R. Baragar

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DEPARTMENT OF ENERGY,
MINES AND RESOURCES

ECONOMIC GEOLOGY
REPORT No. 22

GEOLOGY OF IRON DEPOSITS IN CANADA

Volume II

Iron Deposits in the Appalachian and Grenville Regions of Canada

G. A. Gross

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1967

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As stated in the Preface, this volume is the second of a series.

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PLATE I. The Hilton mine near Shawville, Quebec, 1962.

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PREFACE

Study of more than 200 iron occurrences in the Appalachian, Grenville, and Labrador Coast regions has revealed specific relationships between different types of iron deposits and the major tectonic and geological features. Application of this information will help in appraising the iron potential of the regions, and, more specifically, in guiding future exploration, evaluation, and development of individual iron deposits.

This is the second in a proposed series on iron deposits of all regions of Canada.

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

OTTAWA, February 25, 1964

WIRTSCHAFTSGEOLOGISCHER BERICHT
Nr. 22 — Die Geologie der kanadischen Eisenerzlager.
Band II: Eisenablagerungen in den kanadischen Appalachen und in der Grenville-Region.
Von G. A. Gross

Anhand der Untersuchung von ungefähr 200 Eisenvorkommen beschreibt der Bericht die verschiedenen Arten der Eisenablagerungen und ihre Beziehung zu den wichtigsten tektonischen und geologischen Zügen der kanadischen Appalachen und der Grenville-Region.

ЭКОНОМИЧЕСКАЯ ГЕОЛОГИЯ, ОТЧЕТ № 22—
Геология месторождений железа в Канаде.
Том II — Месторождения железа в Аппалачской и Гренвильской областях Канады.
нады.
Гордон А. Гросс

Описывает различные типы месторождений железа и их взаимоотношения с главными тектоническими и геологическими элементами Аппалачской и Гренвильской областей. Заключения основаны на изучении приблизительно двухсот месторождений железа.

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Acknowledgments

A very extensive geological literature for eastern Canada has been utilized in the preparation of this report, and private communications from interested geologists have greatly benefited the writer. Special acknowledgment and thanks are given to property owners and company staff who permitted the writer to examine iron deposits and who provided information and hospitality in the course of the field investigations. The kind interest and cooperation extended by officers of the Department of Natural Resources of the Province of Quebec are gratefully acknowledged.

IRON DEPOSITS IN THE APPALACHIAN, GRENVILLE, AND LABRADOR COAST REGIONS

Abstract

Iron deposits in the Appalachian and Grenville regions were among the first mineral occurrences worked in Canada. Nearly every known type of iron occurrence is included in the 200 deposits described in this volume. The Clinton type iron-formations, composed of hematite, siderite, and chamosite, at Wabana, Newfoundland, are the principal source of iron ore in the Appalachian region, and have been mined for over 70 years. Other Clinton type iron-formations in Nova Scotia and Algoma type iron-formations and iron-manganese beds in New Brunswick are potential sources of iron ore.

Magnetite deposits of replacement origin and syngenetic ilmenite and titaniferous magnetite deposits are predominant in the Grenville region. The occurrence of a few small magnetite-hematite-quartz iron-formations in metasediments in the south part of the Grenville Province has been confirmed. A study of the regional distribution of all types of magnetite and ilmenite deposits in the Grenville Province, associated host rocks, mineralogy, and iron-titanium ratios in deposits shows that ilmenite deposits occur as injected and disseminated masses in anorthosite rocks, titaniferous-magnetite deposits occur as syngenetic bodies in gabbro and gabbroic anorthosites, and magnetite deposits containing less than one per cent TiO_2 occur as replacement masses in metasediments, particularly in limestone and amphibole-rich host rocks.

A close genetic relationship between anorthosite intrusions and related gabbro, diorite, and granitic intrusions on the one hand, and the ilmenite, titaniferous magnetite, and replacement magnetite deposits on the other is indicated by their spatial relationship and by the variations in iron and titanium ratios in the iron deposits with different host rocks. Iron-titanium ratios in ilmenite and magnetite deposits are lowest in the east and northeast part of the Grenville Province where very large anorthosite masses are exposed, and are highest in the southwest where only small gabbro and anorthositic gabbro intrusions are known and where replacement magnetite deposits are numerous.

Résumé

Les gisements ferrifères des régions des Appalaches et de Grenville sont parmi les premières venues qui aient été exploitées au Canada. Les 200 gisements décrits dans le présent volume comprennent presque tous les genres connus de minerai de fer. Les formations ferrifères de type Clinton, à Wabana (T.-N.), composées d'hématite, de sidérite et de chamosite, sont les principales sources de minerai de fer de la région des Appalaches et elles sont exploitées depuis plus de 70 ans. Des formations de type Clinton en Nouvelle-Écosse, de même que d'autres de type Algoma et des lits ferrifères à manganèse au Nouveau-Brunswick, sont des sources possibles de minerai de fer.

