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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 61-7

IRON AND TITANIUM IN THE ANORTHOSITE ST. URBAIN, QUEBEC

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Edward R. Rose

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By

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IRON AND TITANIUM IN THE ANORTHOSITE OF ST. URBAIN, QUEBEC

INTRODUCTION

Scope of Present Work

This report contains the results of the writer's geological investigations of the St. Urbain anorthosite body, its contained ilmenite deposits, and the surrounding rocks. The field work was carried out during 6 weeks of the summers of 1958 and 1959. The investigations included a general survey of the anorthositic rocks, the collection of dip-needle data, the examination of available diamond-drill core, and the collection of several oriented specimens of ilmenite and host rocks for magnetic measurements, mineralographic studies, and spectrographic analyses. Samples of biotite-rich selvedge rock were collected from the ilmenite-anorthosite for potassium-argon dating.

Acknowledgments

The writer is grateful for the kindness of the Quebec Seminary, the National Lead Company Limited, and M.J. O'Brien Company Limited in making aeromagnetic information available; and to the Continental Iron and Titanium Mining Limited (renamed Continental Titanium Corporation in 1960) for granting free access to its mine workings and diamond-drill core. Mr. Mickel Zwonuk of the latter company was particularly helpful in guiding the writer to ilmenite occurrences and localities of geological interest in the area. Capable assistance was given in the field in 1958 by H.L. Lovell, and in 1959 by the late G.F. Rose.

Location and Access

The village of St. Urbain in Charlevoix county, Quebec, lies on Gouffre River in the south-central part of an oval-shaped body of anorthosite, about 8 miles north of the village of Baie St. Paul. The latter is at the mouth of Gouffre River on the north shore of the St. Lawrence, about 60 miles northeast of Quebec City.

Both St. Urbain and Baie St. Paul are serviced by modern highways connecting to Quebec City, and Baie St. Paul is on the north-shore branch of the Canadian National railway. The harbour at Baie St. Paul is a sand- and silt-filled, U-shaped tidal estuary that extends about a mile into the St. Lawrence River. The estuary is shallow and suitable only for small vessels of shallow draught, but might be deepened by dredging to enable larger ships to dock. At high tide the sand flats are water-covered, and the brackish waters of the St.

Lawrence River and Gulf enter Gouffre River reversing its flow for some distance above its mouth. Deep-water wharf sites at Cape Corbeau and at Les Eboulements—both to the east of Baie St. Paul—are being considered by the federal Department of Public Works as alternative dock locations.

Topography

The land rises abruptly from the St. Lawrence River in massive rounded hills mantled by thick unconsolidated deposits of glacial till, sand, and gravel. Rock outcrops are mainly confined to the river-banks and road-cuts, and to the mountainous terrain at the Laurentide Park boundary north of St. Urbain. Gouffre River occupies a narrow but relatively gentle valley that is flanked by bush-covered hills rising more than 2,000 feet above the valley floor at St. Urbain, and by abrupt rock-bound hills reaching elevations of well over 3,000 feet 10 miles to the north. The flat, sand-and-clay-covered valley floor rises from an elevation of about 30 feet above sea-level at Baie St. Paul to about 400 feet at St. Urbain. Both sides of the valley are marked—at elevations up to 600 feet above sea-level—by striking terraces of sand and gravel which extend for 15 miles or more north from Baie St. Paul. Recent marine shells have been recovered from these terrace sands (Logan et al., 1863)[1]. Several wave-cut rock benches are also visible along the valley sides. The most recent sand deposits in the Gouffre River delta at Baie St. Paul in places carry dark grains of ilmenite, and the bay also may be underlain by ilmenite-bearing sands.

Previous Work

In 1666, French settlers reported an iron deposit in the Gouffre River valley, and it was subsequently investigated by order of Louis XIV. The first geologist to report on the area was Sir William Logan (1850), who later (1863) described the limestones and their included fauna at the mouth of Gouffre River, and the ilmenite near St. Urbain. Hunt (1853) analyzed rutile-rich ilmenite from St. Urbain and also discussed saline springs near Baie St. Paul (in Logan et al., 1863). Russell and Low investigated part of the area in the 1880's (unpub. GSC map) as did Abbé Laflamme (1890). Dulieux (1912) reported on the ilmenite deposits, and Warren (1912) made a detailed petrographic study of them. Mawdsley (1927) made a complete geological study of the St. Urbain area together with an accurate geological map, and Osborne (1928, 1944) refers to the ilmenite deposits there.

Gillson (1932) examined the deposits and considered them to be of hydrothermal origin, in contrast to previously published opinions. P.E. Bourret (1958) prepared a special report on sampling of the Couloumbe and Furnace ilmenite mines. Tuttle (1943) discussed

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[1] Names and dates in parentheses refer to publications listed in the References.

the orientation of ilmenite and andesine in the deposits at St. Urbain, and Karpoff (1953) described mining and methods of beneficiation of the ore.

During 1948 and 1949 a combined aeromagnetic, geophysical, and geological survey of the anorthosite area was made for the National Lead Company Limited and M.J. O'Brien Company Limited, over territory largely owned by the Quebec Seminary and including the ilmenite deposits; the results were interpreted by Scharon (1950). Several interesting aeromagnetic anomalies were discovered at this time and some diamond-drilling was done, but no large new deposits of ilmenite were found and interest in the area was dropped. Since then, however, control of the known deposits has been acquired by Continental Iron and Titanium Mining Limited, which has succeeded in locating additional ilmenite in the Bignell (Plate IB), General Electric, and Coulombe (Plates IA, IIA) deposits and their extensions. The area is included in a regional gravity survey of the Dominion Observatory that was described by Thompson and Garland (1957).

Summary of Conclusions

The anorthosite massif at St. Urbain consists of a central core of anorthosite surrounded by a broad zone of dioritic, gabbroic, and granitic rocks. It was emplaced into the surrounding gneiss of the basement complex as a composite igneous intrusion. The darker, heavier, more strongly magnetic, dioritic and gabbroic rocks around the borders of the main anorthosite mass represent more basic differentiates of the parent magma, and they carry more ferromagnesian minerals and more disseminated iron-titanium oxide minerals than the true anorthosite. These rocks have a higher iron/titanium ratio than the anorthosite and may have crystallized slightly later than most of the anorthosite.

Massive ilmenite deposits commonly occur as vein-dykes in the anorthosite, emplaced after consolidation and fracture of the host rock. (See Plates IIA and IIB.) In places gabbroic anorthosite is the host rock.

Emplacement of ilmenite was accompanied by minor wall-rock alteration and the formation, locally at the contacts of ore and rock, of dark mica and sapphirine. This mineral development was followed or accompanied by a more or less intense, pervasive alteration of the rock to zeolites, carbonates, and chlorites, which locally extends for 50 - 100 feet into the wall-rock. Ilmenite in both disseminated and massive form in the anorthosite commonly contains exsolved blades and blebs of hematite, and the plagioclase of the anorthosite also commonly shows swarms of exsolved microscopic feldspar lenticles, suggesting exsolution after crystallization in both instances.

