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GEOLOGICAL SURVEY OF CANADA

BULLETIN 45

IRON DEPOSITS OF EASTERN ONTARIO AND ADJOINING QUEBEC

By

E. R. Rose

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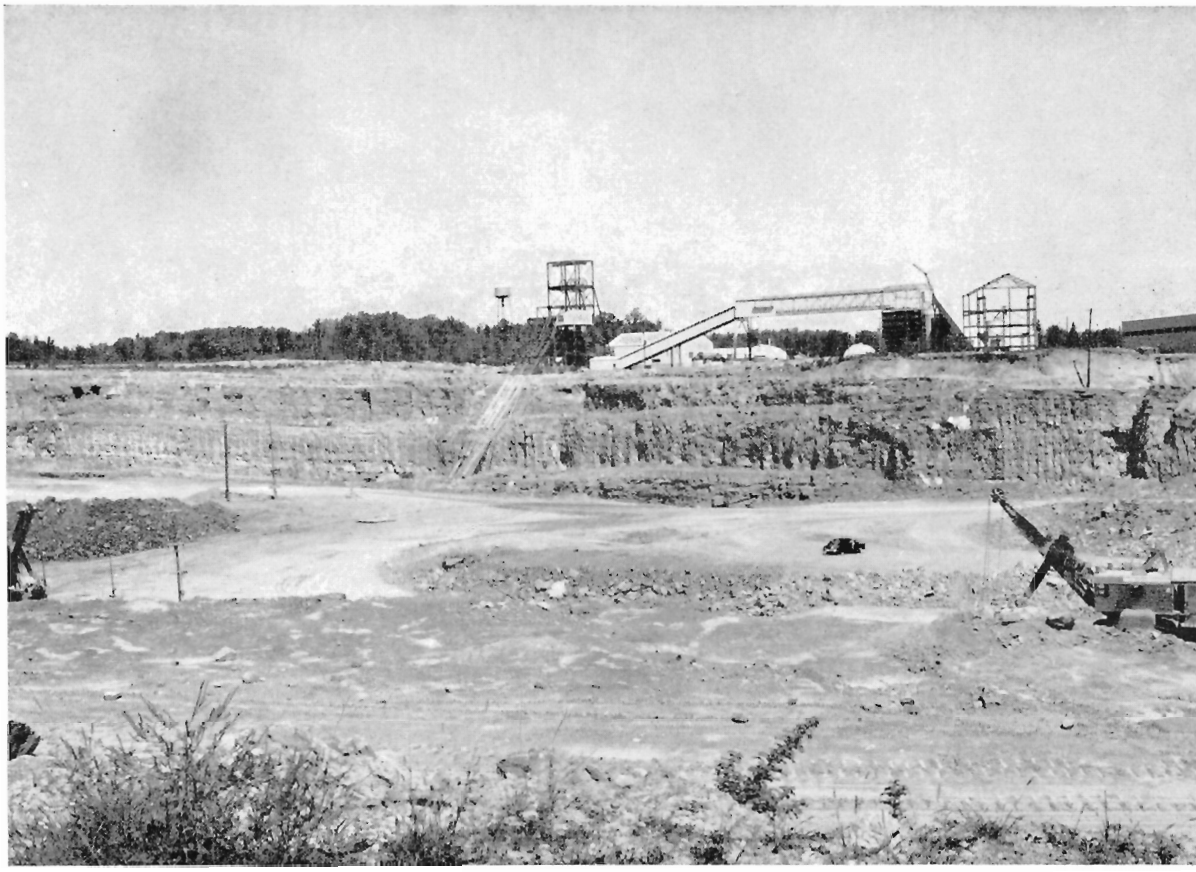

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Plate I. *Bethlehem Mines Corporation Limited, Marmoraton mine, 1954. Looking northeast across open pit. Shows flat-lying Ordovician limestone and shale being removed from the underlying magnetite iron ore. A stockpile of ore, the first ore removed in the third bench, lies behind the electric shovel to the left. Open incline shaft, crushing and concentrating plant are under construction in the centre, and the pelletizing plant is on the right.*

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PREFACE

Iron deposits in the Grenville rocks of southeastern Ontario and adjoining Quebec were among the first in Canada to be mined. They are receiving renewed attention as a result of the depletion of other sources of iron and especially as a consequence of the recent iron developments at Marmora, Ontario, and Bristol, Quebec.

This bulletin gathers together data on all reported deposits, adds new data, includes the results of detailed studies of some of the more important occurrences and suggests certain relationships between ore and rocks as an aid to exploration and development.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, February 28, 1957

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IRON DEPOSITS OF EASTERN ONTARIO AND ADJOINING QUEBEC

Chapter I

Introduction

This report deals with geological features of the magnetite and hematite deposits of a region comprising some 16,000 square miles in eastern Ontario and that part of Quebec near the lower Ottawa River. The report summarizes the results of an investigation made during 1952, 1953 and 1954, and is intended to assist in understanding the nature of occurrence and the origin of the deposits with a view to aiding their orderly development and the search for other deposits. Brief comparisons are made between this and other iron districts, especially the Adirondack region of the state of New York.

History

Many of the deposits in the region were known before Confederation of Canada in 1867 and most of them had reached their greatest production before 1900, when the iron ores at Steep Rock, Algoma and Labrador were known simply as possibilities or occurrences mentioned in reports of the Geological Survey of Canada. Total production from the iron deposits of eastern Ontario prior to 1950 is estimated at about 900,000 tons, comprising some 150,000 tons of hematite and 750,000 tons of magnetite. Most of the ore was exported to the United States. The chief magnetite producers were Blairton, Wilbur, Bessemer, Coehill, Glendower, Williams or Black Bay, Radnor, and the Matthews and Chaffey mines. Hematite came mainly from the Wallbridge, Playfair (Dalhousie) and McNab mines.

The discovery of large deposits of hematite on the Mesabi Range of Minnesota in 1890 and subsequent production from it largely removed the United States market for Canadian iron ore, and about 1896 a system of bounties was inaugurated by the Federal and Ontario Governments to encourage the manufacture of iron and steel from native ores. Blast furnaces were built at Hamilton (1895), at Deseronto (1898), at Midland (1899), at Sault Ste. Marie (1904), and at Port Arthur (1907); iron prospecting and mining were revitalized and several deposits in eastern Ontario were reopened on a small scale. Most of the ore was hand cobbed, and only the higher grade material was shipped.

Iron ore production in Canada increased after 1896 but blast furnace consumption outstripped it, and by 1916 the Canadian production of iron ore accounted for only about 15 per cent of the ore smelted. By this time

all of the eastern Ontario iron mines had been closed and, although the Helen and Magpie mines in the Michipicoten district were then in operation, the bulk of the ore consumed in Ontario blast furnaces came from the Lake Superior district of the United States.

Meanwhile, in Quebec, magnetite deposits near Hull and Bristol, known since 1830 and 1845, respectively, had been developed as the Forsyth (1855-80) and Bristol (1885-89) mines. Both these mines operated intermittently for some years and most of their production went to the United States. In 1867 a blast furnace was erected near Hull at Ironsides but could not compete with larger plants.

None of the deposits in eastern Ontario or Quebec, as known prior to 1950, was large; most contained considerable waste rock, low grade material and deleterious ingredients, and the ores required concentrating to maintain a 55 per cent iron grade. Such magnetite ores, however, can now be readily concentrated magnetically and sintered or pelletized for use in the blast furnace. Present economic conditions and improved concentrating methods have again made some of the deposits attractive as sources of iron.

Reserves of direct shipping hematite ore from Lake Superior have declined drastically since 1940 and much attention is being given to beneficiation. Mines at Steep Rock Lake are helping to swell iron ore production in Canada, and production from Wabana was added to the Canadian total following the entry of Newfoundland into Confederation in 1949. Ore from Labrador and New Quebec is now the major source of iron in Canada, and magnetite from Marmora in eastern Ontario and from Bristol (the new Hilton mines) in Quebec is contributing considerably to Canadian production of iron ore. The International Nickel Company of Canada Limited recently began to recover iron ore from its Sudbury district ores at Copper Cliff, Ontario, and Noranda Mines Limited is recovering iron from pyritic ores at its new plant at Port Robinson, Ontario. However, although Canada now exports considerable iron ore, Canadian blast furnaces in 1951 still used about twice as much imported, Lake Superior district ore, as Canadian ore. In 1953, for the first time this century, Canada's domestic production of iron ore exceeded indicated consumption with a production of 5,812,337 tons valued at $44,103,000. During the next decade Canada's iron ore production is destined to become increasingly important and will probably supplant most of our leading ores in point of value.

Previous Work and Acknowledgments

It is not possible to present fully the contribution made by previous workers to our knowledge of the geology of the area. Logan, Murray, Vennor, Selwyn, Dawson, Ells, Chapman, Adams, Barlow, Coleman, Miller, Knight, Baker and Wilson, in the past, and more recently Harding, Harrison,

Meen, Thomson, Satterly, Hewitt, Kay, Peach, Quinn, Smith, Engels and others have contributed materially. Reports dealing directly with the iron deposits in the area are those of Ingall, Cirkel, Lindeman, Lindeman and Bolton, Robinson, Tanton, the Ontario Iron Ore Committee, Hurst, Abraham and Harding. Aeromagnetic maps, made by the cooperation of the Ontario Department of Mines and the Geological Survey of Canada and published by the Department of Mines and Technical Surveys (Geophysics Section, Geological Survey of Canada), have indicated concentrations of magnetite, as at Marmora, and they are also used in interpreting geology. G. D. Garland (1951)[1] illustrated the value of gravimetric surveys in conjunction with magnetic surveys in outlining magnetite deposits. The present report is based on all this previous work.

A great deal of private investigation, including magnetic surveys, geological mapping and diamond drilling, has been done on many of the deposits. Private reports and theses have been written on some. Much of this information was made available to the writer by the following companies and individuals. Algoma Ore Properties Limited, Messrs. G. W. MacLeod and J. V. Huddard; Bethlehem Mines Corporation, Messrs. H. O. Olsen, A. Baxter, and Simon Lake; Frobisher Exploration Company Limited, Dr. A. S. Dadson; Jones and Laughlin Steel Corporation, Messrs. Fleck and West; National Lead Company, Messrs. Allen and Van Meter; Republic Steel Corporation, Messrs. Linney and Meyers; Steel Company of Canada Limited, Mr. C. C. Huston; and Trent River Iron Limited, Messrs. W. S. Moore and K. F. Bickford.

The writer is indebted to Dr. J. E. Hawley, Miller Memorial Research Professor, Queen's University and to Drs. D. F. Hewitt, T. L. Tanton, M. E. Wilson and W. E. Hale for discussions on the geology of the region; and to W. K. Buck, Mines Branch. Capable assistance was given in the field by G. F. Rose. Mr. Buck's survey of the iron ore industry of Canada (1953) provides a concise account with much valuable information on the industry.

[1]Dates in parentheses are those of references cited at end of report.

Chapter II

General Geology

The part of eastern Ontario and neighbouring Quebec containing the iron deposits is within the Precambrian Grenville province of the Canadian Shield as defined by Gill (1952). On its southern fringe the Shield is overlapped by gently folded, or almost flat-lying Palæozoic sedimentary rocks of the Lake Ontario homocline as outlined by Kay (1942). The Precambrian terrain includes a complex of massive and contorted igneous and sedimentary rocks, many in advanced stages of metamorphism. An obvious unconformity separates the Precambrian from the Palæozoic rocks at most places of contact. Prominent structures in the Precambrian rocks trend in two main directions, the one northeasterly and the other northwesterly. The latter parallels faults in the Palæozoic rocks that include the prominent fault-line scarps of the Ottawa Valley and the Ottawa-Bonnechère graben of Kay that have dropped outliers of Palæozoic sedimentary rocks below the present surface of the Shield. Unconsolidated deposits of Pleistocene glacial drift and Recent peat and soil accumulations overlie both groups in many parts of the area.

The Precambrian rocks probably represent the deeply eroded roots of ancient mountain ranges that had northeasterly trends. The strata are highly metamorphosed and have been complexly folded, faulted and intruded, and as a result, many problems in the geological history of the area remain unsolved. Accordingly, the following table of formations is presented as a suggested geological history for discussion by readers interested in the regional geological setting of the iron deposits.

TABLE I

Table of Formations

Era	Period	Epoch or sub-epoch	Description
Cenozoic	Quaternary	Recent	Peat, marl, sand, clay
		Pleistocene	Glacial drift
		Unconformity	
?	?	Post Ordovician	Calcite-fluorite-barite, calcite-hematite-specularite, calcite-galena, etc., veins

	Unconformity		
Palæozoic	Ordovician	Trenton and Black River	Mainly limestone
		Chazy	Mainly limestone and shale
		Beekmantown	Mainly dolomite
	Cambrian (?) or Cambro-Ordovician	Potsdam-Nepean	Mainly sandstone, arkose and conglomerate
	Unconformity		
Archæan or Proterozoic			*Trap (fine-grained gabbro, diabasic)
			Pegmatite Granite-syenite-felsite (granitization)
			[1]Nepheline syenite (nephelinization)
			*Trap (fine-grained gabbro and gabbroic anorthosite)
			Syenite-granite Diorite Gabbro Gabbroic anorthosite } Related (differentiated?) sequence with associated magnetite
	Intrusive contact		
	Hastings type		Meta-sedimentary rocks including blue-grey limestone, buff-weathering dolomite, and conglomerate (carrying crystalline limestone, "Eozoan", volcanic and granitic cobbles)
	Unconformity		
Archæan (?)			Granite (?) (granitization?)
	Intrusive contact		
	Grenville type		Gneisses, schists, crystalline limestone, quartzite, amphibolite, conglomerate; rocks of obscure origin
	Disconformity (?)		
	Keewatin type		Chloritic schists, meta-volcanic rocks (Period of vulcanism and granitization (?) or granite intrusion (?)

*These trap dykes may be equivalent in age as may some of the granites.

[1]Approximate position suggested by D. F. Hewitt, Ontario Department of Mines.

Precambrian Rocks and Mineral Deposits

Meta-Volcanic Rocks (Keewatin type)

Several bands of chloritic hornblende rocks, some containing amygdules and pillows, were recognized by Miller and Knight (1914) as an essentially submarine volcanic series, their "Keewatin complex", lying beneath the Grenville series. These dark green rocks are composed mainly of fine-grained hornblende, chlorite, feldspar, quartz and epidote with epidote-calcite amygdules. In most places the flow rocks are schistose and in part slaty, and on the west side of Belmont Lake a lens of quartzite with hematite and magnetite resembling "jaspilyte" iron-formation is intercalated with schist.

M. E. Wilson (1933) considered that the basic volcanic rocks form part of the Grenville series and that in the Madoc–Marmora area they generally lie immediately beneath the Hastings series of sediments. V. B. Meen (1942) reported that agglomerate and tuff as well as massive to ellipsoidal, basalt to andesite lava flows, with minor acidic lavas, form the base of the sequence in the Grimsthorpe-Barrie area. He also reported that narrow bands of amphibolite, similar to some of the tuff, and agglomerate are interbedded with Grenville limestone in Barrie township. W. D. Harding (1942) reported that beds of normal sediments including conglomerate, quartzite, greywacke and slate are scattered throughout the volcanic rocks in the Kaladar-Kennebec area, and B. L. Smith (1951) suggested that a conglomerate carrying boulders of granite underlies volcanic rocks (Keewatin type) in one small area south of Plevna Lake.

Meta-Sedimentary Rocks

Grenville Type—Gneisses, schists, crystalline limestone, crystalline dolomitic limestone and amphibolite form the bulk of this group along with minor quartzite and limestone breccias. Harding (1942) reported conglomerate, greywacke and dark-coloured quartzite as of probable Grenville type; also that the conglomerates in Kaladar-Kennebec area contain boulders of fresh grey granite and boulders and pebbles of pink granite, greenstone, quartzite and vein quartz. Elsewhere in Grenville type rocks, however, conglomerates and greywackes are rare. Grenville type rocks are intruded by igneous rocks ranging from gabbro to granite and pegmatite in many places.

Hastings Type—The Hastings series of Miller and Knight (1914) consists of schistose conglomerate, quartzite, greywacke, slate and limestone, an assemblage similar to that of the Grenville series and not easily separated from it. The conglomerate consists mainly of water-worn pebbles of granite, felsite, greenstone, schist, crystalline limestone and quartz. The pebbles of pink and white crystalline limestone and "Eozoan" are evidently derived from the underlying Grenville rocks. The blue-grey limestone that

Adams and Barlow (1910) regarded as the less metamorphosed equivalent of the Grenville crystalline limestone was considered as part of the Hastings series by M. E. Wilson (1933). Wilson included argillite and schists in the Hastings series in the Madoc area (1940).

Harding (1942) found it impossible to separate the Hastings from the Grenville series in Kennebec township, but noted fresh Hastings type conglomerates carrying pebbles mainly of quartzite and limestone, with some of granite, greenstone, quartz porphyry and diorite. He considered the Grenville and Hastings series as belonging to one sedimentary group.

It is evident that detailed mapping will be required to separate strata of the Hastings from those of the Grenville series. It may be impractical to attempt the separation in some areas because of local variations in metamorphism.

Metamorphosed Rocks of Obscure Origin

Within all three of the preceding groups of rocks, but particularly in the first two, there are many rocks of obscure origin. Chloritic hornblende schists of Keewatin type have been interpreted as meta-volcanic rocks; in Grenville type rocks, the origin of many of the amphibolites, gneisses and schists intercalated with the crystalline limestone is problematical, and some question the mode of origin of the crystalline limestone; finally in rocks of the Hastings type, the origin of certain of the schists and of the basal conglomerate is disputed, the conglomerate being regarded by some as a sheared breccia.

Intrusive Rocks

A succession of intrusive rocks that range in composition and texture from anorthosite and gabbro to granite, felsite and pegmatite has invaded the region and one or more of these intrusions are known to cut rocks of all three preceding groups. One, and perhaps two periods of granitic intrusion earlier than the Hastings conglomerate are indicated by the presence of granitic pebbles in conglomerates of probable Grenville type and of Hastings type. The advanced state of metamorphism of Grenville strata throughout the region as compared to that of the Hastings type rocks, excepting locally, is also suggestive of two periods of orogeny. Much of the so-called Grenville type strata has been extensively granitized, as on the borders of the Clare River syncline (Wilson, 1933), and it is possible that this accompanied the intrusion of a post-Grenville pre-Hastings granite. In places, however, as in the Marmora area, Hastings type limestone is metamorphosed to the equivalent of the Grenville type. It does seem clear that granitization did to some extent precede the intrusion of the gabbro-diorite bodies (Harrison, 1944). Evidence is presented by Smith (1951) on the occurrence of a small mass of granite of possible pre-Grenville age near Plevna Lake.

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Intrusions of gabbro-diorite and fine-grained equivalents (trap) cut rocks of all three groups and in places are cut by intrusions of granite, syenite, nepheline syenite or pegmatite. Some syenite-granite may be genetically related to the diorite-gabbro intrusions, but, in addition, granite-syenite and felsite have been found cutting nepheline syenite and nepheline gneisses in the Bancroft–Craigmont area (Hewitt, 1955, p. 29). The granitic pegmatites so widespread throughout the Grenville province, probably are late Precambrian in age and accordingly are correlated with granite of this age. Near Kingston, at Bear Creek, trap dykes cut pegmatite (personal communication from J. E. Hawley). In view of the fact that there appear to have been three or four periods of granitic intrusion, only by detailed mapping supplemented by modern methods of dating granitic rocks will it be possible to assign definite ages to individual masses.

Mineral Deposits

Adams and Barlow (1910) listed about 40 mineral species found in crystalline limestone of the Haliburton–Bancroft areas. Apatite, barite, brucite, calcite, chalcopyrite, corundum, dolomite, feldspars, fluorite, galena, garnet, gold, graphite, hematite, magnetite, molybdenite, phlogopite, pyrite, uraninite, sphalerite and talc have all been mined and granite, marble, nepheline syenite, sodalite and trap have been quarried from time to time. At present crystalline dolomite is being used as a source of magnesium near Haley, talc is being mined near Madoc, some crystalline limestone is being quarried north of Madoc, trap and syenite are being quarried in the Havelock–Madoc area and uranium deposits are being developed in the Bancroft area. Several iron deposits are undergoing active investigation (*see* Plates I and II) and Bethlehem Mines Corporation commenced production from a deposit of magnetite southeast of Marmora in April, 1955. In southwestern Quebec the iron deposit at the old Bristol mine is being prepared for production (1956) jointly by Pickands Mather and Company, Jones and Laughlin Steel Corporation, and the Steel Company of Canada, Limited.

Palæozoic Rocks and Mineral Deposits

Sedimentary Rocks

The recognized Palæozoic rocks include basal conglomerate, sandstone and arkose of possible Upper Cambrian or Lower Ordovician (Potsdam) age, overlain by dolomite, shale and grey to grey-brown limestone of Ordovician age (Beekmantown, Chazy, Black River, Trenton). Conglomerate and other clastic beds are composed of fragments of the underlying Precambrian rocks and, near iron deposits, carry fragments of iron ore. The rocks of these beds are characteristically stained red and mottled green. In a few places at the Precambrian contact, small deposits of hematite occur in the basal beds, and also in the succeeding dolomite that is stained with hematite

and resembles iron-formation. The overlying grey, fossiliferous limestone is in part lithographic, and together with minor intercalated beds of shale this is the most abundant Palæozoic rock in the area. Certain of the beds are used in the manufacture of Portland cement, others as building stone, and others as a source of agricultural lime and as road metal.

Mineral Deposits

Calcite veins bearing fluorite, barite, celestite, selenite, sphalerite, specularite, hematite, and anthraxolite cut the Potsdam sandstone and Black River limestone beds and these occurrences extend into the Precambrian rocks as well, so such deposits are of post-Ordovician age. At the Kingdon mine near Galetta a calcite-galena vein is present mainly in crystalline Grenville type limestone but the vein also cuts an overlying remnant of Beekmantown dolomite, and the deposit is of Palæozoic or later age.

Pleistocene and Recent

The area was heavily glaciated in Pleistocene time and erratics, boulder clay, gravel and sand cover much of the rock. Valleys, such as the Ottawa, were invaded by the sea on the retreat of the Pleistocene ice and the glacial deposits are covered by marine clay and shoreline sand deposits. Such deposits reach elevations of 690 feet above present sea-level in the Gatineau hills north of Ottawa, and extend upstream along the Ottawa River to and beyond Pembroke. Dark muck and peat have accumulated in poorly drained depressions in Recent time. Marl is accumulating in some of the lake bottoms and was uncovered recently in a swamp south of the Marmora pit. River terraces mark the former courses of many of the modern streams.

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Chapter III

Classification and Description of Iron Deposits

The iron deposits of eastern Ontario and adjoining Quebec that might supply iron ore are divided into three classes (1) magnetite deposits high in titanium; (2) magnetite deposits low in titanium; and (3) hematite deposits. This is an arbitrary classification, but it seems to fit the deposits well. Gradations exist between those magnetite deposits that are high or low in titanium, and some of the magnetite deposits contain martite and hematite and thus pass into hematite deposits.

The deposits lie in deeply eroded terrain, mainly in Precambrian rocks, and deposits of the most abundant ore mineral, magnetite, are confined to those rocks. A minor part of the hematite is found in the Palæozoic rocks at or near the contact with the Precambrian complex, and is in part at least of Palæozoic or later age.

Classification

High titanium magnetite deposits are defined as those that contain more than one per cent of titanium. They commonly occur as irregular pods, bands, veins, and disseminations in gabbro and gabbroic anorthosite. Those of the group that carry more than 3 per cent titanium commonly carry discrete grains of ilmenite, magnetite-ilmenite intergrowths, titanmagnetite and magnetite in disseminations or segregations in mafic igneous rocks.

Low titanium magnetite deposits are those that contain less than one per cent of titanium. Most of the magnetite deposits of eastern Ontario and adjoining Quebec fall within this category, but several of the deposits seem to be transitional between the high and low classes in that spectrographic or chemical analyses have shown a titanium content of about one per cent. Examples of these are Boulter, Christie's Lake, Dacre, Dominion, Glendower, Pershing, Radnor, Robertsville, New York and Victoria.

Hematite deposits here refer to those that contain iron mainly in the form of hematite, but include also hematite-martite and hematite-martite-magnetite occurrences, the latter being similar and perhaps transitional to the magnetite-martite-hematite assemblages that cap some of the magnetite deposits.

Description of Iron Deposits

This part of the report contains a summary description of certain features of many of the iron deposits of eastern Ontario and adjoining Quebec based on information from the literature and from personal investigation.

The conclusions and speculations drawn from these facts are found in the chapters following. Deposits are arranged alphabetically under the headings, high titanium magnetite deposits, low titanium magnetite deposits and hematite deposits. Their general geological relationships are shown on Figure 1. For spectrographic analyses of the rocks, ore materials, and magnetic concentrates from them *see* Tables III to X.

High Titanium Magnetite Deposits

Blessington (Eagle Lake)—The Blessington or Eagle Lake workings are in lots 29 and 30, concession I of Hinchinbrooke township, Frontenac county, near the south end of Eagle Lake, between the lake and highway 38, about 6 miles south of Sharbot Lake and about 30 miles north of Kingston. The deposit was mined at one time for apatite, and about 700 tons of titaniferous magnetite were recovered.

A tongue of anorthositic gabbro cuts gneissic granite, and is bordered on both sides by granitic rocks. The gabbro is itself cut by masses, veins and irregular dykes of coarse- to fine-grained pinkish granitic pegmatite. The gabbro is gneissic in part and other parts contain coarse segregations, veins or dykes of pyroxene, hornblende, green apatite and calcite. Titaniferous magnetite occurs sparingly in the apatite-pyroxene rocks that occur within and around the margins of the gabbro, in the gabbro, and to a limited extent in rocks intruded by the gabbro (Harrison, 1944). The titaniferous magnetite-bearing apatite-pyroxene rocks are cut by granitic pegmatite. Coarse anorthositic gabbro north of the pits, near the farmhouse on the highway is cut by a ½-inch-wide vein of hornblende and magnetite which in turn is cut and displaced about 1 foot to the left by a dyke 6 inches wide of fine-grained black trap (gabbro) (*see* Plate III A). Harrison (1944) gives evidence suggesting a close genetic relationship between the basic dykes and the gabbroic intrusions and also between the apatite-pyroxene dykes and the gabbros. Scapolite is a fairly common constituent of the gabbros, according to Harrison, and a scapolite-amphibole rock has formed from limestone by action of the gabbro magma that formed the west side of the Tichborne mass.

Chemical analyses of the ore indicated as much as 3 per cent titanium, 0.1 per cent sulphur, and traces of vanadium, chromium and nickel, in addition to phosphorus. Spectrographic analysis shows, in addition, traces of aluminum, silicon, magnesium, manganese, calcium, sodium, barium, strontium, boron, copper and cobalt.

Blithfield—A small lens of titaniferous magnetite in dark hornblende gneiss (sheared meta-gabbro) is exposed in a rock cut on the Kingston-Pembroke branch of the Canadian Pacific Railway, about 3 miles south of Calabogie, and on lot 13, concession I, Blithfield township, Renfrew county. A band of hornblende gneiss overlies banded coarse-grained crystalline

limestone that contains abundant diopside, serpentine, tremolite and micas near the contact. The gneissosity, magnetite lens, sheared contact and banding in the crystalline limestone all strike about south 35 degrees east and dip 35 degrees northeast. A lens of dark massive titaniferous magnetite, 6 feet thick at its widest point, is exposed for a length of about 62 feet, in the hornblende gneiss above the contact with the crystalline limestone. This lens rakes northerly and tapers to the south ending in disseminations. Algoma Ore Properties Limited diamond drill holes revealed that some magnetite also occurs in the crystalline limestone.

The magnetite is cut by a few ½-inch-wide stringers of pyrite and by calcite veinlets lightly stained with hematite. A chemical analysis of a sample of the magnetite showed about 40 per cent iron, 3 per cent titanium, and traces of phosphorus and sulphur.

Chaffey—The Chaffey workings in lot 27, concession VI, of South Crosby township, Leeds county, are on a small island near the northwest shore of Newboro (Mud) Lake, on the Rideau Canal system about 28 miles north of Kingston. The deposit was reported by Alexander Murray of the Geological Survey of Canada in 1852, and in 1858 Chaffey brothers of Kingston, Ontario, commenced development. Titaniferous magnetite was shipped by barge to United States markets; it was offered for sale at Kingston at $3.00 a ton. Despite its content of titanium, Chaffey ore provided severe competition for the Forsyth mine near Hull, Quebec, and eventually forced the latter to close, because the Chaffey was closer to markets at Pittsburgh, Chicago and Cleveland.

Magnetite was mined mainly from three long parallel pits on the island. The part of the pits below lake level is filled with water, and undergrowth is thick on the small island. Outcrops are of banded gabbroic anorthosite with disseminations and segregations of titaniferous magnetite that follow the northeasterly trend and steep northwesterly dip of the banding. Chemical analyses of material from the dump indicate about 50 per cent iron, 10 per cent titanium, 7 per cent silica, 5 per cent alumina, 1 per cent sulphur, and traces of vanadium, phosphorus, chromium and manganese.

Little more geological information on the deposit is available, but probably the occurrence is similar to that of the nearby Matthews mine. Dip-needle readings indicate that some magnetite is left on the island.

Matthews (Yankee)—The Matthews or Yankee deposit is in lot 1, concession VI of North Crosby township, Leeds county, near the northwest shore of Newboro (Mud) Lake, on the farm of W. A. Preston, about a mile south of Newboro village and about 28 miles north of Kingston. Production of titaniferous magnetite from an open pit on this property was added to that of the Chaffey in 1860. The pit, about 300 by 100 feet, is filled with water and was reported in 1871 to be 40 feet deep (*see* Figure 2).

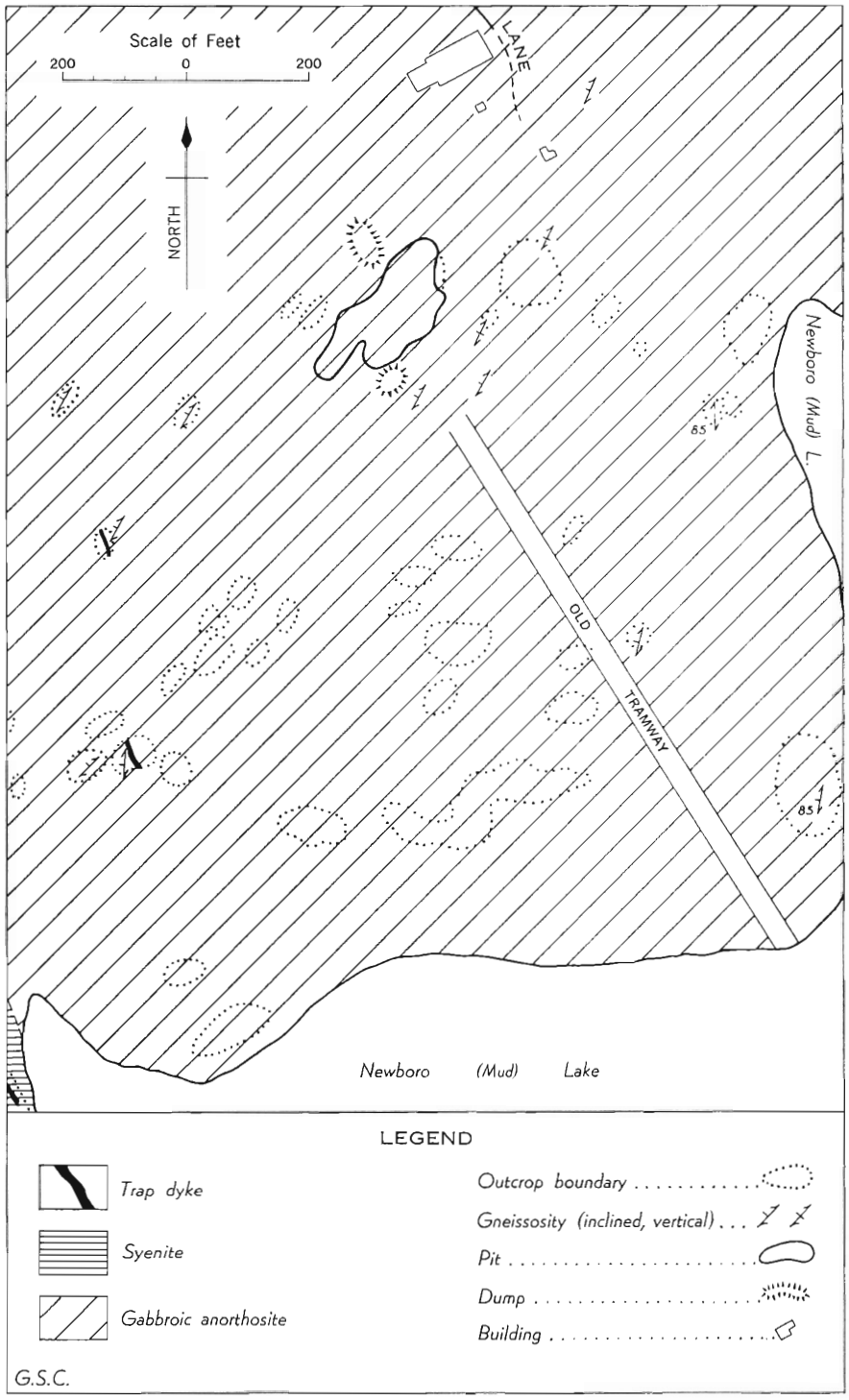

Figure 2. *Matthews deposit, Leeds county, Ontario.*

Around the pit the rock is markedly banded gabbroic anorthosite in which disseminations, stringers and bands of titaniferous magnetite generally parallel the banding. The bands are the results of a segregation of light-coloured feldspars and dark-coloured pyroxene, biotite and iron oxides (*see* Plate III B). The bulk of the rock, however, has a coarse-grained igneous texture formed by interlocking crystals of fresh, twinned plagioclase feldspars (andesine) and titanaugite, with accessory brown biotite and iron oxides. The lighter coloured bands approach anorthosite in composition and texture. Iron oxides seem to be primary constituents of the rock (*see* Plate V B), and the rock grades to ore material by an increase in magnetite content. Magnetite appears to vary inversely as the content of feldspar.

To the south and west the banded gabbroic anorthosite seems to be transitional to a medium- to coarse-grained syenite. The syenite shows coarse-grained zoned, and zonally altered feldspars, with some very fine-grained magnetite and pyrite crystals. Both anorthosite and syenite are cut by fine-grained, light weathering, titanmagnetite-bearing, dark dykes of essentially the same composition as the coarse-grained gabbroic anorthosite.