Dans la région de Grenville, on trouve surtout des gisements de magnétite formés par substitution et des gisements d'ilménite syngénétique et de magnétite titanifère. On a confirmé l'existence de quelques petites formations ferrifères de quartz à magnétite et à hématite dans les métasédiments de la partie sud de la province de Grenville. Une étude de la répartition régionale de tous les genres de gisements de magnétite et d'ilménite dans la province de Grenville, des roches encaissantes associées, de la minéralogie et des rapports fer-titane dans les gisements, indique que les gisements d'ilménite se présentent sous formes de masses injectées et disséminées dans de l'anorthosite. Elle montre aussi que les gisements de magnétite titanifère se trouvent sous forme de massifs syngénétiques dans le gabbro et les anorthosites gabbroïques et que les gisements de magnétite, dont la teneur en TiO_2 est inférieure à 1 p. 100, se présentent en masses de substitution dans les métasédiments et en particulier dans les roches encaissantes à forte teneur en calcaire et en amphibole.

Une étroite relation génétique entre les intrusions d'anorthosite et les intrusions apparentées de gabbro, de diorite et de granite, d'une part, et les gisements d'ilménite, magnétite titanifère et de magnétite de substitution d'autre part, est révélée par leur mode de répartition et par les variations des rapports fer-titane dans les gisements ferrifères ayant des roches encaissantes différentes. Les rapports fer-titane dans les gisements d'ilménite et de magnétite sont les plus faibles dans les parties est et nord-est de la province de Grenville où affleurent d'importantes masses d'anorthosite, et les plus élevés au sud-ouest où l'on ne retrouve que de petites intrusions de gabbro et de gabbro anorthositique et où abondent les gisements de magnétite par substitution.

PART I

IRON DEPOSITS IN THE APPALACHIAN REGION

Introduction

The Appalachian region of Canada lies east of the St. Lawrence River and includes the Eastern Townships, Gaspé Peninsula, and Anticosti Island, of Quebec; the provinces of New Brunswick, Nova Scotia, and Prince Edward Island, and the Island of Newfoundland. This region forms the northeast part of the Appalachian belt of folded and deformed rocks that extends northeast along the east side of the continent from near the Gulf of Mexico to the east coast of Newfoundland. Geological conditions in this belt are favourable for the occurrence of a great variety of minerals. The region has long been noted for important deposits of coal, gypsum, barite, asbestos, iron, copper, and gold, and for smaller deposits of nearly every other metallic and non-metallic mineral commodity. Large deposits of copper and of copper-zinc-lead have recently been discovered and brought into production in Gaspé, New Brunswick, and Newfoundland, and mineral production, except for coal, has been greatly increased in the past decade. The iron deposits have not been the most impressive mineral resource in this region, although the Wabana mines with large ore reserves have been important producers of iron ore for foreign and domestic markets for nearly 70 years. Most of the other iron occurrences are small and vary greatly in type, but as a group constitute an appreciable quantity of potential ore.

Topography

The topography in most of the region is characterized by high, flat-topped plateaux over the more resistant rocks, and by broad lowlands with very little relief over the less resistant rocks. The flat plateaux are thought to be old erosion surfaces or peneplains that have been uplifted and subjected to several cycles of erosion. The plateaux are incised by deep, steep-walled valleys; the topography over the higher ground is rugged.

Evidence of recent glaciation is abundant. Raised beaches in many parts of the region are believed to have been elevated through large-scale uplift and warping of the earth's crust after the ice melted. Glacial deposits several feet thick are distribu-

MS. received August 1963

ted over much of the region, and the unconsolidated material is a decided impediment to surface prospecting and a hindrance to geological study.

General Geology

The major geological units and groups of rocks and the location of iron occurrences are shown on Figure 1 (*in pocket*). Although the geology of the Appalachians is highly complex in detail, this figure (prepared by field officers of the Geological Survey of Canada) shows the general geological setting of the iron deposits.

The region is underlain mainly by a number of parallel, northeast-trending folded belts of Palaeozoic sedimentary, metasedimentary, and volcanic rocks. Other rock groups, both older and younger than the Palaeozoic, are present but in small amounts. Deformation in the region is related to two main periods of mountain building, (1) the Taconic orogeny, which took place at the close of the Ordovician, and (2) the Acadian orogeny, in Devonian time. Eastern parts of the region were further affected by a major orogeny at the close of the Palaeozoic, which was more clearly manifested by major deformation in the southern part.