On the basis of present field and laboratory evidence, the rock and ore were both formed as magmatic differentiates at high temperatures. Volatile ingredients such as oxygen, hydrogen, sulphur, chlorine, phosphorus, and potassium probably acted as pneumatolyzers,

increasing the fluidity and lowering the fusion temperature of rock and ore, especially in the late stages of mineralization when more abundant sulphur, carbon dioxide, and water vapour became available for the formation of pyrite, carbonates, and zeolites. The vuggy nature of part of the ilmenite-hematite intergrowth, and of part of the pyrite, along the contact of ore and wall-rock in the Bignell deposit, suggests the evolution of vaporous fluids in the late stages of ore emplacement. Zeolite and calcite veins cutting the ore, and vugs in the host rock that are lined with zeolite and calcite crystals, indicate post-ore, low-temperature hydrothermal activity.

Ore emplacement appears to have been accomplished principally by forceful injection of ore magma into joints, faults, and other zones of weakness in the consolidating anorthosite. There was evidently some metasomatic replacement of the host rock in thin stringers and disseminations of ilmenite-hematite; and probably also some assimilation and recrystallization of host rock by the ore magma, as indicated by relict bands and areas of both disseminated ore and unmineralized rock within massive ore.

A potassium-argon age determination on biotite that formed at the time of ore emplacement in what is now the Bignell pit, indicates an age of 890 million years. The deposit thus appears to have originated in late Precambrian time, and the anorthosite host rock in which it is enclosed is presumably only slightly greater in age.

The distribution of the known deposits of ilmenite-hematite and titanomagnetite in the St. Urbain region, and the strong aeromagnetic anomalies surrounding the anorthosite, indicate that the anorthosite massif (including its marginal dioritic and gabbroic phases) still has considerable potential as a future source of these minerals.

GENERAL GEOLOGY

Field Relationships

The oldest known rocks in the area are highly metamorphosed silicic to mafic gneisses and schists. They have been intruded by granitic masses and basic dykes. Rocks of undoubtedly sedimentary origin, such as crystalline limestone and quartzite which are typical of the Precambrian Grenville series elsewhere, are not found in this area.

An oval-shaped mass of anorthosite about 18 miles long and 10 miles wide is intrusive into the gneisses and schists. This anorthosite consists of a labradorite phase and an andesine phase. Mawdsley (1927) reported that blocks of labradorite anorthosite are included in andesine anorthosite in an outcrop north of St. Urbain, and that rounded blocks of anorthosite and fragments of andesine crystals similar to those in the anorthosite are in places included in the diorite-granite series. The anorthosite is completely encircled by a belt of igneous rocks including diorite, gabbroic anorthosite, some granite and syenite, and possibly monzonite. Contact relations of these various rocks are generally obscured by drift. Pegmatite dykes apparently cut them all.

A few outcrops of Palaeozoic sedimentary rocks occur exposed on the flanks of the hills around the estuary at Baie St. Paul, and up the valley of Gouffre River as far as St. Urbain. These rocks consist mainly of fossiliferous, grey, fine-grained limestone with intercalated dark shale and breccia lenses. A zone of grit and dirty conglomerate about 10 feet thick underlies these beds on the cape just east of Baie St. Paul. Both the limestone and the conglomerate enclose some brownish bituminous material. Fragmentary trilobite and brachiopod shells and other fossils in the limestone indicate a Middle Ordovician (Black River - Trenton) age for these sedimentary rocks (Mawdsley, 1927; see also Logan et al., 1863). These Middle Ordovician rocks generally overlie Precambrian rocks, but they are much disturbed in places along the flanks of the hills and are folded and brecciated along fault contacts with Precambrian rocks on both sides of Gouffre River valley. Bedrock is covered in the lowland of the bay mouth, but a graben-like structure is suggested by the available structural information. Both Palaeozoic and Precambrian rocks are cut in places on both sides of the bay—notably on the west side—by nearly vertical calcite veins that carry green fluorite, quartz, and sporadically distributed specks of galena, sphalerite, and pyrite.

Palaeozoic Outliers

Outcrops of steeply dipping Ordovician limestone on the east side of Gouffre River valley, about 1/2 mile south of St. Urbain, appear to be associated with a series of ill-defined, light-coloured, schistose, fragmental rocks that in turn appear to be associated with altered, pinkish white anorthosite. Altered anorthosite probably underlies most of the drift-covered hill east of the valley, and the fragmental rocks and grey limestone are exposed only sporadically along the side of the hill just east of the river. Vein-like lenses and small pods of ilmenite are also encountered locally in the fragmental rocks along the hillside and in the valley.

These rocks and ilmenite occurrences, and their puzzling relationships, have not been previously described. The light coloured anorthosite of this area resembles the altered anorthosite near the Bignell ilmenite deposit; both consist mainly of plagioclase altered in part along cleavages and fractures to masses of fine-grained zeolites and carbonates, of pinkish white colour. In places along the river and on the highway to Murray Bay just east of Gouffre River valley, the altered anorthosite is overlain by a veneer of fragmental rocks. This comprises schistose layers of conglomerate or breccia, and along the river it also includes arkose and shale. The layers generally dip westerly. The pebbles or fragments in the conglomerate-breccia consist mainly of altered anorthosite in a matrix of fine-grained particles of altered anorthosite and feldspar. For the most part, neither fragments nor bedding is well-defined, but in places conglomeratic layers grade into finer-grained, light-coloured arkose, which shows distinct banding and in which narrow bands of ilmenite and of black shale and slate are intercalated. All these rocks show the effects of shearing and brecciation, and are penetrated by veinlets of quartz and calcite. In addition to anorthosite and feldspar, the fragmental rocks contain a few pieces of chloritic material (presumably altered gabbroic anorthosite) and of ilmenite. The fragments are

subangular to rounded in both the conglomerate-breccia and arkose. Both rock types are poorly sorted, but the ilmenite grains are relatively well sorted and separated from the other grains.

The ilmenite bodies, the arkose, and the conglomerate-breccia appear to be the poorly sorted products of weathering of ilmenite-bearing anorthosite, associated with beds of shale and limestone presumably of Ordovician age. However, as they lie in a fault zone along which Ordovician beds have been much disturbed and dropped down into Precambrian anorthosite terrain, the fragmental nature and granularity of these rocks may have been caused by brecciation and grinding that accompanied faulting. The ilmenite seams at this locality are thus in rocks of late Precambrian or early Palaeozoic (Cambro-Ordovician) age, and they are brecciated and displaced by faults that affect both the Precambrian and Ordovician rocks. The earth movements causing the infolding and faulting of the Palaeozoic rocks probably occurred during the formation of the Appalachian mountain system to the southeast, and they may be related to the thrust faulting that produced 'Logan's line' along the St. Lawrence River nearby.

Petrography of the St. Urbain Anorthosite Massif

Typical anorthosite of the high hills of the central core is a mauve-tinged, coarse-grained, equigranular plutonic rock that consists mainly of plagioclase feldspar. A similar type of anorthosite is found in smaller amounts near the main ilmenite deposits west of St. Urbain, where it grades into a more plentiful grey-green variety of anorthosite. Locally the anorthosite is very coarse grained and porphyritic. Throughout much of the anorthosite body, the plagioclase is fresh and twinned, but near the main known ore occurrences and along the east side of Gouffre River near St. Urbain, it is locally highly altered to a patchwork of pinkish white zeolites and carbonates. Small amounts of one or more of the minerals—pyroxene, amphibole, biotite, chlorite, ilmenite, and rutile—occur with plagioclase here and there in the anorthosite. Their abundance generally increases toward the margin of the anorthosite body, where dark dioritic and gabbroic phases are found. Fine-grained titaniferous magnetite and ilmenite are more abundantly disseminated throughout these marginal areas than elsewhere within the anorthosite. Narrow bands of the gabbroic rock appear to intersect the anorthosite in some diamond-drill cores. The gabbroic rocks are in turn cut locally by narrow, irregular pegmatite dykes.

