disseminated iron-titanium oxides in gabbroic anorthosite; parts richer in titanomagnetite generally give strong positive anomalies and parts richer in ilmenite generally give weakly negative anomalies. The general geological relationships are much the same as at St. Hippolyte-Lac Pin Rouge, but in one place a mass of grey quartz monzonite occupies part of the western margin of the anorthosite and is itself cut by small fine-grained dykelets of gabbroic anorthosite. The latter are in turn cut by tiny pegmatite dykelets. As at Lac Pin Rouge, late fine-grained vertical black diabase dykes appear to be the youngest igneous rocks intruded in the area.

ECONOMIC GEOLOGY

Throughout many parts of the world the unique group of igneous rocks known as anorthosite and gabbroic anorthosite has been found to carry ilmenite and titaniferous magnetite deposits. The Morin anorthosite is no exception. A massive ilmenite deposit in anorthosite was opened near Ivry in Beresford township in 1910, and soon after, a titaniferous magnetite deposit in gabbroic anorthosite and anorthosite was found at Desgrosbois 1 mile to the north. Other deposits have since been found and the old Ivry mine was reopened in 1958, but no further mining development has taken place, partly because of the limited market for titanium and partly because of difficulties in smelting titaniferous magnetite.

The metallic-mineral occurrences within the area include low titanium magnetite, chalcopyrite, nickeliferous pyrrhotite and pyrite, in addition to ilmenite and titaniferous magnetite, all of which show a close relationship to the Morin (anorthosite) series of igneous rocks. The occurrences may be generally classified as magmatic concentrates, but they range from early to late magmatic and hydrothermal environments. The close genetic relationship of ilmenite and titaniferous magnetite to anorthosite and gabbroic anorthosite respectively, is shown by their distribution and intimate intergrowths. Ilmenite with exsolved hematite is the main ore mineral of the ilmenite deposits, and titanomagnetite of the titaniferous magnetite. Each may occur singly or together, in disseminated or massive form, and where the deposits merge they do so either abruptly or by transitions. Both ilmenite and titanomagnetite may crystallize early and separate by gravity, or crystallize later and become 'frozen' in the solidifying magma, or they may remain fluid and become concentrated in a residual liquid which later drains or is injected into zones of weakness in the surrounding rocks. Thus the disseminated deposits of titaniferous magnetite (consisting of discrete grains of titanomagnetite and ilmenite) may be regarded as late magmatic for the most part, whereas the massive ilmenite lodes (consisting mainly of ilmenite with exsolved hematite) may be regarded as residual liquid or fluid injections. Little evidence is now left in most of the deposits to prove the presence of large amounts of volatile ingredients such as water, chlorine, fluorine, phosphorus and sulphur that might have acted to fluidize the magmatic extracts, but the presence of pyrite, apatite and zeolites in places in the deposits and in the surrounding rocks suggests that such was the case.

Description of Deposits

Most of the known deposits of iron and titanium within the area are in Terrebonne county. Other occurrences are known in Argenteuil, Montcalm and Joliette counties, but only those examined by the writer are described here; all are in Terrebonne county.

Beresford Township

Two iron-titanium deposits are known in the central part of the anorthosite body in Beresford township, one near Ivry, the other near Desgrosbois station. Fine-grained disseminations of titanomagnetite and ilmenite occur in the gabbroic anorthosite west of Lac Brûlé.

Ivry: On lots 37 and 38, and extending into lots 36 and 39, range V, a massive deposit of ilmenite occurs in coarse-grained dark anorthosite near Ivry. The main pit on lot 38 is owned by Mr. Emile Latremoille, and the Titanium Development Corporation holds claim on part of lot 37. The ilmenite of the Ivry deposit is characteristically coarse grained with a well-developed exsolution texture of aligned hematite blades and lenses. The ilmenite is intergrown with dark green spinel, dark plagioclase feldspar, pyroxene, amphibole, mica, apatite, and sulphides (mainly pyrite), and is cut by irregular veins of pyrite with minor pyrrhotite and chalcopyrite. A carbonate mineral, possibly siderite, is finely dispersed through some of the feldspar grains.

A massive ilmenite lens about 60 feet wide cuts with sharp contact through dark anorthosite and contains large inclusions or horses of anorthosite. The main lens strikes northwesterly, dips steeply southwesterly, tapers to the northwest and splits at the southeast end of the pit into two or more bands. A substantial tonnage of ilmenite is indicated in the deposit and its extension, with several hundred thousand tons of ilmenite in sight. As a result of magnetometer survey, Keys calculated the deposit to be at least 186 feet deep at the main pit. Because of the erratic nature of the magnetic readings, a patchwork of ore pods was proposed. The deposit is rather inconspicuous when tested with the dip needle, as it gives both low-positive and low-negative readings from spot to spot even on massive ilmenite. This may be caused by conflicting orientation of induced and remanent magnetism.

The Ivry deposit was reopened in 1958 and more than 36,000 tons of massive ilmenite is said to have been shipped by Heavy-Rock Mines in 1958-59, for use as heavy aggregate in concrete.

Desgrosbois: About a mile to the north of the Ivry mine at Desgrosbois station on the Canadian Pacific Railway, in lots 38-41, range VI, an irregular titaniferous magnetite deposit occurs in dark, rusty-weathered, medium-grained, gabbroic anorthosite and coarse-grained grey anorthosite. It is controlled by Pershing Amalgamated Mines Limited. Part of the deposit is exposed in pits and outcrops south of Highway 11 near Desgrosbois station. The gabbroic anorthosite is foliated in part and is crushed and brecciated together with the anorthosite, but in places it cuts and reticulates through coarse-grained anorthosite. Titanomagnetite and ilmenite, with exsolution texture in places in medium-grained intergrowths, replace the crushed groundmass of anorthosite and include unreplaced anorthosite remnants, crystals and crystal fragments of plagioclase, pyroxene and apatite. Fine-grained pyrrhotite is disseminated through much of the titaniferous magnetite. Corona zones of altered material occur about many of the feldspar grains included in the titaniferous magnetite.