The tectonic boundary of the Appalachian Province is marked on the northwest by Logan's Line, a major fault zone or tectonic break that extends from Lake Champlain northeast through the Quebec City area and eastward under the St. Lawrence River. Northwest of this line, Ordovician limestone, dolomite, and shale in the St. Lawrence Valley west of Quebec and similar Ordovician and Silurian beds on Anticosti Island in the Gulf of St. Lawrence and along the northwest coast of Newfoundland are nearly flat lying.

The Schickshock-Gaspé belt parallels the St. Lawrence River, and extends from Lake Champlain northeast through Gaspé Peninsula and across the northwest corner of New Brunswick. It is an area with very rugged but moderate relief, and is underlain by tightly folded Palaeozoic sedimentary and volcanic rocks, of Ordovician to Devonian age, that have been deformed by thrusting from the southeast. Local areas at the east end of Gaspé Peninsula and along the shores of Chaleur Bay are underlain by Carboniferous red sandstones, shale, or conglomerate, and volcanic rocks of the Bonaventure Formation. Serpentinized ultrabasic masses are distributed in the central part of this belt, south of Quebec, and in the eastern part in central Gaspé. Small intrusive masses of granite and related rock types, believed to be of Devonian age, occur in the belt. At least seven post-Palaeozoic intrusive plugs of alkaline rock, which are dated by K/Ar isotope ratios as probably Cretaceous, extend locally in a row eastward through the Montreal area.

A highland belt about 30 miles wide, composed of highly deformed rocks and granitic intrusions, forms a broad V-shaped pattern in New Brunswick and Nova Scotia. The western segment of this belt extends southwest from Bathurst, New Brunswick, to the International border near McAdam. It is composed of a highly complex assemblage of early Palaeozoic volcanic rocks, argillites, greywackes, and quartzitic rocks and their metamorphic derivatives, which are intruded by large masses of Devonian granite or related intrusions. This belt swings eastward to the coast from McAdam and follows northeast along the north shore of the Bay of Fundy and through Cobequid Hills north of Minas Basin. A large part of the belt north of the Bay of Fundy is underlain by metamorphosed sedimentary and volcanic rocks, and numerous intrusions of Precambrian age.

Within the 'V' outlined by this belt of deformed rocks, a broad syncline of Carbonaceous sediments and minor volcanic rocks plunges northeast under the Gulf of St. Lawrence and underlies central and eastern New Brunswick, northwestern Nova Scotia, and Prince Edward Island. Mississippian rocks at the base of this Carboniferous succession include the Windsor Formation composed of limestone, gypsum, anhydrite, salt, shale, sandstone, and acid volcanic rocks. This formation is of great economic interest because of the variety of mineral products it contains. Extensive coal beds in the Pennsylvanian rocks in the syncline are of particular economic significance. Carbonaceous rocks are also present on the west side of the Bathurst–McAdam highland belt in the area north of Woodstock and in the central part of Victoria county, New Brunswick.

This syncline of Carboniferous rocks is bounded on the south by a belt of early Palaeozoic rocks that form Cobequid Hills. East of these hills and extending north to Cape George in Pictou and Antigonish counties is another area of early Palaeozoic deformed rocks that are intruded by Lower Ordovician granite, monzonite, and rhyolite. Lower Carboniferous rocks underlie a 10-to-25-mile-wide belt that extends east of Minas Basin to Canso Strait. These rocks continue northeast through Cape Breton, where they underlie the coastal and lowland areas. Large coal deposits are present in these rocks at North Sydney and along the west coast of Cape Breton Island. The Carboniferous rocks are separated in Cape Breton by a number of linear highland belts of Precambrian and early Palaeozoic metasedimentary volcanic rocks, and granite or gabbro intrusions. Minas Basin and the Bay of Fundy are underlain by a broad, southwest-plunging syncline composed of Triassic sediments, basalt, and diabase. Rocks of this group underlie Annapolis Valley, and together with late Palaeozoic beds occur intermittently along the north shore of the Bay of Fundy. The southern half of Nova Scotia is underlain by slate, argillite, quartzite, and metasediments of the Meguma and Goldenville Formations of Cambro-Ordovician age. These highly folded and deformed rocks are intruded by large masses of granite and related rocks that were emplaced in Lower Devonian time.

The Island of Newfoundland is underlain by a number of northeast-trending Palaeozoic and Precambrian rock belts, which are generally recognized as extensions of tectonic belts mapped on the mainland. Three major divisions of the island are distinguished for purposes of outlining regional geology. The western division lies northwest of a fault zone extending from near Port aux Basques to the south side of Grand Lake and northeast to Green Bay on Notre Dame Bay; the central division lies east of this fault and west of a line joining Fortune Bay and the west coast of Bonavista Bay; and the eastern division lies east of Fortune Bay.