As seen under the microscope the anorthosite is composed essentially of interlocking crystals of twinned plagioclase ranging in composition from andesine (An_{30}) to labradorite (An_{65}) (Mawdsley, 1927). Swarms of microscopic antiperthitic rods and blebs of another feldspar are commonly included in the plagioclase; these may be exsolution lenticles. In porphyritic varieties of the anorthosite, the phenocrysts are andesine or labradorite, whereas the groundmass is albite in places. Interstitial grains of anorthoclase are also present in specimens from some outcrops (Mawdsley, 1927). Accessory minerals include hypersthene, augite, ilmenite, hornblende, biotite, and apatite. Introduced minerals locally include ilmenite, rutile, and pyrite, and secondary alteration minerals include biotite, sapphirine, chamosite,

chlorite (prochlorite and penninite), serpentine, prehnite, zeolites, and carbonates. A narrow alteration corona (or selvedge) of biotite, accompanied locally by chamosite and sapphirine, is commonly developed at the contact of ilmenite and feldspar grains in the anorthosite. Irregular veinlets of white calcite, pinkish white zeolites (laumontite and phillipsite), rutile, and pyrite, locally intersect the anorthosite and ilmenite, and pockets of these minerals are found at some of these intersections.

The anorthosite grades into gabbroic anorthosite by an increase in ferromagnesian-mineral content, but the noritic or gabbroic phases reported to occur in some parts of the anorthosite body (Scharon, 1950) are apparently only common in the outer margins of the intrusion.

The gabbroic and dioritic rocks are characteristically composed of plagioclase, hypersthene, hornblende, and biotite, along with interstitial orthoclase, titanomagnetite, ilmenite, apatite, zircon, and in some places, a little quartz, titanite, and pyrite. The plagioclase ranges from oligoclase to labradorite, but is commonly andesine. Microscopic antiperthitic rods of another feldspar are found in most of the plagioclase grains. Titanomagnetite is more abundant than ilmenite and locally forms more than 20 per cent of the rock.

The gabbroic and dioritic rocks apparently grade through monzonite and granodiorite into syenite and granite. The granitic rocks are composed of microperthitic orthoclase, hypersthene, hornblende, oligoclase, myrmekite, and quartz, with augite, diopside, and biotite in places, and accessory magnetite, ilmenite, zircon, and apatite (Mawdsley, 1927). The orthoclase comprises about 50 per cent of the granitic rocks and is commonly filled with exsolution spindles of plagioclase.

Geochemistry

Judging from pertinent chemical analyses available in the literature and from the writer's spectrographic analyses, the true anorthosite at St. Urbain, like the Morin anorthosite (Rose, 1960), is lower in iron and titanium than the average igneous rock (see Table I). However, if the ilmenite-hematite deposits in the anorthosite and the titaniferous magnetite-bearing gabbroic and dioritic rocks associated with the anorthosite are taken into account, the overall iron-titanium content of the massif is probably higher than that of the average igneous rock. The anorthosite appears to be typically low in magnesium, chromium, manganese, and cobalt, as well as in iron and titanium, and about average in nickel and vanadium, as compared with the respective content of each of these elements in the average igneous rock; whereas the gabbroic and dioritic phases of the anorthosite appear to be higher in iron, magnesium, and manganese, about average in titanium, and lower in vanadium, chromium, cobalt, and nickel. Samples of gabbroic anorthosite, diorite, syenite, and garnetiferous gneiss from the area appear to be similar to one another in their ferride-element content, but pegmatite is lower in iron and titanium.

Ilmenite-hematite ore material from massive lodes in the St. Urbain anorthosite is typically higher than the enclosing anorthosite in iron, titanium, vanadium, chromium, manganese, nickel, and cobalt, but only in its iron and titanium content is it enriched notably above the average igneous rock (see Table II). On the other hand, pyrite associated with massive ilmenite-hematite is enriched in nickel and cobalt, but low in titanium, chromium, vanadium, and manganese. Of the two distinct types of pyrite—massive and cellular—found in massive ilmenite-hematite at the Bignell deposit, the paragenetically later cellular type has a higher nickel content and a lower cobalt/nickel ratio. Table III compares the cobalt and nickel contents of the two types of pyrite with those of pyrite from several other localities, as determined by spectrographic analysis.

Although precise determinations of Fe:Ti ratios for these rocks and ores have not yet been made, the data in Table III suggests that the ratio is higher in the gabbroic and dioritic rocks than in the anorthosite and massive ilmenite-hematite deposits. Wager and Mitchell (1951) have demonstrated that the Fe:Ti ratio in successive layers of strongly fractionated layered intrusions increases with increasing differentiation—that is, Fe tends to increase with respect to Ti as differentiation progresses, and the Fe:Ti ratio of late-crystallizing fractions is higher than that of early-crystallizing fractions. It follows that gabbroic anorthosite with its higher Fe:Ti ratio is probably a slightly younger differentiate of the parent magma than anorthosite. A similar age relationship is indicated for titaniferous magnetites and ilmenite-hematite deposits on the basis of their respective Fe:Ti ratios.

Magnetic Anomalies and Their Interpretation

The aeromagnetic survey of the area that was made in 1948-49 for the National Lead Company Limited and M. J. O'Brien Company Limited, over land owned by the Quebec Seminary (Scharon, 1950), resulted in a considerable program of ground investigation and diamond-drilling, but no new large orebodies were discovered. Scharon therefore concluded that the anorthosite should no longer be considered as a potential source of "titaniferous-hematite" ore.

The aeromagnetic data is of considerable interest, however, for it reveals the remarkable coincidence of the magnetic pattern with the geological boundaries of the anorthosite as mapped by Mawdsley (1927) (see Fig. 1, in pocket). The anorthosite is characterized by low magnetic field intensity, with relatively little magnetic relief. Mawdsley's diorite-granite series, which encloses the anorthosite, is characterized by a belt of strong, positive aeromagnetic anomalies showing high magnetic relief. The surrounding rocks are generally more strongly magnetic than the anorthosite, although less magnetic than the dioritic-granitic phases of the massif. Scharon (1950) noted that sharp magnetic-susceptibility contrasts existed between the anorthosite, the known orebodies, and the surrounding rock types, so that the anorthosite was readily outlined as an area of low magnetic relief against the surrounding rocks. He concluded that large ore occurrences within the anorthosite should also be delineated by magnetic anomalies of high relief.