In places the titanomagnetite appears to invade and cement ilmenite-hematite grains. Because of the preponderance of titanomagnetite over ilmenite, the deposit has a higher iron/titanium ratio than the Ivry deposit. Dip-needle readings are strongly positive and erratic at the old mine pits. The aeromagnetic anomaly produced by the deposit is positive but only moderately strong.

Wexford Township

St. Hippolyte: Near the village of St. Hippolyte in the southeast corner of the Morin anorthosite body, a belt of strongly positive aeromagnetic anomalies, containing some inversions, stretches northerly towards Lac Masson. In lots 6-9, ranges II and III, in this belt near Lac Pin Rouge, Laurentian Titanium Mines Limited located an ilmenite deposit and reported it to contain 15 million tons of ilmenite-bearing material averaging 19.9 per cent TiO_2 and 27.6 per cent Fe, calculated to a depth of 225 feet.

The ilmenite deposit forms part of a series of larger, low-grade, titaniferous magnetite deposits that are roughly outlined by aeromagnetic anomalies. The anomalous area consists of a belt of dark, medium-grained, foliated, gabbroic anorthosite that carries disseminated ilmenite, ilmenite-hematite, titanomagnetite, and intermediate members of a solid solution series that commonly show exsolution textures. In places these iron-titanium oxide minerals are concentrated in irregular clots, veins, and massive bands, and may contain associated pyrite, pyrrhotite and chalcopyrite, but generally in small amounts. The belt of partly banded, iron-titanium-bearing gabbroic anorthosite trends northerly and is flanked by grey anorthosite, poor in iron-titanium oxide minerals. The iron-titanium-bearing belt covers a length of about 6 miles, and a variable width of about 1,000 feet. It probably extends to considerable depth. Eight surface samples taken by the writer from exposures along this belt were analyzed in the Geological Survey chemical laboratory and found to be uniformly high in iron and titanium, ranging in composition from 23.5 to 31.9 per cent iron oxide, and from 5.4 to 17.0 per cent titanium oxide. In two zones within the belt, one north and one south of Lac Pin Rouge, Laurentian Titanium Mines Limited in 1958-59 drilled two holes to a depth of 175 feet. The north hole was reported to average 18.62 per cent iron and 6.26 per cent titanium oxide; the south hole, 24.07 per cent iron and 9.08 per cent titanium oxide. In 1959, on the basis of surface samples, the company estimated conservatively, to a depth of 100 feet, more than 28 million tons of ore averaging 20.11 per cent iron and 6.95 per cent titanium oxide in the north area, and more than 17 million tons of ore averaging 23.52 per cent iron and 7.59 per cent titanium oxide in the south area. As these two areas form only a part of the iron-titanium mineral belt and as the mineralization is deep-seated, this estimated tonnage represents only a small part of the total tonnage of low-grade titaniferous magnetite in this belt.

Titanomagnetite, ilmenite, ilmenite-hematite, and intermediate members, in places showing exsolution textures, commonly form as much as 30 per cent of the host rock, but range from 5 to 50 per cent or more. After crushing and grinding, the heavy black iron-

titanium minerals may be readily separated from the gangue minerals, mainly feldspar, pyroxene, garnet and apatite, by heavy media or magnetic separation. Titanomagnetite and ilmenite may be further separated by high-intensity magnetic separation, but because of solid solution inclusion of titanium in magnetite it is not possible to separate mechanically all of the titanium from the magnetite concentrate. However, it is possible by these methods, to free the iron of much of the titanium and vice versa, obtaining a titanomagnetite-rich concentrate on the one hand and an ilmenite-rich concentrate on the other.

Tamara Mining Limited and Drummond Copper Corporation jointly hold claims on the northern part of this belt, in which they are reported also to have outlined a large occurrence of low-grade titaniferous magnetite. An estimated combined potential of 230 million tons averaging 20 to 23 per cent iron and 6 per cent titanium oxide is reported.

Other disseminated occurrences of titaniferous magnetite in Wexford township were noted by the writer south of Lac Castor; on the Canadian Pacific Railway line less than a mile north of Ste. Marguerite station; and near the road south of Wexford Lake (Lac des Îles).

Wolfe Township

An occurrence of ilmenite was noted by the writer on the road about a mile south of St. Faustin, in Wolfe township, in an area of low magnetic intensity. A narrow band or bands of dark gabbroic anorthosite carrying sporadically disseminated ilmenite was traced for a length of 1,200 feet and a width of 200 feet, flanked on both sides by grey anorthosite and containing bands of grey anorthosite. In polished sections the ilmenite shows exsolution blades of hematite, a few grains of magnetite and a little pyrite and pyrrhotite. Blades of ilmenite are shown to penetrate deeply along the cleavage planes of feldspar crystals. Negative dip-needle readings were obtained in several places along part of this area, much of which is covered by overburden.

Farther south along the road near Lac Larin, rusty boulders and outcrops of gabbroic anorthosite carry considerable fine-grained titanomagnetite and ilmenite. At Lac Larin the gabbroic anorthosite is cut by narrow, tourmaline-bearing, pegmatite dykes that are weakly radioactive. Strong positive aeromagnetic anomalies occur near the lake.