The ore material varies from disseminations to near massive segregations of fresh, medium-coarse, crystalline, black, titaniferous magnetite with the same interlocking igneous texture as the rock. In addition to titaniferous magnetite, discrete grains of ilmenite, of magnetite with very fine blades of hematite or ilmenite, and rare tiny clots of pyrite and silicate gangue minerals may be observed in polished section. Chemical analyses of material from the dump show a content of about 52 per cent iron, as much as 10 per cent titanium, 7 per cent silica, 0.05 per cent phosphorus, 0.2-0.6 per cent sulphur, and traces of vanadium and chromium.

Orton (Horton?)—Workings operated by the Tivani Steel Company of Belleville in 1912-13 are on lots 56 and 57 west of the Hastings road, Tudor township, Hastings county, at a point about 5 miles north of Millbridge and about 18 miles northwest of Madoc. The main workings consist of three small open-cuts, a shaft and some surface stripping and are crossed by the Hydro-electric Power Commission power line. It is reported that a diamond drill hole put down about 1885 on the property ended in ore at a depth of 70 feet. Titaniferous magnetite was shipped to Belleville where it was successfully smelted and converted directly to steel in an electric furnace.

The ore-minerals are irregularly distributed through a large sill-like intrusion of medium-coarse, dark massive gabbro that lies between northwesterly dipping bands of crystalline limestone. The intrusion measures about 8 miles long by 2 miles wide on surface and several titaniferous iron deposits occur within and around the body. According to Morley (1952) this body (the Millbridge gabbro) exhibits no inverse remanence, but on its

southeastern margin has a positive remanence of one-quarter the total magnetic intensity. The strongest susceptibility is near the centre but towards the northwestern contact with crystalline limestone. This is the position of the Orton mine deposits. (*See* Figure 1.)

Bands and segregations of massive magnetite and their gradations to rock are exposed in the workings, thus indicating the close genetic relationship between ore-minerals and rock. The magnetite-bearing zone trends southwesterly, parallel with the contact of the gabbro sill, but the bands of magnetite trend westerly and dip steeply to the north. The magnetite-bearing zone is cut by north-trending shears that dip steeply east.

Chemical analyses of selected material from the deposits show that iron runs from about 48 to 55 per cent, titanium 5 to 9 per cent, silica 6 to 10 per cent, and alumina, about 5 per cent.

Ricketts—This occurrence is on lots 16 and 17, concession XII, Lake township, Hastings county. The workings lie along the strike of the Millbridge gabbro intrusion and about 1,600 feet southwesterly from the Orton deposit. The occurrence is similar in character to the Orton. Chemical analysis of selected material shows an iron and titanium content of 46 per cent and 8.5 per cent, respectively.

Lots 41, 42, 54 and 55, Hastings road, Tudor township—In the Millbridge gabbro body, about a mile southeast of the Orton, small segregations of titaniferous magnetite of a similar mode of occurrence and composition to that at the Orton have been found.

Low Titanium Magnetite Deposits

Allan Mills—A magnetic anomaly on lots 24, 25 and 26, concession XIX, Seymour township, Northumberland county, about 6 miles southwest of Marmora was outlined, optioned, and diamond drilled by Trent River Iron Limited, during 1951 and 1953.

On Crowe River, Precambrian granitic gneisses are exposed near the old mill site but most of the area nearby is underlain by Palæozoic limestone. The magnetite deposit is known only from drill core, fifteen diamond drill holes having been put down. The first hole intersected a magnetite zone at a depth of about 85 feet directly below the basal Palæozoic conglomerate. An assemblage of dark green to black igneous rocks ranging in mineral composition from andesite to gabbro and trap, exhibits varying degrees of chloritization, brecciation, and shearing. These rocks are intruded by a few dykes of fine-grained, pink rhyolite. This assemblage occurs above, and is intermixed with a zone of much altered crystalline limestone. At a depth of about 900 feet the limestone zone is succeeded downward by altered gabbro-diorite. Magnetite is disseminated in the gabbro-diorite, and also occurs in disseminations, stringers and bands in propylite (fine-grained, dark green, altered igneous rock), breccia and crystalline limestone.

The magnetite zone appears to dip very steeply. It contains some brecciated and sheared magnetite, commonly cemented by carbonates with hematite, and seamed with serpentine veinlets locally containing chlorite and hematite. Some of the serpentine is colloform and some is polished and slickensided along shear surfaces. White asbestos fibres (chrysotile) are present in some of the serpentine.

Almost all the magnetite is fine grained and contains disseminations and stringers of pyrite, pyrrhotite and chalcopyrite. Some coarse-grained magnetite forms seams in brecciated zones. Magnetite and sulphides are veined and in part replaced by red hematite in the upper part of the magnetite zone. This was noted to a depth of 90 feet in diamond drill hole No. 1, or to a depth of about 5 feet below the lightly hematite-stained Palæozoic conglomerate. A thin section of a grey, altered, igneous-looking rock in the magnetite-bearing zone shows mainly fibres and flakes of grey serpentine with brownish carbonate, much disseminated coarse-grained pyrite, fine-grained pyrrhotite and some magnetite. Ghost crystals and relict structures represented by serpentine, and fractured crystals of quartz, rimmed, cemented, and replaced in part by pyrite and brown carbonate, are recognizable in places. Pyrite is veined and in part replaced by fine-grained pyrrhotite, magnetite, carbonates, serpentine and epidote. In polished sections rare tiny interstitial grains of ilmenite or hematite occur with fine-grained magnetite, pyrite, pyrrhotite, chalcopyrite and gangue. In one section fine-grained magnetite replaces schist and a band of pyrite-pyrrhotite in it. Pyrrhotite also replaces pyrite to some extent in this band.

Baker—The Baker workings consist of three small open-cuts and several test pits situated in lot 18, concession XVIII, Tudor township, Hastings county, Ontario. They may be reached by following a side road to a sand pit about ¼ mile west of highway 62 and about 1¾ miles west of Gilmour station. The deposit is about ¼ mile west of the sand pit.

Fine-grained magnetite occurs there in disseminations, stringers and bands in the zone of contact rocks between a body of meta-diorite on the west and coarsely crystalline limestone along with some fine-grained diorite or andesite on the east. At the north end (*see* Figure 3) several bands of felsite and trap occur in the crystalline limestone and the limestone is impregnated with amphiboles, mica, chlorite and magnetite. The magnetite mineralization appears to follow the poorly preserved banding in the impure crystalline limestone that strikes generally slightly east of north and dips about 75 degrees to the east. The mineralized zone is exposed over a width of about 25 feet in one of the pits, but the deposit is of an erratic, pockety nature. An average sample taken across the deposit at one of the pits, reported by Lindeman and Bolton (1917), showed 38.7 per cent iron, 0.20

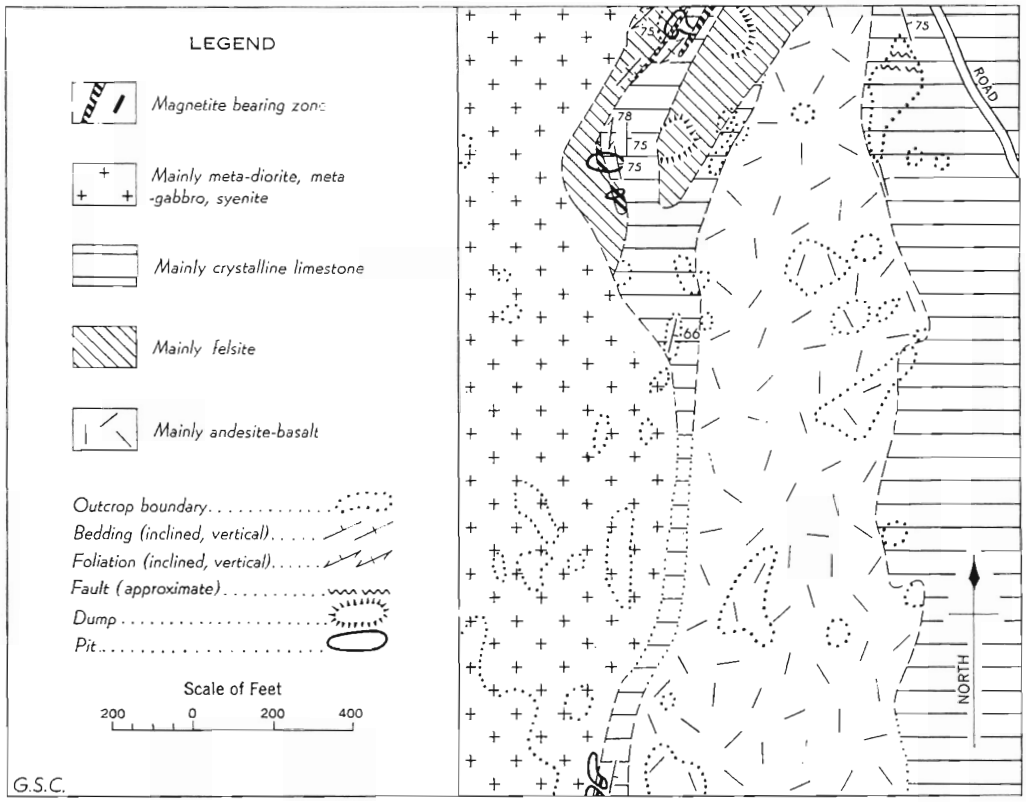

Figure 3. *Baker magnetite deposit, Tudor township, Hastings county, Ontario. (Base map after E. Lindeman.)*

per cent phosphorus and 3.35 per cent sulphur. Spectrographic analysis showed in addition a strong trace of titanium, a trace of vanadium and manganese, and a faint trace of chromium, cobalt and copper.

Bankers Lake (Dominion Mine)—On lot 2, concession II, Madoc township, Hastings county, just west of Bankers Lake and about 2 miles west of Madoc old mine workings are called the Dominion Mine on F. E. Coste's geological map of 1886. A Hydro-electric Power Commission line crosses the northern edge of the waste dump. The workings consist of an open-cut about 18 feet wide by 125 feet long, which extends as three benches, southeasterly into the side of a ridge of dark banded Precambrian agglomerate and trap. The ridge is flanked on the north and west by outcrops of flat-lying Palæozoic limestone. Grey-black, flinty trap layers, interbanded with minor pink rhyolite and black slate, strike southeasterly and the slate beds dip about 60 degrees northeasterly. At the cut a narrow band of calcareous diopsidic rock is intercalated with crystalline limestone and all the rocks are sheared and contain magnetite in a zone about 15 feet wide.

Fine-grained magnetite occurs as disseminations and as bands in the trap, slate, and altered crystalline limestone in the shear zone, accompanied by veinlets of epidote and carbonates, and occasional disseminations of pyrite. Minor hematite and martite in this zone are an alteration of magnetite. Small dykelets of pink rhyolite and felsite cut certain rocks of the ore zone, but their relationship to the magnetite is not evident. Some smaltite in the magnetite and coatings of erythrite on the magnetite were described by W. F. Ferrier (1895).

A thin section of the dark-banded rock shows a micro-crystalline, foliated aggregate of green hornblende, quartz and feldspar, containing stringers and tiny idiomorphic crystals of magnetite, considerable epidote and some brown biotite. Some tongues and layers are more feldspathic than others and give faint banding. The rock is much like the fine, black crystalline trap (gabbro) dykes that intersect andesitic-basaltic rock on highway 7 west of Marmora (*see* Plate V A). The trap rock of Building Products Limited, Havelock quarry nearby also is similar except that it carries a little chlorite, less hornblende, and more feldspar than the Bankers Lake trap. The trap at the Havelock quarry also contains finely disseminated magnetite.

Belmont—The Belmont or Ledyard deposit, lot 19, concession I, Belmont township, Peterborough county, lies ½ mile south of Cordova Mines about 8 miles northwest of Marmora. The workings consist of two small open-cuts and a concrete-lined shaft about 260 feet deep. The main pit and shaft are partly filled with water. Levels are reported to have been opened from the shaft at depths of 100, 170, and 230 feet. Surface mining was done before the turn of the century and in 1911 Canadian Furnace Company Limited sank the shaft but abandoned the operation a few years later.

The country rock in the vicinity of the pit is dark-coloured gabbro-diorite with coarse- and fine-grained phases to the east, and fine-grained green schistose basalt-andesite to the west. A discontinuous band of crystalline limestone that strikes north and dips west separates the fine- from the coarse-grained dark rock (*see* Figure 4). Magnetite is disseminated through both the fine- and coarse-grained gabbro-diorite, but is concentrated in a zone at the contact of the gabbro-diorite with crystalline limestone that apparently forms the hanging-wall of the deposit. The magnetite zone strikes northerly and dips steeply west. The crystalline limestone along the contact with gabbro-diorite contains abundant silicates. A zone about 50 feet wide by 300 feet long consisting almost entirely of dark brown garnet, amphibole and epidote, is exposed on the east side of the main pit and sporadic lenses of magnetite occur in this garnet skarn rock.

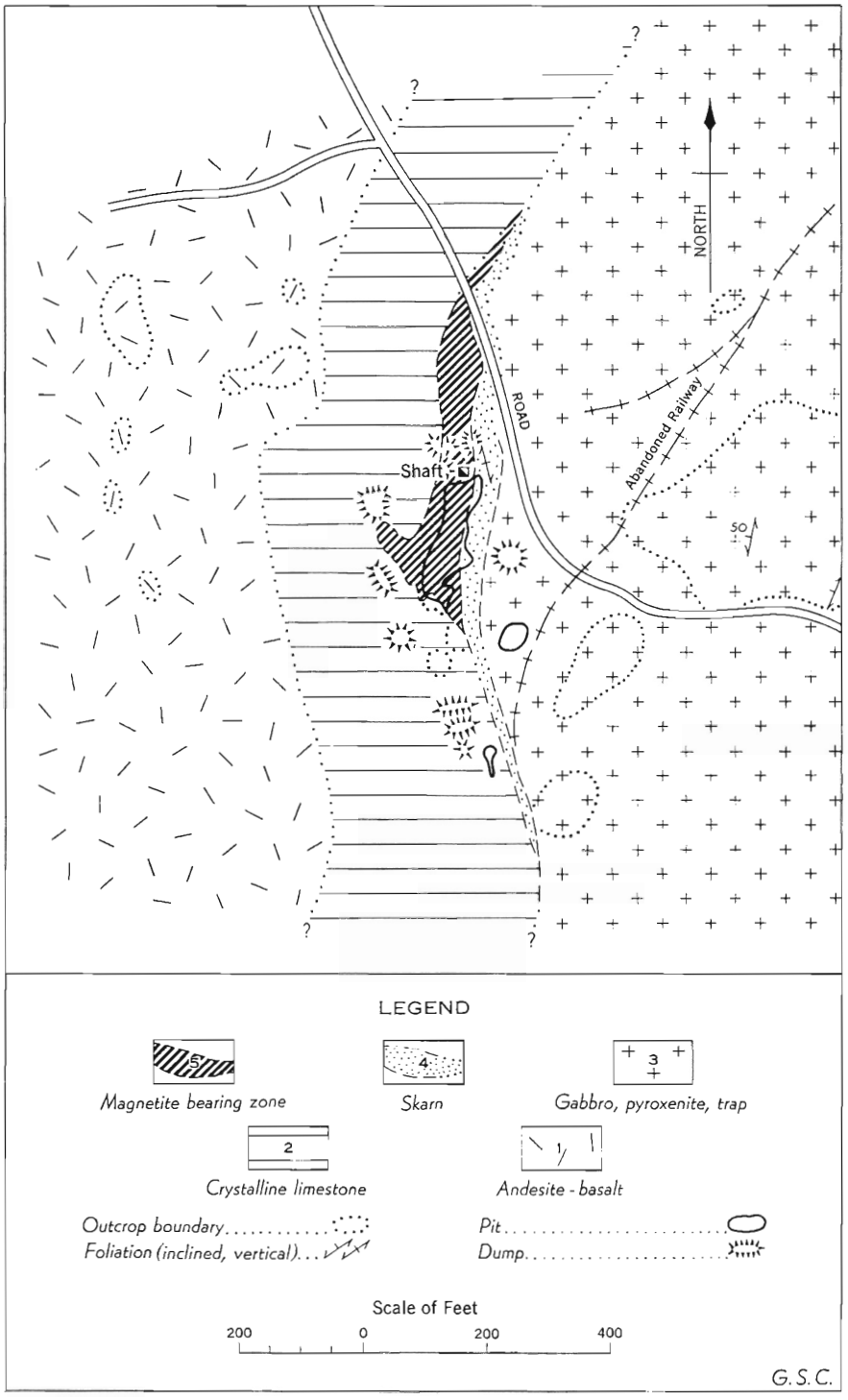

Figure 4. *Belmont magnetite deposit, Belmont township, Peterborough county, Ontario. (Base map after E. Lindeman.)*

Thin sections of the skarn show a variety of minerals including brown garnets, vesuvianite, amphiboles, epidote, chlorite, carbonates, pyrite, magnetite and some hematite. In polished sections garnets are rimmed and partly replaced by magnetite and pyrite, fine-grained magnetite replaces gangue minerals, coarse-grained magnetite is flecked with gangue, minor pyrite, pyrrhotite and chalcopyrite, and ore and host rocks are reticulated by quartz, epidote and carbonate veinlets. Part of the quartz in these veinlets is bottle green. The veinlets locally carry small amounts of sulphides, magnetite and hematite. Some of the red hematite appears to be an alteration product of magnetite.

A chemical analysis by Lindeman (1913) of a sample selected from the main pit showed about 51 per cent iron, 12 per cent silica, 5 per cent lime, 4 per cent magnesia, 0.3 per cent sulphur, 0.1 per cent titanium, and 0.03 per cent phosphorus.

Samples of the coarse-grained gabbro and fine-grained trap from this area were analyzed spectrographically, and they showed similarities in content of trace elements such as zirconium, yttrium, scandium, vanadium, and cobalt, as well as in the main components, silicon, aluminum, magnesium, calcium, iron and titanium.

Bessemer—The Bessemer property includes lots 2, 3, 4 and 5, concession VI, and lot 1, concession VII, Mayo township, Hastings county and is about 10 miles east of Bancroft. Between 1902 and 1913 about 100,000 tons of magnetite were shipped from four workings, more than 90 per cent of this production coming from No. 4 mine, just east of Little Mullet Lake. Nos. 1 and 2 workings were very small pits, No. 3 had two pits, and No. 4, was explored first by open-pit and later by underground workings from an inclined shaft, with levels at 55, 101, 161 and 236 feet. The underground workings are reported as being about 500 feet long, and the pit at the surface about 270 by 75 feet. The workings are now water filled. The property is controlled by Frobisher Exploration Company Limited, who investigated and diamond drilled the deposits in 1941 and 1942. Fourteen holes were drilled on deposit No. 4 from underground and 13 from surface. The latter intersected the deposit at about the 500-foot horizon where the average grade of material is said to be 35.4 per cent iron over a width of about 50 feet.

The magnetite occurs as discontinuous lenses in a belt of crystalline limestone, amphibolite and quartzite that trends northeasterly. These are flanked on the north by gneisses of dioritic to granitic composition (*see* Figure 5). Granite dykes cut the gneisses in places.

Bands of crystalline limestone are exposed on both the foot-wall and the hanging-wall of the magnetite body at No. 4 pit. The limestone beds

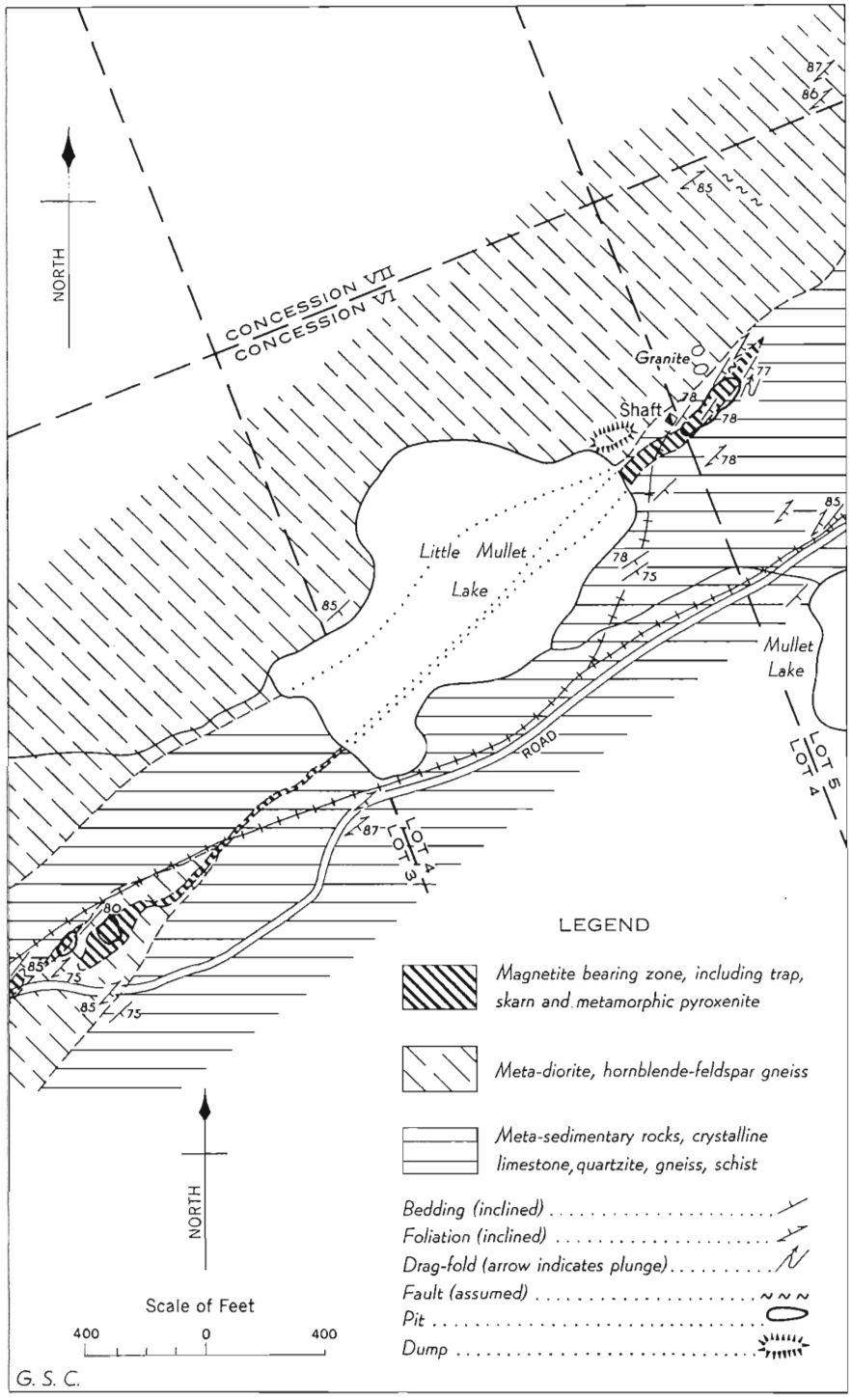

Figure 5. **Bessemer magnetite deposit, Mayo township, Hastings county, Ontario. (Base map after E. Lindeman.)**

are drag-folded and sheared, and the drag-folds plunge northeasterly. Foliation, banding and magnetite zone strike northeasterly and dip southeasterly at about 75 degrees. On company plans of the deposit (*see* Thomson, 1943), dykes of diorite are shown as cutting the magnetite bands.

In detail the deposit consists of disseminations, stringers and bands of magnetite in a well-developed skarn consisting mainly of dark green pyroxenes and amphiboles, carbonates, coarse dark brown garnet and epidote. In specimens from the dumps, both fine- and coarse-grained magnetite are intersected in places by veinlets of quartz, epidote and garnet, and by others of sulphides, of white and pink calcite, and of buff, limonite-stained ferruginous carbonate. In places the skarn is vuggy and well crystallized, and in others fragments of magnetite are cemented by garnet and epidote.

Chemical analyses of material from the dump showed 36.5 per cent iron, 5.7 per cent lime, 0.3 per cent sulphur and 0.026 per cent phosphorus. A representative analysis of 28,000 tons of crude ore from the Bessemer No. 4 was given by Canada Iron Mines (*O.I.O.C.* 1943, p. 167) as 49.30 per cent iron, 0.465 per cent sulphur, and 0.020 per cent phosphorus (*see* Thomson, 1943, p. 457).

Blairton—The Blairton deposit is on lots 7 and 8, concession I, Belmont township, Peterborough county, about a mile north of highway 7, on the south shore of Crowe Lake, about 4 miles west of Marmora. Magnetite totalling about 300,000 tons was mined there intermittently from about 1820 to 1875, and the mine became one of the largest producers in eastern Ontario. In 1908 and 1910 considerable diamond drilling was done, proving ore to a depth of 550 feet (Lindeman and Bolton, 1917). The deposit is now controlled by Frobisher Exploration Company Limited and Trent River Iron Limited, the latter holding the northern tip and extension.

The main workings consist of three open pits now filled with water. These are known as Lake (northernmost), Derrick (central), and Morton (southern). The central pit is reported to be 125 feet deep and measures about 150 by 200 feet. The Lake pit is flooded to lake level (*see* Figure 6).

In general, an intrusive body of gabbro-diorite forms the east or hanging-wall of the deposits, with crystalline limestone and chloritic schist on the west or foot-wall. A sinuous, northerly trending shear zone in skarn and metamorphic pyroxenite carries magnetite and dips steeply east. The magnetite zone and adjacent rocks are overlain by conglomerate succeeded by ferruginous dolomite and limestone, all of Palæozoic age, and which at the central pit strike northwest and dip 12 degrees northeast. In places at and near the central pit, fragments of martite and hematite occur in the overlying Palæozoic rocks, which are in part stained red with hematite, and locally contain small concentrations of massive red hematite.

The gabbro varies from coarse to fine grained, carries disseminated magnetite and probably forms part of the same mass as the gabbro at the

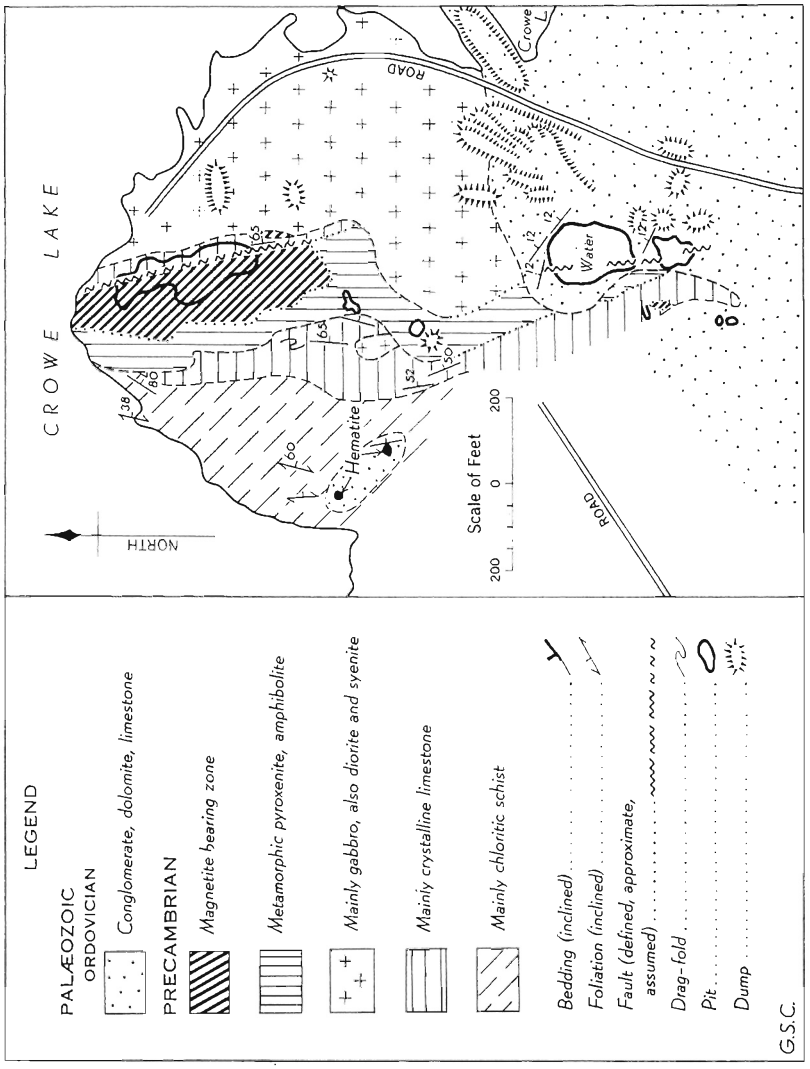

Figure 6. Blairton magnetite deposit, Belmont township, Peterborough county, Ontario. (Base map after E. Lindeman.)

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Belmont pit. This gabbro consists essentially of pyroxene altered to green hornblende, chlorite and plagioclase (labradorite) with coarse magnetite, siderite and epidote. A few patches of dioritic to syenitic composition may be noted on the hanging-wall side of the body. The fine, green rock in the magnetite zone consists essentially of fine granular twinned pyroxene with hornblende and chlorite, and a considerable amount of magnetite that replaces both. This fine-grained rock is interbanded with one composed almost entirely of brown garnet, epidote and green hornblende after pyroxene, with some magnetite, and which grades into metamorphic pyroxenite containing carbonates. Stringers of calcite containing pyrite, chalcopyrite and hematite, and veinlets of quartz intersect the wall-rocks and the magnetite zone. In places tourmaline, tremolite and epidote occur in the calcite veinlets cutting the magnetite.

In Trent River Iron Limited diamond drill core, from beneath Crowe Lake and north of the Lake pit, crystalline limestone is interbanded with chloritic amphibolite that is lightly stained with hematite and seamed by epidote. The amphibolite grades into a calcite-pyroxene-amphibole rock, or metamorphic pyroxenite.

Fine-grained, black magnetite occurs in disseminations, stringers and bands in the sheared and altered skarn. Some of the magnetite is sheared, slickensided and cut by serpentine-bearing calcite veinlets. Much of the iron mineral in specimens on a dump beside the Derrick pit consists of martite, a mineral resembling magnetite, but which is only weakly magnetic and gives a red streak. An X-ray powder photograph of this mineral showed the structure of hematite; this is characteristic of martite. Martite and hematite were not observed in the Lake pit, but are present as grains, pebbles, and cobbles in the immediately overlying clastic Palæozoic rocks. This suggests that martite and hematite may be restricted to the weathered parts of the deposit.

In thin section veins of equidimensional granules of silvery martite cut magnetite (*see* Plate VII A). These veins are intersected by veinlets of carbonate and red hematite. In places carbonate veinlets show a central part of concentrically banded red hematite and carbonate (limonite stained), which is also penetrated by other carbonate veinlets (*see* Plate VI B).

Some green and red banded Palæozoic dolomite is jaspery and resembles iron-formation. A thin section of it shows that hematite stain is the result of migration of iron from tiny clastic grains of martitic hematite present in some of the beds.

Polished surfaces of magnetite-bearing material show medium-grained magnetite partly replacing silicate-carbonate gangue and less commonly, cubes of pyrite. Some hematite stain was noted in the gangue minerals. A

section of brecciated martitic material showed grains of both magnetite and martite intersected by carbonate veinlets that are in part stained with red hematite.

Chemical analysis of a sample taken across the north end of the Lake pit by Lindeman in 1911 (1913) gave an iron content of 50.1 per cent, silica 9.88 per cent, lime 3.52 per cent, alumina 1.73 per cent, magnesia 1.64 per cent, sulphur 1.42 per cent, titanium dioxide 0.1 per cent and phosphorus 0.046 per cent.

Bluff Point—The Bluff Point workings are on lot 16, concessions X and XI, Bagot township, Renfrew county, immediately north of Grassy Bay, Calabogie Lake, about 12 miles south of Renfrew. Magnetite was mined there sporadically from 1881 to 1901, and came from several small open pits and three shafts, one of which is reported to be 300 feet deep. The property is now controlled by Algoma Ore Properties Limited who put down two diamond drill holes in 1952.

The rocks beside the deposit strike northeasterly and dip about 35 degrees southeasterly (*see* Figure 7). Crystalline limestone forms most of the western or foot-wall part of the deposit, with a hornblende-feldspar gneiss on the hanging-wall and an intermixed zone between the limestone and gneiss. These contact rocks include crystalline limestone, amphibolite, and sheared hornblende-chlorite schists that are brecciated and carry the magnetite. The body is seamed with carbonate veinlets.

Magnetite occurs in disseminations, stringers and bands in the sheared contact rocks. It forms lenticular masses in a zone that strikes northeasterly towards the Calabogie (Main) deposit about a mile to the northeast. Some pyrite is present in both the limestone and magnetite of the Bluff Point deposit. A magnetic survey (Lindeman, 1913) indicates that magnetite occurs intermittently over a length of about 1,400 feet but is confined mainly to two lenses, each about 500 feet long. The maximum width of the deposit is estimated to be about 40 feet.

Chemical analysis of a shipment of material from the deposit (Lindeman, 1914) showed 59.5 per cent iron, 9.1 per cent silica, 4.8 per cent alumina, and traces of sulphur, phosphorus and lime.