Table I

Ferride-element Content of Certain Rocks and Minerals

Rock or Mineral	Locality	Iron (% Fe)	Titanium (% Ti)	Chromium (% Cr)	Vanadium (% V)	Manganese (% Mn)	Cobalt (% Co)	Nickel (% Ni)
Average igneous rock[1]	Earth's crust.....	5.1	0.5	0.02	0.015	0.1	0.002	0.008
Average gabbro[1]	Earth's crust.....	6.8	0.58	0.034	0.006	0.12	0.008	0.016
Gabbroic anorthosite[2]	St. Urbain.....	1-10	0.1 - 1.0	< 0.001	<0.01	0.1 - 1.0	<0.001	<0.001
Anorthosite, mauve[2]	St. Urbain (centre).....	1-10	0.01 - 0.1	< 0.001	<0.001	<0.01	<0.001	<0.001
Anorthosite, pink[2]	St. Urbain (Coulombe)..	0.1 - 1.0	0.01 - 0.1	<0.001	<0.001	<0.01	<0.001	<0.01
Anorthosite, green[2]	St. Urbain (Bignell).....	0.1 - 1.0	0.01 - 0.1	<0.001	<0.001	<0.01	<0.001	<0.001
Anorthosite, grey-green[2]	St. Urbain (Furnace)....	0.1 - 1.0	0.01 - 0.1	<0.001	<0.001	<0.01	<0.001	<0.001
Anorthosite, grey[2]	St. Urbain (General Electric)...	1-10	0.1 - 1.0	<0.001	<0.01	0.01 - 0.1	<0.001	<0.001
Gabbroic anorthosite[2]	St. Urbain (General Electric)...	1-10	0.1 - 1.0	<0.001	<0.001	0.1 - 1.0	<0.001	<0.001
Diorite[2]	Baie St. Paul.....	1-10	0.01 - 0.1	<0.001	<0.001	0.01 - 0.1	<0.001	<0.001
Syenite[2]	Remi Brook.....	1-10	0.01 - 0.1	<0.001	<0.001	0.01 - 0.1	<0.001	<0.001
Pegmatite[2]	Baie St. Paul.....	0.1 - 1.0	<0.01	<0.001	<0.001	0.01 - 0.1	<0.001	<0.001
Garnet gneiss[2]	Cape Corbeau.....	1-10	0.01 - 0.1	<0.001	<0.001	0.01 - 0.1	<0.001	<0.001
Plagioclase from anorthosite[3]	Chateau Richer.....	0.1 - 1.0	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[1] Data from Rankama and Sahama (1950).

[2] Data from Spectrographic Laboratory, Geological Survey of Canada.

[3] Data from Adams (1896).

Table II

Ferride-element Content of Certain Minerals and Ores

Mineral, Ore or Rock	Locality	Iron (% Fe)	Titanium (% Ti)	Chromium (% Cr)	Vanadium (% V)	Manganese (% Mn)	Cobalt (% Co)	Nickel (% Ni)
Ilmenite (theoretical)[1]...	.....	36.8	31.6	—	—	—	—	—
Ilmenite[2]	Chateau Richer.....	42.5	23.9	—	—	—	—	—
Ilmenite concentrate[3]	CIT St. Urbain.....	39.3	44.4	0.21	trace	trace	—	—
Ilmenite-hematite[4]	St. Urbain (Furnace)....	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.001	<0.01
Ilmenite-hematite[4]	St. Urbain (Bignell).....	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.001	<0.01
Ilmenite-hematite[4]	St. Urbain (Coulombe E).	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.01	<0.01
Ilmenite-hematite[4]	St. Urbain (Coulombe W).	10-100	10-100	<0.01	0.01 - 0.1	0.01 - 0.1	<0.001	<0.001
Ilmenite-hematite[4]	St. Urbain (General Electric)...	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.01	<0.01
Ilmenite-hematite[4]	St. Urbain (Bouchard)...	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.01	<0.01
Ilmenite-hematite[4]	St. Urbain (Glen).....	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.01 - 0.1	<0.001	<0.01
Ilmenite-hematite[4]	Ivry.....	10-100	10-100	0.01 - 0.1	0.01 - 0.1	0.1 - 1.0	<0.01	<0.01
Ilmenite-hematite ore[5]	QIT Lac Tio.....	23	40+	—	—	0.8	—	—
Average gabbro[6]	Earth's crust.....	6.8	0.58	0.034	0.006	0.12	0.008	0.016
Average igneous rock[6]	Earth's crust.....	5.1	0.5	0.02	0.015	0.1	0.002	0.008
Average anorthosite[4]	St. Urbain.....	0.1 - 1.0	0.01 - 0.1	<0.001	<0.001	<0.01	<0.001	<0.001
Average gabbroic anorthosite[4]	St. Urbain.....	1-10	0.1 - 1.0	<0.001	0.005	0.1 - 1.0	<0.001	<0.001

[1] Data from Dana's Textbook of Mineralogy.

[2] Data from Adams (1896).

[3] Data from Continental Iron and Titanium Mining Limited (CIT).

[4] Data from Spectrographic Laboratory, Geological Survey of Canada.

[5] Data from Quebec Iron and Titanium Corporation (QIT).

[6] Data from Rankama and Sahama (1950).

Table III

Comparison of Cobalt and Nickel in Certain Pyrite Samples

Sample and Locality	Cobalt (% Co)	Nickel (% Ni)
A. Cellular pyrite in ilmenite, Bignell deposit, St. Urbain.....	0.01 - 0.1	0.1 - 1.0
B. Massive pyrite associated with cellular pyrite, in ilmenite, Bignell deposit, St. Urbain.....	0.01 - 0.1	0.01 - 0.1
C. Pyrite from magnetite deposits in eastern Ontario.....	0.03 - 1.0	0.005 - 0.6
D. Pyrite from gold deposits in northern Ontario and Quebec.....	0.02 - 0.1	0.02 - 0.1
E. Accessory pyrite from Finnish Precambrian rocks (average).....	0.2	0.09
F. Magmatic sulphides (average of 57 samples)	0.21	3.14

A and B—Data from Spectrographic Laboratory, Geological Survey of Canada.
C—Data from Rose (1958).
D—Data from Hawley (1952).
E and F—Data from Rankama and Sahama (1950).

The known ilmenite-hematite deposits west of St. Urbain do, in fact, correspond to an area of aeromagnetic high that shows a maximum positive magnetic intensity of about 3,000 gammas. In contrast, the great Lac Tio orebody near Allard Lake (W. Bourret, 1949; Hammond, 1952) has a maximum negative magnetic intensity of about 3,000 gammas. Drilling of several other lesser anomalies within the St. Urbain anorthosite indicated that they were associated with masses of gabbroic or noritic anorthosite. Scharon (1950) concluded that the major magnetic anomalies were associated with a gabbroic phase of the anorthosite (noritic anorthosite) and that they did not reflect "titaniferous-hematite" occurrences of major size. He believed, however, that there was a definite association of the gabbroic phase and the ore deposits.

The known ore deposits west of St. Urbain do not appear to be directly associated with gabbroic anorthosite, although other occurrences in the contact belt of anorthosite and Mawdsley's diorite-granite series may be so related. To explain the relatively strong intensity of the aeromagnetic anomaly immediately west of

St. Urbain, the writer suggests that there may be an adjacent, partly underlying, deep-seated belt of disseminated ilmenite and titanomagnetite. A similar, although less-pronounced anomaly in the northeastern margin of the anorthosite deserves more investigation than it has received. As has been reported in the Morin anorthosite area, ilmenite deposits may grade into titaniferous magnetite deposits (Rose, 1960), and the intensity of the resulting magnetic anomaly depends to a large extent on the amount and ratio of titanomagnetite and ilmenite present. Other magnetic minerals as well as diverse orientations and textures may also influence the anomaly, but generally, as the proportion of titanomagnetite increases relative to ilmenite, the magnetic anomaly passes from negative to positive and becomes increasingly intense.