Two large areas in the western division, on the west and the east sides of White Bay, are underlain by Precambrian gneisses and intrusions. These areas are bounded mainly by Cambrian and Ordovician limestone, shale, sandstone, and volcanic rocks, which are folded and deformed except in the area along the northwest coast of the Great Northwest Peninsula. Large masses of serpentinized ultrabasic rocks and gabbros are present in a northeast-trending belt that crosses Bay of Islands, in belts both east and west of Baie Verte, and in the area north of Hare Bay. A large anorthosite mass, evidently Precambrian, occurs east of the head of St. George's Bay. Carboniferous beds, mainly Mississippian, are distributed in the valley between White Bay and Grand Lake and in the coastal area west and north of St. George's Bay.

The central division is formed by a eugeosynclinal assemblage of early Palaeozoic volcanic and sedimentary rocks that range from Ordovician to Devonian in age. These are intruded and metamorphosed by large masses of Devonian granite and related intermediate rocks. The southern part of the division is underlain mainly by narrow granite masses which separate linear volcanic and sedimentary belts. One of these belts, the Red Indian Lake syncline, plunges northeast and broadens towards Notre Dame Bay. Small gabbro masses are distributed throughout the central division, and small ultrabasic masses lie along a narrow southwest-trending zone that crosses Gander Lake west of Bonavista Bay.

Rocks of the eastern division consist mainly of metamorphosed and structurally deformed Precambrian sediments and volcanic rocks, and in a few places granitic rocks. Some of the granite bodies are Precambrian, others are Devonian. Numerous small isolated synclines and outliers of early Palaeozoic sediments and volcanic rocks unconformably overlie Precambrian rocks—their general distribution is shown on Figure 1. Notable among these outliers is the succession of Lower Ordovician shale, sandstone, and Clinton type iron-formation that underlies Conception Bay and outcrops on Bell Island.

Further information on the general geology of this region may be obtained from *Geology and Economic Minerals of Canada*, Economic Geology Report No. 1; from the geological maps of the Maritime Provinces (Map 910A), southern Quebec (Maps 703A, 704A, and 705A), the Island of Newfoundland (Map 1043A), and other maps and reports; all are published by the Geological Survey of Canada.

Iron Deposits in Clinton Type Iron-Formation

Wabana Iron Deposits, Newfoundland (1)[1]

The Wabana deposits consist of selected zones in three Clinton type iron-formations (Gross, 1965, p. 92) within the Lower Ordovician rocks exposed on Bell Island in Conception Bay. Submarine mine workings extend down dip from the island outcrop for 2.7 miles, and the areal extent of the iron-formation has not been determined. The iron-formations were first recognized as potential ore in 1892 and more than 70 million tons of ore has been produced since 1895 for consumption in the domestic steel industry in the Maritime Provinces and for export to Europe and the United States. The composition of the ore, on the basis of average dry analyses, is 51.6 per cent iron, 11.8 per cent silica, 0.9 per cent phosphorus, and 1.5 per cent

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[1] Numbers refer to locations on Figure 1 and to listing in Appendix II.

moisture. The mines are owned and operated by Dominion Wabana Ore Limited, which is a wholly owned subsidiary of the Dominion Steel and Coal Corporation, Limited. Annual ore production over the past 5 years has ranged from 2 to 3 million tons with roughly equal amounts going to the United Kingdom, to Western Europe, and to domestic plants.

Geological Setting

The regional geology of this area has been described by Rose (1952), Hutchinson (1953), and McCartney (1954); only a few prominent features are mentioned here. Conception Bay is surrounded by tightly folded and faulted Precambrian volcanic rocks (Harbour Main Group) and siltstones, sandstones, slates, and greywackes (Conception Group), except for a narrow strip around its south shore between Topsail and Brigus. This strip is underlain by sediments ranging in age from Lower to Upper Cambrian and consisting of red and pink shales and limestone, red to grey or black shales in the lower part and dark grey, green, or manganiferous shales, thin sandstone beds, and limestone in the upper parts. The Cambrian beds are in unconformable contact with the Precambrian rocks, and the dip changes progressively from 8°NW in the southeast area around Topsail to 50°E in the Brigus area on the west side of the bay where open folds are developed. On the islands on the east side of Conception Bay, Lower Ordovician sediments dip 8°NW and are structurally concordant with the nearest Upper Cambrian beds. They consist of sandstone, grey to black shale, argillaceous beds, and Clinton type iron-formations; the section is more than 8,000 feet thick. The Ordovician rocks are divided into two groups on the basis of palaeontology and a minor disconformity. The lower beds form the Bell Island Group, and the upper 1,000 feet of the section forms the Wabana Group. The division between the two groups is made at the top of the Dominion or 'Lower' bed of iron-formation.