Boulter—On lot 17, concession V, Carlow township, Hastings county, about a mile west of Boulter and north of Fraser Lake, surface stripping has exposed a small magnetite-hornblende zone. On lot 17, concession VI, about half a mile to the north of this occurrence two shallow pits and stripping have exposed a magnetite-hornblende zone about 38 feet wide and 200 feet long. It is reported (Hewitt, 1954, pp. 56-58) that a magnetic survey of part of the area was made by Louis Moyd in 1949 and 1950, and that 8

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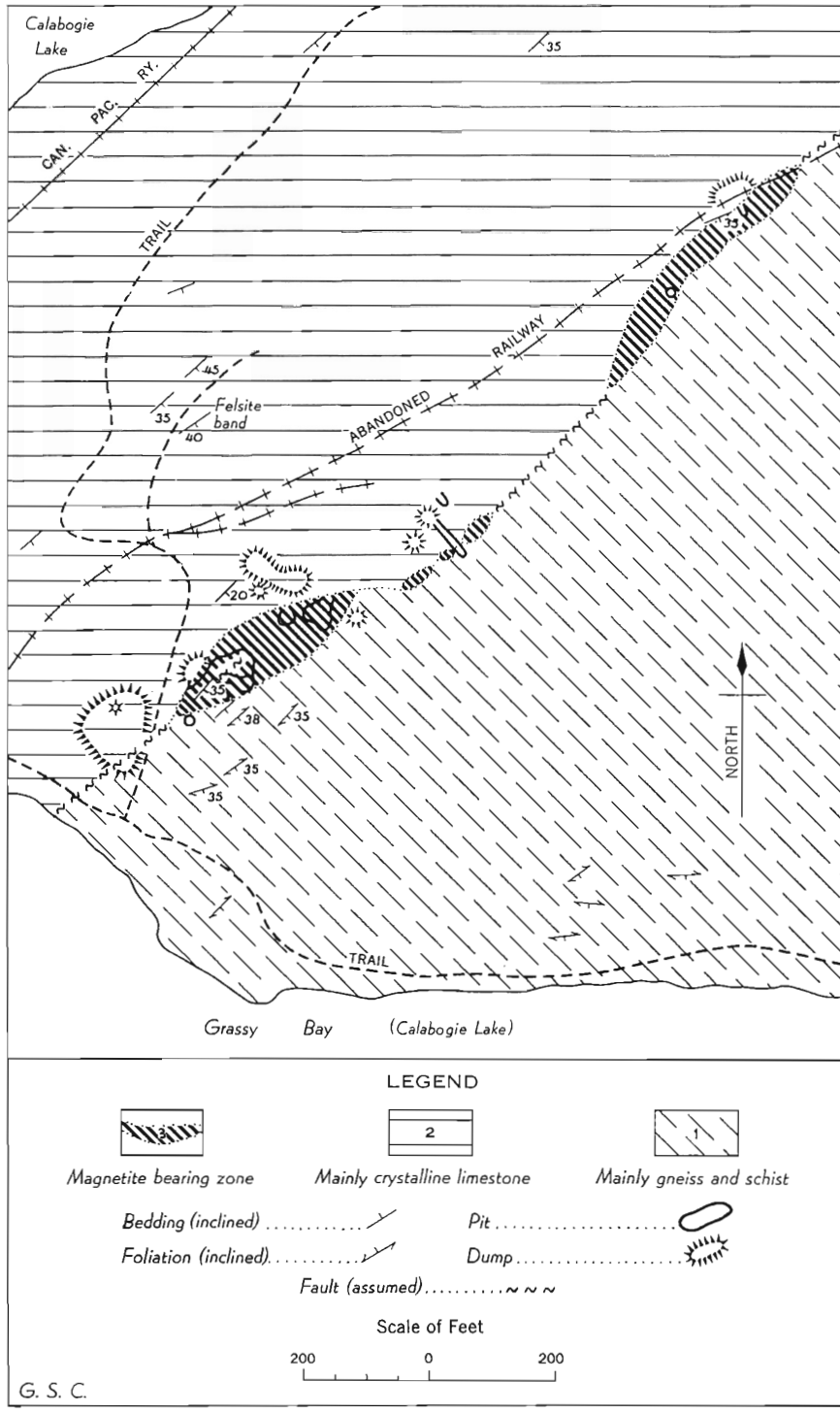

Figure 7. *Bluff Point magnetite deposit, Bagot township, Renfrew county, Ontario. (Base map after E. Lindeman.)*

holes totalling 1,012 feet were drilled on lot 21, concession VI, and lot 17, concessions V and VI, Carlow township, in 1950. These occurrences are about 12 miles northeast of Bancroft.

The magnetite occurs both in a hornblendic and in granitic to syenitic gneiss containing bands of crystalline limestone. The syenite gneiss is intruded by granite, syenite and gabbro. Pegmatitic granite and pegmatite dykes, which locally carry some magnetite, cut all rocks of the area including the magnetite-hornblende zone. The foliation of the gneiss and limestone trends mainly northwesterly and dips steeply northeast. A large body of intermixed coarse- and fine-grained gabbro carrying disseminated magnetite intrudes the gneisses (*see* Plate IV A) east of the pits. The precise relation of this gabbro to the magnetite deposits is unknown. Both phases of the gabbro are cut by pegmatitic granite and by pegmatitic dykes carrying black tourmaline distributed sporadically. Crystalline limestone is confined mainly to lot 17, concession V.

Chemical analyses of a sample from the magnetite-hornblende zone showed about 44 per cent iron, 10 per cent silica, 1½ per cent titanium, and traces of sulphur, phosphorus and vanadium (*see* Lindeman and Bolton, 1917; Hewitt, 1954). A hole on lot 17, concession VI of Carlow township, drilled southwesterly at a dip of 45 degrees into the main showing, penetrated a magnetite zone averaging 37.95 per cent iron over a length of 19.2 feet (*see* Hewitt, 1954, p. 58).

Bow Lake—The Bow Lake workings, consisting of several small open-cuts and test pits are located on lot 21, concession X, and lot 21, concession XI, Faraday township, Hastings county, Ontario, just west of Bow Lake and north of highway 28 about 6 miles west of Bancroft.

Much of the bedrock exposed is pink and red granite with bands and inclusions of amphibolite, biotite schist and crystalline limestone in the vicinity of the magnetite occurrences. Small irregular pegmatite dykes cut these rocks, and they are sheared along faults that trend northeasterly and dip about 40 degrees to the southeast (*see* Figure 8).

Medium- to coarse-grained magnetite occurs in the biotite schist, amphibolite and altered crystalline limestone at or near contacts with the granite. The occurrences are of an irregular and pockety character. A sample is reported (Lindeman and Bolton, 1917) to have given 51 per cent iron, 9.03 per cent silica, 1.94 per cent phosphorus and 0.070 per cent sulphur. Spectrographic analysis of a selected sample showed in addition strong traces of titanium and manganese, a trace of vanadium and faint traces of cobalt, copper and zinc, etc.

Bristol—At the old Bristol mine in the north half of lots 21 and 22, range II, Bristol township, Pontiac county, Quebec, about 5 miles north of Arnprior, Ontario, magnetite occurs in foliated amphibolitic rocks and

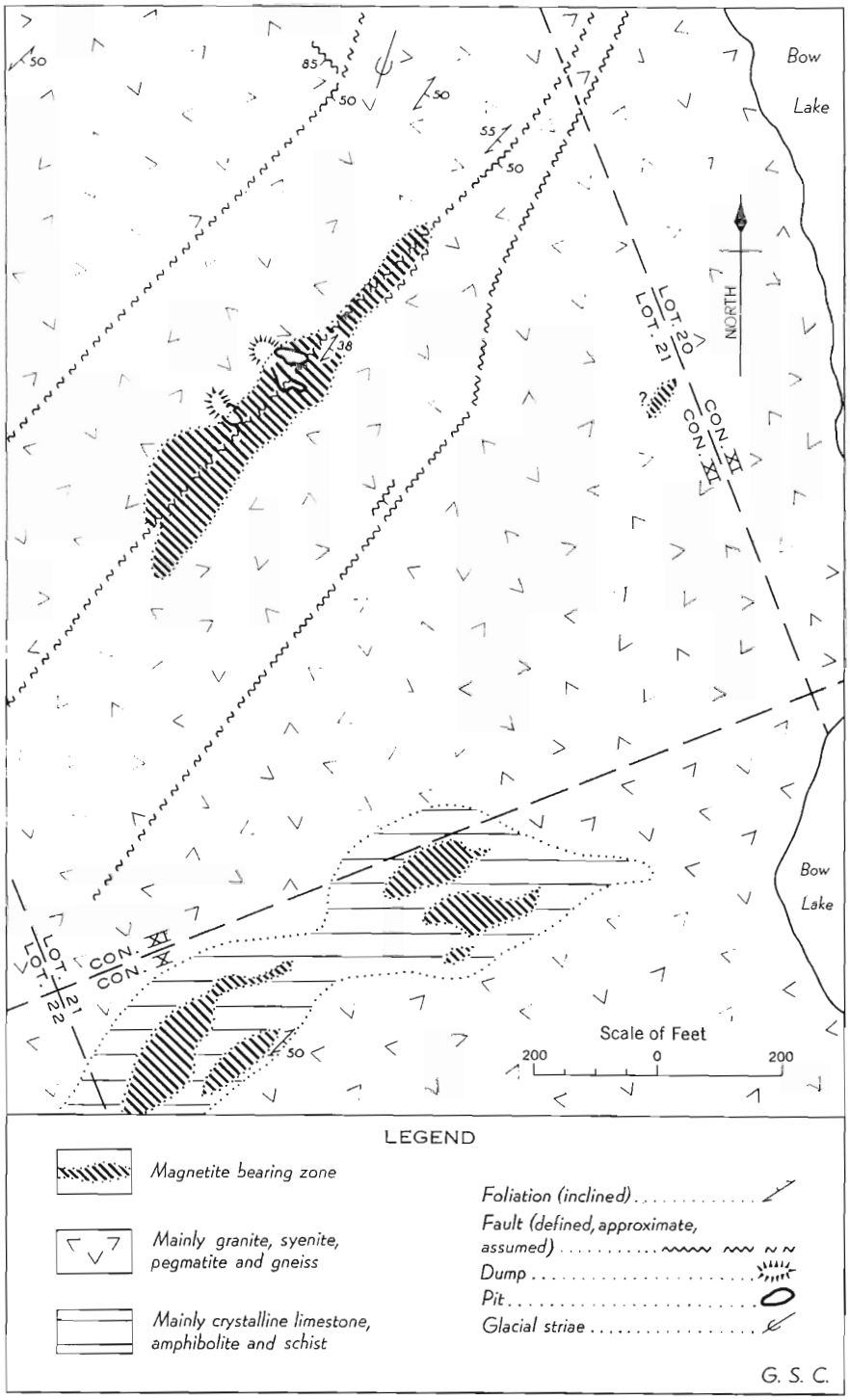

Figure 8. *Bow Lake magnetite deposit, Faraday township, Hastings county, Ontario. (Base map after E. Lindeman.)*

near their contacts with intercalated impure crystalline dolomitic limestone. Magnetite was mined intermittently, and smelted on a small scale, at the property from 1872 to 1894. In 1951 Trent River Iron Limited began a ground magnetic survey and diamond-drilling program on the property, and subsequently were joined by Pickands Mather and Company, who together with the Steel Company of Canada, and Jones and Laughlin Steel Corporation, are proceeding (1956) with plans to develop the deposits by open pit in 1957. A concentrating and pelletizing plant is being built on the property, now to be known as the Hilton mines.

Gneissic granite outcrops to the north of the deposit and crystalline limestone to the south (*see* Figure 9). In the zone between, remnants of a formation of impure calcareous meta-sedimentary rocks, amphibolite and quartzite, are intruded by a tongue of gabbro-diorite on the northeast and by irregular masses and dykes of pink granite, syenite and pegmatite. Bands of serpentinite in this zone probably represent altered mafic intrusions. The regional trend of banding, foliation and of magnetite zones is northwesterly and the general dip is about 60 degrees to the northeast (*see* Plate II B). Steeply inclined shear and breccia zones cut the rocks and are generally parallel to the regional strike.

Magnetite, the main ore mineral, occurs discontinuously within this zone of sheared, altered rocks, but mainly in amphibolite, over a length of about 2,500 feet and a horizontal width of about 500 feet. The magnetite is generally medium grained and is in places rimmed with red hematite and partly altered to martite. The chief gangue minerals are amphiboles, micas, scapolite, chlorite, talc, serpentine, carbonates and epidote. Pyrite and chalcopyrite are disseminated in small grains, but pyrite is locally coarse grained and abundant in aggregates and seams in the magnetite. Serpentine-carbonate and quartz-pyrite veinlets intersect the magnetite. Magnetite commonly fills fractures in, and marginally replaces, pyrite cubes and shows mutual boundaries with chalcopyrite. Martite occurs as an alteration of magnetite from surface to a depth of at least 264 feet. Red hematite is also found to this depth, but is more abundant at surface.

Chemical analyses of selected samples showed from 43 to 62 per cent iron, 6 to 28 per cent silica and 0.3 to 2.5 per cent sulphur. Spectrographic analysis of a selected sample showed only faint traces of titanium, vanadium, and copper.

Bygrove—An occurrence of magnetite on an open hill in lot 3, concession I, South Sherbrooke township, Lanark county about 8 miles south of Maberly in the Perth area, was explored by a pit about 28 feet wide and 38 feet long, and several smaller pits. An experimental shipment of the magnetite is said to have been made. Four small dumps containing an estimated 150 tons of ore-grade material remain.

The magnetite-bearing zone contains coarse-grained hornblende, pyroxene, scapolite and calcite developed in granitic gneiss, the foliation of which strikes northeasterly and dips steeply southeasterly. Crystalline limestone is exposed on a hill to the northwest of the pits. Magnetite in scattered grains and lenses impregnates the rock, and coarsely crystalline magnetite occupies vuggy parts.

In polished section the magnetite-rich material showed a mosaic of coarse crystals of magnetite, magnetite with vermicular and rod-like intergrowths possibly of hematite or ilmenite, a few grains of hematite, sparsely disseminated pyrite and gangue.

Chemical analyses of ore samples reported in 1899 showed an iron content of 59.55 to 62.95 per cent, negligible phosphorus and titanium, and 6.59 per cent insoluble matter.

Calabogie, Main (Caldwell and Campbell)—The workings exposing the Caldwell and Campbell deposits are on lot 16, concession IX, and lot 16, concession VIII, respectively, Bagot township, Renfrew county, about a mile east of Calabogie and about 11 miles south of Renfrew. From 10,000 to 15,000 tons of magnetite are said to have been shipped between 1883 and about 1901. The workings consist of several small open pits and numerous pits and trenches. The two largest pits are near the corner post between lots 15 and 16, concessions VIII and IX, just west of the road running between the lots. The property is controlled by Algoma Ore Properties Limited, who have completed an intensive diamond-drilling program, and have outlined a lenticular magnetite-bearing zone that averages at least 25 per cent iron over a length of 3,000 feet, with a maximum true thickness of about 270 feet. The old workings are in part filled with water and are overgrown with bush so that little information may now be obtained from their study (*see* Figure 10).

The magnetite-bearing zone as outlined by diamond drilling is enclosed in hornblende-bearing gneisses and schists interbanded with crystalline limestone. A stock-like body of pink syenite occurs about 2,000 feet east of the deposit, and a sill-like tongue of gabbro in the gneisses parallels the deposit about 800 feet west of the pits and to the north of the deposit. About a mile east of the deposit, the pink syenite on its eastern margin intrudes gabbro and on its western margin it also intrudes limestone exposed on the Calabogie–Perth road. Sills of pink felsite are interbanded with crystalline limestone on the road just east of Calabogie.

The regional trend of foliation, banding, bedding, and of the magnetite zone itself is northeasterly with a southeasterly dip from 35 to 60 degrees. The magnetite-rich zone is a complex assemblage of intercalated gneisses, schists and silicated crystalline limestone, with metamorphic pyroxenite, amphibolite (in part bearing scapolite) and skarn, all sheared and brecciated.

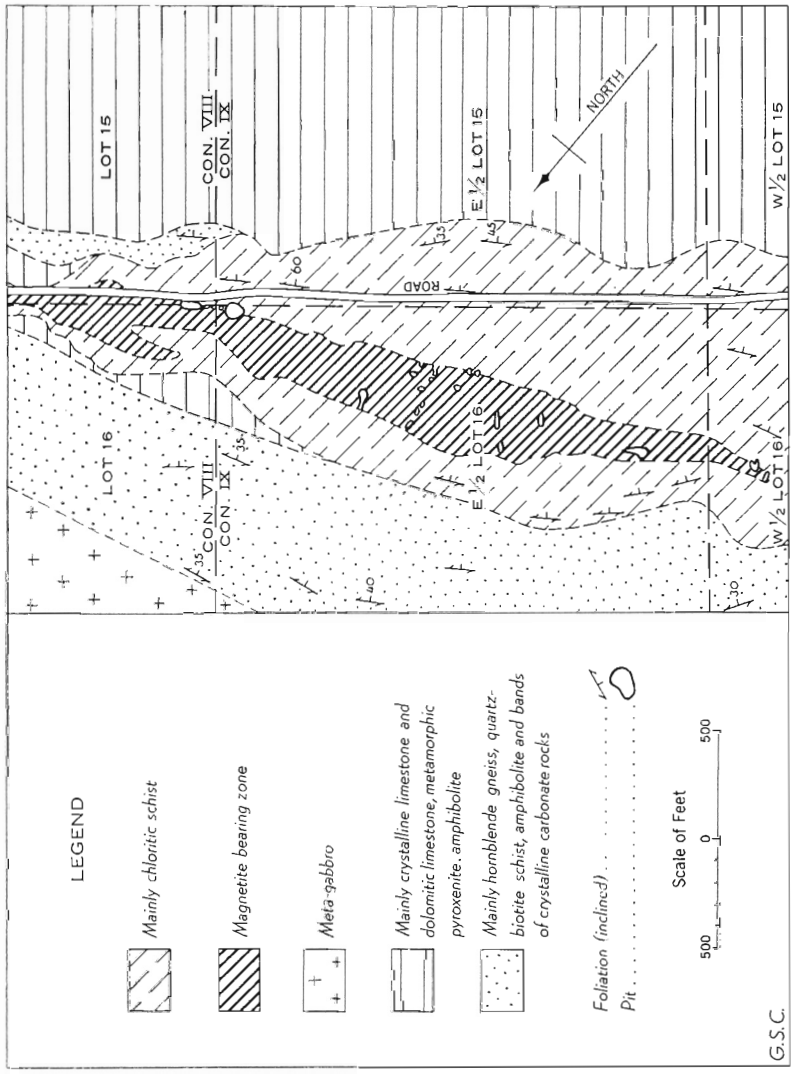

Figure 10. Calabogie, Main (Caldwell and Campbell) magnetite deposit, Bagot township, Renfrew county, Ontario.

This zone contains both fine- and coarse-grained magnetite and is cut by carbonate veinlets.

The gneisses and schists are dark green, and intermediate or dioritic in composition, consisting mainly of hornblende, biotite, chlorite, feldspar and quartz, with magnetite, pyrite and carbonates. The crystalline limestone commonly carries pyroxenes, amphiboles, micas, chlorite, and serpentine, in addition to pyrite in the magnetite zone. Skarn zones of metamorphic pyroxenite and of epidote with brown garnet are common throughout. Quinn (1952, p. 42) reported a rare reddish brown magnesian tourmaline (dravite) along with a bright green pyroxene of the diopside-hedenbergite series and plagioclase in a 15-foot-wide zone of light grey to silver-grey schist in the foot-wall rocks. A thin section of amphibolite from the hanging-wall rocks shows a few small, brown, pleochroic wedge-shaped crystals with brown alteration rims, perhaps of radioactive sphene, in addition to green hornblende, feldspar, quartz, brown biotite and tiny blebs of apatite. A fine-grained black rock below the amphibolite consists of very fine idiomorphic crystals of green hornblende, feldspars (albite) and quartz, with small crystals and interrupted stringers of magnetite. One of the most abundant of the host rocks is a fine-grained, lightly foliated, grey "pepper and salt" gneiss, composed of fine quartz, feldspar, ragged hornblende and biotite, carbonates and some magnetite.

Magnetite occurs in desseminations, stringers and in near-massive bands, some as much as 2 feet thick and all follow the foliation of the rocks. Most of the magnetite is in fine veinlets but some of it is in coarse crystals half an inch in diameter. Pyrite, some pyrrhotite and traces of chalcopyrite are sparsely distributed as specks and small veinlets in the magnetite. Red hematite as a minor constituent is found associated, in places, with pyrite and as coatings on magnetite. A polished surface of pyritic ore shows coarse blocky pyrite partly rimmed with silicates and carbonates, and partly replaced marginally by magnetite and hematite. In the chloritic schist of the ore zone pyroxene remnants and biotite are in part marginally altered to pale green chlorite and serpentine, with carbonates. Quartz rims are also present on the pyroxenes in places. A chloritic alteration seems to characterize the magnetite zone.

Childs—This deposit is on the south halves of lots 11 and 12, concession IX, Mayo township, Hastings county, about 3 miles northeast of the Bessemer No. 4 pit and about 12 miles east of Bancroft. The workings consist of three small pits opened and abandoned in 1913, and some trenching and stripping. Parts of these are now under a beaver pond. The property is controlled by Frobisher Exploration Company Limited, who diamond drilled the deposit in 1941 and 1942.

The workings are overgrown and flooded, but in the few exposures examined magnetite in scattered grains follows the regional foliation of a group of hornblendic gneisses and biotitic schists. South of the deposit crystalline limestone intercalated with amphibolite is intruded by a sill of gabbro-diorite and a tongue of granite. Most of the magnetite occurs as a fine-grained impregnation of banded, calcareous amphibolite and the magnetite zone includes a brown garnet-pyroxene-hornblende-epidote-calcite-magnetite skarn, penetrated by a few granitic dykelets. Some pyrite is present in the garnet skarn of the magnetite zone, and pyrite as well as coarse pink calcite penetrates some of the magnetite. Gneissic granitic dykes also appear to intersect the magnetite in places.

A shipment of material to the Trenton concentrator in 1913 is said to have averaged 38.7 per cent iron, 0.149 per cent sulphur and 0.049 per cent phosphorus.

Christie's Lake—On the north shore of Christie's Lake magnetite is exposed in rock cuts along the Canadian Pacific Railway line in South Sherbrooke township, Lanark county about 12 miles southwest of Perth. The property comprises lots 18, 19 and 20, concession III. The country rocks include dark gneiss, crystalline limestone and dark green pyroxenite. The deposit is exposed by small open-cuts on the lake shore and two or three small pits on the slope of the railroad embankment, towards the lake. Narrow bands of magnetite striking northeasterly, and some coarse crystalline magnetite, are contained in green metamorphic pyroxenite that is in part vuggy and carries considerable pinkish calcite in irregular patches and veinlets. In places coarse crystals of magnetite line the vugs and at other places such crystals occur with pyroxenes and amphiboles in a skarn in recrystallized limestone. Quartz and pyrite stringers cut the magnetite and occur in the vugs as well.

In the first rock cut west along the tracks from the workings, magnetite is disseminated through a rusty quartzose zone 12 feet wide at the contact of diopside-bearing crystalline limestone and grey-green pyroxenite. The banding of the rock and the contact zone strike northeasterly and dip 75 degrees southeasterly. Scapolite, apatite, hornblende and pyroxene were noted in the contact zone.

Chemical analyses of selected specimens show iron ranging from 59 to 61 per cent, titanium from 0.5 to 1 per cent, sulphur from 0.1 to 4.5 per cent and phosphorus from 0.003 to 0.009 per cent.

Coehill—This deposit is located on lots 15 and 16, concession VIII, Wollaston township, Hastings county, just west of Coehill station on a branch of the old Central Ontario railway. Between 1884 and 1887 about 100,000 tons of magnetite ore were mined, about one third of which was stock piled. Much of this material remains on the dumps in a rusted condition. Ore

was mined from an open-cut and later from three shafts, each about 100 feet deep. The property is controlled at present by Frobisher Exploration Company Limited.

The country rock is pink syenite with included bands of crystalline limestone, metamorphic pyroxenite, and amphibolite (*see* Figure 11). Wollaston Lake gabbro there containing disseminated magnetite, occurs about 2,000 feet to the south. At the pit an easterly trending, southerly dipping, band of metamorphic pyroxenite and amphibolite about 80 feet wide lies above a 50-foot-wide band of crystalline limestone, all impregnated with magnetite and intruded by syenite dykes (*see* Plate IV B). Magnetite occurs as disseminations, stringers and narrow bands in this metamorphic pyroxenite-amphibolite over a length of about 600 feet, accompanied by pyrite and, in one place, by molybdenite. The host rock is essentially a lightly foliated, greenish metamorphic pyroxenite in which part of the pyroxene is altered to amphiboles and mica. The pyroxenite is intruded in places by pink syenite dykes that carry considerable pyrite and sphene. The alteration of pyroxene to dark green hornblende is especially notable in the pyroxenite near these dykes, and the margin of the dykes contains some magnetite associated with ragged crystals of green hornblende after pyroxene. The dykes are low in magnetite and were probably intruded after the emplacement of the magnetite.

In one place a 4-inch-wide band of coarsely crystalline magnetite with minor pinkish calcite, pyrite, flakes of molybdenite and green mica, cuts almost vertically through and across the magnetite-bearing pyroxenite-amphibolite, in a manner analogous to that of the syenite dykes.

Chemical analysis of an average sample taken across the deposit by Lindeman (1913) gave about 47 per cent iron, 2.2 per cent sulphur, and 0.018 per cent phosphorus. Two representative grab samples taken from the dumps by Jas. E. Thomson showed, for the west dump, 58.09 per cent iron, 1.10 per cent silica, 0.17 per cent titanium oxide, 1.26 per cent sulphur, .009 per cent phosphorus, and no vanadium; for the east dump 44.40 per cent iron, 9.25 per cent silica, 0.28 per cent titanium oxide, 0.90 per cent sulphur, 0.02 per cent phosphorus, and no vanadium.

The Jenkins workings consist of a shallow open-cut and some small pits and trenches on lots 17 and 18, concession VIII, Wollaston township, Hastings county, Ontario, about a mile west of Coehill and just south of the gravel road to Chandos. The occurrence is similar to that at Coehill, but crystalline limestone is not exposed in the vicinity. Magnetite occurs in irregular disseminations and stringers in a metamorphic pyroxenite-amphibolite band near the contact with pink syenite on the north (*see* Figure 11).

Lindeman and Bolton (1917) reported that an average sample taken across the deposit at the main pit showed 46.08 per cent iron, 0.52 per cent sulphur, 0.054 per cent phosphorus and 35.30 per cent insoluble matter.

Culhane—The Culhane deposit is on lot 21, concession VII, Bagot township, Renfrew county, near the southeast shore of Norway Lake about 10 miles south of Renfrew. The workings consist of four small pits with shallow shafts on the two largest of these, on the northeast. Friable, granular magnetite is exposed in bands in the workings and on the small dumps, and a diamond drill hole is reported to have intersected "a 3-foot rib of ore"; no records of shipments are available.

The country rock is granitic gneiss with crystalline limestone interbanded on the hanging-wall, and dioritic gneiss on the foot-wall of the deposit. All have a regional northeasterly strike and northwesterly dip of from 20 to 30 degrees (*see* Figure 12).

Magnetite occurs chiefly as sporadic disseminations and narrow bands over a 10-foot width and 2,000-foot length in a discontinuous band of calcareous amphibolite or metamorphosed impure, amphibolitic, dolomitic crystalline limestone, mainly towards the foot-wall side of the limestone band and also in irregular, calcareous and chloritic lenses near the foot-wall contact of the limestone with the dioritic gneiss.

The ore material is banded, calcareous and of medium grain. Weathered parts are hematite stained. A thin section shows an intimate mixture of carbonates and tremolite, and a mosaic of interlocking, medium-grained crystals of magnetite, that replace these minerals in part.

Dacre—A small occurrence of magnetite on lot 14, concession XVIII, Brougham township, Renfrew county, was tested in 1901 by the Canada Iron Furnace Company. This deposit is about 300 feet west of a gravel road from a point about 900 feet south of the settlement of Dacre about 14 miles southwest of Renfrew. The workings consist of a small pit where pink granite is in contact with magnetite-bearing grey gneiss, and both are cut by small grey pegmatite dykes. The mode of occurrence is similar to that of Radnor described on page 49.

Emily or Gilmour—A long open-cut on lot 7, concession XIX, Tudor township, Hastings county, at a point about 1¾ miles northeast of Gilmour station on an abandoned stretch of road, represents the Emily workings. The open-cut is about 125 by 15 feet with a 20-foot face, but little magnetite was seen on the walls of the cut or in specimens on the dump. The cut apparently follows a skarn zone between meta-sedimentary rocks (mainly crystalline limestone) on the east, and granite on the west. The granite is highly epidotized and syenitic on the west side of the cut, whereas, on the east side a skarn of pyroxene, dark brown to black garnet, epidote, magnetite and carbonates is present at places. About 200 feet east of the cut, corrugated, calcareous meta-sedimentary rocks are intersected by a 4-inch-wide dyke of white albite syenite. The magnetite-bearing skarn is commonly separated from granite or syenite by an epidotized zone, and the magnetite is cut by epidote veins.

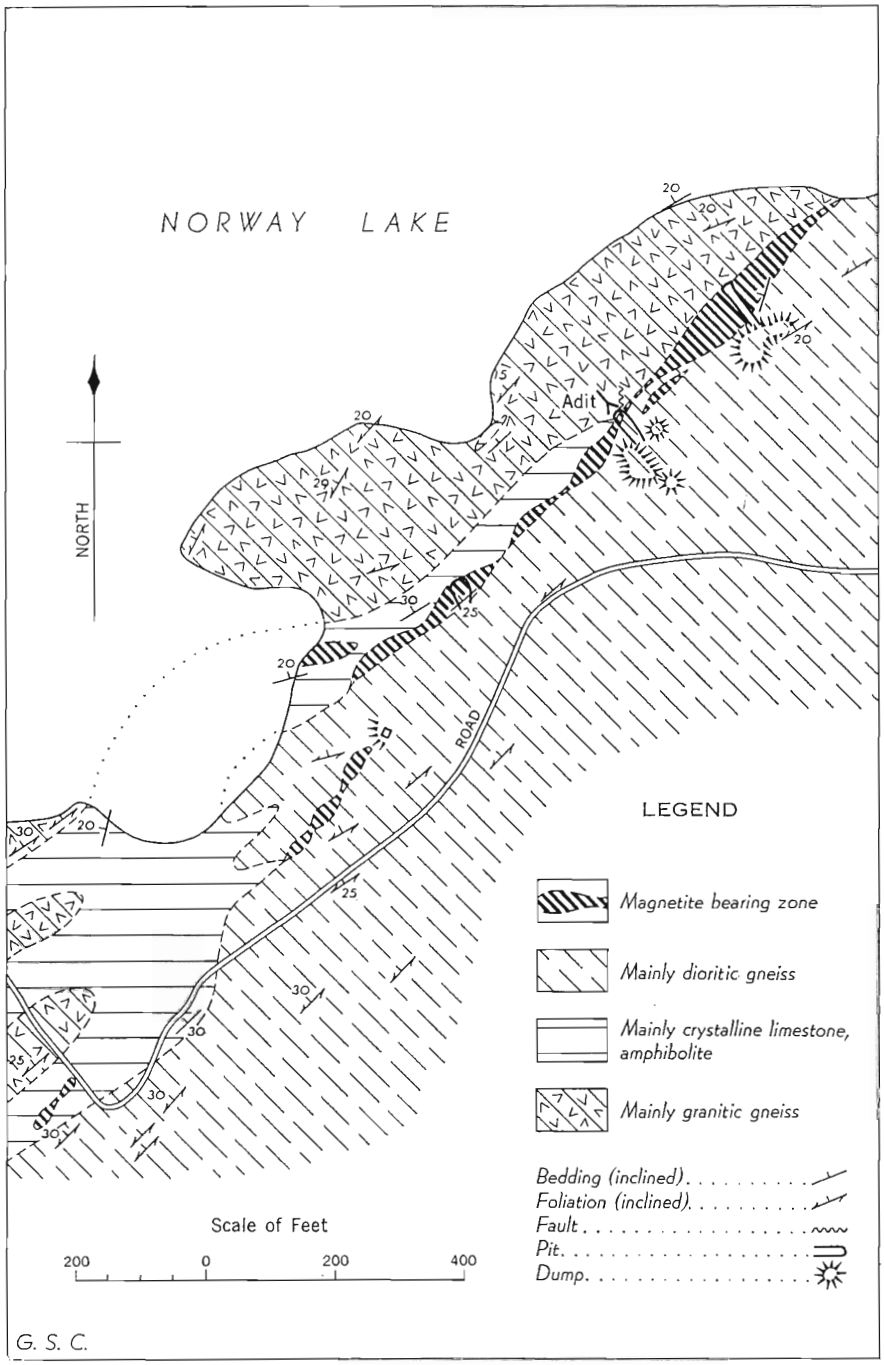

Figure 12. *Culhane magnetite deposit, Bagot township, Renfrew county, Ontario. (Base map after E. Lindeman.)*

A chemical analysis of samples of ore picked from the dump by Jas. E. Thomson (1943) showed 47.87 per cent iron, 6.64 per cent silica, 0.08 per cent sulphur, 0.25 per cent titanium oxide, 0.08 per cent phosphorus, and no vanadium.

Forsyth and Baldwin—Magnetite deposits on the southern part of lots 11 and 13, range VII, Hull township, Ottawa county, Quebec, were known before 1830, and early reports of the Geological Survey of Canada indicated the occurrence of a considerable quantity of magnetic iron ore. In 1848 Forsyth and Company of Pittsburgh began to develop the deposits and it is reported that about 13,000 tons of ore averaging about 60 per cent iron were shipped during the years up to 1858. In 1867 a blast furnace was built at Ironsides, Quebec, to smelt the ore, but the operation was not economically successful.

The Forsyth workings consist of a sinuous open-cut about 700 feet in length, 10 to 120 feet in width and about 50 feet deep with a deeper central shaft and a second cut 110 feet long, 20 feet wide and about 50 feet deep now filled with water. The Forsyth open-cut begins at a point just south of the Mine road about 4 miles northwest of the city of Hull and about 2 miles west of the village of Ironsides. Both cuts trend westerly most of their length, being separated by a zone 150 feet long in which old trenches poorly expose a narrow irregular zone of magnetite.

The deposit occurs within a large belt of crystalline limestone that lies in a terrain of granitic gneiss. Crystalline limestone forms both hanging-wall and most of the foot-wall of the deposit. Irregular, discontinuous magnetite seams follow sheared zones in coarse-grained crystalline limestone and amphibolite. Bands of amphibolite, some of which carry magnetite, are found in the walls of the cut. Irregular veins of coarser grained calcite and vugs lined with calcite cut the crystalline limestone. At the west end of the main cut a zone in altered amphibolitic crystalline limestone carries magnetite over a 10-foot width. The magnetite zone strikes westerly and dips at about 70 degrees to the north. Crystalline limestone on the hanging-wall is sheared and friable in a 5-inch-wide zone in contact with massive magnetite. Graphite flakes are present in both the magnetite and the crystalline limestone host rock, and are reported to have been found in seams within the magnetite deposit. Little may be seen in the south cut, but judging from its attitude, it appears that the magnetite zones narrowed and steepened in dip to about 85 degrees to the north.

Magnetite is the main ore mineral, but some hematite also occurs interstitially. Amphibole, calcite, chlorite, talc, graphite, pyrite and quartz are the chief gangue minerals admixed with the magnetite.

Lindeman and Bolton reported (1917) that diamond drilling proved sufficient magnetite on the property to yield 430,000 tons of concentrates

grading about 57 per cent iron, 11 per cent silica, 0.6 per cent sulphur, 0.02 per cent phosphorus and 1.5 per cent lime. No anomaly shows on the aeromagnetic sheet at the locality. Spectrographic analysis of a selected sample showed in addition to iron, a trace of titanium and manganese, and faint traces of vanadium, copper and barium.

Fournier—Magnetite was mined from several small pits on lot 14, concession I, South Sherbrooke township, Lanark county, about 14 miles southwest of Perth, and in 1873 a shaft was sunk from one of the pits to a depth of 110 feet. It is reported that about 600 tons of good ore were produced. Very little magnetite remains in situ in the rocks or on the dumps.