Titaniferous magnetite is most abundant in the foliated zone of gabbroic and dioritic rocks about the main anorthosite mass. Positive aeromagnetic anomalies of several thousand gammas are abundant here, and the zone appears favourable for the occurrence of low-grade titaniferous magnetite and ilmenite deposits.

Rock Polarization and Its Interpretation

Remanent-magnetization measurements made at the Geological Survey on four oriented specimens of ilmenite-hematite from deposits near St. Urbain showed that two specimens were reversely or negatively polarized—i.e. polarized upwards; and the other two were normally or positively polarized—i.e. polarized downwards. The four specimens had different inclinations and declinations. Similar measurements on four oriented specimens of wall-rock anorthosite indicated that all four were polarized downwards, with different inclinations and declinations. All eight specimens had a different inclination and declination from those of the earth's present magnetic field. (See Table IV and Fig. 2.) All specimens proved very stable when exposed to an alternating field of slowly decreasing amplitude, thus indicating an important, stable component of remanent magnetism in them. This seems to be characteristic of specimens carrying ilmenite-hematite intergrowths, both here and in other localities within the Morin anorthosite (see Rose, 1960).

One of the ore specimens that was polarized upwards acquired a normal component of thermomagnetization when it was heated to 750°C and cooled to room temperature in the earth's field. Exactly why two ore specimens are polarized upwards—and thus differ from the others—is not known. But they appear to be anomalous in this regard as dip-needle readings on the ilmenite-hematite deposits and surrounding rocks were entirely positive, suggesting the general downward polarization of the ores and anorthosites in situ near St. Urbain. If this is indeed true, the general positive polarity of the ilmenite-hematite in the St. Urbain deposits is contrary to that found in many ilmenite-hematite deposits elsewhere (Balsley and Buddington, 1958; W. Bourret, 1949; Hammond, 1952). In addition many of the latter ilmenite-hematite deposits are associated with negative aeromagnetic anomalies whereas those at St. Urbain are associated with a positive one. The ilmenite-hematite exsolution intergrowths so so characteristic of ilmenite-hematite deposits in the Adirondacks are considered by Balsley and Buddington (1958) to result in a

Table IV

Directions of Magnetization* of Certain Ores and Rocks, St. Urbain

Specimen	Locality	Before Magnetic Washing		After Magnetic Washing to 90 Volts	
		Mean Declination (degrees true azimuth)	Mean Inclination	Mean Declination (degrees true azimuth)	Mean Inclination
1. Ilmenite-hematite massive ore	Furnace deposit.....	342	-79.5	343	-78.5
2. Grey anorthosite, foot-wall	Furnace deposit.....	140	+41	140.5	+40
3. Grey anorthosite, hanging-wall	Furnace deposit.....	181.5	+40	185.5	+36
4. Ilmenite-hematite massive ore, foot-wall band	General Electric deposit	258	+77	270	+78.5
5. Grey anorthosite, immediately above No. 4	General Electric deposit	72.5	+47.5	82	+49.5
6. [illegible]k anorthosite, 'horse' or inclusion in ilmenite-hematite	Coulombe West deposit	67	+20	73	+24
7. Ilmenite-hematite massive ore	Coulombe West deposit.....	132	+44	131.5	+45
8. Ilmenite-hematite massive ore	Bignell deposit.....	104.5	-71	87.0	-68.5
Present magnetic field	St. Urbain area, 1960	340.2 (deviates 2.1' annually)	+76.2 (deviates 2.1' annually)		

*Data from Palaeomagnetism Laboratory, Geological Survey of Canada.

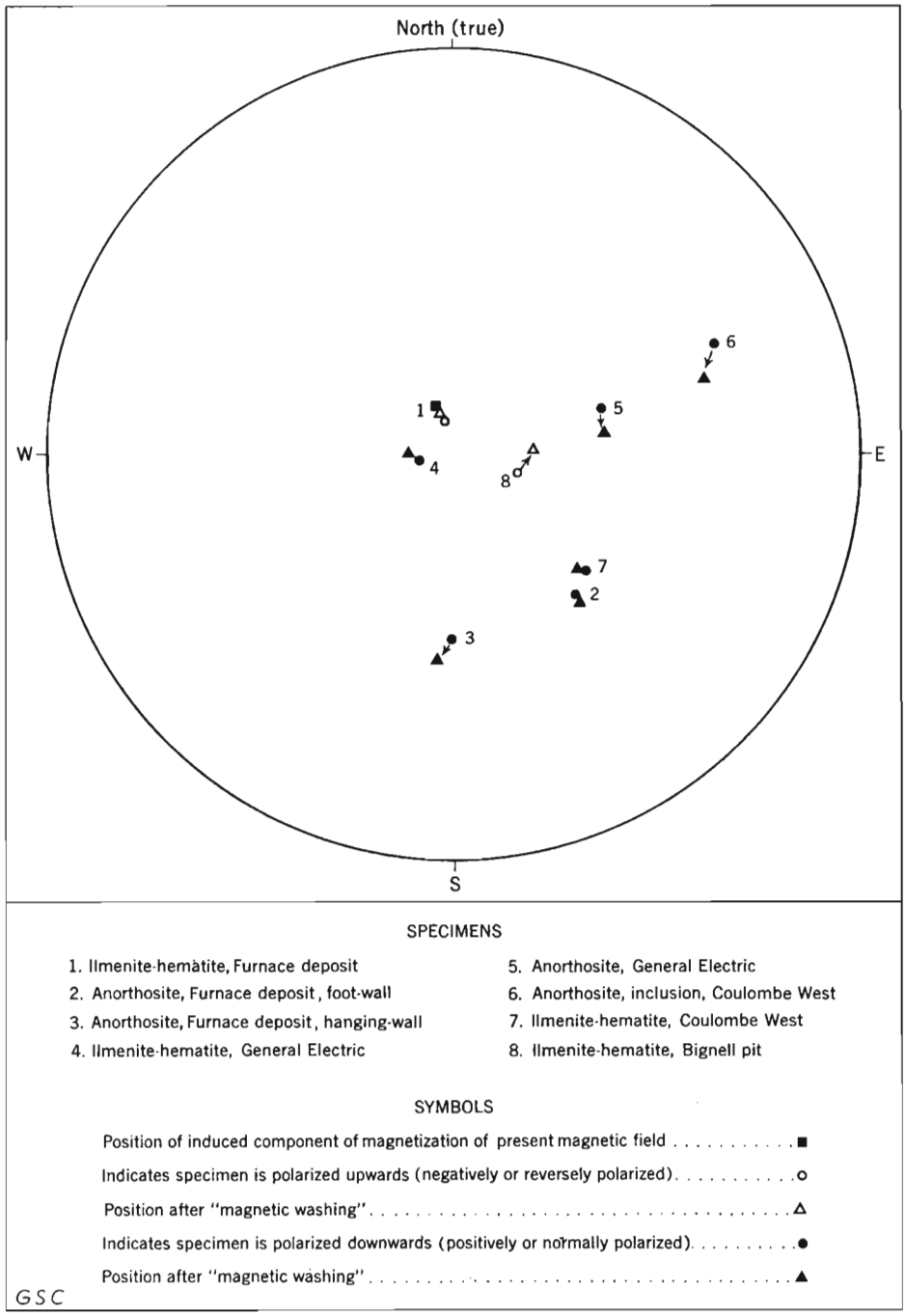

Figure 2. Stereographic projection of magnetic declination and inclination of oriented specimens of anorthosite and ilmenite-hematite from St. Urbain, showing positions before and after "magnetic washing"

self-reversing magnetic mechanism, which would explain their reverse polarization. However, although the exact cause of the normal polarization of ilmenite-hematite in the St. Urbain anorthosite is not established at present, it is evident that remanent- and induced-magnetism components may be directed along widely different directions and may act either to oppose or augment one another, thus affecting the intensity of the resulting magnetic anomaly. Remanent magnetism is thus indicated as an important factor in the ilmenite-hematite deposits and anorthosite at St. Urbain.