The Precambrian rocks are tightly folded, cut by thrust faults, with the predominant trend of fold axes and faults to the northeast. One of the most conspicuous fault zones passes along the east shore of Conception Bay from Topsail to Cape St. Francis; Cambrian beds terminate against this fault. The attitude of the Cambrian beds, where exposed in the south, suggests that Conception Bay is underlain by a northerly plunging syncline which is asymmetrical about an axis that passes through Harbour Main. The iron-formations in the Ordovician rocks lying concordantly above the Cambrian area are on the east limb of this syncline.

The stratigraphy of the Palaeozoic rocks is summarized as follows: (Information mainly from Rose, 1952, and Hutchinson, 1953.)

Lower Ordovician (Wabana Group)—More than 1,000 feet thick, base of group at top of Dominion or 'Lower ore bed'. Lithologically similar to the Bell Island Group, but black shale is more abundant and oölitic pyrite and pyritiferous beds are present. Contains a number of oölitic hematite-chamosite-siderite iron-formations.

Lower Ordovician (Bell Island Group)—Estimated thickness 4,000 feet, base not exposed. Composed of thin-bedded, grey, grey-brown, and greenish sandstones, grey, brown, and black shale, micaceous sandy shale, whitish sandstone, red oölitic hematite and chamosite, and ferruginous sandstone and shale. Sandstones consisting of subangular quartz grains with glauconite chamosite, altered feldspars, ferromagnesian minerals and accessory zircon, sphene, and magnetite are common, a siderite matrix is present in some beds. Evidence of shallow water deposition is shown by crossbedding, ripple-marks, rain-drop impressions, worm burrows, boring-algae tubules and fossil fragments found in the iron-formation and clastic sediments.

Upper Cambrian (Elliot Cove Group)—At least 300 feet thick (top is not exposed), thin-bedded, dark grey and black shale with nodular pyrite, lenses of limestone and sandstone.

Middle Cambrian (Acadian Group)—300 feet thick. Black and grey shale, slate, and siltstone with nodules, lenses and thin beds of red and grey limestone, pyritiferous slate, manganiferous and phosphatic beds.

Lower Cambrian—500 to 800 feet thick, composed of interbanded red, pink to green, wavy banded limestone and red or green slate. Quartz-pebble conglomerate cemented by red limestone at the base of the section is in angular unconformity with Precambrian rocks.

Further detail on the part of the stratigraphic succession in which the iron-formations occur is quoted from Hayes (1915, pp. 10-11):

> Oolitic iron ore and ferruginous rocks have been found in six zones on Bell Island and these are given in stratigraphical order, beginning with the lowest.
> Zone 0—A thin ferruginous band occurs in the strata, forming the extreme southwest part of the island, outcropping from Lance Cove westwards to the western shore near the "Clapper".
> Zone 1—This zone is partially exposed by shallow cuttings along the tramways of the Nova Scotia Steel and Coal Company and of the Dominion Iron and Steel Company near their intersection at Kents bridge. It may be traced by intermittent outcrops from Eastern head on the east coast of the islands to the northwest coast between Big head and the Bell. It contains bands of oolitic hematite, two of which appear to be continuous, one attaining a thickness of about 2 feet.
> Zone 2—Including the Dominion Bed—The lowest oolitic hematite of this zone is about 600 feet stratigraphically above Zone 1, and the whole zone consists of a series of bands of oolitic hematite alternating with shales and crossbedded, fine grained sandstone, comprising about 100 feet of strata culminating in the Dominion bed. The top 35 feet of strata are composed largely of oolitic hematite in thick beds with thin ferruginous sandstone and shale parting rocks.
> Zone 3—Pyrite Beds—Oolitic pyrite occurs in from one to three bands extending through strata from a few inches up to 4 feet in thickness, and found from 1 to 10 feet above the highest oolitic hematite of zone 2.
> Zone 4—Scotia Bed—This zone commences 210 feet above zone 3 and is confined to about 15 feet of strata.
> Zone 5—Including the Upper Bed—The lowest band of this zone is separated from the Scotia bed by about 40 feet of sandstone and shales, and the oolitic iron ore continues upwards through about 50 feet of strata.

Another section of detailed stratigraphy is shown in Figure 2 by the graphic logs of vertical bore-holes through the iron-formations drilled from No. 6 slope about 6,000 feet from the Bankhead (*after* Gilliatt, 1924).