The country rocks are mixed granitic and dioritic gneisses, the foliation of which strikes northeasterly and dips from 45 to 65 degrees southeasterly. They are intruded by dykes of syenite, granite and pegmatite, all of which are cut by narrow trap dykes (fine-grained, dark green to black gabbro) with chilled edges. Magnetite veins up to 4 inches wide occur in mixed gneiss on the dump and such veins are commonly bordered by pyroxene, amphibole, greenish feldspar and biotite. Veinlets of these minerals intersect both trap and magnetite.

In polished section magnetite is included in partly replaced gangue minerals, and in coarse crystals of hematite that are in part replaced by the magnetite. Magnetite is intersected by veinlets carrying crystals of biotite, pyroxene, amphibole, and feldspar. These veinlets contain pyrite, chalcopyrite and minor carbonates.

Chemical analyses of samples of the magnetite reported in 1899 by E. D. Ingall showed an iron content of 59.59 to 60.89 per cent, with negligible amounts of phosphorus and titanium, and 10.01 per cent insoluble matter.

Glendower—The Glendower workings are in lot 6, concession II and lot 6, concession III, Bedford township, Frontenac county, on the west shore of Thirty Island Lake, about 25 miles north of Kingston. The mine was operated from 1873 to 1880 by the Glendower Company and from 1883 to 1888 by the Zanesville Company, which built a railway spur to the deposit. About 50,000 tons of magnetite iron ore averaging more than 50 per cent iron had been shipped prior to 1895, mainly from open-cuts. Some underground mining from shafts (one reported to be 180 feet deep) was also done. Six diamond drill holes, completed prior to 1895 from the hanging-wall side of the deposit, indicated a considerable amount of ore below the mine workings. E. D. Ingall (1899) made an examination and magnetic survey of the deposit in 1896. In 1899 the Hamilton Steel and Iron Company mined and shipped a little ore from pit No. 9 to supply a demand for phosphatic ore. Apatite occurred abundantly with magnetite in this pit. Trent River Iron Limited investigated the property in 1951-52 by magnetic

and geological surveys and five diamond drill holes. R. E. Jones studied it in 1953 and described it in a Queen's University Master's thesis.

A study of the surface geology, and of a Trent River Iron Limited diamond drill core shows that concentrations of magnetite occur mainly at the contact of crystalline limestone and metamorphic pyroxenite and in both rock types near this contact. The magnetite-bearing zone strikes northeasterly and dips very steeply southeasterly. Crystalline limestone forms the hanging-wall, and metamorphic pyroxenite, locally enriched in scapolite, apatite, amphiboles and diopside, the foot-wall, (*see* Figure 13). Diopside is an abundant constituent of the crystalline limestone near this contact, and fine flakes of phlogopite and graphite are abundant. Brown garnet is present in places but is not abundant. Steeply inclined veins as much as 4 inches wide and composed mainly of dark amphibole intersect a scapolite-rich rock (scapolite gabbro) on the foot-wall. Both rock types and the magnetite are invaded by a pegmatitic tongue, possibly from an intrusion of pink syenite on the north. Coarse crystals of apatite and scapolite are abundant in crystalline limestone in places near such intrusions. Fine-grained dark trap (gabbro) dykes cut crystalline limestone on the hanging-wall side of the deposit and elsewhere intrude the syenite and pegmatite.

Magnetite occurs in disseminations, stringers and bands in the sheared and brecciated zone of contact rocks. It varies from massive, coarsely crystalline, to medium grained where calcite and diopside are replaced. The coarsely crystalline magnetite carries minute interstitial ilmenite and hematite at some boundaries between the crystals and gangue minerals. This ilmenite is visible only under the reflecting microscope and the identification of it was confirmed by an X-ray powder photograph. Chalcopyrite and pyrite occur sparingly as tiny disseminations and in veinlets with carbonates that cut the magnetite. Serpentine is also common in the veinlets $\frac{1}{16}$ to $\frac{1}{8}$ inch wide that intersect the magnetite.

Chemical analyses of selected sections of drill core made by the Mines Branch, for Trent River Iron Limited, show an iron content ranging from about 23 to 45 per cent, sulphur from 0.9 to 2.7 per cent, and titanium oxide from 0.4 to 0.8 per cent. Traces of copper, nickel and phosphorus were also detected. Magnetic concentrates that carried more than 62 per cent iron were made at minus 10 and minus 20 mesh grinds (Mines Branch, M.D. 2915, 1952).

Howland—The workings of the Howland deposit are on lot 26, concession IV, Snowdon township, Haliburton county, about 13 miles south of Haliburton, on the crest of a high wooded ridge south of Irondale River. A bush road, branching west from the main road at Irondale station, leads to the mine. The workings consist of two shafts, 25 feet apart, and an open-cut 15 feet wide and 120 feet long; from these 1,500 tons of magnetite iron

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ore grading about 58 per cent iron, 0.005 per cent phosphorus and 0.06 per cent sulphur, were shipped in 1881 and 1882.

Magnetite occurs in the contact zone between a gneissic scapolite-bearing amphibolite or gabbro on the south, or hanging-wall, and a band of crystalline limestone containing a few narrow bands of amphibolite on the north, or foot-wall. The magnetite zone apparently follows the easterly trend and steep southerly dip of the contact, and of the banding and gneissosity of the enclosing rocks. Some magnetite is also disseminated through the amphibolite. Occurrences have also been reported from lots 25 and 27 of concession IV.

Hobson, Nelson and Knob—Some workings on lot 19, concession I, and on lots 18 and 19, concession II, of Madoc township, Hastings county, about 6 miles northwest of Madoc, were called the Hobson, Nelson and Knob mines respectively, on Coste's map of 1886. No record of production is available. The workings consist of small pits and shafts, with small separate dumps of pyrrhotite and magnetite.

The iron deposits occur within sheared crystalline limestone about 100 feet north of pink granite outcrops (*see* Figure 14). Ordovician limestone and conglomerate overlie these rocks in patches, and in one of the Hobson workings flat-lying Palæozoic conglomerate and limestone, both of which are stained red with hematite, unconformably overlie a sheared zone that contains magnetite, hematite and limonite. The crystalline limestone-granite contact is not well exposed, but it trends easterly and is generally parallel to the strike of the crystalline limestone. The mineral deposits extend intermittently over a distance of 2,400 feet parallel to the contact. The deposits probably occupy a series of *en échelon* shear zones dipping steeply northerly and developed in the chevron folded crystalline limestone near the granite contact. At the eastern end of the mineralized zone outcrop a tongue of granite intersects limestone and its contained pyrrhotite deposit.

Magnetite in the occurrences varies from massive, fine grained, to a scoriaceous, vuggy, crystalline type, in which the vugs are lined with hematite, limonite, chert, argillaceous material, and carbonate crystals. Hematite occurs mainly as an alteration product after carbonates. Pyrrhotite occurs as disseminated to massive, replacement deposits in dark green fine-grained pyroxenite intercalated with the crystalline limestone. Pyrrhotite also occurs as disseminations and as veins, along with black sphalerite and carbonates, in parts of the magnetite.

In polished section magnetite in a fine-grained mosaic is flecked with gangue, and contains sporadic coarse crystals of hematite that are in part replaced by the magnetite. Pyrrhotite is disseminated but also occurs in coarse grains with black sphalerite in a veinlet that cuts the other minerals.

No analyses are available.

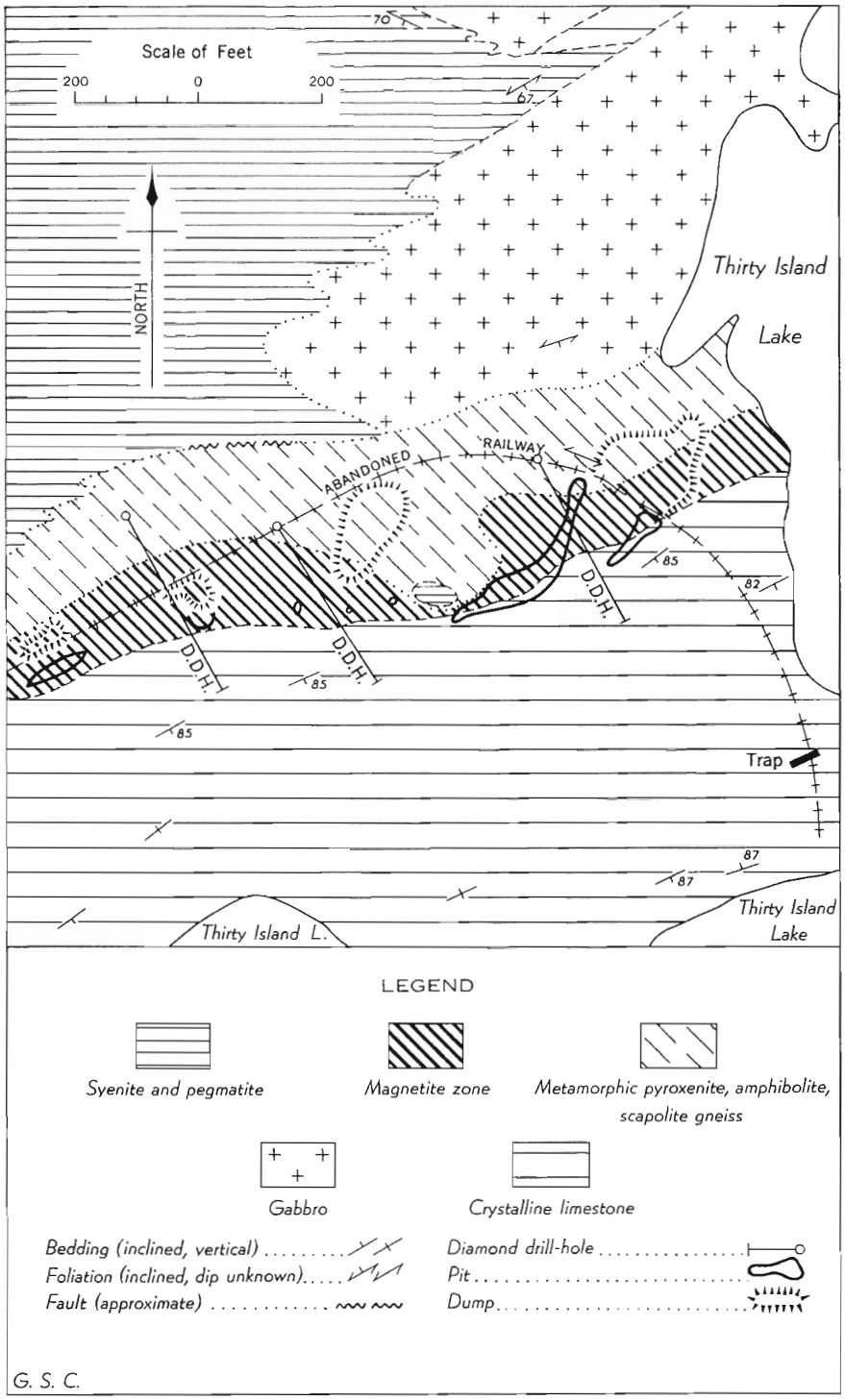

Figure 13. **Glendower magnetite deposit, Frontenac county, Ontario. (Base map after Trent River Iron Ltd.)**

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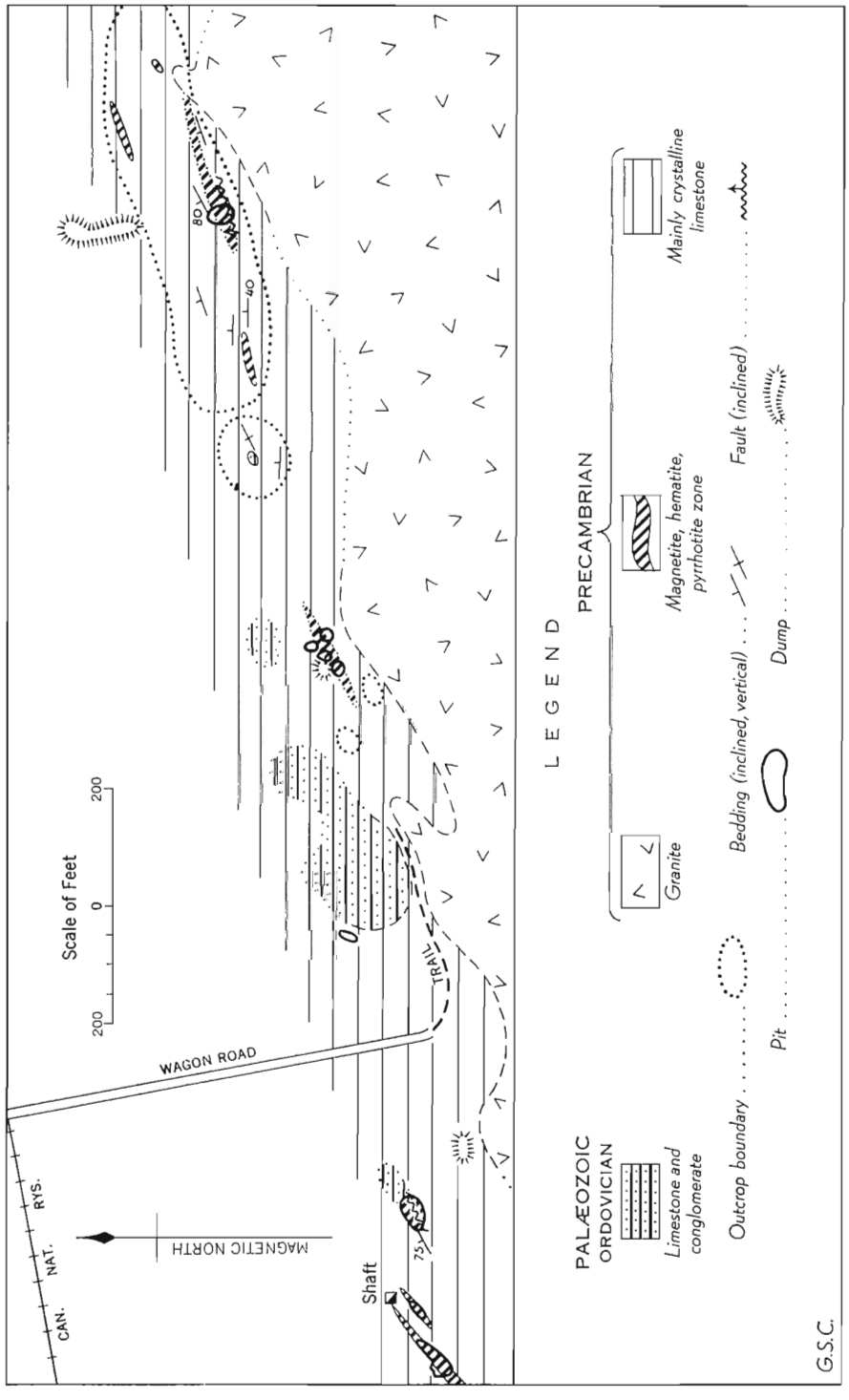

Figure 14. Hobson, Nelson and Knob magnetite-pyrrhotite deposits, Madoc township, Hastings county, Ontario.

Little Silver Lake—A small pit on the southeast shore of Little Silver Lake, on lot 16, concession IV, South Sherbrooke township, Lanark county, about 5 miles southeast of Maberly in the Perth area, represents the workings of the so-called Silver Lake mine. Other occurrences are also reported on lots 13, 14 and 15, in concession IV. Little magnetite is exposed but some good pieces may be picked from the dump.

The north shore of the lake is bordered mainly by granitic gneisses that are cut by pegmatite dykes. The southwest shore of the bay in which the mine is located is bordered by contorted crystalline limestone. Magnetite occurs on the southeast shore of the bay in dark amphibolite and metamorphic pyroxenite locally containing pink calcite.

A chemical analysis of a selected sample of ore material reported in 1899 gave 64.15 per cent iron, 1.75 per cent sulphur and 5.75 per cent insoluble matter.

Maberly—In a rock cut on the north side of highway 7 just west of McGowan Lake about 2 miles east of Maberly in Lanark county, Ontario, a band of magnetite-bearing hornblende gneiss is exposed. The surrounding country rocks are gneisses of granitic to dioritic composition with bands of crystalline limestone and amphibolite. These are cut by pegmatite dykes that in places carry tourmaline and rarely minor amounts of radioactive minerals.

Several bands of dark hornblendic gneiss trend northeasterly towards the magnetite-bearing diorite of the Foley occurrence. Magnetite occurs as fine disseminations and stringers in the hornblende gneiss, which may be the metamorphosed equivalent of the more massive diorite at the Foley deposit.

Mag Iron—This property, formerly held by Tomahawk Iron Mines Limited, is located about 20 miles northwest of Madoc on the east side of Whetstone Lake, in lot 20, concession IV, Lake township, Hastings county. It may be reached by a private road that branches west from the Hastings road north of Millbridge. The workings include the main open-cut about half a mile northeast of the east shore of the lake, and some test pits and trenches on the east shore of the lake. The open-cut measures about 250 by 25 feet and averages about 20 feet deep. Considerable diamond drilling is reported to have been done. The surface plant includes a small concentrating mill from which shipments of powdered magnetic concentrate are reported to have been made to Bristol, England, and to the United States in 1953-54. The property has been examined and reported on by Jas. E. Thomson (1943) and by T. L. Tanton (1945).

Magnetite occurs as disseminations, stringers, and bands in amphibolite and in actinolite-talc rock along with light buff-coloured feldspar and carbonates near the contact of a meta-sedimentary series on the west, and meta-diorite-amphibolite on the east. Pink felsite dykelets intersect the

amphibolite in places, and quartz veinlets in the meta-sedimentary rocks locally carry small clots of magnetite and ilmenite. A large irregular mass of granite is reported to occur a short distance to the north and east of the deposits.

Amphibolitic rocks at the contact of meta-diorite and meta-sediments are sheared and micaceous. The sheared zone, sporadically mineralized with magnetite, strikes northerly and dips about 75 degrees to the east. Slickensides on the surface of the slip planes plunge 60 degrees to the south.

In polished section some of the massive, finely laminated, bluish black magnetite shows a vague rectilinear pattern formed by faint brownish coloured bands in the massive magnetite. It contains considerable finely disseminated gangue. Very tiny veinlets of talc and carbonates and of amythestine quartz in places intersect the magnetite.

A 5-ton shipment of selected magnetite-bearing material from the main pit was analyzed by the Mines Branch (1945) and found to contain 54.91 per cent iron and 13 per cent silica. Other selected samples are reported to have shown as much as 67 per cent iron, with low amounts of sulphur, titanium and phosphorus.

Marmora—The magnetic anomaly, on which the large open pit of Marmoraton mine of Bethlehem Mines Corporation is located, lies across lots 4 and 5, concessions V and VI, Marmora township, Hastings county, Ontario, about a mile southeast of Marmora post office. A private road has been constructed south to the mine from a point on highway 7 about a mile east of Marmora.

A conspicuous magnetic anomaly shown on an aeromagnetic map prepared by the Geophysics section of the Geological Survey of Canada for the Ontario Department of Mines led almost immediately to the optioning of land in the vicinity of the anomaly, chiefly by Bethlehem Mines Corporation. Diamond drilling in 1950 and 1951 proved the presence of a large deposit of magnetite on the site of the anomaly and the company exercised its option to purchase the property. Plans were then prepared to mine the ore by open pit, and to concentrate and to pelletize it on the property. Stripping of overburden and waste rock began in March 1952. Construction of loading docks was completed at Picton in 1954, and the first shipment of pelletized concentrate was made May 11, 1955 to the company's plant at Lackawanna near Buffalo, New York. A report (1955) by H. O. Olsen, General Superintendent of the mine gives a concise account of the mine's operations.

On the aeromagnetic map that led to the discovery of the ore the anomaly appears as a southeasterly trending ellipse, measuring about three-quarters of a mile wide and a mile long. This area shows high magnetic relief and a maximum intensity of about 8,500 gammas. The open pit, which measures about ¼ by ½ mile on the surface and may eventually be 500 feet deep (*see* Figure 15), is in the northwest quadrant of the anomaly.

The deposit is overlain by about 125 feet of gently undulating sedimentary rocks, mainly grey limestone of Ordovician age, and Pleistocene glacial drift. This cover was stripped at a rate of about 15,000 tons per day, using electrically operated rotary drills, power shovels and diesel trucks. Approximately 20 million tons of waste were removed in four years.

Although the rocks and ore underlying the Palæozoic cover had not in 1953 been exposed in the pit, the results of a study of the rocks in the surrounding district and of available geological maps suggested that magnetite might occur in a lenticular, southeasterly trending, southwesterly dipping deposit in Precambrian, Hastings type meta-sedimentary rocks, at or near the contact with an igneous intrusion such as the Belmont gabbro-diorite.

Through courtesy of the company management the writer examined the pit exposures and sampled selected specimens of diamond drill core from the deposit. An irregular unconformity exposed in 1954 in the open pit of the property separated overlying relatively undisturbed Ordovician beds from underlying metamorphic rocks and ore. Drill core indicated that a sequence of impure crystalline limestone structurally overlying and intercalated with fine-grained, grey, impure meta-quartzite, all striking slightly west of north and dipping steeply southwesterly, is intruded on the west of hanging-wall side by a mass of pink to grey syenite that grades to diorite. Diorite and syenite are separated from less altered crystalline limestone of the foot-wall by thick zones of metamorphic pyroxenite-amphibolite and epidote-pyroxene-garnet skarn, all of which carry magnetite.

A lenticular deposit of magnetite ore averaging 37 per cent iron has been outlined having a length of about 2,400 feet and a maximum true thickness of about 400 feet. The deposit dips steeply southwesterly and apparently is controlled by semi-parallel bands, shear zones and breccia zones in the skarn, and perhaps by a steeply plunging fold in the meta-sedimentary foot-wall strata. At least one steeply inclined fine-grained diabase or trap dyke about 35 feet wide intersects the deposit near the foot-wall side at a slight angle to its strike. This rock is similar to fine-grained dykes associated with the Millbridge and Belmont gabbro masses. Its relationship to the Marmora syenite is not known, but it is in part altered to micaceous amphibolite, and is in part magnetite bearing. The syenite is also veined and replaced to a small extent along its margin by epidote and magnetite.

The ore consists mainly of fine-grained magnetite in disseminations and veinlets impregnating dark green, fine-grained, chloritic, epidote-pyroxene-garnet skarn and metamorphic pyroxenite. Magnetite is commonly rimmed with serpentine and accompanied by epidote. Veinlets of pyrrhotite, chalcopyrite and pyrite, of epidote, serpentine and carbonates, some with pyrite and marcasite partly altered to hematite intersect the magnetite locally. In places these veins are banded and vuggy. The vugs are lined with crystals of dog-tooth spar calcite, commonly covered with a thin sooty

or brown coating of tiny crystals of goethite on hematite. A polished surface of the ore shows that pyrrhotite, magnetite and gangue seem to replace parts of the pyrite crystals (*see* Plate VI A). Only a trace of manganese, titanium and copper appeared in spectrographic analysis of magnetic concentrate from a sample of ore from a drill core.

Mount Pleasant—A magnetic anomaly under Palæozoic cover near Mount Pleasant in Tyendinaga township, Hastings county, Ontario, about 3 miles west of Napanee, was diamond drilled by Trent River Iron Limited. A deposit of magnetite was discovered but was considered too small for present development. Drill-hole No. 1 penetrates vertically some 231 feet of flat-lying Palæozoic limestone and shale with a 3-foot-thick basal conglomerate that contains fragments of martite and hematite. This is underlain by brecciated, chloritized amphibolite and metamorphic pyroxenite in which magnetite stringers and bands are encountered from a depth of 241 feet to 440 feet. Scapolite, diopside and epidote are recognizable in parts of the mineralized zone. Magnetite is seamed with carbonate veinlets and contains sporadic disseminations and stringers of pyrite, pyrrhotite and chalcopyrite.

In polished section magnetite of medium grain size is flecked with gangue and carries some pyrite and traces of chalcopyrite. Pyrite is partly replaced by chalcopyrite, and by fine-grained magnetite, but pyrite occurs along with carbonates in a stringer that cuts the magnetite. No analyses of the magnetite are available.

Paxton—The Paxton deposit is in lot 5, concession VI, Lutterworth township, Haliburton county, Ontario, about a third of a mile north of a rough road between Kinmount and Miners Bay, off the map, but about 7 miles west of Furnace Falls. A trail leads north to the mine from a sharp southwesterly bend in this road at the foot of a steep rocky ridge composed mainly of pink gneissic granite, with bands of grey gneiss, pegmatite, amphibolite and minor crystalline limestone. The mine workings consist of two water-filled open pits with large rock dumps. About 1,000 tons of magnetite iron ore are said to have been shipped.

The two pits are *en échelon* and about 125 feet apart. In the larger of the two pits a zone of magnetite-bearing hornblende gneiss is exposed over a width of about 35 feet below a hanging-wall of pink gneissic granite, the foliation of which dips from 25 to 40 degrees southeasterly. Pink pegmatite occurs in the granite, and dykes of pegmatite probably intrude the magnetite zone. Hornblende gneiss is exposed on the foot-wall or west side of the pit. Between the pits crystalline limestone outcrops, and at the smaller pit it is intercalated with granite and pegmatite. Some magnetite occurs in a skarn zone in the crystalline limestone. Pegmatite on the dumps contains a variety of minerals including magnetite, quartz, feldspar, calcite, hornblende, diopside, black garnet and scapolite.

No chemical analyses of typical ore are available, but spectrographic analysis of an ore sample showed strong traces of titanium and manganese and a trace of vanadium. Titanium was reduced to a trace in the magnetic concentrate.

Pershing—A magnetic anomaly in Precambrian rocks beneath a Palæozoic cover was located, optioned and drilled by Trent River Iron Limited, in and near lots 1 and 2, concession IV, Belmont township, Peterborough county. This property, about 3 miles south of the Blairton deposit, and about 8 miles southwest of Marmora, was explored in 1954. As shown by diamond drill core of one hole the deposit of magnetite lies immediately beneath the Palæozoic conglomerate at a depth of about 133 feet. Magnetite occurs in an assemblage of greenstone, chloritic schist, breccia, metamorphic pyroxenite, crystalline limestone, diorite, trap and syenite. Intense and complete alteration to epidote-garnet rock is common and veinlets and breccia cement of calcite are abundant. Pyrite, pyrrhotite and chalcopyrite occur in fine disseminations and in carbonate veinlets.

The magnetite is characteristically fine grained and flecked with gangue minerals that are at places replaced by the magnetite along their edges. Tiny $\frac{1}{16}$-inch-wide veinlets of carbonates, chlorite and serpentine intersect, or fill fractures in, the magnetite. Fine-grained pyrite, pyrrhotite and chalcopyrite, are common in the magnetite but are not abundant. Polished sections show mainly fine-grained magnetite with a rare intergranular fine grain of an anisotropic mineral, possibly ilmenite or hematite.

Radenhurst and Caldwell—These workings are on the west half of lot 22, concession III, and the east half of lot 22, concession IV, Lavant township, Lanark county, about a mile north of Flower Station on the Kingston and Pembroke branch of the Canadian Pacific Railway and about half a mile east of the railway. The development consists of several small pits, a shaft and strippings extending over a distance of about 3,000 feet. The property is now controlled by Frobisher Exploration Company Limited which conducted a magnetic survey and diamond-drilling program in 1941 and 1942. Twenty-seven holes were drilled and four magnetite-bearing lenses were outlined, one about 2,000 feet long averaging about 30 feet in width. The others total about 1,600 feet in length.

The country rocks are fine-grained, hornblendic, "salt and pepper", gneisses and schists, with intercalated crystalline limestone. These are flanked on the west by a band of crystalline limestone and on the east by intrusive pink granite and granitic gneiss (*see* Figure 16). Foliation, banding and intrusions trend northeasterly and dip southeasterly. In the vicinity of the workings, gneisses and schists are most abundant with a few recognizable remnants of crystalline limestone, particularly on the west, or foot-wall side of the deposit. The gneisses and schists are impregnated with magnetite and

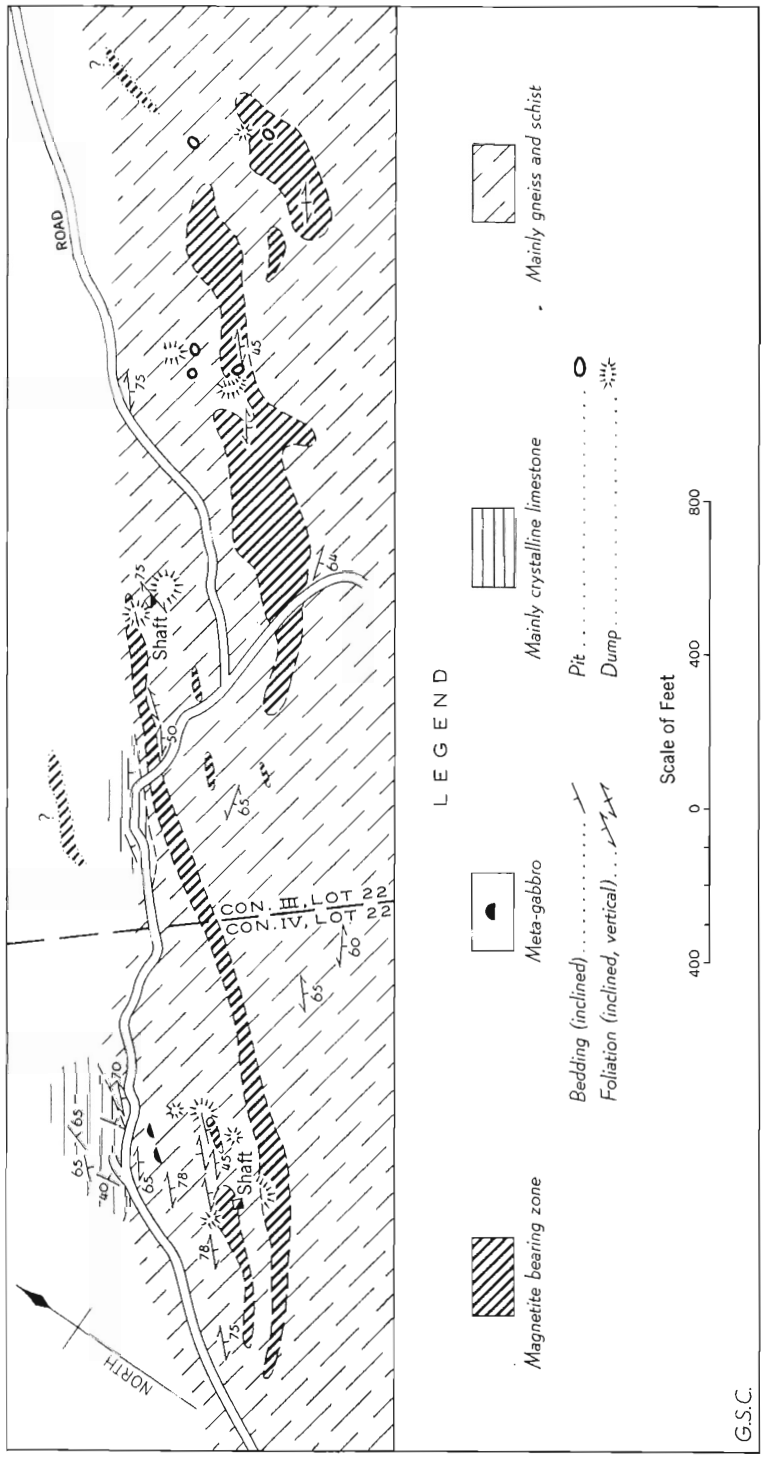

Figure 16. Radenhurst and Caldwell magnetite deposits, Lavant township, Lanark county, Ontario. (Base map after A. H. A. Robinson, 1916.)

some pyrite, and drilling has shown these minerals to be concentrated in three or four long, narrow deposits *en échelon*. The gneisses and schists are composed essentially of foliated aggregates of fine-grained quartz, feldspar, green hornblende, biotite and chlorite, with accessory apatite and zircon or sphene. Thin sections from the magnetite-bearing zone show a pleochroic green pyroxene, green-brown hornblende, biotite, carbonates, magnetite, quartz, plagioclase, epidote, apatite and scapolite. Local quartz and carbonate veinlets, with some chlorite and serpentine intersect the magnetite, as do rare microscopic veinlets of a reddish to yellowish brown mineral possibly chondrodite. Magnetite largely replaces many of the host rock minerals.

In polished sections the magnetite is seen to contain considerable unreplaced gangue and some disseminated pyrite. Pyrite tends to occur in small euhedral crystals partly embayed and replaced by magnetite. Pyrrhotite and chalcopyrite occur beside or near each other, and in some specimens near pyrite. The sulphides locally replace magnetite.

Chemical analyses of the magnetite-bearing material indicate a 1.6 per cent sulphur and 0.07 per cent phosphorus content with the iron and silica.

Radnor—The Radnor workings are on lot 16, concession IX, Grattan township, Renfrew county, about 8 miles southeast of Eganville, Ontario. They consist of long narrow, open-cuts and pits extending more than 1,300 feet in a roughly semi-circular course and these workings average about 20 feet wide and 35 feet deep. Most of the pits are now partly filled with water, but extensive dumps remain. The mine is said to have operated continuously from 1901 to 1907 during which time about 19,000 tons of ore grading more than 48 per cent iron were shipped to Radnor Forges, Quebec.

Occurrences of magnetite are also reported from the nearby Parks property, lot 16, concession VIII, and the Big Jim property, lot 17, concession X, Grattan township. These are apparently similar in occurrence to the Radnor. In 1950–51, these properties were optioned, surveyed and diamond drilled by Algoma Ore Properties Limited.

The Radnor magnetite deposit is surrounded by pink, gneissic granite that is exposed at intervals for at least a mile in all directions from the deposit; this granite intrudes and includes bands of gneiss and crystalline limestone. Pegmatite dykes cut all these rocks and commonly those dykes in crystalline limestone have mica selvages at their contacts. Another body of fresh salmon-red granite occurs about 2 miles northeast of the deposit. At the mine a long sinuous band of grey hornblende-feldspar gneiss is included within the pink gneissic granite, and the gneiss and the granite are cut by pegmatitic granite and pegmatite dykes (coarse syenite) some of which are 25 feet wide (*see* Figure 17). Magnetite occurs mainly in the grey gneiss as disseminations, stringers and bands that in places are of ore grade. Small clots and crystals of magnetite also occur in the pegmatitic

dykes that cut the magnetite-bearing zone. Such dykes have a high proportion of pink feldspars (microcline and orthoclase) and the colour of these fades to a greenish grey in a narrow zone adjacent to the intruded magnetite-bearing gneiss.