The foregoing indicates the need for caution in the quantitative and qualitative interpretation of aeromagnetic maps made over areas of anorthosite and ilmenite-hematite bodies. These remarks also indicate that the St. Urbain anorthosite massif should be investigated further for iron-titanium deposits.

ECONOMIC GEOLOGY

The iron-titanium mineral deposits for which the St. Urbain area is noted consist chiefly of assemblages of ilmenite-hematite, rutile, and titanomagnetite. Other intermediate members of the iron-titanium-oxygen system may also be present but are not discussed here.

The deposits from which ore has been produced are known as the Furnace, General Electric, Coulombe East (Plate IA), Coulombe West (Plate IIA), Bouchard, Bignell (Plate IB), Seminary, and Glen orebodies. They are clustered on the hillside west of St. Urbain village near the southwestern margin of the St. Urbain anorthosite, and are composed essentially of ilmenite with microscopic intergrowths of hematite. Both minerals are probably mutually contaminated with iron and titanium. Several other ilmenite-hematite occurrences are known west of these eight deposits and also east of them within the central part of the anorthosite mass. Additional but still undiscovered ilmenite-hematite deposits are suggested by the widespread distribution of loose pieces of ilmenite-hematite in the glacial drift to the south, west, and northwest of the producing deposits. Rutile occurs sporadically throughout both the ore and the associated anorthosite and is most abundant in the General Electric deposit. Titanomagnetite occurs sparingly in these deposits, but is abundant as fine-grained disseminations in gabbroic and dioritic rocks surrounding the anorthosite proper.

History of Development

The first attempt to exploit the ilmenite-hematite deposits was in 1872-73 when the Canadian Titanic Ore Company built furnaces on the hill-slope west of St. Urbain, using wood charcoal as fuel. A good grade of iron was produced, but the operation was financially unsuccessful and was closed in 1874. Shipments of ore were made in 1899 and 1908 to the Titanium Alloy Company of Niagara Falls, New York, to test the application of the ore in the manufacture of ferro-titanium alloys in the electric furnace. Dupont Chemical Company investigated the deposits between 1928 and 1932, and about

2,000 tons a year was mined, mainly for shipment to the General Electric Company in the United States. About 200,000 tons of ore was recovered between 1940 and 1946; then production (by American Titanic Ore Company and St. Lawrence Iron and Titanium Mines Limited) was intermittent until 1956-57 when Continental Iron and Titanium Mining Limited began work in the area. In 1956 this company acquired mining rights on the seemingly unimpressive Bignell deposit on lot 608, St. Jerome parish, and proved 3 million tons of ore. Mining rights to the Furnace, Coulombe, and General Electric deposits were subsequently acquired by Continental. In 1959 the company estimated that these four deposits collectively hold more than 22 million tons of high-grade ilmenite. Between 1957 and 1959 about 100,000 tons of massive ilmenite was mined, crushed, and shipped by the company from the Bignell, Furnace, and General Electric deposits. Most of this ore was shipped by rail for heavy aggregate in the concrete used in laying the natural-gas pipeline from Western Canada. Some has also been used in concrete shields for nuclear reactors, and some has been shipped to Italy.

To date probably about half a million tons of ore has been removed from these deposits, and substantial reserves are indicated underground. However, easily accessible high-grade ore is becoming increasingly difficult to find at the surface.

Description and Origin of the Deposits

Lode Deposits

The lode deposits are mainly dyke-like, sill-like, or massive veins of ilmenite-hematite, that cut with sharp contacts through anorthosite host rock. The vein-dykes are extremely irregular in many of the deposits; they range in width from a few inches to more than 50 feet, and are as much as 300 feet long. Some of the deposits are nearly vertical and extend to great depth; others are nearly horizontal. Most are lenticular in horizontal plan, but locally they branch and split around large 'horses' of barren anorthosite (Plate IIA). In general they are composed of a massive to nearly massive, ilmenite-hematite intergrowth, but in many places they contain areas of disseminated rock and gangue material, and of anorthosite inclusions (Plates IIA, IIB). Relatively small areas of disseminated intergrown ilmenite-hematite grains are found at and near some of the main ore-rock contacts. Seams and bands of ilmenite-hematite, some directly connected to the main lode, commonly penetrate the host rock—generally parallel to the main deposits. Trace of discontinuous banding within massive and disseminated ore are present here and there. Intersecting sets of well-developed joints are abundantly developed in both ore and host rock, and appear to have acted as structural controls in the rock for the localization of mineralization. The ends and sides of some of the deposits show evidence of a little contact metamorphism and shearing in the development of biotite, pyrite veins, and slickensides. In places at the Bignell deposit the ore is vuggy and scoriaceous in a narrow zone near the wall-rock contact. Some of the vugs are partly filled with pyrite, limonite, and hematite. At one contact the ore appears as an aggregate of grains from which the interstitial material has been removed, and at another it appears ropey, as if

partly fused or quickly chilled.

Pyrite is of two types—massive and cellular; both types intersect the ore and cement ilmenite-hematite grains, but the cellular type also intersects the massive type of pyrite. Some faults are post-ore as shown by displaced ends of ore stringers and by slickensides on both ore and rock, as well as by rare vertical shear zones within the orebody. Veins of calcite and zeolite cut ilmenite and anorthosite in many places, commonly in shear zones and at the contacts of ore and rock. In the General Electric pit, veinlets of brownish red rutile are locally abundant. Rutile is also found in both anorthosite and ilmenite of the Bignell, Coulombe, and Furnace deposits, generally in fractured contact areas between ore and rock.

Most anorthosite at the immediate contact with massive ilmenite-hematite is essentially unaltered and grey. Locally it has a greenish hue owing to a slight chloritic alteration, or a pinkish hue because of a trace of zeolitic alteration. However, some of the anorthosite within a few feet of the contact with the ilmenite-hematite is soft and pinkish white, as it is extremely altered to zeolites and carbonates. Similarly within the ore, although most of the anorthosite inclusions are apparently unaltered, a few large blocks near the upper contact on the west end of the Bignell pit are also in part altered to zeolites yet apparently surrounded by ilmenite. The distribution of the zeolite-carbonate alterations indicates their post-ore development, as might be expected. This type of alteration and its distribution relative to the ilmenite-hematite bodies seems to be peculiar to the St. Urbain area.

Pale green chlorite, pinkish white zeolites, and calcite crystals, which all occur in vugs in the ore, and zeolite-calcite veins cutting the ore, represent the latest hydrothermal activity in the ore zone. The zeolite-calcite veins also intersect late pyrite seams in the ilmenite. Calcite and pyrite veins cut ilmenite-hematite deposits at Ivry and Lac Tio as well, but the association of these veins with zeolites and perhaps also the zeolitic alteration seems to be unique to the St. Urbain area. Limonite and goethite, which occupy vugs and joints in the ore, are apparently products of the surficial weathering of pyrite in the ore.