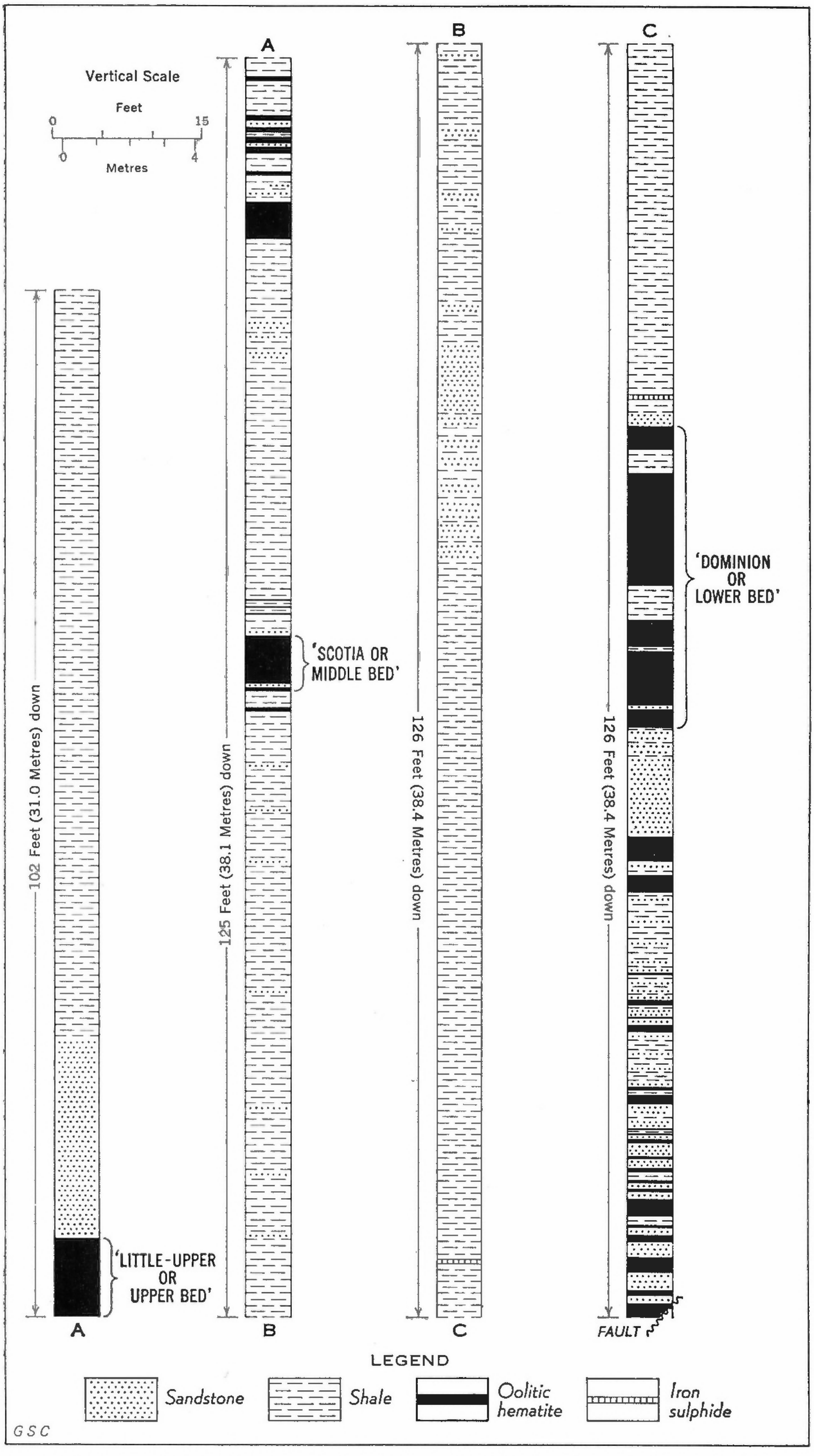

FIGURE 2. Graphic log of bore-hole No. 1 drilled vertically from No. 6 slope Upper bed, Wabana, Newfoundland (*after* J. B. Gilliatt, 1924, by courtesy of Dominion Steel and Coal Corporation).

The Wabana Iron-Formation and Deposits

Iron ore has been mined from three beds in the Wabana mines, the Dominion or 'Lower' bed, the Scotia or 'Middle' bed, and the 'Upper' bed. These beds are similar in their general characteristics and mineral composition, but none is uniform in thickness or in mineral distribution. Typically they are deep red to purplish red and massive, and are composed of oölites or spherules consisting of hematite, chamosite, and siderite. Bedding thicknesses range from less than an inch to 15 feet, and the iron-formation breaks in rectangular blocks due to two well-developed sets of joints (Pl. II).

The oölites are formed around nuclei of fossil fragments, sand grains, or granules, which are now siderite and siderite-chamosite mixtures. Alternate concentric rings of hematite and chamosite surround the nuclei, and oölites are held in a matrix of hematite or siderite with one or the other predominant in a zone or bed. The outer rings of the oölites are nearly always formed of hematite, and the spherules average about $\frac{1}{2}$ mm in size. Hayes (1915) has shown that there has been little alteration of the spherules since they were deposited as indicated by delicate well-preserved algae borings that cut across some of the oölite rings.