At surface the gneissosity and banding of the magnetite-bearing zone vary in dip from 25 to 45 degrees south and west, with dips in general gradually steepening from the north to the south end of the deposit. Gneissosity in the granite 50 feet from the south end of the south pit dips 75 degrees westerly, suggesting a marked steepening of dip of the southward extension of the structure. Diamond drilling has shown that the dip of the magnetite-bearing zone steepens to about 65 degrees below a depth of 150 feet.

The pink granite consists mainly of quartz, microline, plagioclase, perthitic plagioclase, and minor green hornblende with some accessory sphene, magnetite, and in places some pyrite, in part altered to hematite. Perthitic plagioclase in ragged crystals is more abundant in the grey-green contact zone of the granite than in the pink granite. The grey gneiss characteristically contains much dark green hornblende, pyroxene, plagioclase, magnetite, crystals and rounded grains of sphene, flakes of biotite, carbonates, chlorite, and rarely some tiny rusty veinlets of epidote. Magnetite occurs in $\frac{1}{16}$-inch crystals and as well seems to replace the minerals of the gneiss, mainly along planes of foliation. In a polished section of medium-coarse ore material magnetite in $\frac{1}{10}$-inch grains, carrying finely included gangue, is the main constituent. A few tiny, irregular interstitial grains of ilmenite and a rare remnant of pyrite altered in part to hematite also are present.

Rankin—The Rankin workings are on lot 10, concession IX, Mayo township, Hastings county, Ontario, about a quarter mile west of the Childs, and between it and the Bessemer. A trail south of Sharrow Creek leads west from the road to the workings, which consist of an open-cut, considerable stripping and trenching over an area about 70 by 300 feet. Frobisher Exploration Company Limited optioned and diamond drilled the deposit in 1941 and 1942 but subsequently dropped their option. The property was later taken over by Trent River Iron Limited, which made a magnetic survey and drilled two holes, but dropped their option in 1954.

The deposit lies in gneissic rocks of dioritic to granitic composition of obscure origin. Foliation strikes northeasterly and dips generally steeply southeasterly. The deposit is flanked by meta-diorite, hornblende gneiss and amphibolite. Impure crystalline limestone and amphibolite outcrop to the south, and about 3 miles to the northeast along strike of the gneiss, a group of grey to black, pebble-bearing, meta-sedimentary rocks, similar to those at Upper Hermon, are intruded by granite. Small, vague, pegmatitic dykes are present at one place in the zone containing magnetite.

Magnetite impregnates chloritic, hornblende-pyroxene gneisses and schists along planes of foliation, and forms small clots and tiny stringers in the intercalated granitic gneiss on the hanging-wall side. Considerable pyrite and pyrrhotite accompany the magnetite in places, and at the surface the magnetite-bearing rocks are oxidized to brown limonite to 1 inch in depth in places. Cross-faults with small right-hand displacement offset bands in the magnetite-bearing zone.

Robertsville and Mary—The Robertsville or Mississippi workings are on lot 3, concession IX, and those of the Mary are on lot 4, concession IX, Palmerston township, Frontenac county, Ontario, about 10 miles north of Sharbot Lake. Idle since 1895, the deposits are said to have yielded about 7,000 tons of magnetite ore. The main workings are small open-cuts, pits and adits, the largest being a pit 50 by 100 feet reported to be 200 feet deep. The property was optioned, magnetically surveyed, and tested by two diamond drill holes by Trent River Iron Limited, in 1951.

In the immediate vicinity of the main workings a group of mixed gneisses, in part of dioritic and in part of granitic composition, form most of the country rock; the foliation strikes northeasterly and dips generally about 50 degrees southeasterly (*see* Figure 18). Both coarse- and fine-grained phases are represented. A large body of pink granite is intrusive into the gneisses on the north and east sides, and dykes, veinlets and emanations from this granite have intimately penetrated and altered the gneisses. At the main workings a narrow band of crystalline limestone is included as an altered remnant in the gneisses. Magnetite occurs in pyroxene-amphibole-calcite skarn developed at the contact of this narrow limestone band and the gneiss. Epidote is abundantly developed in the gneisses near the magnetite zone, and together with pyroxene, feldspar and magnetite forms tiny veinlets that intersect the gneisses and the magnetite zone in places. Fine-grained dykes of pink felsite (granite) are present in the magnetite zone.

Extremely coarse- and fine-grained, black magnetite occur as irregular masses, 6-inch clots, and crystals as much as a half inch across, in altered epidotized gneiss, silicated crystalline limestone, and coarse, pink calcite-green pyroxene, pegmatitic skarn. Apatite, pyrite and chalcopyrite are sparingly distributed. At places in the skarn, crystals of green pyroxene as much as 2 inches long are altered along their margins to black hornblende. Magnetite also commonly rims the altered pyroxene crystals and penetrates them in tiny veinlets.

Polished sections of the magnetite-bearing material show coarse magnetite with gangue, cut by quartz-carbonate-pyrite veinlets that carry a few spots of chalcopyrite.

A chemical analysis of Robertsville magnetite showed 56.68 per cent iron and 0.046 per cent phosphorus. Spectrographic analysis of an ore

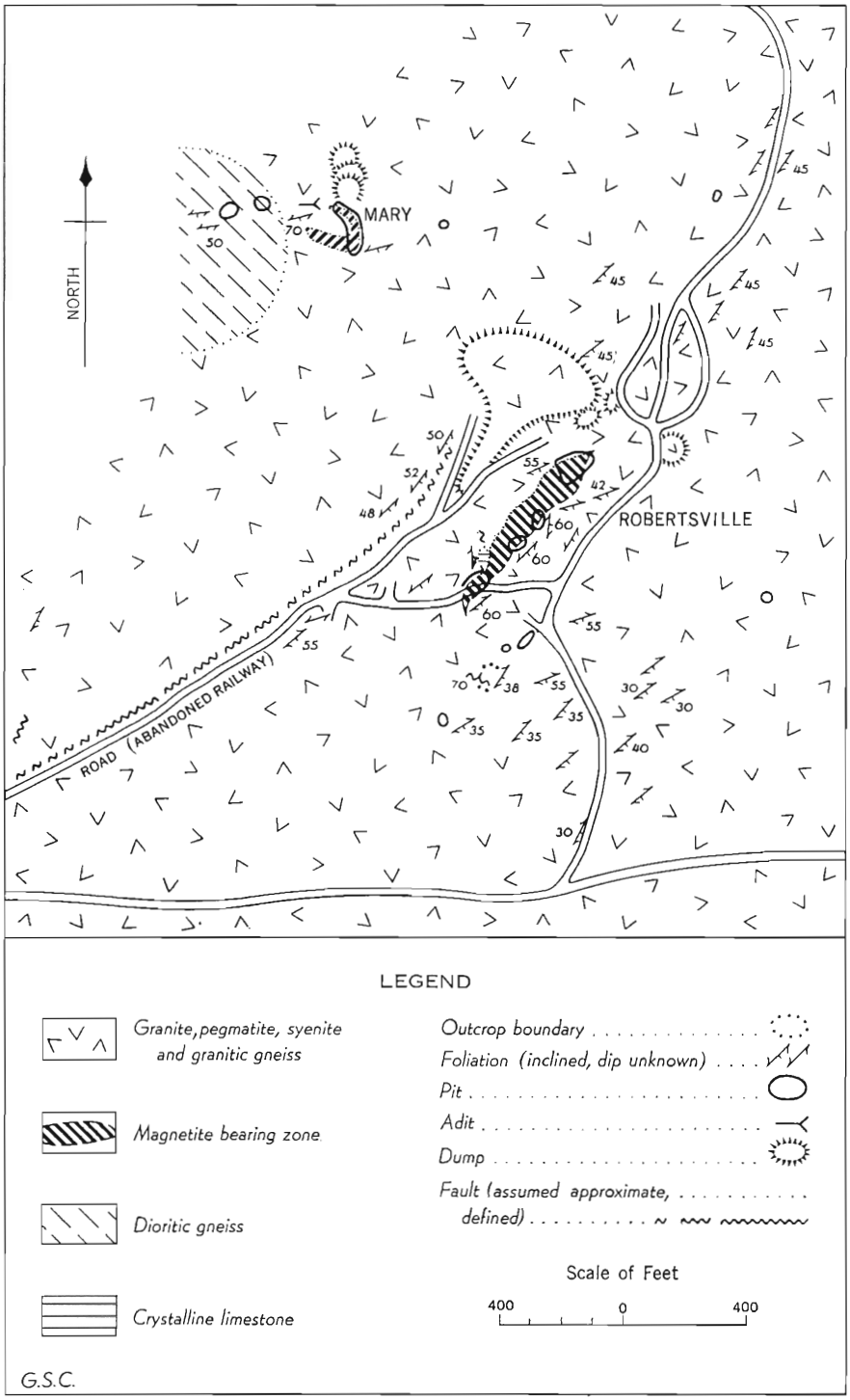

Figure 18. *Robertsville magnetite deposit, Palmerston township, Frontenac county, Ontario.*

sample showed a minor content of titanium and a trace of vanadium, which were reduced to faint traces in the magnetic concentrate.

Seymour—A deep open-cut measuring about 200 by 20 feet, in which a shaft reported to be 125 feet deep is situated, and a long waste dump, represent the Seymour workings on the west half of lot 11, concession V, Madoc township, Hastings county, Ontario, about 4 miles north of Madoc. Ore from this deposit was smelted in Madoc from 1837 to 1845. The deposit is near a long-abandoned railway line.

The easterly trending open-cut exposes dark, fine-grained, banded, flinty rhyolite and banded amphibolite. Fine-grained magnetite occurs as disseminations, stringers and bands in these rocks along with actinolite and chlorite. Tiny carbonate veinlets cut the magnetite in places. It is recorded (Johnston, 1915) that uraconite was found in fissures in the magnetite. Small trap dykes cut pink and grey banded felsite about 250 feet west of the cut.

In polished section the magnetite-bearing material shows fine-grained magnetite flecked with gangue and displays a sporadic bit of hematite or ilmenite in the magnetite. No analyses of ore material are available.

St. Charles—This deposit is on lot 19, concession XI, Tudor township, Hastings county, Ontario, about 1,000 feet west of highway 62, north of Madoc, and a short distance south of the power line that crosses the highway. Magnetite was mined from four small open pits at the turn of the century. About 3,000 tons of ore running from 57 to 60 per cent iron and 0.5 to 1 per cent sulphur are reported to have been shipped from this deposit in 1900.

The deposits lie at the north contact of the long easterly trending sill-like intrusion of Millbridge gabbro where it intrudes a narrow band of crystalline limestone and fine-grained greenstone (basalt-andesite). The contact strikes easterly and dips 45 degrees to the north (*see* Figure 19). Gabbro forms the foot-wall and crystalline limestone the hanging-wall. Fine-grained dark trap, garnet skarn, magnetite, felsite and crystalline limestone occur in a zone about 60 feet wide north of the gabbro. Brown garnet is localized in a fringe at the main contact and at the contacts of fine-grained trap (gabbro) in the crystalline limestone.

Magnetite of fine to medium-coarse grain occurs erratically in the skarn zone over a width of 50 feet and in the marginal contact rocks on both sides of the contact zone. Coarse-grained magnetite in bands with fine-grained margins occurs in the crystalline limestone on the hanging-wall. The crystalline limestone is coarser grained beside these bands than away from them. Most of the magnetite occurs as fine impregnations in the dark green trap of the contact zone. The contact zone is cut by calcite veinlets and by some sulphides including pyrite and pyrrhotite.

A sample from the magnetite zone (Lindeman, 1913) gave 42 per cent iron, 0.832 per cent sulphur and 0.08 per cent phosphorus. Spectrographic analysis showed strong traces of titanium and manganese and a trace of vanadium which were all reduced to smaller amounts in the magnetic concentrate.

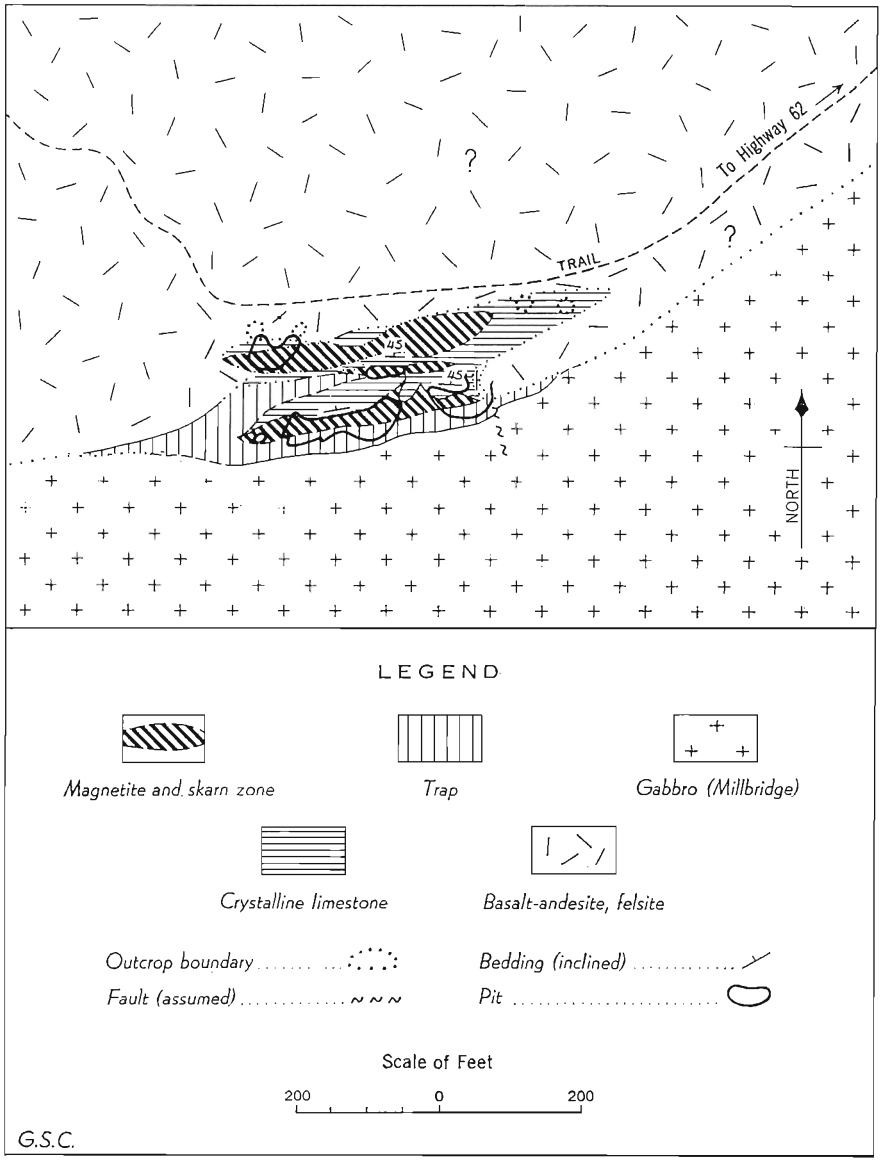

Figure 19. *St. Charles magnetite deposit, lot 19, con. XI, Tudor township, Hastings county, Ontario. (Base map after E. Lindeman.)*

Stormy Lake (New York)—On lot 27, concession XV, Glamorgan township, Haliburton county, Ontario, about 6 miles north of Gooderham, several well-defined veins carrying magnetite occur in a body of pink biotite granite-gneiss, a short distance north of Stormy Lake and about 500 feet south of the foundation ruins of a school house beside the abandoned road that followed the concession line. This is probably at or near the location of the so-called New York mine where a pit was sunk by C. J. Pusey about 1880.

Between 500 and 700 feet south of the road three or more semi-parallel veins cut the biotite granite-gneiss almost at right angles to the northwesterly trending gneissosity. A few small granitic dykes also cut the gneiss. The veins dip 65 degrees northwesterly. The most northerly vein contains an irregular vug, about 8 inches wide at the surface, lined with crystals of biotite, magnetite and feldspars. A few feet south of this a second vein, about 4 feet wide at one point, traceable for about 150 feet in length consists mainly of coarse-grained magnetite (in part lodestone) and pink calcite with feldspar, biotite and apatite. About 150 feet farther south a third vein is exposed in two small pits where calcite and biotite predominate with some apatite and a little fluorite. Other veins of similar nature probably occur in the vicinity. The veins present sharp contacts against the gneiss. They might be considered as calcite pegmatites.

Spectrographic analysis of a sample of the magnetite showed minor titanium, a strong trace of manganese and a trace of vanadium. In the magnetic concentrate of this, titanium and manganese appeared only as traces, and vanadium as a faint trace.

Victoria—The Victoria deposit is on lot 20, concession I, Snowdon township, Haliburton county, Ontario, about 8 miles southwest of Gooderham. Magnetite was mined before 1883 from a trench-like open-cut about 25 by 200 feet in area and, at the time of examination, partly filled with water. A few small pits were also sunk about 500 feet to the northwest.

Both sides of the open-cut expose crystalline limestone, the layers of which strike west-northwest and dip 65 to 75 degrees northerly. The limestone, with some interbands of gneiss, outcrops at intervals to the Peterborough county line on the south. Southward from the pit the layers in the crystalline limestone maintain their northwesterly strike, but their dip flattens to about 15 degrees northeasterly at the county line. The hanging-wall (north side) of the magnetite-bearing zone consists mainly of hornblende-feldspar gneiss with disseminated magnetite and to the north this is followed by rusty granitic gneiss (*see* Figure 20).

Magnetite occurs in a zone at the contact of crystalline limestone and hornblende-feldspar gneiss and at places in both of the adjoining rocks. A skarn assemblage of coarse magnetite, carbonates, pyroxenes, hornblende

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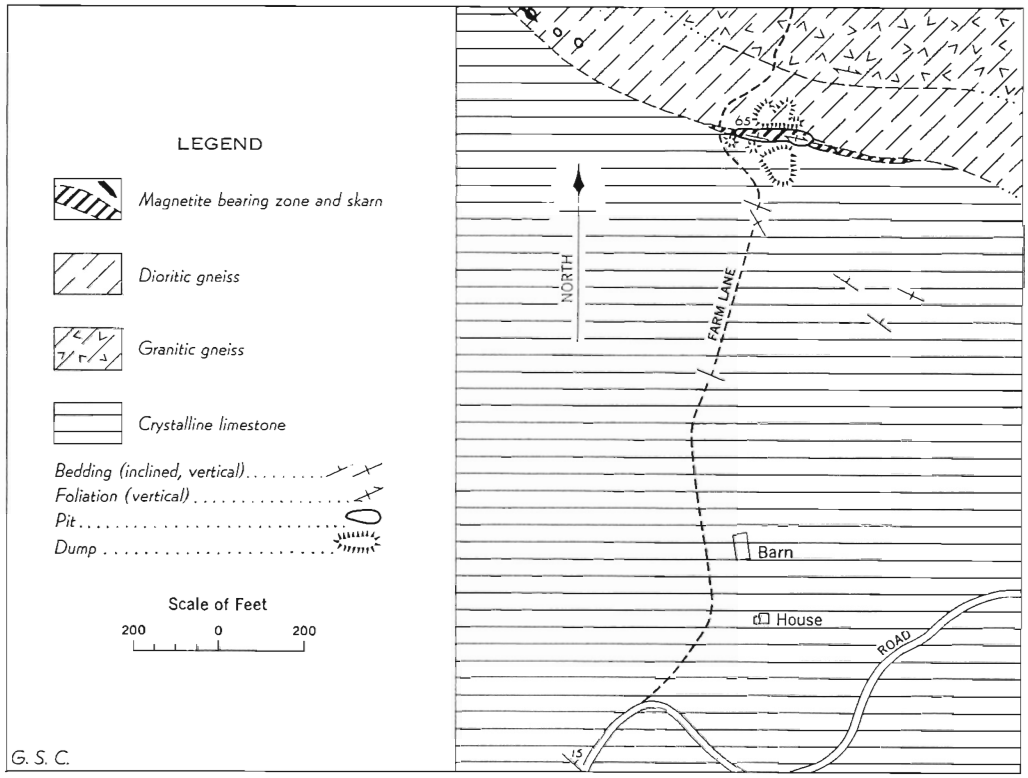

Figure 20. *Victoria magnetite deposit, Snowdon township, Haliburton county, Ontario.*

and garnet is developed in the contact zone. Magnetite is exposed in a shallow trench at the east end of the open-cut, but at the west end of the cut little magnetite is visible in the gneiss. It is recorded (Johnston, 1915) that uraconite was observed in minute cavities in the magnetite.

A chemical analysis of a specimen of magnetite-skarn by Chapman gave about 60 per cent iron, 11 per cent silica, a little magnesium and calcium, and traces of titanium, aluminum, manganese, sulphur and phosphorus.

Wilbur—The Wilbur workings are on lot 4, concession XII, and lot 4, concession XIII, Lavant township, Lanark county, Ontario, about a half mile east of the Kingston and Pembroke branch of the Canadian Pacific Railway, and about 18 miles north of Sharbot Lake. Several shipments of magnetite were made before work was finally abandoned about 1911. The workings consist of fairly large open pits, shafts, and shallow pits. A hydro-electric power line crosses the property.

In general, the magnetite deposits lie in lenses along, or near, the sheared contact of crystalline limestone on the northwest, and pink granite and granitic gneiss on the southwest. The contact curves from north to east but for the most part it strikes northeasterly and dips steeply southeasterly. The crystalline limestone and its intercalated bands of amphibolite are drag-folded, sheared, and faulted with left-hand displacement; granite and magnetite are also partly sheared. Some drilling was done on the deposit prior to 1900, but records are not available. Ingall (1899) recorded that ore was encountered in the drilling, as well as thick zones of epidote, chlorite, and talcose schistose material. Veinlets of carbonates, actinolite, chlorite, mica and serpentine cut the magnetite in places, and in thin sections magnetite grains are seen to be commonly rimmed with these minerals. Polished sections of ore material show a medium-coarse mosaic of $\frac{1}{20}$-inch magnetite grains and some gangue, cut by $\frac{1}{16}$-inch veinlets of carbonates, carrying some fine-grained magnetite in their central parts.

Williams—The Williams or Black Bay deposit is on lot 22, concession XI, Bagot township, Renfrew county, Ontario, about 2 miles northwest of Calabogie. Shipments of about 10,000 tons of magnetite iron ore are reported to have been made to Cleveland, Ohio, prior to 1910. Ingall (1899) reported that the workings penetrate from 10 to 80 feet. A shaft was also sunk on the hanging-wall side.

Medium-coarse to fine-grained magnetite, with red hematite and bluish martite apparently as alteration products, occurs in disseminations, stringers and bands, in a lenticular deposit, or series of deposits, along the contact of crystalline limestone (foot-wall) and diorite-amphibolite (hanging-wall), and in the immediately adjacent contact rocks. A light-coloured banded "skarn" zone composed essentially of pyroxene, hornblende, carbonates and magnetite is found at the contact, which strikes northeasterly and dips about 40 degrees northwesterly (*see* Figure 21).

A thin section from the "skarn" zone shows coarse green hornblende in ragged crystals partly altered to chlorite, twinned carbonates (in part strained), magnetite and brownish epidote. Polished sections of ore material showed an intimate mixture of fine-grained magnetite and gangue, and some disseminated pyrite, pyrrhotite and chalcopyrite. A veinlet banded parallel to its walls with jasper, and carrying specks of magnetite, hematite and gangue, cuts the magnetite. Sulphides appear to be more abundant near this veinlet than elsewhere in the deposit. A section of porous reddish hematite and bluish martite from a central pillar shows much fine-grained magnetite in a gangue of brownish carbonate that is flecked with magnetite.

A chemical analysis of a sample reported in 1899 showed 51.89 per cent iron, 0.016 per cent phosphoric acid and 15.95 per cent insoluble matter.

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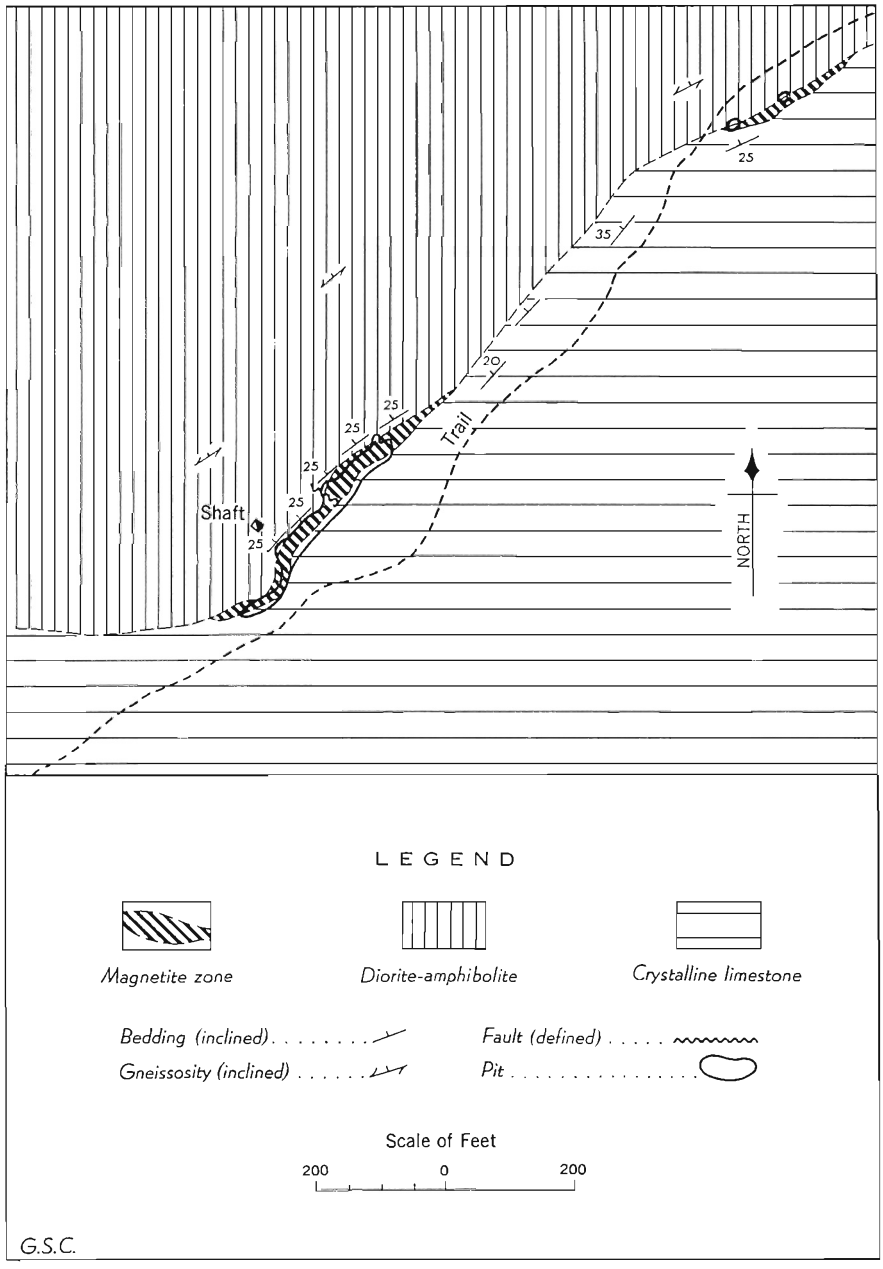

Figure 21. *Williams or Black Bay deposit, Renfrew county, Ontario. (Base map after E. Lindeman.)*

Yuill—The Yuill open-cut is located on a rocky bush-covered hill about a quarter mile east of Broad Brook in the east half of lot 25, concession V, Darling township, Lanark county, Ontario, south of White Lake, in the Calabogie area. The cut measures about 90 feet long by 30 feet wide at the west end and 15 feet wide at its east end. It averages about 30 feet deep, but at the west end it is much deeper than average and is there filled with water. Most of the ore has been removed from the low dump at the west end of the cut.

John A. Craig kindly guided the writer across his farm to the deposit. He recalled that the workings had been started before 1890 and had remained idle until 1898 when the magnetite on the dump was contracted for, and moved overland by wagon in winter to Mile Lake siding, from whence it was shipped by rail to Hamilton. The pit is thought to be 80 feet deep.

The cut trends easterly along the contact between contorted crystalline dolomitic limestone on the south and fine-grained meta-gabbro on the north. The crystalline dolomitic limestone contains a few silicate minerals near the contact with meta-gabbro. The limestone dips steeply southward at the contact and magnetite apparently follows the parallel banding of the limestone and the contact. Quartz veinlets cut both rocks at the west end of the cut. At the east end of the cut a nearly massive band of magnetite 2 feet wide is exposed between silicated crystalline dolomite and fine-grained meta-gabbro. At the contact the crystalline dolomite on the hanging-wall is sheared and there contains magnetite. The contact of the magnetite band and meta-gabbro on the foot-wall is sharp. The magnetite-bearing rock is commonly fine grained and low in sulphides. It is reticulated in places by veinlets of calcite and silicates, and seams of chlorite. Some of the magnetite is massive and has a marked platy or blocky structure, which seems to be the reflection of a rectangular joint pattern shown in the meta-gabbro but better developed in the magnetite. Some of the magnetite is natural lodestone. Dip-needle readings indicate that some magnetite remains near the pit, but the aeromagnetic survey map shows no marked anomaly.

In polished section ore material showed a fine-grained aggregate of magnetite and silicate gangue, with sporadic grains of pyrrhotite, and all are cut by a few tiny carbonate-silicate veinlets. Some of the magnetite grains are flecked with microscopic blebs and rods of a mineral too small for identification that may be hematite or ilmenite.

An analysis of a sample reported in 1899 gave 62.42 per cent iron, 0.01 per cent phosphorus and 9.11 per cent insoluble matter.

Hematite Deposits

Belmont Lake Iron-Formation—An occurrence of iron-formation ("jaspilyte") is described by Miller and Knight (1914), about 8 miles northwest of Marmora, on lot 20, concession IV, Belmont township, Peterborough

county, Ontario, just east of the road, and about a quarter mile west of Deer River on the northwest side of Belmont Lake. The iron-formation is described as a belt about a quarter mile long by 50 or 60 feet wide resting with sharp contact on Keewatin-type schist. Another smaller band is reported to be interbanded with calcite and is shown in crystalline limestone just east of the bridge over Deer River.

A lens of siliceous rock resembling a quartzite and banded with hematite (both red and specular varieties), magnetite and quartz, and apparently enclosed in chloritic greenschist, was found at the first locality. The rock is composed essentially of a banded quartz mosaic replaced by seams, clots and disseminations of magnetite with red and specular hematite that follow the regional northeasterly strike and steep southeasterly dip of the quartzite and enclosing schists. An analysis of a richer part of the "iron-formation" by Miller and Knight (1914) gave 24.06 per cent iron, 0.024 per cent sulphur and 0.126 per cent phosphorus. A smaller band of similar material is overlain structurally by crystalline limestone at the Deer River locality.

Eldorado Iron-Copper—The Eldorado Copper mine on lot 17, concession V, Madoc township, Hastings county, Ontario, about 6 miles north of Madoc, was formerly known as the Moore mine and was originally worked for hematite. The deposit is about a half mile west of Eldorado village and a short distance north of the railway track. The workings consist of two deep open pits and several cuts with large dumps of ferruginous rock and slag. The main pit is circular, sheer, and about 30 feet deep from the surface to the water level. The pit is said to be 75 feet deep and below this a shaft was sunk 75 feet with three underground levels extending from it. Drifts on these levels are reported to extend about 175 feet along the easterly strike of the hematite-bearing zone.

Pink granite cut by amethystine quartz veins forms the north or hanging-wall side of the deposit, and crenulated grey crystalline limestone of the metamorphosed Hastings type forms the foot-wall. The iron minerals occur at the contact of the two rocks in zones parallel to the banding of the limestone and striking easterly and dipping 52 degrees to the north (*see* Figure 22).

It is reported (Corkill, 1906) that hematite passed downward into chalcopyrite and pyrite, with chalcocite, at depths varying from 60 to 80 feet below the surface. The sulphides were mined subsequently as copper ore.

Red hematite may be observed in a zone on the east wall of the main pit, a green malachite stain on the south wall, and dark martitic magnetite on the north side or hanging-wall. Veins of vuggy, coarsely crystalline quartz, the vugs lined with tiny magnetite crystals, cut the martite as do carbonate veins. Hematite stain is evident on both quartz and carbonates in these veins.

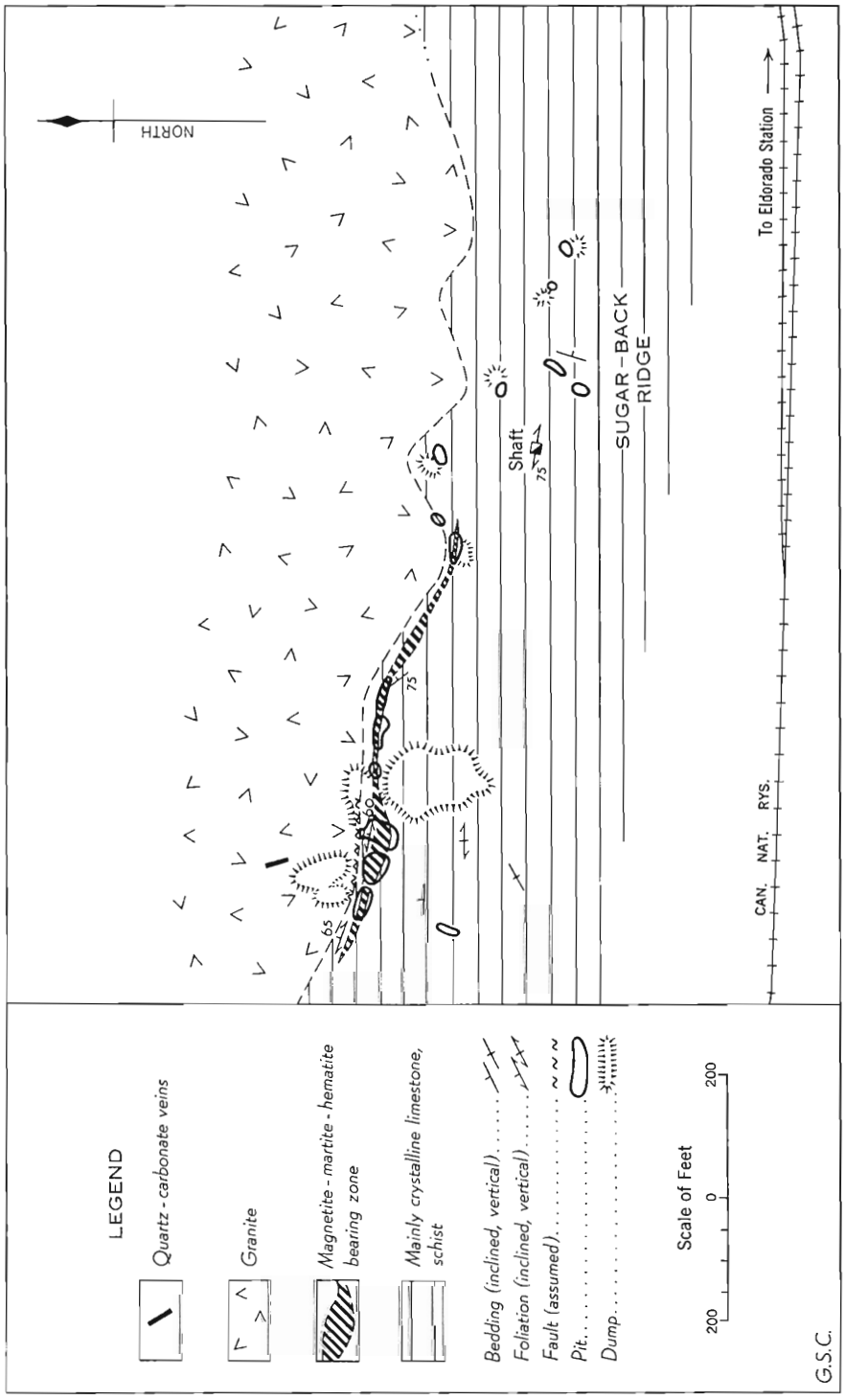

Figure 22. Eldorado iron-copper deposit, Madoc township, Hastings county, Ontario.