In polished and thin sections under the microscope, the ore appears as a mosaic of interlocking grains of ilmenite in which blades, lenticles, and blebs of hematite are exsolved. The hematite is of at least two generations—one relatively coarse grained and the other relatively fine grained. Both host and guest minerals are probably impure varieties as each contains submicroscopic inclusions of the other. Grains of gangue, mainly plagioclase, are commonly rounded and penetrated by tongues of ilmenite-hematite, and corona structures are developed in places about the ilmenite-hematite grains in contact with plagioclase. The contact alteration products are commonly biotite, chamosite, chlorite, and minor sapphirine, which rim some of the ilmenite-hematite grains and penetrate the plagioclase along fractures and cleavages. Hematite blades generally form less than 25 per cent of the massive ilmenite-hematite grains, but they form about 50 per cent of the intergrowth at the hanging-wall contact

of the Bignell deposit, where they occur as an aggregate of coarse-grained, platy crystals.

Pyrite, both massive and cellular, with associated minor chalcopyrite and pyrrhotite, invades and cements ilmenite-hematite grains. Cellular pyrite penetrates massive pyrite and commonly rims ilmenite-hematite grains, which are in places rounded and polished. Cells in the pyrite are lined with tiny pyrite cubes, and occasionally with calcite. Rare crystals of pyroxene caught up in pyrite are intensely altered to an aggregate of chlorite and serpentine and rimmed with a selvedge of biotite; inclusions of anorthosite or crystals of plagioclase cemented in pyrite are also rimmed by biotite.

The exsolution textures of the ilmenite ore indicate a relatively high temperature of formation (possibly 600° C). Accompanying rock and mineral alterations range from moderate temperatures (as indicated by the development of sapphirine and the biotite rims around pyroxene and plagioclase) down to low temperatures of about 100° C (as indicated by the development of the zeolites).

The main lode deposits of ilmenite-hematite appear to have formed by complex injection of a high-temperature ore magma into joints, fractures, and faults in consolidated anorthosite. The viscosity and temperature of the ore magma was undoubtedly lowered by an appreciable content of volatile ingredients so that it was able to penetrate, assimilate, and replace considerable amounts of wall-rock anorthosite. Emplacement of the ore was accompanied by a light, medium-temperature contact alteration of wall-rock minerals, and by some more extensive low-temperature alteration of feldspars away from the immediate contact zone. It was followed by low-temperature hydrothermal activity including the formation of zeolites in cavities in the ore.

Clastic Deposits

Several vein-like bodies of ilmenite-hematite occur in Cambro-Ordovician(?) rocks in the fault zone on the east side of Gouffre River south of St. Urbain. One of these ilmenite occurrences, on the land of Mr. Oscar Bouchard about 1 1/2 miles south of St. Urbain, is at least 30 feet long and 7 feet thick; it strikes N35° E and apparently dips southeasterly. Another, about 1/2 mile south of the bridge at St. Urbain, is at least 25 feet long and ranges in thickness from about 6 inches to 5 feet; it strikes N65° E and dips from 65° southeasterly to nearly vertical.

Although the ilmenite bodies have the appearance of veins with off-shoots projecting irregularly into the granular host rocks, they generally parallel the banding of the host and have a similar granular texture, which suggests sedimentary origin but could also be due to crushing of the two in the fault zone.

Under the microscope, specimens from these ilmenite bodies are seen to consist largely of granular aggregates of sub-angular to rounded grains of ilmenite-hematite, with subordinate

grains of plagioclase, spinel, rutile, and pyrite. Ilmenite-hematite grains exhibit striking exsolution textures of hematite lenticles in ilmenite. Ilmenite-rich bands grade into feldspar-rich bands of the enclosing arkose. Both are penetrated by very narrow crosscutting veinlets of ilmenite, hematite, pyrite, and a gangue mineral. Some brecciation and fracturing of feldspar and ilmenite-hematite grains are also visible. Within one crushed ilmenite seam, some of the ilmenite-hematite grains are replaced in part by a paragenetically later phase of fine-grained 'brown leucoxene', which preferentially replaces the ilmenite of the intergrowths; in another, irregular fragments of ilmenite-hematite are surrounded by biotite-phlogopite, laumontite(?), chlorite, and calcite, all of which appear to have been originally introduced as a result of igneous and related hydrothermal activity. The writer interprets the occurrences as detrital beds of ilmenite derived from the weathering of ilmenite in the anorthosite, which have subsequently been crushed and modified by replacement. If this hypothesis is correct it is the first record of detrital ilmenite-hematite material in the early Palaeozoic sediments of Eastern Canada.

Economic Potential

The entire St. Urbain anorthosite mass is generally considered to be favourable for the occurrence of ilmenite-hematite lodes. No direct relationship between ore occurrences and the pervasive, low-temperature alteration of the anorthosite feldspars to zeolites and carbonates is positively established, but field evidence strongly suggests such a relationship, and areas of altered rock deserve special attention.

The zone of gabbroic, dioritic, and granitic rocks surrounding the anorthosite carries considerably more disseminated titanomagnetite and ilmenite than the anorthosite, and it is favourable for the occurrence of low-grade titaniferous magnetite and ilmenite deposits. The association of strong positive aeromagnetic anomalies with this zone of rocks is an indication of the occurrence of titaniferous magnetite there.

Detailed gravity surveys might prove valuable aids for the location of concealed deposits of ilmenite-hematite and titanomagnetite, because of the high specific gravity of these minerals. If used in conjunction with aeromagnetic and ground magnetic data, gravity information might also aid in the interpretation of obscure and possibly misleading magnetic effects.

Although ilmenite-hematite is a potential ore of titanium, no titanium metal is yet being recovered from any of the Canadian ilmenite deposits. However, ilmenite-hematite from Lac Tio north of Havre St. Pierre is being treated by Quebec Iron and Titanium Corporation at Sorel, Quebec, to recover titanium oxide in the form of slag, with iron as a by-product. The titanium-oxide-rich slag is further processed and used mainly in the pigment industry. As at Ivry, Quebec, much of the current production of ilmenite-hematite by Continental Iron and Titanium Mining Limited from the St. Urbain

deposits has been used as heavy aggregate in concrete used in laying natural-gas pipelines. Although titaniferous magnetite is a potential ore of iron, with ilmenite and possibly titanium oxide or titanium metal as by-products, no Canadian deposit of titaniferous magnetite is now being mined. Both ilmenite and magnetite are recovered by the National Lead Company from its deposit at Tahawus, New York, however, and it is not unlikely that similar developments in Canada may take place in the not too distant future.