The mineral composition of the ore beds is given in Table I; this represents ore mined in 1927. The mineralogy of the ore was determined by A. O. Hayes, and the chemical analyses were calculated in terms of these minerals in order to show the relative amounts of different constituents in the major beds.

Table I

Minerals in Wabana Ore as Determined by Microscopic Examination

(Based on recalculations of the chemical analysis)

Mineral		Chemical Composition	'Lower' Bed Average	'Middle'–'Upper' Bed Average
	%		%	%
Chamosite (green hydrous silicate similar to thuringite)	25.64	SiO_2	23.2	22.7
	19.75	Al_2O_3		
	39.74	FeO		
	2.98	MgO_2		
	11.89	H_2O		
Hematite		Fe_2O_3	61.5	54.8
Siderite		$FeCO_3$	2.8	13.3
Quartz (sand grains)		SiO_2	6.1	3.6
Calcium phosphate (shell fragments)		$Ca_3(PO_4)_2$	4.7	4.4
Calcite (in joints and faults)		$CaCO_3$	0.8	1.2
Manganese oxide		MnO_2	0.3	0.3
Titanic acid		TiO_2	0.3	0.4
Pyrite		FeS_2	0.1	0.1
Total			99.8	100.8

From Lyons 1957

112341-D1

PLATE II. Clinton type hematite–chamosite–siderite iron-formation with well-defined rectangular joint pattern, Wabana mine, Bell Island, Newfoundland.

The ore beds are separated by thin beds of ferruginous shale composed of fine-grained clastic material with isolated granules or oölites similar in form to those just described. Transitional zones between ore beds and shale, where present, consist of interbanded layers of shale and oölitic hematite and parts of the stratigraphic units that contain ore may have lenses of this intermixed material. Sandy beds with chamosite granules and siderite or fine clastic matrix material are commonly interlayered with the shale and iron beds. The layers range in thickness from a few millimetres to a few feet. The thin shale beds are ferruginous, whereas the iron content of the thicker beds is not greater than that of shales outside the ore zone. The oölitic hematite beds show many shallow water sedimentary features such as crossbedding, ripple-marks, scour-and-fill structures, worm burrows, and abraded fossil fragments. Considering this evidence for wave or current action, it is remarkable that the iron-formation beds are as uniform over as broad an area as they are.