Minute disseminations of sulphides, chiefly pyrite and chalcopyrite, occur in the martite of the hanging-wall, and in the crystalline limestone of the foot-wall. Some of the coarse carbonates show an apparent alteration to red hematite and are, in places, stained red with hematite, or green with malachite. In some specimens from the dumps, chalcopyrite is fresh or altered surficially to malachite, and some chalcopyrite is rimmed with red hematite, or forms a tiny core in red hematite. The hematite may in turn be rimmed with green malachite. A polished section of martitic magnetite shows a fine-grained dissemination of a pale brownish tinted, hard, magnetic, isotropic to very weakly anisotropic martitic magnetite, with a few blades of more strongly anisotropic martite or hematite, in a silicate-carbonate gangue (*see* Plate VII B). Several tiny grains of pyrite in reticulating quartz veinlets are rimmed and in part replaced by magnetite, forming oval-shaped granules in the martite. Under high magnification some chalcopyrite in minute particles was observed in the magnetite rim and also in the pyrite nucleus of one of the granules. Quartz and martite both seem to replace to a limited extent the margins of magnetite granules.

Red hematitic material from the foot-wall is strongly magnetic, evidently due to finely dispersed magnetite. It gives the pattern of hematite in X-ray powder photograph. In the magnetic concentrate from this, aluminum was reduced to a trace, silicon, magnesium, calcium and titanium to faint traces, and vanadium, cobalt and strontium were eliminated. Spectrographic analysis of a sample of martitic magnetite yielded major iron and silicon, minor magnesium and aluminum, a strong trace of titanium, traces of vanadium and manganese, and faint traces of cobalt, copper, calcium and barium. In the magnetic concentrate from this, aluminum was reduced to a strong trace, silicon and magnesium to traces, titanium and manganese to faint traces, and vanadium and cobalt were eliminated.

Martite of a similar nature to that at the Eldorado was noted at the Blairton (Derrick pit), the Dominion (Bankers Lake), the Williams (Black Bay) and the Bristol deposits, and some in the fragments in Palæozoic conglomerate near some of these deposits.

Playfair—The Playfair or Dalhousie workings are located on lot 1, concession IV, Dalhousie township, Lanark county, Ontario, about 10 miles northwest of Perth, on the north side of Mississippi River east of Sheridan's Rapids. The property is crossed by a side road. Several thousand tons of high-grade hematite are reported to have been shipped from this deposit to the United States shortly after Confederation. The main workings appear to have been a long, narrow open-cut, a smaller parallel cut, and several pits and shafts with underground drifts. The workings extend over a length of 1,600 feet, and a width of about 20 feet at surface; at the northern extremity, on a knoll of crystalline limestone, is an open steeply inclined shaft, (*see*

Figure 23). On a plan of the mine dated at Perth, 18th July, 1873 (*see* Ingall, 1899) this shaft is shown to be 94 feet deep, of which the lower 60 feet are indicated to be in ore.

The country rock of the area is dolomitic crystalline limestone, the beds of which strike northeasterly and dip steeply southeasterly. It carries some tremolite and talc and is stained and replaced in part by hematite near the shaft and pits. To the east of these workings a few beds of brecciated quartzite are intercalated with the crystalline limestone. To the southeast some rusty gneiss and a band of trap are exposed.

In the workings that follow the regional trend of the rocks, some shearing and light brecciation of the crystalline limestone are marked by zones of soft, chloritic, and micaceous schist, and impregnations of red hematite. At the north end of the main cut the hematite body rakes northerly under the crystalline limestone, and hematite was intersected in the shaft 40 feet to the north. A 2-foot-wide fragment of pyrite in quartz from beside the site of the southernmost shaft displays a net or box-work structure. In addition to hematite this zone contains some pinkish carbonates and a coarse white carbonate that is surficially stained red and replaced in part by hematite.

Thin sections of rocks in the hematite-bearing zone show hematite, and a variety of minerals including carbonates, tremolite, biotite, quartz, epidote, chlorite and serpentine. In a few places small grains of hematite are filmed with carbonates succeeded by hematite. Elsewhere a few small grains of pyrite are fractured and rimmed with hematite, and in other places by limonite, and limonite with hematite. A section from a pyrite-quartz boulder shows brecciated crystalline pyrite cemented and veined by quartz and minor amounts of carbonates. Hematite was noted as a light stain in one part of the section of the quartz-carbonate matrix only around small remnants of pyrite. A polished surface of porous, hard, blue-red hematite shows a box-work, cellular structure with hematite replacing gangue enclosed in this box-work.

St. Charles (hematite)—An abandoned pit measuring about 200 feet long by 20 feet wide and 20 feet deep, represents the St. Charles workings on lot 4, concession VI, Madoc township, Hastings county, a short distance north of Madoc, Ontario. The pit exposes a narrow, irregular, north-trending lens of altered, hematite-bearing carbonate rock, between pink rhyolite (fine-grained granite) on the west and dark felsite-rhyolite and granite on the east.

Red hematite occurs as an alteration product of ferruginous carbonate and magnetite in vuggy zones that are lined with crystals of specularite, martite and some magnetite. Some of the carbonate rock contains bands of hematite and these on surface are altered to limonite. Quartz veins and calcite veins cut the hematite-bearing zone, and in places the carbonate veins carry specularite. Chloritic bands and seams occur in the hematitic

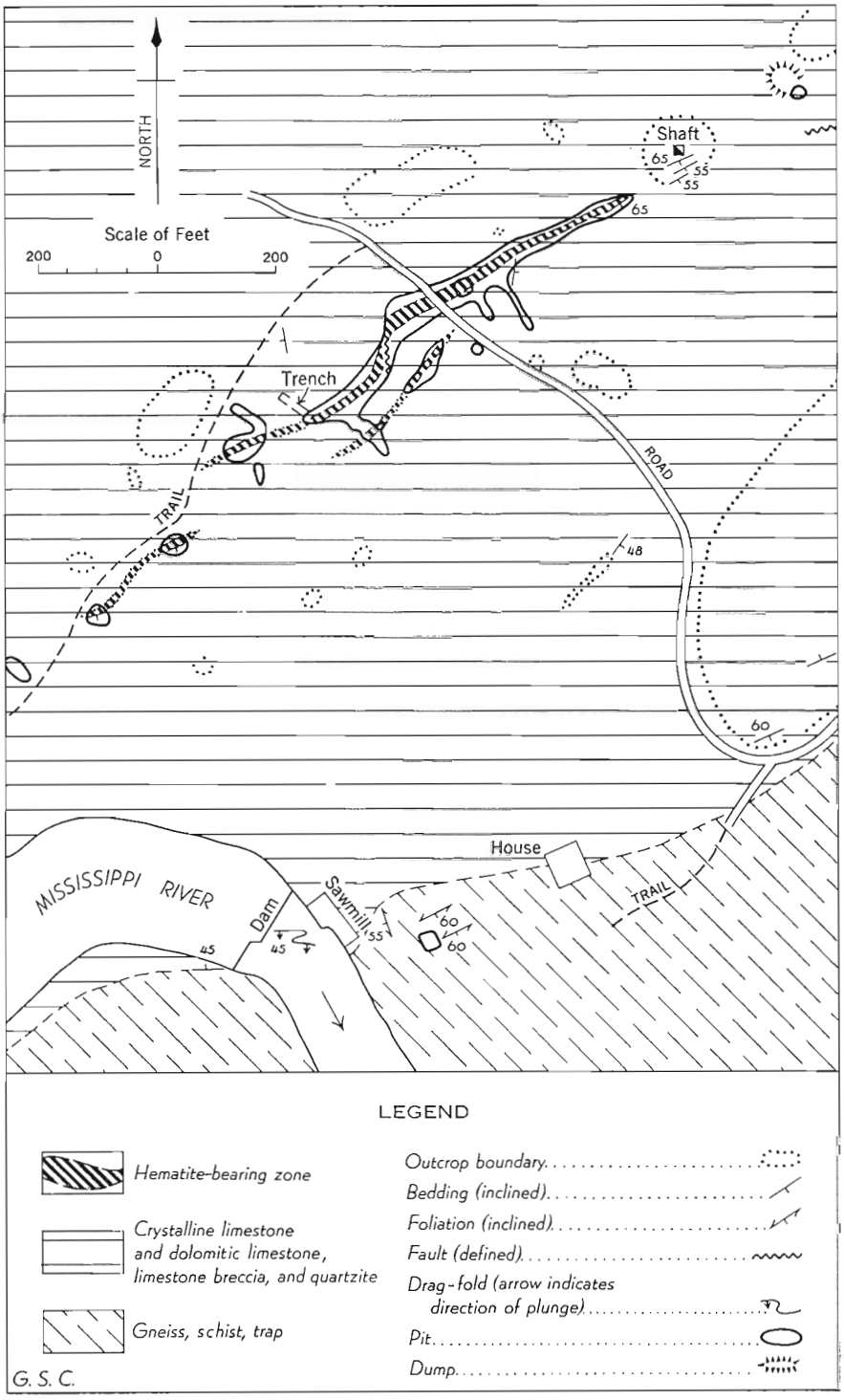

Figure 23. **Playfair or Dalhousie hematite deposit, Dalhousie township, Lanark county, Ontario.**

parts of the carbonate rock. Some of the red hematite contains disseminated partly altered, crystals of magnetite.

In polished section fine-grained hematite is flecked with carbonate gangue, and in addition includes coarse crystals of magnetite that are in part, or completely, altered to martite. Pisolitic hematite occurs in larger-than-average-sized grains around the margins of irregular vugs that are filled with calcite and in part with quartz.

No record of production or grade is available.

Wallbridge—The Wallbridge deposit is situated on lot 12, concession V, Madoc township, Hastings county, on the west side of highway 62, about 4 miles north of Madoc, Ontario. Little is known about the deposit except that a considerable amount of red hematite iron ore was mined before 1900 from an open pit 60 feet deep. A shaft extended 35 feet below the bottom of the pit and some drifting was done. The deposit was described as a large mass of hematite in dolomite with no defined wall. The occurrence was diamond drilled by Trent River Iron Limited in 1952.

The open pit is rudely circular, about 140 feet in diameter, and is sheer about 30 feet to water level. On the north side creamy buff ferruginous crystalline dolomitic limestone is exposed and this is overlapped on the south and east by chloritic, iron-stained arkose, dolomite conglomerate (with hematite fragments), and grey dolomitic limestone of Ordovician age. The beds of the Palæozoic rocks strike easterly and dip gently southerly. Crystalline limestone outcrops to the north and pink granite a few hundred feet to the south.

Faint banding in the crystalline carbonate rocks strikes easterly and dips steeply south towards the pink granite. In drill core the granite appears to be transitional through a grey, syenitic zone to impure crystalline carbonate rocks. Many varieties of marble were intersected, ranging from pure whites and greys, to buff, and from pure carbonate to serpentine and ferruginous types.

Hard and soft red hematite as mined apparently occurred in a large pocket in the crystalline carbonate rocks, at or near the contact with overlying Palæozoic rocks. A narrow band of soft red hematite was intersected in the crystalline carbonate rocks about 20 feet below the Palæozoic contact in a drill hole east of the main pit, so the hematite here is not entirely confined to the Palæozoic-Precambrian contact, in fact most of the hematite occurs within the Precambrian rocks.

Pieces of ore from the dump show fine-grained, hard, red hematite with vugs, some of which are lined or filled with specularite, magnetite, goethite and calcite crystals. Goethite or calcite commonly partly coat the tiny crystals of specularite and magnetite in the vugs. Coarse carbonates are locally coated and partly replaced by red hematite. In the buff marble

to the north of the pit, small pockets and grains of red hematite seem to have resulted in part from alteration of disseminated chalcopyrite and pyrite.

White Lake—Several occurrences of hematite have been reported (Quinn, 1952) east of White Lake, in Darling township, Lanark county, Ontario. The western shore of White Lake is formed mainly of pink granite, and the eastern of crystalline limestone.

Two of the hematite occurrences were located, namely the old Fahey or Bell mine, and a deposit on lot 23, concession XI, Darling township. These deposits are poorly exposed in test pits and trenches. The hematite appears to represent essentially replacement veins in crystalline limestone. At the Fahey occurrence some tremolite occurs in the crystalline limestone adjacent to the hematite-bearing zone which contains a medium-coarse, blood-red rock with jaspery red phenocrysts of quartz and hematite. Some of the jasper shows hexagonal crystal zoning and such crystals are rimmed with fine carbonates, and intersected by carbonate veinlets. Such jasper fragments are cemented in a coarser grained carbonate matrix containing warped muscovite flakes and quartz grains. Matrix and veinlets contain red hematite dust.

Hard, fine-grained, bluish red hematite occurs in the other deposit in a replacement zone about 10 feet wide in brecciated crystalline limestone. A polished surface of this hematite-bearing material shows mainly hematite replacing a very fine-grained gangue in a cellular, box-work structure.

Chapter IV

Mineralogy and Magnetic Anomalies

High Titanium Magnetite Deposits

The magnetite deposits of this class occur as irregular pods, bands, veins and disseminations in gabbro and gabbroic anorthosite. These rocks commonly carry less than 25 per cent iron, but locally reach this grade mainly because of their titanmagnetite content. The titanium content of these deposits commonly ranges from more than 1 to about 10 per cent but in some deposits is less than 1 per cent. It is present in the form of ilmenite, titanmagnetite, sphene, and other silicate minerals such as titanaugite and biotite.

Those of the group that contain more than 3 per cent of titanium, especially the Blessington, Blithfield, Chaffey, Matthews and Orton, commonly carry discrete grains of ilmenite, as well as of titanmagnetite, along with silicate gangue minerals including intermediate to basic plagioclase, pyroxene, hornblende and biotite. Microscopic exsolution intergrowths may be present in the iron-titanium oxide minerals, as at the Orton and at the Matthews occurrences where Cousineau (1940) described blades of ilmenite in magnetite, and minor fine blades of hematite in ilmenite. Sub-microscopic intergrowths of ilmenite in magnetite possibly account for some of the titanium content of the remainder of the deposits. Tiny clots of pyrite may be disseminated through the rock, and at the Blithfield occurrence titanmagnetite is cut by veinlets of pyrite and calcite as much as a half inch wide. Apatite and scapolite also occur as gangue minerals in some of the deposits.

Low Titanium Magnetite Deposits

Most of the magnetite deposits of eastern Ontario and adjoining Quebec contain less than 1 per cent titanium. This is carried mainly in solid solution in magnetite and in sphene, but in a few of the deposits rare grains of ilmenite and exsolution intergrowths of ilmenite in magnetite occur. Rare interstitial grains of hematite also occur with the magnetite. Because of the different modes of occurrence a variety of gangue minerals are found. The most common host rock is amphibolite in which case the gangue minerals include amphiboles, pyroxenes, feldspars, quartz, carbonates, epidote, chlorite, talc and serpentine. In skarn and tactite zones at crystalline limestone contacts, dark garnet of the andradite group, pyroxene, epidote and carbonates predominate, and in deposits within crystalline limestone, carbonates, diopsidic pyroxene and amphiboles are the main gangue minerals. Many of these deposits are near or in, what appears at one time to have been diorite.

However, widespread high-grade regional metamorphism obscures the nature of the original rock and makes it difficult to distinguish between regional and contact metamorphic effects and those alterations produced during the deposition of the magnetite.

In one place at least, magnetite occurs as 2-inch crystals in a calcite-feldspar-mica "vein-dyke". In many places magnetite, epidote, chlorite and serpentine occur together and appear to have been developed after the garnet. In several deposits magnetite is sheared, polished and slickensided along fault surfaces, or is brecciated and cemented by carbonates. Pyrite, pyrrhotite and chalcopyrite are disseminated through the deposits and also occur in stringers and veinlets that penetrate the magnetite. Of the three sulphide minerals pyrite is most abundant. In places it occurs in coarse cubic crystals that are fractured and in part replaced by magnetite, and also by pyrrhotite and chalcopyrite suggesting some overlapping in age of the minerals. Pyrite and rarely magnetite also occur in some of the carbonate veinlets that cut the magnetite, in which case the pyrite is commonly colloform and in part altered to red hematite.

Martite and red hematite occur as surface cappings and in the weathered zones of some of the deposits. Martite replaces magnetite both marginally and in the centres of grains. It retains some of the outward appearance of magnetite and some of its magnetism, due to included remnants of unaltered magnetite, and passes gradationally to red hematite.

Hematite Deposits

The iron deposits in this class include hematite, hematite-martite, and hematite-martite-magnetite occurrences, the last being similar and perhaps transitional to the magnetite-martite-hematite assemblages that cap some of the magnetite deposits. Hematite occurs in replacement veins, lenses and pods, apparently of secondary origin in zones of altered ferruginous rock where it commonly replaces pyrite, chalcopyrite, iron-bearing carbonates and magnetite. The hematite is in several forms, soft red, hard red, specular and martite. Most of it is found in Precambrian rocks at or near the contact with Palæozoic sedimentary rocks, but some occurs in the Palæozoic rocks and is of Palæozoic age. The basal Palæozoic beds commonly carry cobbles, pebbles and grains of hematite of martitic character, and are stained red by hematite derived from these fragments and from the underlying iron deposits.

These deposits contain iron mainly in the form of hematite, but may also contain martite, iron-bearing carbonates and sulphides, and magnetite. They commonly hold betwen 0.1 and 0.01 per cent titanium. This is probably carried mainly in the martite and hematite, as spectrographic analyses of magnetic concentrates of hematite-martite-magnetite material showed less titanium than the unconcentrated materials, but traces of titanium are also present in the magnetite.

Gangue minerals include quartz, carbonates, tremolite, chlorite, pyrite and chalcopyrite. Hematite is apparently secondary after pyrite and chalcopyrite, and martite after magnetite. Pyrite is rimmed and replaced by magnetite where it is present. Quartz veins and calcite veins carrying tiny crystals of magnetite and specularite cut the martitic magnetite in places. Vugs in these veins have pisolitic hematite and hematite films on the crystal faces. Small vugs in red hematite may be filled with calcite or be open and lined with tiny crystals of magnetite, specularite, jarosite(?), goethite and calcite.

Hematite was noted in calcite veins cutting the magnetite to a depth of at least 400 feet in drill core at the Glendower deposit, and to comparable depths in several other occurrences. At the Bristol (Hilton mines) deposit in Quebec a quarter-inch seam of magnetite, with selvages of actinolite-tremolite, talc, phlogopite and reddish brown carbonates, is intimately altered in part to red hematite at a depth of 264 feet.

Magnetic Anomalies

In a very strong magnetic field all minerals are influenced by the magnetic force, those that are attracted being called paramagnetic and those that are repelled diamagnetic. Paramagnetic substances include iron, cobalt, nickel, manganese and platinum, and diamagnetic minerals include calcite, zircon, wulfenite, etc. Morley (1952) defined ferromagnetic materials loosely as those which have magnetic properties similar to iron. He noted that it is sometimes difficult to distinguish ferromagnetic from paramagnetic substances as they also have a positive magnetic effect. Iron, cobalt, nickel, some of their alloys, and some seventeen minerals are ferromagnetic. The most common ferromagnetic minerals are magnetite, pyrrhotite, ilmenite and hematite. Of these magnetite is most strongly ferromagnetic, exhibiting four times the susceptibility of pyrrhotite, ten times that of ilmenite and twenty times that of hematite (Morley, 1952). Because of its magnetic strength and abundance, therefore, magnetite largely controls the magnetic properties of most rocks.

Magnetic anomalies are produced in areas of relatively high or low magnetic attraction and are mainly due to increase in abundance or mass of ferromagnetic minerals in the rocks below. In addition to the magnetism being induced by the present terrestrial field in its own direction, such rocks or ores may possess a remanent magnetism induced during the crystallization of the rock by the magnetic field then existing, which may add to or detract from the induced component. Strong remanent magnetism is acquired as the crystals cool to lower temperatures through their Curie point, which for magnetite is about 580°C. The direction and strength of the remanent magnetization depends on the direction and strength of the magnetic field then applying, modified as it is by pre-existing magnetic substances, and on the permeability of the crystals. In some cases remanent magnetism exceeds

induced magnetism. A measure of remanence called crystallization remanence can be given also in the temperature range from 100°C. to 500°C. (Morley, 1952).

Other factors affecting magnetization are magnetic anistropy, crystal structure, exsolution intergrowths, strain and impurities in single crystals and crystal aggregates, concentration and grain size in rocks.

A smaller negative magnetic anomaly should occur to the north of a positive anomaly in the northern hemisphere. Negative anomalies associated with positive anomalies may be caused by inversions of polarity or by areas of low susceptibility. Negative anomalies isolated from positive anomalies may be caused by inverse polarity or opposite remanence.

In this part of Ontario and Quebec anomalies on aeromagnetic maps are generally broad and strong over mafic intrusions, gabbro and anorthosite, and over some stocks of syenite, and weaker over felsic intrusions and areas of infolded meta-sedimentary strata. Marked linear positive anomalies are common to folded belts of amphibolite and meta-volcanic rocks and on the margins of intrusions. Magnetic anomalies of smaller area but of greater intensity within this pattern are commonly attributable to deposits of magnetite, of pyrrhotite, or of magnetite with ilmenite. Ilmenite-bearing deposits in some cases may produce a marked negative anomaly, possibly because of opposite remanence. Generally the magnetic effect of the mineral deposit is modified or masked by that of the mass of its host rock, leading to considerable difficulty in interpretation of the anomaly. Figure 1 shows the general relationships between deposits, geology and aeromagnetic anomalies.

Chapter V

Geochemistry

Spectrographic analyses of some of the rocks, iron deposits and magnetic concentrates are given in Tables III to X. The distribution of the elements in the deposits described are compared with one another and also with comparable deposits in other mining camps. The tables present information on the composition of the iron ore materials and magnetic concentrates from them that may be useful to those interested in the potential value of the deposits, and to those who may wish to make comparisons with other deposits. The data in the tables are arranged so that direct comparisons may quickly be made between the chemical composition of an unconcentrated sample and that of the magnetic concentrate from it. As the magnetic concentrate represents an extract of almost pure magnetite the deleterious ingredients present in the unconcentrated material are generally eliminated or reduced in amount in the concentrate.

The qualitative spectrographic analyses were made in the Geological Survey's spectrographic laboratory under the supervision of W. H. Champ. A few milligrams of the powdered samples were burnt in a direct-current arc between graphite electrodes in a Jarrell-Ash 21-foot grating spectrograph. Visual comparisons of the spectra obtained on photographic plates were compared with those of standard plates, and results were obtained that are considered to be reasonably accurate approximations of the true values of the samples. Results are presented under the headings of "Major, Minor, Strong Trace, Trace, and Faint Trace Elements", representing approximately 100 to 10, 10 to 1, 1 to 0.1, 0.1 to 0.01 and 0.01 to 0.001, per cent respectively. The accuracy of the method is limited, and possible overlappings in these percentage ranges may be expected. For this reason the spectrographic results were compared with those of available chemical analyses and many of the ores and rocks were examined microscopically. By and large, the percentages obtained and those to be expected agree. Apparently anomalous content in general may be accounted for by variations in distribution of the elements rather than merely by limitations in the accuracy of the qualitative spectrographic analytical method. On the whole, however, the agreement in spectrographic, chemical and geological information is satisfactory.

Semi-quantitative spectrographic analyses of powdered pyrite samples involved careful weighing, mixing with an equal amount of palladium chloride, fusion and comparison of spectra with standard plates. More precise results are given by this method.

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General Distribution of Elements

The rocks of the crust of the earth have been estimated by Clarke and Washington (1924) and Goldschmidt (1937) to average slightly more than 5 per cent iron. It is the fourth element in abundance in the earth's crust. Iron is a most important metal geochemically. It is the chief member of the ferride series of elements consisting of titanium, vanadium, chromium manganese, iron, cobalt and nickel. Of the two types of iron ions, the ferrous and ferric, the former is the larger. In all classes of igneous rocks ferrous iron is more abundant than ferric, but in sedimentary rocks the reverse is true because of the dominantly oxidizing environment of sedimentation.

The average granite is more siliceous and alkalic than the average gabbro, and each has certain elements characteristically associated, such as potassium, sodium, lithium, beryllium, zirconium, gallium and tin, etc. with granite, and the ferrides, scandium, etc. with gabbro. In general terms mafic rocks exemplified by the average gabbro are more femic—i.e., contain more iron and magnesium—and felsic rocks exemplified by the average granite are more salic, containing more silicon and aluminum.

Of the common sedimentary rocks only shales have an average iron content approaching that of igneous rocks. Comparatively little iron is present in the clastic sediments, because of the susceptibility of most of the igneous ferromagnesian minerals to weathering; magnetite and ilmenite being notable exceptions.

The following table modified from Rankama and Sahama (1950, pp. 658, 668) listing the total iron content of various rock classes shows the relative abundance of iron in mafic igneous rocks.

TABLE II

Iron Content of Selected Rocks

Rock	Fe (per cent)
Dunite	6.30
Hornblendite	11.76
Gabbro	8.84
Diorite	5.63
Shale	4.71
Granodiorite	3.28
Granite	2.48
Sandstone	0.99
Limestone	0.38

The bulk of the iron in igneous rocks is present in the dark minerals including olivine, pyroxene, amphibole, dark mica, magnetite and ilmenite. Pyrrhotite, pyrite, chalcopyrite, hematite, and the spinels are other common iron carriers. Because of similarities in ionic radius and electrostatic charge Fe^{2+} usually accompanies and substitutes for Mg^{2+}, and Fe^{3+} for Al^{3+}.

In eastern Ontario and western Quebec, felsic rocks presumably relatively low in magnesium, calcium, iron, titanium, manganese, chromium and vanadium predominate, and the average of the area might be expected to be slightly above the world average in salic elements. However, comparisons of spectrographic analyses of selected rock samples from eastern Ontario with the estimated chemical composition of the average igneous rock (as shown in Table III) suggested that the rocks of the area may be slightly more femic than the crustal average. It is thus suggested that the area is slightly enriched in elements characteristic of mafic rocks.

In general, it seems that iron, titanium, chromium, scandium, and to some extent vanadium, cobalt, nickel and manganese are more abundant in the mafic rocks of the area, as also of course are magnesium and calcium, and that zirconium, beryllium, gallium and of course silicon, are more abundant in the felsic rocks. Traces and faint traces of the rare yttrium and ytterbium in granite, syenite, rhyolite, gabbro and trap from the area, support the suggestion that they form part of a related suite of igneous rocks.

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TABLE III

Spectrographic Analyses of Selected Eastern Ontario Rocks

Rock and Locality	Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Gabbroic anorthosite Newboro	Si Al Ca Fe	Mg Na	Ti Mn Sr	V Ba Cu	Cr Sc Co Zr Zn
Syenite Newboro	Si	Al Ca Na Fe	Ti Mn Mg Ba	Cu Sr	V Cr Sc Co Ni B Zr Zn Pb
Syenite Coehill	Si	Al Ca Na Fe	Ti Mg	Mn Cu Zr Ba Sr	V Cr B Zn Pb
Syenite Marmora mine	Si	Al Ca Na Fe	Mg	Ti Mn Cu Ba Sr Y Yb	V Co Zr Zn
Granite Moira (Madoc)	Si	Al Na Fe	Ti Zr	Mg Ca Ba Y Yb	Be Ga Mn Cu
Rhyolite (black) quarry n. of Madoc	Si Fe	Al	Ti Na	Mg Ca Mn Ba Zn Zr Y Yb	Be Sr Cu
Gabbro Belmont mine	Si Fe	Al Mg Ca Ti	Na Ba Mn	Y Yb	V Sc Co Cu Zr Sr
Trap Belmont mine	Si Fe	Al Mg Ca Ti	Mn	Cr Sr	Y V Sc Co Ni Cu Zr Ba
Trap Havelock quarry	Si Fe	Al Mg Ca Ti	Na	Mn Ba Sr	Y V Cr Sc Co Ni Cu Zr

Gabbro Blairton mine	Si Fe	Al Mg Ca Ti	Na Cr	Mn V Ba Sr	Sc Co Ni Cu
Gabbro Millbridge	Si Fe	Al Mg Ca Ti		Mn V Cr Ni Na Sr	Sc Co Ba Cu
Crystalline limestone Dalhousie mine	Ca Mg	Si	Fe Sr	Mn Cu	Al Ba

TABLE IV

Spectrographic Analyses of High Titanium Magnetites and Magnetic Concentrates of Eastern Ontario

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Blessington	o.....	Fe	Si Al	Mg Ca Na Ti Mn	Cr V Ba Sr	Ni Co Cu
	c.....	Fe			Si Al Ti Mn	Mg Ni Cu B Ca
Blithfield	o.....	Fe	Mg Al Ti Ba	Si Mn Cr	V Ni Co Ca B Sc Sr	Cu
	c.....	Fe		Ti V Al	Si Mg Mn B	Cu Ca Ba
Chaffey	o.....	Fe	Mg Si Al	Ti	V Mn Co Ca	Ni Cu Ba Sr
	c.....	Fe		Ti	Mg Al Mn	Si Ni Co Cu Ca Ba
Matthews	o.....	Fe	Mg Si Al Ti Ca	Cr	V Mn	Ni Co Cu Zn Ba Sr
	c.....	Fe		Al Ti	Si Mg Mn	Cr V Ni Co Cu Ba
Orton	o.....	Fe	Al Ti	Si V Cr	Ca Mn Co	Cu Ba
	c.....	Fe	Ti	Mg Al	Si Mn	Cr V Ni Co Cu Ca

TABLE V

Spectrographic Analyses of Adirondack Magnetites and Concentrates

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Benson	o.....	Fe Si	Al	Mn Mg	Ti V Ca	Cr Ni Co Cu Ba Sr
	c.....	Fe		Si	Mg Al Ti Mn	V Cu Zn Ca Ba
Clifton	o.....	Fe	Si Al	Mn Mg	Ti V Ca	Ni Co Cu Zn Sr
	c.....	Fe			Mg Al Ti Mn	Si Zn Cu Ca
Lyon Mountain	o.....	Fe Si	Mg Al Ca	Mn Na	Ti V	Cr Ni Co Cu Ba Sr Be
	c.....	Fe			Mg Si Al Ca Ti Mn	V Cu
Mineville	o.....	Fe Si	Ca	Mn Mg Al	Ti V Sc Y Yb La Ce	Cr Ni Co Cu Ba Sr Be
	c.....	Fe			Si Al Ti Mn	Mg Cu Ca
Tahawus	o.....	Fe	Si Al	Mn Mg Ti	Cr V Co Ca	Ni Cu Ba
	c.....	Fe	Ti	Mn Mg Al	Si Cr	Ni Co Cu Ca

o = ore or magnetite-rich material c = magnetic concentrate

TABLE VI

Spectrographic Analyses of Low Titanium Magnetites and Magnetic Concentrates of Eastern Ontario and Adjoining Quebec

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Allan Mills	o.....	Fe	Mg	Al Co	Si Ti Mn Cu B	Ni Ag Mo Ca Ba
	c.....	Fe		Si Al Mg B	Mn Co	Ti Ag Cu Ca
Baker	o.....	Fe	Si Al Mg Ca	Ti	V Mn	Cr Co Cu Ba Sr
	c.....	Fe			Si Al Ca	Ti Mn Cu Mg
Bankers Lake (Dominion)	o.....	Fe	Al Ti	Si Mn	V Ca	Cr Co Cu Zn Ba
	c.....	Fe			Al Mn Ti	V Cu Mg Si Ba
Belmont	o.....	Fe	Al	Si Mg	Ca Ti Mn Zn	V Co Mo Cu Ba Sr
	c.....	Fe		Si Al Mg	Mn	V Ti Cu Ca
Bessemer	o.....	Fe	Si Al Mg Ca	Ti	V Mn	Co Cu Ba Sr
	c.....	Fe			Si Al Ca	Ti Cu Mn Mg
Blairton	o.....	Fe	Mg	Si Al Ti Mn		V Cr Ni Co Cu Mo Ca Ba
	c.....	Fe		Si Al Mg	Mn	Ti Cu Ca
Bluff Point	o.....	Fe	Mg	Si Al Ti Mn	Co Cu	V Cr Ni Mo Ca
	c.....	Fe		Mg	Si Al Ti Mn	Cu Ca
Boulter	o.....	Fe	Si Al Ti	Ca	V Mn	Cu Ba
	c.....	Fe			Al Mg Ti Mn	V Cu Si Ca Ba

TABLE VI (*cont'd*)

Spectrographic Analyses of Low Titanium Magnetites and Magnetic Concentrates of Eastern Ontario and Adjoining Quebec