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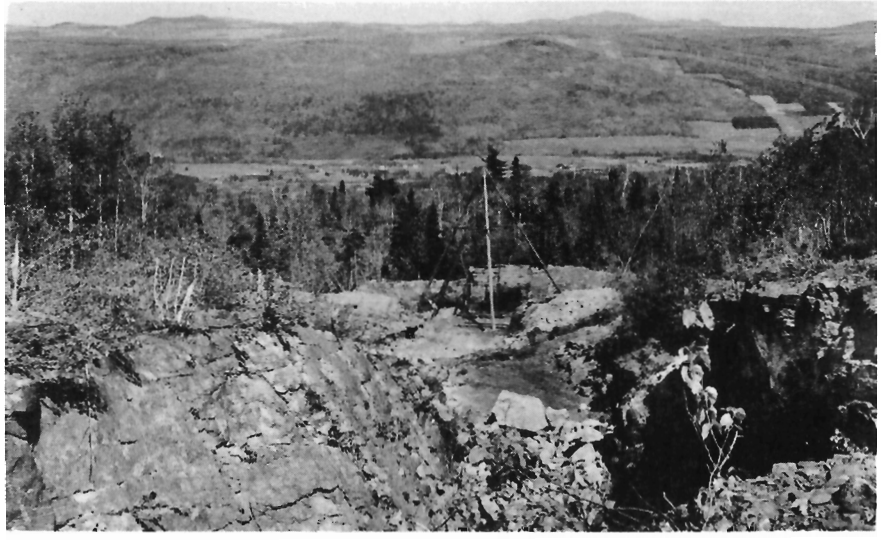
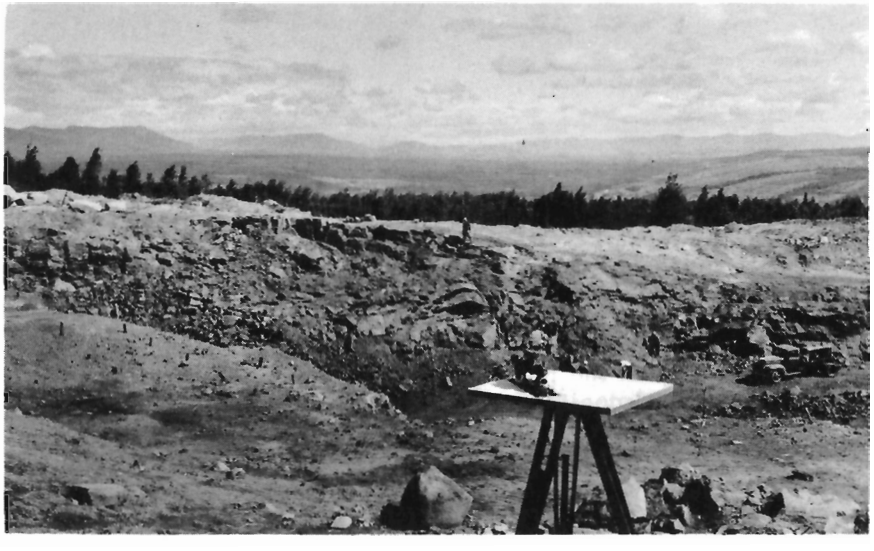
A. View across Gouffre River valley near St. Urbain, showing diamond-drill set up to probe the eastward extension of the Coulombe East ilmenite deposit. The anorthosite is dark and banded, with ilmenite on both hanging-wall (left) and foot-wall (right). The bands dip steeply to the south. (Rose, 58-1-7.)

PLATE I

B. View northerly of Bignell deposit showing pit in massive, well-jointed ilmenite lode that strikes easterly and dips gently southerly towards the foreground. The pegs to the left of the plane table are in drill-holes on the hanging-wall surface of massive ilmenite that is in sharp contact with grey anorthosite at the lower left. The stadia rod is on the steeply dipping foot-wall contact. (Rose, 58-6-1.)

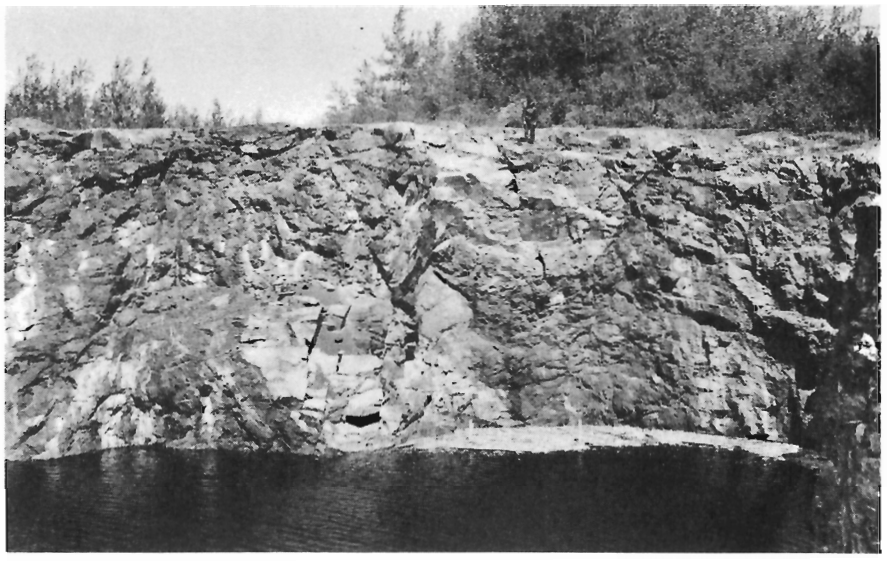


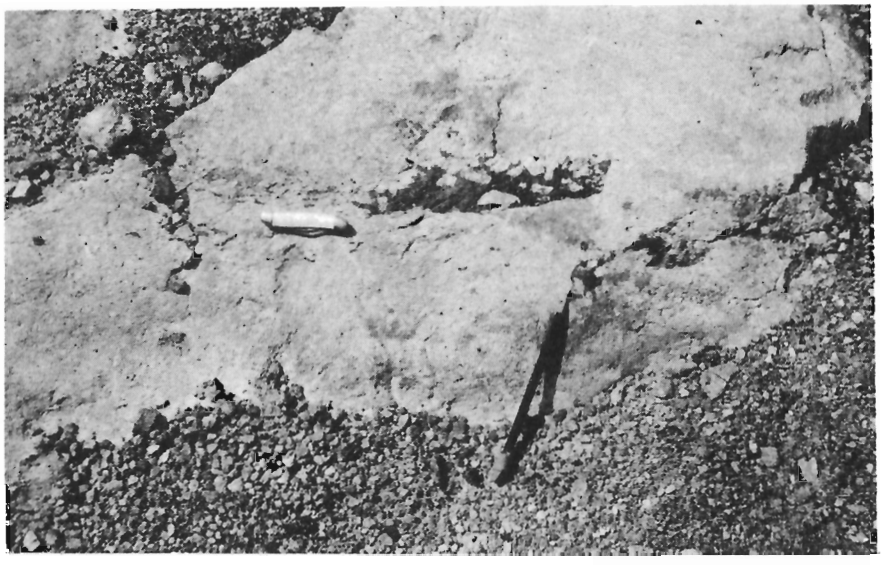


A. View easterly towards the east wall of Coulombe West pit, showing irregular vein-dykes of ilmenite (dark), which cut through anorthosite (light) and dip steeply to the south (right). H.L. Lovell standing on a large inclusion (or 'horse') of anorthosite indicates the scale. (Rose, 58-1-6.)

PLATE II

B. Close-up view of a small lens of ilmenite (dark) enclosed in anorthosite (light) at the Coulombe West deposit. The relationships shown here in miniature resemble those found in large scale in the main orebody (Plate IIA). A tail of disseminated ilmenite lies above the pocket knife at the end of the ilmenite lens, and a small fault displaces the lens abruptly a few inches to the right along the line of the pencil. (Rose, 58-2-1.)





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