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Bow Lake	o.....	Fe	Si	Ti Mn Mg Al	V	Co Cu Zn Ca Ba
	c.....	Fe			Ti Mn Al	V Cu Si Mg
Bristol (Hilton)	o.....	Fe		Si Al Mg	Ca Mn Ti	V Co Mo Cu Ba
	c.....	Fe			Si Al Mg Mn	Ti V Cu Ca Ba
Calabogie (main)	o.....	Fe	Al	Si Mg Ti Ba	V Mn Co Ni Zn Ca	Cu Mo Sr
	c.....	Fe			Si Al Mg Mn	V Ti Cu Ca Ba
Childs	o.....	Fe	Si Al Mg Ca		V Ti Mn	Co Cu Zn Ba
	c.....	Fe			Si Al Mg Mn	V Ti Cu Ca Ba
Christie's Lake	o.....	Fe	Al Ti	Mn	Si Mg V Ni Co Zn	Cr Cu Mo Ca Ba
	c.....	Fe		Al	Ti Mn	Si Mg Cu Ca
Coehill	o.....	Fe	Si Al Mg Ca	Ti Mn	V	Co Cu Zn Ba Sr
	c.....	Fe		Al	Si Ti Mn	V Cu Mg Ca Ba
Culhane	o.....	Fe		Si Al Mg	Ti Mn	V Co Cu Mo Ba Ca
	c.....	Fe		Mg	Si Al Mn	Ti Cu Ca
Dacre	o.....	Fe	Ti	Si Al Mg Ca	V Mn Ni Co	Cr Cu Mo Ba Sr
	c.....	Fe			Si Al Ti Mn Ca	Cu Mg
Emily (Gilmour)	o.....	Fe	Si Mg	Al Ti Ca	V Mn	Ni Co Cu Zn Ba Sr
	c.....	Fe		Al	Si Mg Mn Ca	Ti Ni Cu

Forsyth	o.....	Fe	Si Al Mg	Ca	Ti Mn	V Cu Ba
	c.....	Fe			Mn Si Al Mg	Ti Cu Ca Ba
Glendower	o.....	Fe	Al Ti	Si Mg Ba	Cr V Mn Co Zn	Ni Cu Mo Ca
	c.....	Fe		Al Mg	Si Ti Mn	V Cu Ca Ba
Howland	o.....	Fe	Si Al Mg Ca	Ti	V Mn	Co Cu Ba Sr
	c.....	Fe			Al Ti Mn	V Cu Mg Ca Si
Marmora	o.....	Fe	Si Al	Ti Ca	Cu Mn	V Co Zn Ba
	c.....	Fe			Al Mn	Ti Cu Mg Si Ca
Paxton	o.....	Fe	Si Al	Ti Mn Ca	V Zn	Co Cu Ba Sr
	c.....	Fe		Si	Al Mg Ti Mn	Cu Zn Na Ca
Pershing	o.....	Fe	Ti	Si Al V	Mg Ca Mn	Ni Co Cu Mo Ba Sr
	c.....	Fe			Si Al Ca Ti V Mn	Cu Mg
Quarry Lake	o.....	Fe Si Mg	Al Ca	Ti Na Ba	V Mn	Cr Co Cu Sr
	c.....	Fe			Al Ba	Mn Si Mg
Radenhurst-Caldwell	o.....	Fe	Al	Si Mg Ti	Mn Co Ca Cu	V Ni Mo Ba
	c.....	Fe			Si Al Mg	Ti Mn Cu Ca
Radnor	o.....	Fe	Al Ti		Si Mg Mn Ca V	Ni Co Cu Mo Sn Ba
	c.....	Fe			Al	V Ti Mn Cu Mg Si
Rankin	o.....	Fe	Si Al	Mn Ca	V Ti Cu Ba	Co Zn Sr
	c.....	Fe		Si	Al Mg Mn	Ti Cu Ca Ba
Ridge	o.....	Fe	Si Al Ca	Ti	V Mn	Cr Cu Zn Ba Sr
	c.....	Fe		Si	Ti Mn Al Mg	V Cu Ca

TABLE VI (*conc.*)

Spectrographic Analyses of Low Titanium Magnetites and Magnetic Concentrates of Eastern Ontario and Adjoining Quebec

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Robertsville	o.....	Fe	Mg Al Ti	Ca	Si V Mn Co Ba	Ni Ag Cu Mo Sn Sr
	c.....	Fe			Al	V Ti Mn Cu Mg Si
Sexsmith	o.....	Fe	Si Al Mg Ca	Ti Mn	V	Co Cu Zn Ba Sr
	c.....	Fe			Si Al Ca	Ti Mn Cu Mg
St. Charles	o.....	Fe	Si Al Mg Ca	Ti Mn	V	Co Cu Ba Sr
	c.....	Fe		Al	Si Ca Mn	Ti Cu Mg
Stephens	o.....	Fe Si	Mg Al	Ti Mn Ca	V	Ni Co Cu Zn Ba Sr
	c.....	Fe			Mn Al	Ti V Ni Cu Si Mg Ca Ba
Stormy Lake (New York)	o.....	Fe	Si Ti	Mg Al Mn	V	Co Cu Zn Ca Ba
	c.....	Fe			Al Ti Mn	V Cu Zn Mg Si
Victoria	o.....	Fe	Si Al Ti	Ca	V Mn	Cr Cu Zn Ba Sr
	c.....	Fe			Al Ti	V Mn Cu Mg Si Ca
Wilbur	o.....	Fe	Al	Si Mg Ti Mn	V Ni Co Zn Ca	Cr Cu Mo Sn Ba Sr
	c.....	Fe			Si Al Mg Mn	V Ti Ni Co Cu
Williams (Black Bay)	o.....	Fe		Si Al Mg Cr	Mn Ca	Ti Co Cu Mo Ba Sr
	c.....	Fe		Si	Al Mg	Mn Cu Ca

o = ore or magnetite-rich material c = magnetic concentrate

TABLE VII

Spectrographic Analyses of Eastern Ontario Hematites and Magnetic Concentrates

Deposit		Major 100-10	Minor 10-1	Strong Trace 1-0.1	Trace 0.1-0.01	Faint Trace 0.01-0.001
Belmont Lake (iron-formation)	o.....	Fe	Si	Al	Mg Ca Ti	V Mn Co Cu Ba
	c.....	Fe		Si	Al Mn	Ti Cu Mg Ca
Blairton (martite)	o.....	Fe	Al	Si Mg	Ti Mn Ca	V Co Cu Mo Ba Sr
	c.....	Fe		Al Mg	Si	Ti Mn Cu Ca
Crowe Lake	o.....	Fe		Al	Si Mg Ti Mn	V Co Cu Mo Ca Ba
	c.....	Fe			Al	Ti Mn Cu Mg Si Ca
Playfair (Dalhousie)	o.....	Fe		Si Al Ca	Mg Cr Mn Mo Ba Sr	V Ti Cu
	c.....					
Eldorado (hematite)	o.....	Fe	Si Al Mg Ca	Ti	V	Mn Co Cu Ba Sr
	c.....	Fe			Al	Ti Mn Cu Mg Si Ca Ba
Eldorado (martite)	o.....	Fe Si	Al Mg	Ti	V Mn	Co Cu Ca Ba
	c.....	Fe		Al	Si Mg	Ti Mn Cu Ca Ba
Fahey	o.....	Fe	Ca	Al Mg	Si V Mn Ba Sr	Cr Ti Ni Cu
	c.....					
Wallbridge	o.....	Fe	Si	Al Mn	Mg Ca Ti	V Co Cu Ba Sr
	c.....					
White Lake	o.....	Fe	Al	Mn Ba Zn Ca	Si Ti Mg	Pb Co Sn Ag Mo Sr V Cu
	c.....					

o = ore or hematite-rich material c = magnetic concentrate

TABLE VIII

Comparisons of the Ferrides in Certain Pyrite Samples

Sample and Locality	Ti	V	Cr	Mn	Fe	Co	Ni
A Pyrite in magnetites							
Belmont mine				.005–.02	>10	.1–.4	.1–.4
Bessemer mine			<.001	<.01	>10	.3–1	.01–.04
Bluff Point mine	<.01			.01–.04	>10	.04–.2	.04–.2
Calabogie (main)	<.01			.01–.04	>10	.3–1	.005–.02
Glendower mine				.005–.02	>10	.03–.1	.04–.2
Marmora mine	.01–.06		<.001	.007–.03	>10	.1–.6	.1–.6
Radnor mine	<.01			<.01	>10	.03–.1	.08–.3
Rankin mine	.01–.05	<.001		.03–.1	>10	.3–1	<.01
Robertsville mine	.005–.02			<.01	>10	.08–.3	.03–.1
B Pyrite in quartz-hematite							
Playfair (Dalhousie) mine	.01–.04			<.01	>10	<.01	<.01
C Pyrite in granite pegmatite							
Macdonald mine	.005–.02			<.01	>10	.3–1	.005–.02

TABLE IX

Comparisons of Cobalt and Nickel in Certain Pyrite Samples

Sample and Locality	Co	Ni
A Pyrite from magnetite deposits in eastern Ontario	.03–1.0	.005–0.6
B Pyrite from gold deposits in northern Ontario and Quebec	.02–0.1	.02–0.1
C Accessory pyrite from Finnish Precambrian rocks (average)	.2	.09
D Magmatic sulphides, average of 57 samples	.21	3.14

A—This report B—J. E. Hawley (1952) C and D—Rankama and Sahama (1950)

TABLE X

Comparisons of the Ferrides in Certain Iron Ore Samples

	Sample and Locality	Ti	V	Cr	Mn	Fe	Co	Ni
	A. High Titanium Magnetites							
Lc	(1) Sanford Lake, N.Y.	7.25	0.36	0.13	0.2	59.1	0.03	0.02
c	" " "	10–1		.1–.01	1–.1	>10	.01–.001	.01–.001
o	(2) Matthews mine, Ontario	10–1	.1–.01	1–.1	.1–.01	>10	.01–.001	.01–.001
c	" " "	1–.1	.01–.001	.01–.001	.1–.01	>10	.01–.001	.01–.001
o	(3) Orton mine, "	10–1	1–.1	1–.1	.1–.01	>10	.1–.01	
c	" " "	10–1	.01–.001	.01–.001	.1–.01	>10	.01–.001	.01–.001
	B. Low Titanium Magnetites							
Lo	(1) Kiirunavaara (apatite)	0.1	0.13	<.001	0.05	69.44	0.013	0.02
Lo	(2) Mineville (apatite)	.2	.01	.003	.1		<.003	.005
o	" "	.1–.01	.1–.01	.01–.001	1–.1	>10	.01–.001	.01–.001
o	(3) Glendower mine, Ontario	1–.1	.1–.01	.1–.01	.1–.01	>10	.1–.01	.01–.001
c	" " "	.1–.01	.01–.001		.1–.01	>10		
Lc	(4) Taberg mine (skarn)	<.01	<.001		1.0		<.001	<.001
o	(5) Bessemer mine, Ontario	1–.1	.1–.01		.1–.01	>10	.01–.001	
c	" " "	.01–.001			.01–.001	>10		
o	(6) Marmora mine, Ontario	1–.1	.01–.001		.1–.01	>10	.01–.001	
c	" " "	.1–.01	.01–.001		.01–.001	>10		
	C. Hematite							
L	(7) Soudan mine, Minn.	0.06	0.004	0.03	0.04		0.003	0.02
	(8) Playfair (Dalhousie) mine, Ontario	.01–.001	.01–.001	.1–.01	.1–.01	>10		
	(9) Wallbridge mine, Ontario	.1–.01	.01–.001		1–.1	>10	.01–.001	
	(10) White Lake, Ont.	.1–.01	.01–.001		1–.1	>10	.01–.001	
	(11) Wabana, Newfoundland	1–.1	.1–.01	.01–.001	.01–.001	>10	.001	.01–.001
	Lithosphere (literature)	.5	.015	.02	.1	5.1	.002	.008
	Gabbro (literature)	.58	.006	.034	.12	6.8	.008	.016

o = ore or magnetite-rich material c = magnetic concentrate L = Landergren analysis (1948)

Distribution of Elements in Ore Materials and Magnetic Concentrates

Non-Ferride Elements

The non-ferride elements of the ore materials and magnetic concentrates are arranged in order of decreasing abundance in the earth's crust, and known significant trends in their local distribution are summarized and compared with the world's crustal average for these elements. The general geochemical trends reflected in the deposits are thus established and in this manner genetic affinities of the ore materials are indicated.

Oxygen—Present in magnetite, ilmenite, hematite, silica, etc.; abundance not determined, but probably above average.

Silicon—Present mainly in gangue minerals in the ore material samples, commonly in amounts under 10 per cent and below average. Usually reduced in the magnetic concentrate.

Aluminum—Present mainly in gangue minerals, commonly under 10 per cent and below average. Usually reduced in the magnetic concentrate.

Sodium—Commonly not detectable; where present, in gangue.

Calcium—Commonly present in gangue minerals under 10 per cent and probably above average; reduced in the magnetic concentrate.

Magnesium—Present in all samples, usually under 10 per cent in the ore material and under 1 per cent in the concentrate, probably above average in the ore material and below average in the concentrate.

Potassium—Not determined.

Carbon—Not determined, but noted as graphite at the Forsyth mine in Quebec.

Phosphorus—Not determined, but noted in some chemical analyses in small amounts, and probably present mainly in apatite.

Sulphur—Not determined, but noted in amounts usually less than 2 per cent in certain chemical analyses. Mainly present in pyrite, pyrrhotite and chalcopyrite.

Fluorine and Chlorine—Not determined; may occur in apatite and scapolite.

Strontium—About 58 per cent of the samples carry strontium, but in amounts mainly less than 0.01 per cent and slightly below average of the crust. Only 8 per cent of the magnetic concentrates carry strontium and the amount present is reduced from that in the ore material.

Barium—Most of the samples carry barium in amounts less than 0.01 per cent, slightly under the world average of crustal rocks of 0.025 per cent. It is limited to 44 per cent of the magnetic concentrates, in amounts slightly decreased from those in the ore material samples.

Zinc—Some 40 per cent of the ores contain zinc in amounts mainly less than 0.1 per cent and are probably near the world average. Zinc is restricted to 6 per cent of the magnetic concentrates, in amounts less than 0.01 per cent, and below the world average.

Copper—All of the samples carry faint traces at least of copper, and faint traces remain in most of the concentrates; probably near the world average.

Tin—Only 8 per cent of the ore materials carry even faint traces of tin (less than 0.01 per cent), and these are eliminated in the magnetic concentrate; mainly below average.

Lead—Lead was detected only in one sample, as a faint trace in hematite from the White Lake area, probably below average.

Molybdenum—About 40 per cent of the ore materials bear molybdenum, mainly in amounts less than 0.01 per cent, and probably slightly above average. All molybdenum is eliminated in the magnetic concentrate.

Scandium—Scandium was detected as a trace in the Blithfield sample. It was eliminated in the magnetic concentrate.

Boron—Boron was noted as a trace in samples from Allan Mills and Blithfield, and this remained in the concentrate.

Silver—Silver was found only in the Allan Mills ore material as a faint trace, and it remained in the magnetic concentrate.

Other elements may be present in amounts mainly less than 0.01 per cent. In addition, the gases, halides, radioactive elements and rare earths are not recorded spectrographically and could conceivably be present even in amounts of more than 0.01 per cent. Radioactivity tests by Geiger counter, however, show that such is not the case for the radioactive elements and it is also improbable for the gases, halides and rare earths.

Ferride Elements

The distribution of the ferride elements is considered here in more detail where they occur in the ore materials above the average values for the lithosphere. They are arranged in order of increasing ionic radii.

Chromium—Cr^{+3}, ionic radius 0.64 kX,[1] was detected in amounts between 1 and 0.001 per cent in 38 per cent of the ore materials, and between 0.01 and 0.001 per cent in 6 per cent of the concentrates. The world crustal average is 0.02 per cent. Only 8 per cent of the ore materials showed more than 0.1 per cent of chromium, all from deposits in mafic rocks that in some cases carry as much as the iron ore materials. In the magnetic concentrates chromium was eliminated from all except those from deposits in mafic rocks, and in these it was reduced to less than 0.01 per cent.

[1] 1 kX = 1.00202 Å
1 Å = 10^{-8} cm.

Vanadium—V^{+3}, ionic radius 0.65 kX, was detected in 98 per cent of the ore materials in amounts between 1 and 0.001 per cent, and in 46 per cent of the concentrates mainly between 0.1 and 0.001 per cent. The amount of vanadium of several samples exceeds the world average of 0.015 per cent; two samples showed between 1 and 0.1 per cent. Only 4 per cent of the ore materials and 2 per cent of concentrates showed between 1 and 0.1 per cent of vanadium, all in deposits in or near mafic intrusive rocks.

Iron—Fe^{+3} and Fe^{+2}, ionic radii 0.67 and 0.83 kX, occur in all ore material and concentrate samples in amounts between 10 and about 70 per cent, and all well above the world crustal average.

Titanium—Ti^{+3}, ionic radius 0.69 kX is present in all ore material samples in percentages between 10 and 0.001 and in 96 per cent of the magnetic concentrates mainly between 0.1 and 0.001 per cent. It is strongest in deposits in mafic intrusions and, in a few other deposits in mafic metamorphic rocks, is slightly above the crustal average of 0.5 per cent. About one-third of the samples seem to be at or above the world average. Only 8 per cent of the concentrates, in all cases from mafic intrusions, carried more than 0.1 per cent titanium.

Nickel—Ni^{+2}, ionic radius 0.78 kX, was found in 36 per cent of the ore materials in amounts between 1 and 0.001 per cent, and in 16 per cent of the concentrates between 0.1 and 0.001 per cent. Only 8 per cent of the ore materials and 2 per cent of the concentrates carried more than 0.01 per cent, the average crustal value.

Cobalt—Co^{+2}, ionic radius 0.82 kX, was found in 82 per cent of the ore materials in amounts between 1 and 0.001 per cent, and in 14 per cent of the concentrates between 0.01 and 0.001 per cent. About 22 per cent of the ore materials and 2 per cent of the concentrates carried more than 0.004 per cent, an estimated crustal average. Cobalt thus appears in more than twice as many samples as does nickel.

Summary

Qualitative spectrographic analyses of more than fifty magnetite- and hematite-bearing samples from eastern Ontario, supplemented by many published chemical analyses, indicate that a total of about twenty-seven elements are present in amounts exceeding 0.001 per cent. Of these elements less than one-half occur in 50 per cent or more of the samples examined, and most of these elements are in amounts of less than 0.1 per cent. Only iron and oxygen are abundant in the samples. Titanium is widespread but less abundant than iron and oxygen. Magnesium, aluminum, silicon, calcium, vanadium, manganese, cobalt, copper, barium, strontium, sulphur and phosphorus are widespread but not relatively abundant or sufficient in amount

to cause any difficulty in the utilization of the concentrated ore. The remainder are neither widespread nor abundant.

In comparison with estimates of the average abundance of elements in igneous rocks of the earth's crust (Rankama and Sahama, 1950) iron is more abundant than the average in all the samples; oxygen, magnesium and calcium are probably more abundant in all the samples; titanium, manganese, vanadium, chromium, cobalt, nickel, copper, zinc and molybdenum, are more abundant in a few, but are below average in most samples. Silicon, aluminum, barium, strontium and most of the others are, in many samples of these ores, below the average of igneous rocks.

The mafic igneous rocks in which several of these deposits occur seem to be relatively high in iron and titanium, and to some extent in manganese, chromium and vanadium, when compared with the world average for igneous rocks. This is to be expected since mafic igneous crustal rocks tend to carry more of these elements than the felsic varieties. A closer correspondence is to be expected in comparisons between similar rock types and between genetically related rocks and ores than between unrelated rocks and ores.

In spectrographic analyses of fifty samples of magnetic concentrates from eastern Ontario magnetite deposits, twenty elements were recognizable in amounts exceeding 0.001 per cent. Iron, titanium manganese, magnesium, silicon, aluminum and copper occur in almost every sample, but all except iron, and, locally, titanium, are present in amounts less than 1.0 per cent, and in most in amounts less than 0.1 per cent. Most of the remaining elements are present in amounts less than 0.01 per cent. Titanium, chromium, vanadium, cobalt, and perhaps also nickel and manganese, are above world average in some deposits, such as those in mafic rocks. Comparison between ore material and magnetic concentrate results shows that in most samples all elements except iron are present in smaller quantities in the magnetic concentrate than in the raw ore material.

Tables IV and V showing the distribution of elements in certain eastern Ontario and Adirondack iron ore materials and magnetic concentrates are given on pages 75, 76. Spectrographic analyses of felsic and mafic rocks from the area show that many of these elements are common to both.

The ore materials show closer similarities in trace element content to the mafic than to the felsic rocks. Gallium and beryllium were not detected in either mafic rocks or ore materials, zirconium was less abundant in mafic rocks and ore materials than in felsic rocks, and yttrium and ytterbium were detected in one magnetite sample from Mineville, New York.

Table X compares the distribution of the ferride elements in selected samples of the three classes of ore material, high titanium magnetite, low titanium magnetite, and hematite, and in magnetic concentrates from them, as shown by spectrographic analyses. Five of the analyses from deposits outside Ontario are taken from Landergren's work (1948). In general, the

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tabulated analyses show a reasonable agreement where comparisons may be made between eastern Ontario ore materials and those given by Landergren, and further that the ferride content, exclusive of iron, is slightly lower in the hematite and low titanium magnetite samples than in those of the high titanium magnetite. With the exception of iron, the ferride elements are generally decreased in amount in the magnetic concentrates as compared with the ore materials.

With the exception of vanadium, the ferride elements occur in slightly greater amounts in the average gabbro than in the average crustal rock and for the most part the amounts of the ferride elements indicated in Table X are close to those for the average gabbro. The ferrides, with the exception of iron, are on the average slightly lower in the low titanium magnetite and hematite and slightly higher in the high titanium magnetite than in the average gabbro. The ferride element content of the magnetic concentrates of the magnetic classes of ore material from eastern Ontario is, in general, lower than that of the average gabbro, with the exception of iron and in some cases of titanium. These relationships suggest that the ferride element content of these eastern Ontario ore materials decreases from the high titanium magnetite, through the low titanium magnetite to the hematite, and that the high titanium magnetite ores show closest correspondence in these elements to mafic ignous rocks as exemplified by the average gabbro. This parallels the decline in ferride elements shown in progression from mafic to felsic igneous rocks. This trend is not so marked in the concentrates, which tend to approach a more uniform and smaller ferride element content. The similarity in trace element content of magnetic concentrates from high and low titanium magnetite deposits is compatible with the concept of a genetic relationship between them. It is believed that differentiation of mafic magma might produce extracts capable of depositing either high or low titanium magnetites.

Chapter VI

Origin

The problem of the origin of the iron deposits of eastern Ontario and southwestern Quebec is complex because of the variations in intensity and overlapping nature of the successive periods of metamorphism the region has undergone. It is believed, however, that the high titanium magnetite deposits are of magmatic origin; the low titanium magnetite deposits of pyrometasomatic origin, but ranging from late magmatic to hydrothermal environments; and the hematite deposits of secondary, hydrothermal to supergene origin.

The high titanium magnetite deposits of eastern Ontario and southwestern Quebec, in contrast with the low titanium magnetite deposits of the same district are apparently directly related to the mafic igneous rocks in which they occur. They are similar to the high titanium magnetite ores of the Adirondack region of New York State as exemplified by the Sanford Lake deposits of the National Lead Company at Tahawus, New York, in that both occur in gabbro and gabbroic anorthosite. High titanium magnetite deposits of a similar nature are known elsewhere, as in the gabbros and anorthosites of Quebec, where ilmenite is predominant in some of the deposits in anorthosites; and also in some of the great stratiform, mafic, differentiated sheets or lopoliths such as the Bushveld complex in South Africa and the norite or nickel irruptive of Sudbury.

The low titanium magnetite deposits of eastern Ontario and southwestern Quebec resemble those of the Adirondack region in some respects but they are by no means identical. Both occur in Grenville type host rocks, but whereas granitic gneisses seem to be the chief hosts in the Adirondacks, crystalline limestone contact zones and amphibolites are the main loci in eastern Ontario and southwestern Quebec.

Many of the Adirondack deposits have thick, near-massive bands of magnetite paralleling the enclosing gneisses, and so persistent were they that they were long believed to be sedimentary beds. Some of the Ontario deposits show banding on a minor scale, but there is nothing so persistent as to be mistaken for a sedimentary bed of magnetite. Many places may be found in both regions where magnetite bands contain fragments of the host rock or transgress the structure of the host, thus discounting the theory that the bands represent metamorphosed sedimentary beds of iron-bearing materials.

Crystalline limestone and skarn contact zones seem much more abundant in the Grenville gneisses of eastern Ontario than in the Adirondacks, but in both districts they are cut by felsic and mafic igneous intrusions, many

of which appear to be related. In places in both regions trap and pegmatite dykes are believed to cut the magnetite. Another point of difference in the host rocks is that the gneisses near the deposits in the Adirondacks generally seem to be coarser grained than those in eastern Ontario.

In general, the ores of both districts are low in phosphorus, but locally carry apatite. In this respect, among others, they are similar to the Kiirunavaara magnetite ore of northern Sweden. The Kiiruna ore, lying as a huge tabular body in syenitic rocks, has been found to intrude these rocks as dykes and to invade breccias, and is regarded by Geijer (1910, 1931) as an injection of late crystallizing residuum. Landergren (1948), on the other hand, believed that it formed by the ultrametamorphosis of a material in which the enrichment of iron took place in a cycle within the upper lithosphere, and that it is of secondary magmatic, or palingenetic origin. The mineral martite does not appear to characterize many of the Adirondack or eastern Ontario ores, but it is found extensively at Jones and Laughlin's Benson mines, in the Adirondacks, and in several of the eastern Ontario deposits. In eastern Ontario it appears to be restricted to a surficial zone, and possibly formed by weathering of magnetite but at Benson mines it occurs at great depths and appears unrelated to weathering.

Spectrographic analyses of ore samples from eastern Ontario and from several Adirondack deposits show considerable similarity in trace element content, but the Adirondack deposits seem to be generally slightly lower in titanium and for the most part also in vanadium.

The eastern Ontario deposits may be compared also with one at Cornwall, Pennsylvania, where a thick Triassic diabase sill-dyke intrudes Cambrian limestone. A magnetite orebody occurs in the contact skarn in the Cambrian limestone above the dyke. The skarn consists essentially of diopside, actinolite, phlogopite, chlorite, calcite and dolomite. Magnetite is more abundant on the hanging-wall where it replaces actinolite, and diopside is predominant on the foot-wall. Hickok (1933) concluded that this deposit formed from water-rich solutions above the critical temperature of water that carried potash, iron, silica, copper, sulphur, "mineralizers", and minute amounts of a few additional elements, into the contact metamorphic zone above the dyke. He believed that the solutions were derived from the diabase rest-magma.

The Texada Island magnetite in British Columbia occurs in lenses in amphibolite and "garnetite" at the contact of limestone and intrusive diorite, all of Mesozoic age (Swanson, 1924). Swanson considered it was formed "by magmatic solutions in which the materials were concentrated by the crystallization of the intrusive" (1924). It also appears to have similarities to many of the eastern Ontario deposits, but is perhaps more vein-like. Calcite and epidote veinlets also appear in the Texada ore zone and adjoining limestone.

The hematite-bearing deposits of eastern Ontario are neither as abundant nor as important as the magnetites. A few are closely connected with magnetite deposits however, and appear to have been formed by oxidation of magnetite perhaps by processes similar to those described by Gruner (1922, 1926, 1946).

Specimens of hard red vuggy hematite, from the Wallbridge mine, with small vugs lined with tiny crystals resemble parts of the ore from Steep Rock Lake in northwestern Ontario. The association with dolomitic carbonate rocks is also similar. Parts of the ore show alteration of carbonates to hematite.

At a depth of about 70 feet the Moore hematite deposit changed from red hematite with residual magnetite and martite to a pyrite-chalcopyrite-hematite assemblage, with hematite about sulphide cores. It was then mined as a copper deposit and known as the Eldorado Copper Mine. The alteration to hematite is attributable to weathering. At the Playfair (Dalhousie) mine red hematite was mined to a depth of about 94 feet and there is no record of the hematite there passing into chalcopyrite, but there are indications that this hematite too is an alteration of pyrite and perhaps also of carbonates.

The St. Charles (hematite) occurrence near Madoc has residual magnetite crystals, that are in part altered through martite to hematite, within a matrix of red hematite. This appears to be a deposit formed by alteration of magnetite and carbonates in a crystalline limestone host.

High Titanium Magnetite Deposits

Titaniferous magnetite and ilmenite occur apparently as primary minerals in gabbroic and anorthositic rocks (*see* Plates III B and V B) and in places they are segregated into bands that have the composition and grade of titaniferous iron ore. Near the Matthews (Yankee) pit dykes of fine-grained rock of about the same mineralogical composition as the coarse-grained, banded, gabbroic anorthosite wall-rock, cut across the gabbroic anorthosite and structurally overlying pink syenite. These dykes carry titanaugite and tiny clots of iron titanium oxides. Some of the stringers and bands of iron oxides in the gabbroic anorthosite transgress the rock bands in part, suggesting that the bands and stringers probably are injections and replacements representing differentiates from the magma that formed the gabbroic anorthosite. The dykes also may have the same source.

Veinlets of titaniferous magnetite cut the Eagle Lake gabbro and are in turn displaced and cut by fine-grained gabbro (trap) dykes that have slightly chilled margins (*see* Plate III A). Cousineau (1940) reported that "iron dykes" occur in the surrounding Grenville gneisses into which the Eagle Lake gabbro intrudes. Harrison (1944) considered that the gabbroic intrusions, the apatite-pyroxene pegmatites and the basic dykes were closely

genetically related and concluded, "If the dykes are pegmatites from the gabbro magma, liquids rich in iron, titanium and phosphorus, and some chlorine were exceptionally abundant in the closing stages of the crystallization of the gabbros".

The crystallizing temperatures of the gabbroic intrusions in general must have been high, judging from their mineral content and contact effects. In crystalline limestone these effects include the formation of zones of skarn, metamorphic pyroxenite, amphibolite and scapolite rocks. The temperature of crystallization however was probably lowered by the presence of volatiles, such as water, phosphorus, chlorine, fluorine and boron, held in solution by confining pressure. These elements might accumulate in the residual fluid when crystallization began, probably at temperatures less than 1200°C. At this temperature only a high confining pressure would prevent the nearby intruded carbonate rocks from dissociating with expulsion of carbon dioxide. Widespread occurrences near gabbroic intrusions of metamorphosed crystalline limestone, skarn, and calcite-bearing pegmatites show that reorganization and migration of carbonates did occur locally, but temperatures must have been quickly lowered or pressures maintained high or these reactions would have been generally even more extensive. Ferride elements in the crystallizing magma would enter early forming silicates and oxides as pyroxene and spinel, ilmenite, magnetite and chromite. The composition of these early crystals and of the residual liquid however would depend largely on the original composition of the magma, for under the high pressure presumed little outside material was probably added. Thus at the Matthews deposit ilmenite and titaniferous magnetite appear to have crystallized from the magma along with titanaugite and andesine, but also were emplaced somewhat later probably as a hot fluid. Ramberg (1952, p. 211 and pp. 264-266) suggested that anorthosites may be formed in a deep level of the earth's crust as the result of diffusion processes acting in deep parts of folded mountain zones. He further ascribed the ilmenite-magnetite ore encountered in anorthosites and in other granulite rocks to this process and stated, "The appearance of titanic ore in this facies is therefore in all likelihood, connected with the exsolution of Ti from the lattices of biotite, hornblende, and sphene when amphibolite facies rocks are rearranged within the granulite facies". He based this opinion on his conclusion (1948) that "... silicates, which are stable in the granulite facies, are unable to incorporate appreciable amounts of titanium in their lattices". Along this line also DeVore (1953) stated, "The anorthosite plagioclases may be the source of titanium in titaniferous iron ores associated with anorthosite. Anorthosite plagioclases are notably high in Ti, Fe, and Mg, most of which occurs as minute, opaque exsolved, rodlike inclusions in the plagioclase. Granulation and recrystallization of the plagioclases are accompanied by notable decreases in Ti and often Fe and Mg in the four anorthosite areas studied."

On the other hand, Buddington, Fahey and Vlisidis (1953) stated, "In igneous rocks of the Adirondack region the amount of TiO_2 in ilmenomagnetite (magnetite with exsolved ilmenite) is greatest in some ore segregations in gabbro and anorthosite (12 to 14 per cent) less in hornblende microperthite granite (5 to 6.7 per cent), and least in microperthite alaskite (3.0 to 4.3 per cent). The titanium variation in the ilmenomagnetite of these plutonic rocks parallels that found by Japanese geologists in magnetite of basaltic, andesitic and rhyolitic volcanic rocks in Japan; it is a function of temperature of formation and affords a wide-range temperature scale. The composition of the ilmenomagnetite, both that accessory in granite and that in ore concentrations in gabbro and anorthosite, leads to an inference of formation at *magmatic* temperatures.

"The magnetites of microcline-rich granitized rocks, formed at temperatures lower than magmatic, has about 2.2 to 3.1 per cent TiO_2. The TiO_2 in magnetites of gneisses reconstituted in the upper temperature range of granulite-amphibolite facies is 3.1 to 4.1 per cent; in the lower range of amphibolite facies it is only 1 to 2 per cent. Free ilmenite is present in all samples."

Shand also considered that these gabbroic rocks and titaniferous iron ores are of igneous origin. He concluded (1947) that, "Crystallization of deep-seated gabbroic magma leaves a residual solution enriched with ferrous iron in the form of ferrous hydroxide hydrosol. Upon dehydration this substance undergoes self-oxidation, yielding magnetite with expulsion of hydrogen."

Many others have contributed to the literature on this subject. Among these Bowen (1928) and Osborne (1928) advanced the theory that crystal fractionation and filter pressing of a residual magnetite-rich liquid fraction from a crystal mush accounts for the formation of such ores. Balk (1944) considered that the separation of crystals and liquid is brought about by flowage friction. As the magma with its enclosed crystals moves through restricted openings, the suspended crystals are retarded, causing a grouping and separation from the residual liquid. Vogt (1926) believed in the idea of liquid immiscibility, and Bateman (1951) has advanced this view to account for the origin of magmatic magnetite deposits by calling on injection of an iron-rich residual liquid.

The concensus of opinion is that these rocks and ores are of igneous, as opposed to Ramberg's newer concept of metamorphic, origin. Extensive investigations will be required to allow a clear-cut distinction to be made between magmatic and metamorphic end-products.

Low Titanium Magnetite Deposits

These deposits carry less than 1 per cent titanium and are commonly free of ilmenite, except for a few that contain minor microscopic grains of

ilmenite with the magnetite. Many of these deposits occur in skarn, metamorphic pyroxenite and amphibolite zones at the contact of crystalline limestone with an intrusive body. The high temperature metamorphism of the wall-rocks is in most places attributable to the effects of a felsic or mafic intrusion nearby or to the emplacement of the magnetite, whereas the formation of lower temperature minerals is traceable to reactions accompanying the deposition of the magnetite. Among the lower temperature effects epidotization and chloritization are characteristic, and in addition, at a few deposits, post-magnetite carbonate-chlorite-serpentine veinlets, some of which carry small amounts of magnetite, are common. For the most part magnetite replaces the high temperature metamorphic silicates such as garnet and pyroxenes but in a few places the magnetite is cut by garnet and epidote veins. However, no evidence was found to suggest that the magnetite deposits are of widely divergent ages.

Although replacement textures and medium to low temperature hydrothermal metamorphism, epidotization and chloritization, attend the magnetite in several of the deposits, the common association of magnetite and garnet and the occurrence of post-magnetite garnet-bearing veins suggest a high temperature emplacement for some of the magnetite. At the St. Charles magnetite deposit which occurs in a skarn zone in crystalline limestone within 70 feet of the Millbridge gabbro contact, a band of massive magnetite in contact with crystalline limestone is bordered by coarse-grained carbonates. The magnetite is finer grained along the contact than in the centre of the band. The carbonate appears to have been coarsely recrystallized and the magnetite slightly chilled along the contact. The magnetite is low in titanium, and probably was formed from iron-rich fluids that were differentiated from the gabbroic magma at depth. At the Coehill deposit a vein of massive, crystalline magnetite 4 inches wide with flakes of mica and molybdenite, cuts across the magnetite-bearing zone, and north of Stormy Lake near Gooderham a pink calcite pegmatite carries coarsely crystalline magnetite along with apatite, feldspar and mica. Veins of magnetite with pyroxene, feldspar and epidote also occur in the gneisses at the Robertsville mine. It would thus appear that emplacement of a solution rich in iron, its freezing point probably more or less lowered by volatiles, played a part in forming these deposits.

It is difficult, however, to deny the possibility that the ultimate origin of these deposits lies in the melting or solution of ferruginous rocks depressed to great depths, mobilized and re-injected into the crustal rocks with attendant hydrothermal activity and metasomatism.

These concepts of Landergren (1948), Backlund (1952), and Ramberg (1952) regarding the formation of iron ores by ultrametamorphism lack positive evidence in that ore material has not been traced through different grades of metamorphism from the unaltered, through the partly

altered, to the completely altered state. Such evidence was not recognized in the deposits and wall-rocks in eastern Ontario and southwestern Quebec, possibly because of the high grade of regional metamorphism that pervades the rocks of the region, but owing to the lack of evidence, and until such time as this is forthcoming, the hypotheses of the mobilization of ferruginous rocks and the concentration of iron therefrom are considered unsupported.

Although few positive statements on source rocks have been made, some previous investigators described the magnetite deposits of eastern Ontario as contact metamorphic deposits at the borders of granitic intrusions, indicating that they are derived mainly from these intrusions (Uglow, 1926). W. G. Miller (1899) suggested that the iron deposits of the Glendower mine originated from solutions, derived from a syenite body that is intrusive into gabbro, now highly scapolitized, and crystalline limestone. The solutions rich in chlorine were thought to have leached iron from the gabbro leaving it scapolitized, and to have deposited the iron in the neighbouring limestone. R. E. Jones (1953) in 1951 found that pegmatite dykes, probably a phase of the syenite, cut the magnetite at the Black Lake occurrence about 1½ miles northeast of the Glendower deposit. He suggested that the magnetite at Glendower was from a source probably related in age to the syenite. Abraham (1951) wrote, "The magnetite replacement deposits within the Grenville meta-sediments are attributed to mineralizing solutions derived from the magma that produced the nearby granitic, syenitic or dioritic rocks".

In the Adirondack region where the magnetite ores have been studied in detail, various theories of their origin have been proposed, but it is generally held that the deposits are genetically related to granite (*Mining and Metallurgy,* 1943). W. J. Miller (1919) outlined a theory of early intrusion of a residual part of a granite magma into the Grenville sediments and interbanded gabbro and hornblende gneiss. Solutions from the granite were thought to have dissolved iron from the basic rocks and then differentiated into a magnetite-rich residual that was injected into the gneisses. Alling (1925) expressed the opinion that the Adirondack magnetites developed directly by differentiation of the syenite-granite series. He regarded the deposits as "magmatic replacement deposits due to aqueo-igneous magnetite-rich solutions derived from a differentiating granitic magma". E. L. Bruce (1933) concluded mainly from a study of the literature of the deposits "that the magnetite came from the syenite-granite intrusive at an early stage in its history, and probably is a high temperature replacement closely following the pegmatitic stage of the cooling intrusive".

The present study however has shown that most of the magnetite deposits are in or at the contacts of rocks of dioritic to gabbroic composition, and a few occur in, or at the contacts of, rocks of granitic composition. In several places the deposits are intruded by dykes of syenite, granite and pegmatite.

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Pegmatite dykes also cut the magnetite ore at Lyon Mountain in the Adirondacks. A close genetic relationship is suggested by the distribution of the deposits and their geochemical features, between some of the mafic intrusions, the magnetite ores, and some of the felsic intrusions, but available evidence does not indicate a simple relationship.

The essential difference between the high and low titanium magnetite deposits lies in the paucity of ilmenite in the low titanium deposits, and in their slightly smaller content of ferride elements. Magnetic concentrates from ore materials of both high and low titanium types show a converging tendency in the ferrides which might be taken to indicate a common origin. Most of the low titanium magnetite deposits are in rocks that are even lower in the ferrides than the ore materials, and the ore forming solutions may have lost some of these elements to the host rocks; the ore materials that are not so low in ferrides may have acquired some of their ferrides in their migration. Other sources of the ferrides, in addition to the iron oxide minerals in the ore materials are the ferromagnesian silicates, sphene and the sulphides. These minerals are reduced in amount in the magnetic concentrates. Thus the concentrates more nearly approach the composition of the pure magnetites. Comparisons here show that the magnetic concentrates derived from high titanium magnetite deposits are characteristically slightly higher than the magnetic concentrates from low titanium magnetite deposits, not only in titanium, but also in chromium and nickel, and to some extent in vanadium and cobalt.

The purest magnetite concentrated magnetically from high titanium magnetite ore materials, however, resembles in composition the magnetite from many of the low titanium magnetite deposits (*see* Tables IV and VI); thus titanium, chromium, vanadium, nickel, cobalt, etc., are separated magnetically from iron. It is apparent from other studies that differentiation in mafic intrusions can also bring about such a separation of elements. Proof of this was not found in eastern Ontario, possibly because of recurrent injection of partly differentiated magmas, and of magmas differentiated at depth, but the great stratiform differentiated mafic sheets, almost universally show successive evolution of chromite, ilmenite and magnetite. For example, the detailed work of Wager and Mitchell (1950-51) on successive differentiates in the Skaergaard intrusion, a strongly fractionated mafic intrusion in East Greenland, shows that ilmenite and magnetite first began to crystallize at a middle stage of differentiation, in a hypersthene-olivine gabbro, and that the amount of ilmenite decreased relative to magnetite with increasing fractionation. They point out further that apatite iron ores belong to a later stage of fractional crystallization than typical titaniferous iron ores. Wager and Mitchell found that the early magnetite contained more chromium, vanadium and nickel than the early ilmenite, and that these elements declined in both with increasing fractionation, whereas cobalt did not decrease as much.

Wager and Mitchell stated that the Bushveld ores, and titaniferous ore studied by Landergren, are richer in chromium and nickel than the early Skaergaard magnetite, but that the apatite ores of Kiiruna are poor in chromium and comparable to the magnetite of Skaergaard middle gabbro. Many of the low titanium magnetites from eastern Ontario are lower in chromium and nickel than the Bushveld, Skaergaard, Kiiruna and central Sweden magnetite ores, and may therefore represent a later and further stage of differentiation from a mafic magma.

Some of the felsic and mafic intrusions of eastern Ontario in places have characteristics suggesting a common origin, both in their field relations and in trace elements. Other felsic intrusions can not be shown to be so related. A complicated history of differentiation and intrusion with concomitant metamorphism and mineralization is postulated. Magnetite is much less abundant in the felsic than in the mafic intrusions of the area which in the course of their differentiation are considered to have been the major contributors of iron in eastern Ontario.

Confirmation of this view is found in semi-quantitative spectrographic analyses of nine selected samples of pyrite taken from low titanium magnetite deposits (*see* Tables VIII and IX). This pyrite, which seems to be intimately related to the magnetite (*see* Plate VI A) through which it is sporadically distributed in stringers and disseminations, shows a greater content of the ferride elements than (a) pyrite from the gold deposits and associated rocks in northern Ontario, which is generally regarded as being derived from felsic intrusions (cf. Hawley, 1952), (b) pyrite from Dalhousie hematite deposit, and (c) pyrite from a granitic pegmatite dyke near Hybla, Ontario. Table IX shows that magmatic sulphides are characteristically slightly higher in cobalt and considerably higher in nickel than average accessory pyrite from Finnish Precambrian rocks (Rankama and Sahama, 1950). The range in amounts of cobalt and nickel in pyrite from eastern Ontario magnetite deposits approaches that of magmatic sulphides considering that the average given (1950) includes nickeliferous pyrrhotites. The enrichment of the ferride trace elements in pyrite associated with magnetite deposits in eastern Ontario above those in certain pyrite elsewhere and also in pyrite from a granitic pegmatite is confirmatory evidence that differentiating mafic intrusions were the source rocks of the magnetite deposits of eastern Ontario.

Hematite Deposits

Hematite in small deposits in eastern Ontario occurs in several forms, hard red, soft, earthy red, specular, and martite; the last is often associated with minor magnetite and soft red hematite. In many places the basal Palæozoic rocks are stained with red-brown hematite, probably the product

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of migration and subsequent dehydration of iron hydroxides derived from clastic particles of the weathered Precambrian martitized magnetite. Unaltered magnetite is not common in the basal Palæozoic rocks, but rounded, porous, fragments of martitic magnetite and hematite are abundant in certain localities.

A bluish tinge to the magnetite commonly accompanied by red hematite on exposed surfaces and the soft, friable nature of the material indicates the presence of martite. In the ores examined martite replaces magnetite, retains some of the physical characteristics of magnetite including some magnetism, due to included remnants of magnetite, but gives a red streak and X-ray powder photograph of hematite. In many places the replacement is not complete and residual magnetite is intermixed with martite; in advanced stages of alteration much red hematite is formed. Certain pebbles in the basal Palæozoic rocks resemble an intermediate state of alteration of the magnetite; others are altered to soft red hematite. This suggests that the formation of martite and hematite is due mainly to weathering. It should be noted, however, that some polished sections show martite replacing the cores of grains of magnetite, a feature more characteristic of hot than of cold solutions, but of course not necessarily confined to either (*see* Plate VII A). Fractures and partings in magnetite might provide even better channels for altering solutions than grain boundaries. Gruner (1922) suggested that martite formed by deep seated oxidation of magnetite and in 1926 showed that magnetite oxidizes slowly in air at variable rates, the rate increasing with decreasing grain size, and that the alteration begins along octahedral planes. Minor films of hematite, commonly associated with late carbonate veinlets, also occur in some of the ores. Examples were noted at the Glendower mine at a depth of 466 feet in diamond drill hole No. 1, and to depths of 200 to 300 feet in several other places. At the Bristol mine in Quebec, at a depth of 264 feet in diamond drill hole No. 4, a ¼-inch seam of magnetite with selvages of actinolite-tremolite, talc, phlogopite and carbonates is intimately altered in part to red hematite, as if by hydrothermal solutions. Possibly both ascending late stage hydrothermal solutions, and cold, meteoric waters may have operated to produce martite and hematite. The apparent lack of magnetite in the Palæozoic detritus suggests that the zone in which martite-hematite was formed represents a zone of pre-Palæozoic weathering.

Rusty brown limonite as opposed to hematite is the characteristic alteration product of the ferruginous minerals, but in some places soft red hematite is formed directly, and in any case limonite is easily dehydrated to form hematite. Magnetite is commonly stable and resistant to this type of normal surficial weathering, in contrast to pyrite, pyrrhotite, chalcopyrite and ferruginous carbonates, which alter readily to limonite.

At the Eldorado deposit red hematite is reported to pass into a sulphide zone at a depth of about 70 feet in which pyrite and chalcopyrite are reported to be in part altered to hematite. This hematite contains microscopic residual magnetite, and at surface hematite is bordered on the hanging-wall by a zone about 8 feet wide carrying martite along with quartz, carbonates, hematite, magnetite, pyrite and chalcopyrite. Pyrite is rimmed and replaced by magnetite where it is present. Martite and quartz appear to replace these magnetite granules marginally in a few places. Quartz veins and calcite veins, each carrying tiny crystals of magnetite and some hematite films on the crystal faces in vugs, cut the martitic zone, so a second development of magnetite is indicated. Hematite is apparently secondary after pyrite and chalcopyrite, and martite after magnetite, in the magnetite-sulphide body.

At the Playfair (Dalhousie) deposit hematite probably has resulted from the alteration of pyrite by oxidizing solutions circulating along a sheared zone in dolomitic crystalline limestone containing pyrite and quartz. The Wallbridge and White Lake hematite deposits are replacements in dolomitic crystalline limestone. Small vugs in the dense red hematite at the Wallbridge pit are lined in places with tiny crystals of magnetite, specularite, goethite and calcite.

There is quite possibly a close relationship in origin and age between magnetite in the vugs in Wallbridge hematite, and magnetite in the vugs of Eldorado quartz-carbonate veins in martite. The location and mode of occurrence of the quartz veins suggest they are differentiates of the intrusive Moira granite. If so the magnetite crystals in these veins and in the vugs at Wallbridge could be hydrothermal in origin and associated either directly or indirectly with the granitic intrusions nearby (*see* Plate VII B), but it is more probable that they are products of recrystallization.

Chapter VII

Economic Geology

General Considerations

The iron deposits of eastern Ontario and southwestern Quebec are relatively close to the blast furnaces and steel plants of Canada and the United States, and most deposits are reasonably close to good transportation routes—railways, highways or waterways. Their distribution with respect to these and to the general geology is shown on Figure 1. Most of them could be mined initially from open pits, and eventually to depth by underground methods. Dumps containing more than 10,000 tons of concentrating material remain on several of the properties. Magnetite is the most abundant ore mineral.

Compared with the great iron deposits of the world the deposits in eastern Ontario and southwestern Quebec are relatively small and low in grade, but considerable tonnages of low-grade concentrating magnetite are available at a number of deposits. Most of the magnetite deposits are sufficiently low in deleterious elements, and of coarse enough grain to provide a good wet magnetic separation at a grind of –48 mesh, but for maximum extraction many require a finer grind. Many of the deposits are estimated to contain a million tons or more of concentrating material averaging 25 per cent iron; several may contain more than 10 million tons, and a few are believed to hold more than three times this amount.

Although an iron content of 25 per cent is low compared with most iron ores, iron is being recovered economically from still lower grade material at Benson mines in the Adirondacks; this in a large-scale, low-grade, open-pit operation in which more than 4,000,000 tons, including both magnetite and martite ore are mined annually, yielding about a million tons of concentrate averaging about 60 per cent iron. Material containing as low as 15 per cent iron is mined and milled. It is readily seen that a combination of factors influence the mining of iron ore, and that each deposit must be considered individually in detail.

Economic Factors

The following tentative conclusions with deductions of possible economic significance are based on this study:

(1) Magnetite is the most abundant source of iron in eastern Ontario. Much of it is disseminated through mafic intrusive rocks with a few occurrences in felsic rocks. Relative concentrations are indicated as magnetic anomalies of differing size and magnitude on

aeromagnetic maps. These anomalies afford one of the best methods of locating deposits, as demonstrated at Marmora, Magnetic, gravity and geological information should be combined in interpreting anomalies, to arrive at the best picture of the nature of the deposit causing the anomaly.

(2) Magnetite deposits of eastern Ontario are classified as high or low titanium deposits on the basis of a titanium content of greater, or less, than 1 per cent.

(3) Ilmenite, with attendant amounts of titanium greater than 1 per cent, characterizes magnetite deposits in mafic rocks. Less than 1 per cent titanium is commonly present in magnetite deposits in other rocks. Deposits in crystalline limestone may be low in titanium even where they are near mafic rocks.

(4) Selected samples from an outcrop, or from a deposit, may not be representative of the grade or trace element content of the deposit. For example, a spectrographic analysis of a sample from a titaniferous magnetite ore that is said to average about 17 per cent titanium (Unpublished report, National Lead Company) showed less than 1 per cent titanium (Table V). Hence the deposits are not uniform in metal content and careful sampling is required to give the average grade of the deposit.

(5) Both high and low titanium magnetite deposits may be expected to persist at least one-half as deep as they are long, although exceptions may be found.

(6) The low titanium magnetite deposits are characteristically controlled by local structure and in part by chemical composition of the host rock. The sheared and fractured contact of crystalline limestone with another rock is the most common locus, but no single rock type seems to be completely essential for localization of magnetite.

(7) Martitization, the pseudomorphous replacement of magnetite by martite, is a minor feature in several of the magnetite deposits. It is most common near surface and seems to be restricted in distribution to a relatively shallow depth in most places within 200 feet of the present, or pre-Palæozoic erosion surface. Martite probably represents a low temperature, near surface, alteration of magnetite, either by meteoric or hydrothermal solutions, or by both.

(8) Hematite is, in many places in eastern Ontario, a product of weathering of martite or martitized magnetite. It is believed that the processes of martitization and hematitization are gradational here, and for this reason both may be attributed to alteration by

weathering or to intermingling of supergene and hypogene solutions. Pebbles of martitic hematite in the basal Palæozoic clastic sedimentary rocks suggest that the alteration was well advanced, if not complete, in pre-Palæozoic time.

(9) Hematite deposits occur as replacements of magnetite, and of iron-bearing sulphides and carbonates. In general hematite does not extend more than 300 feet in depth, and in places it is said to have passed at shallow depths into unaltered sulphide material. It would thus appear that descending meteoric waters were the cause of the alteration. However, the presence particularly of magnetite and goethite crystals lining vugs in dense red hematite at the Wallbridge suggests that hydrothermal solutions were active during the end phases of the formation of this hematite body. Perhaps both hematite and martite may have formed in part from hydrothermal solutions that reached weathered zones in ferruginous rocks, and there intermingled with descending oxidizing, meteoric waters.

(10) Comparisons of spectrographic analyses of ore materials and magnetic concentrates indicate that in all cases the harmful ingredients in the ores may be reduced to traces by fine grinding and magnetic separation. This conclusion is supported by the results of many milling tests in the laboratories of the Mines Branch, Mineral Dressing and Process Metallurgy Division, on ore samples from the area.

Chapter VIII

Conclusions

The iron deposits of eastern Ontario may be classified into three groups, high titanium magnetite deposits, low titanium magnetite deposits and hematite deposits. All have been mined in the past. They lie in a deeply eroded terrain mainly in Precambrian rocks, and the most abundant ore mineral, magnetite, is confined to those rocks. Part of the hematite is found in Palæozoic rocks at or near the contact with the Precambrian complex. The magnetite deposits occur in greater numbers and in larger deposits than the hematite deposits, and appear to be potentially more valuable as sources of iron ore because of their greater size and the ready method of magnetic concentration. This should not discourage search for mineable hematite however, as good grade hematite ore has been mined in the past and may be found in the future. The low titanium magnetite deposits have yielded most ore, and are more favourably regarded because of their low titanium content and relative ease of concentration. Both high and low titanium types include deposits that might be expected to yield more than a million tons of low-grade concentrating ore material.

Geological relationships of the gabbroic host rocks to the ore materials of the high titanium magnetite deposits indicate a close genetic relationship between them. This is supported by the similar distribution of trace elements in the host rocks and ore materials.

Geological relationships between the host rocks and ore materials of the low titanium magnetite deposits do not clearly indicate a close genetic relationship between them. The distribution of the elements in the ore materials of this class is more similar to that in the average gabbro than in the average granite, and it is suggested that these magnetites were derived by differentiation of magma perhaps slightly less mafic than gabbro. The distribution of the ferride elements in magnetic concentrates from high titanium and low titanium magnetite deposits, and in pyrite closely associated with low titanium magnetite deposits, supports this view. It seems reasonable to assume that these magnetite deposits are the result of differentiation and separation from gabbroic rocks, and that the characters are due partly at least, to differences in distance from source and to degree of differentiation at time of emplacement.

Geological relationships between the hematite deposits and their host rocks do not indicate a close genetic relationship, but do suggest that the hematite deposits are, in part at least, derived by alteration of ferruginous minerals originally present in the host rock. Such minerals include pyrite,

chalcopyrite, iron-bearing carbonates and magnetite or martitized magnetite. The variety martite, pseudomorphous after magnetite, seems to be restricted to the old Precambrian zone of weathering. With the exception of iron and possibly of manganese, these hematite-rich deposits seem to be slightly more deficient in the ferrides than the magnetite deposits.

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E.R.R. 8-2-54

A. *Unconformity between massive Precambrian rocks and flat-lying Palæozoic rocks, exposed in third bench of Marmora mine open pit. View looking north shows slope of buried Precambrian surface from ridge on left to valley on right. (Pages 4, 8, 45.)*

Plate II

B. *Test pit on site of Hilton mines open pit looking northwest. Shows exposed magnetite-martite-bearing amphibolitic schist (ore material) under thin cover of overburden. Foliation strikes west and dips about 60 degrees north. (Pages 8, 29.)*

E.R.R. 1-2-53

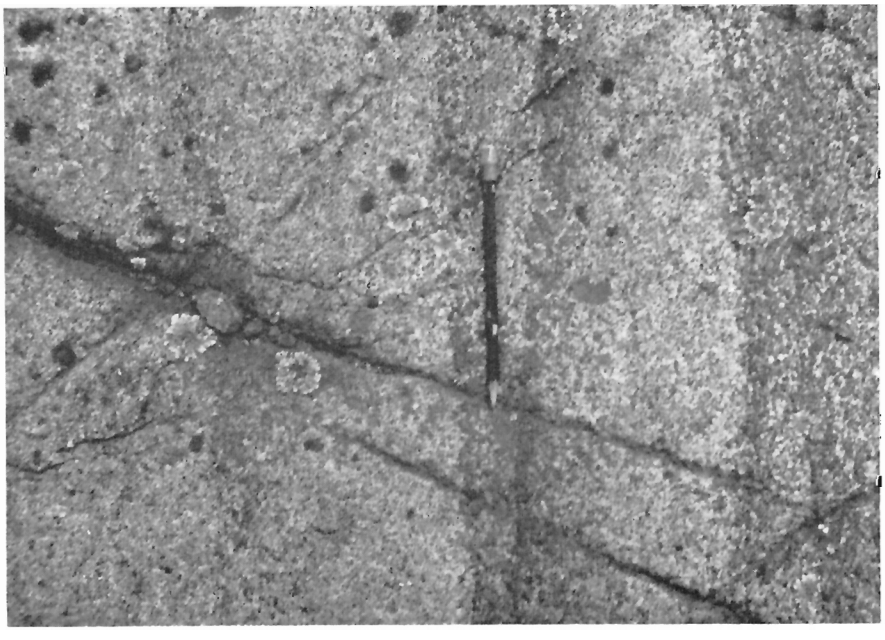
E.R.R. 4-6-54

A. *Fine-grained, dark gabbro (trap) dyke cutting gabbroic anorthosite near the Blessington (Eagle Lake) mine. Hammer lies on the dyke, and points to a veinlet of pyroxene and titaniferous magnetite that has been displaced to the left the length of the hammer handle. (Pages 11, 91.)*

Plate III

B. *Weathered surface of banded gabbroic anorthosite at the Matthews (Yankee) mine. Shows light feldspar and dark pyroxene with converging bands of titaniferous magnetite and pyroxene. (Pages 14, 91.)*

E.R.R. 2-2-58



E.R.R. 4-7-53

A. *Banded syenitic, hornblende-feldspar gneiss near Boulter is shown cut by fine-grained gabbro dyke. Hammer point indicates contact. Pencil lies along direction of foliation of the gneiss and points to a narrow pegmatite dykelet with a centre seam of black magnetite. (Page 27.)*

Plate IV

B. *Light pink syenite dyke cutting dark magnetite-bearing metamorphic pyroxenite-amphibolite at Coehill mine. (Pages 34, 90.)*

E.R.R. 5-1-53

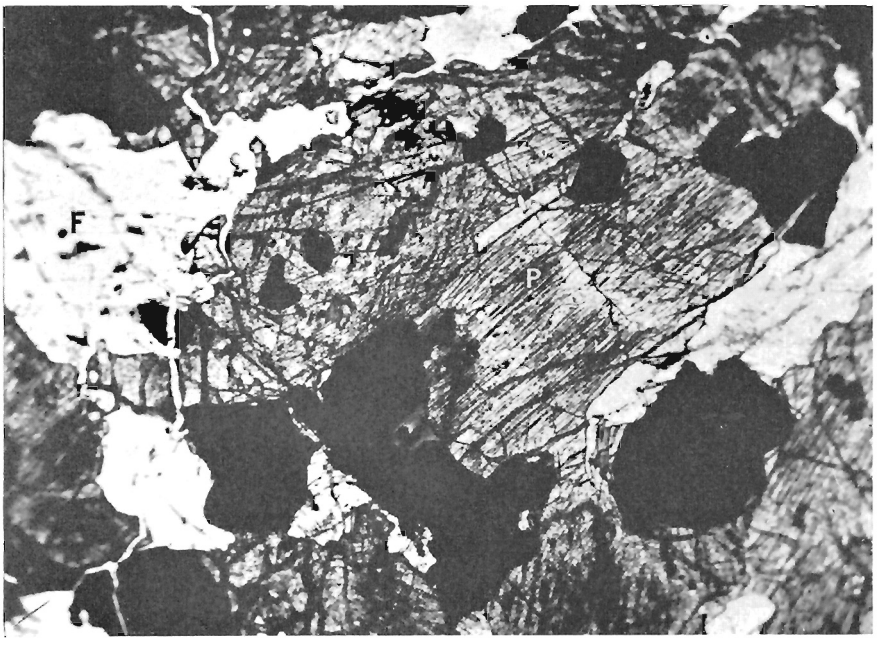
E.R.R. 6-6-53

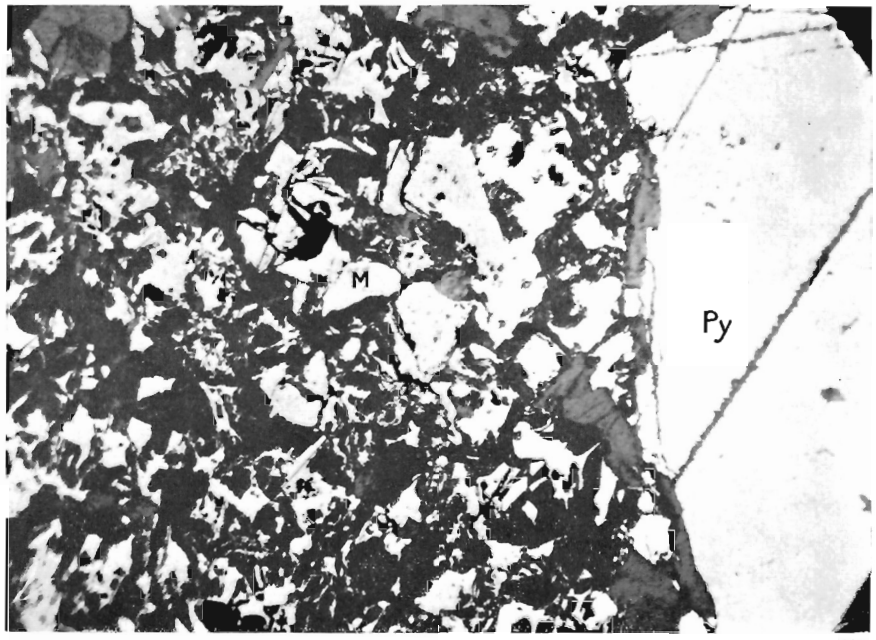
A. *Three ages of igneous rocks in a rock-cut on north side of highway 7, about 3 miles west of Marmora, Ontario. Hammer point indicates contact of fine-grained black trap dyke cutting lighter coloured basalt-andesite. Pencil points towards narrow granite dykelet cutting both trap and basalt-andesite. (Pages 4, 6, 7, 8, 18.)*

Plate V

B. *Microphotograph of gabbroic anorthosite, Matthews mine, Ontario. Shows interlocking crystals of pyroxene (titanaugite) (P), plagioclase feldspar (andesine) (F), and opaque titaniferous magnetite (transmitted light, x 29). (Pages 14, 22, 91.)*

106677





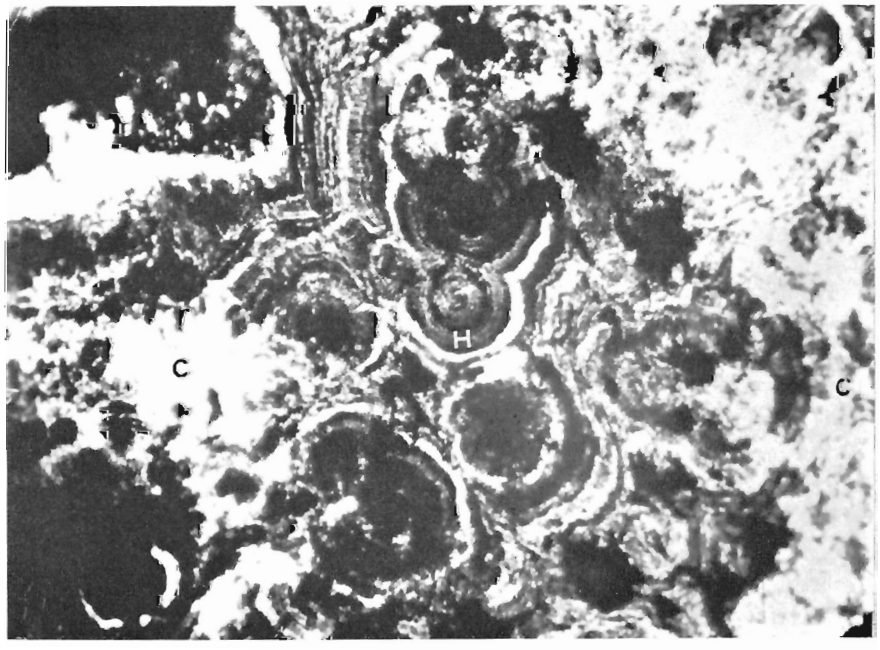
106682

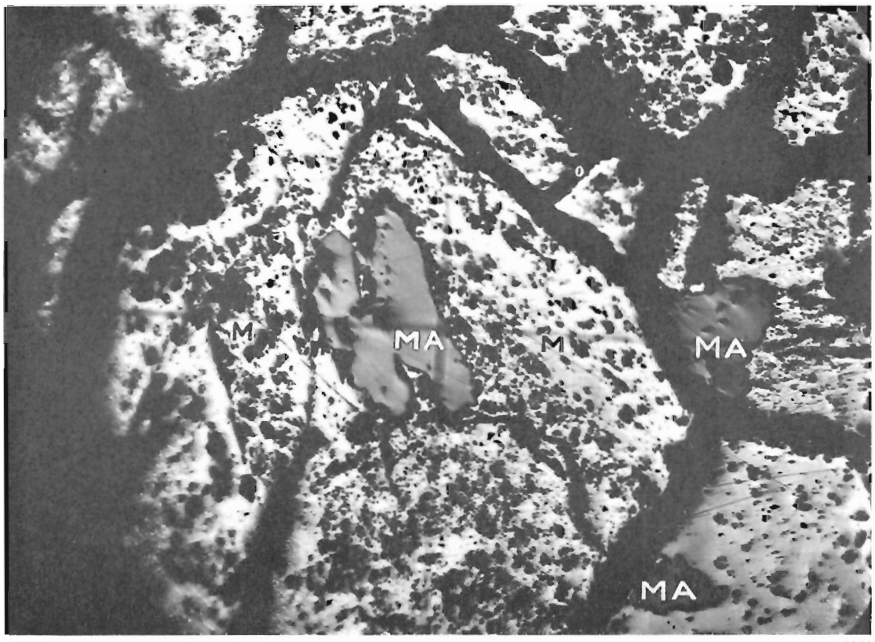
A. *Microphotograph of magnetite ore from Bethlehem Mines Corporation diamond drill hole 5B, Marmora, Ontario. Shows magnetite (M), with some pyrrhotite, in dark-coloured silicate gangue, in part replacing a large pyrite crystal (Py) on the right (reflected light, x 55). (Page 46.)*

Plate VI

B. *Microphotograph of the central part of a hematite-bearing carbonate veinlet, cutting martitized magnetite, from the Blairton mine. Section shows concentrically banded, spherulitic hematite, black (H), and carbonate, white (C) in a carbonate matrix (transmitted light x 150). (Page 24.)*

106678





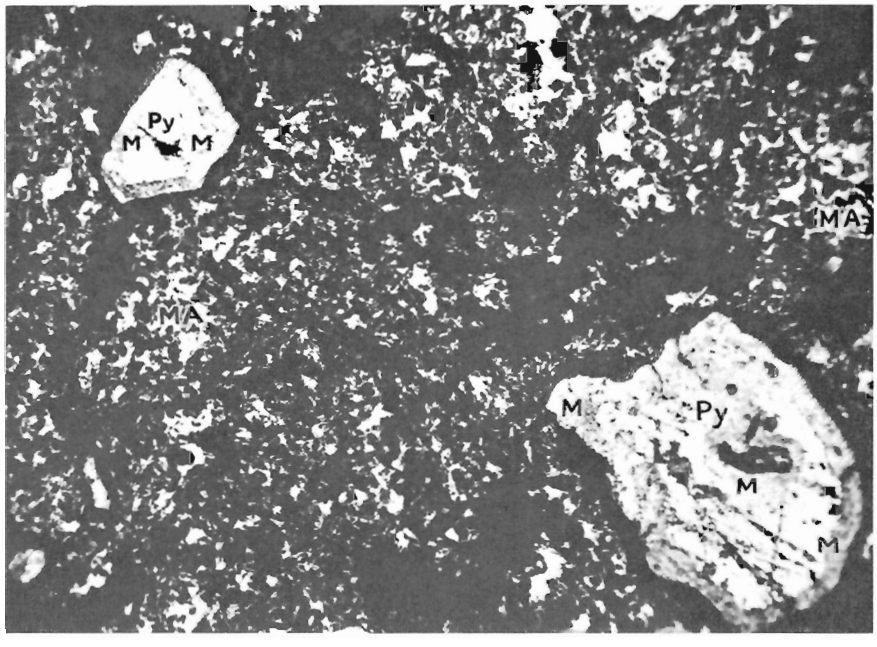
106684

A. *Microphotograph of martitized magnetite from Blairton mine. Shows magnetite grains (M) replaced in part by martite (MA) apparently both at the margins and cores of the grains (reflected light, x 150). (Pages 24, 98.)*

Plate VII

B. *Microphotograph of martitized magnetite from the Moore mine, Eldorado, Ontario. Shows martite (MA) in grey to black coloured quartz-carbonate gangue, with large grains of pyrite (Py) that are rimmed with magnetite (M). Quartz in the gangue appears to replace magnetite in some places along the rims. Magnetite replaces pyrite, in part marginally, and in part centrally (reflected light, x 55). (Pages 62, 99.)*

106683



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