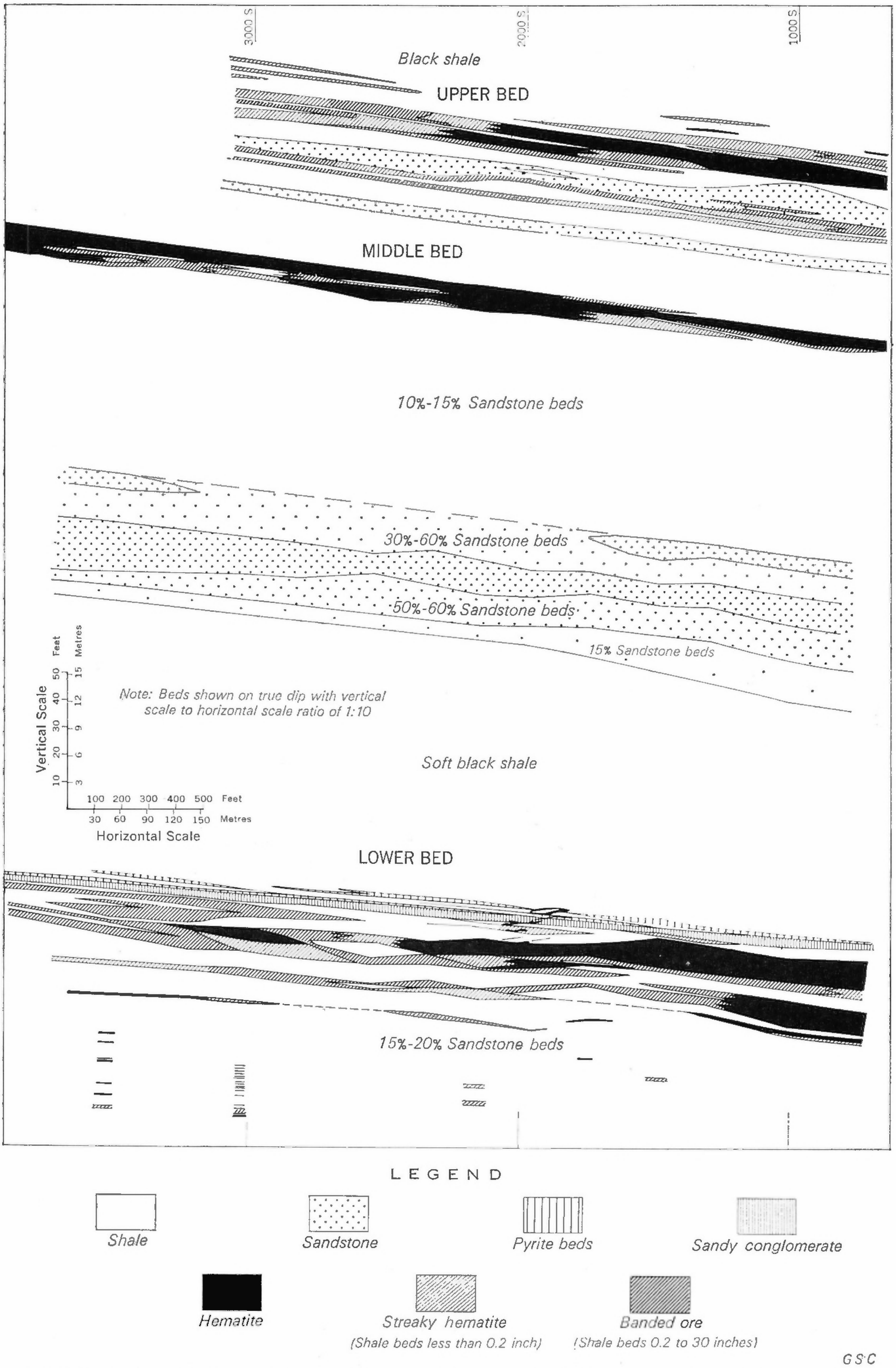

FIGURE 3. Section A, through Upper, Middle, and Lower beds, facing west, Wabana, Newfoundland (after Lyons, 1957).

Actually the ore beds are composed of interfingering lenses of hematite-rich material and shady or sandy lenses with a lower hematite content. Individual lenses range from those a few feet thick that extend for several hundred feet, to thicker lenses that extend a few thousand feet. The nature of these sedimentary structures is shown in Figure 3. The lenticular habit of the iron-rich parts of the ore beds is also emphasized by isopach maps. The thicker ore zones appear to have the shape of sand bars with major units trending southwest more or less parallel with the present shoreline and a few thinner units trending north. The isopach map (Fig. 4) illustrates trends and thicknesses of the explored part of the Lower bed.

The 'Lower' Iron-Formation and Ore Zone

The greatest thickness of mineable material occurs in the bars and lenses of the Lower bed, and consequently most of the ore mined has come out of this bed. The ore zone ranges from 15 to 40 feet thick and consists of several hematite-rich lenses separated by lenses of leaner shaly or sandy material. Lyons (1957) considered three stages in the deposition of this zone:

> (1) a thin bed of hematite one to two feet thick, followed by flooding of the basin and deposition of a ferruginous shale bed one to ten feet thick; (2) the building up in favourable areas of three to fifteen feet of the hematite-chamosite complex, relatively free from shale partings, except at the bottom and top, and again followed by a disconformity in which iron deposition was much more limited and a thickness of six inches to six feet of mud was laid down; (3) hematite-chamosite deposition again resumed, to local thicknesses of eight to fifteen feet.

He further noted that the upper part of this zone is richer in siderite and similar to the Upper bed and marks a change in sedimentation with possible submergence of the basin. Lenses of good quality hematite-chamosite ore are present in the upper and lower parts of this zone and grade into leaner siliceous material over distances of 100 to 300 feet as the amount of clastic material increases in the bed. As seen from Figure 3, the thickest ore zone in the No. 3 mine forms a sedimentary bar or lens 10 to 32 feet thick and more than 4,000 feet wide, the full length of which has not been defined. The composition of the "clean ore", which is relatively free of clastic material, ranges from 57.60 to 45.00 per cent Fe, and 7.50 to 20.00 per cent SiO_2.

The top of the Lower bed is defined by a disconformity, and by a persistent sandy conglomerate bed up to 5 feet thick that contains nodules of black shale and hematite. A pyrite bed up to $1\frac{1}{2}$ feet thick composed of oölites and spherules of pyrite in a cherty matrix is present above the sandy bed. The 210 feet of shale and sandstone between this bed and the Middle bed contains an average of 6.9 per cent iron and 50.4 per cent silica (Lyons, 1957).

The 'Middle' Iron-Formation and Ore Zone

Texturally and mineralogically like the Lower bed, the Middle bed is richer in iron. Its thickness varies from 5 to 15 feet, with an average of 7 feet being mined. The borders of the bed are sharply defined: the lower part is irregular along channel and depression fillings and the upper boundary is relatively uniform. A persistent hematite-rich bed 4 to 6 feet thick forms the upper part of the zone. Lenses and

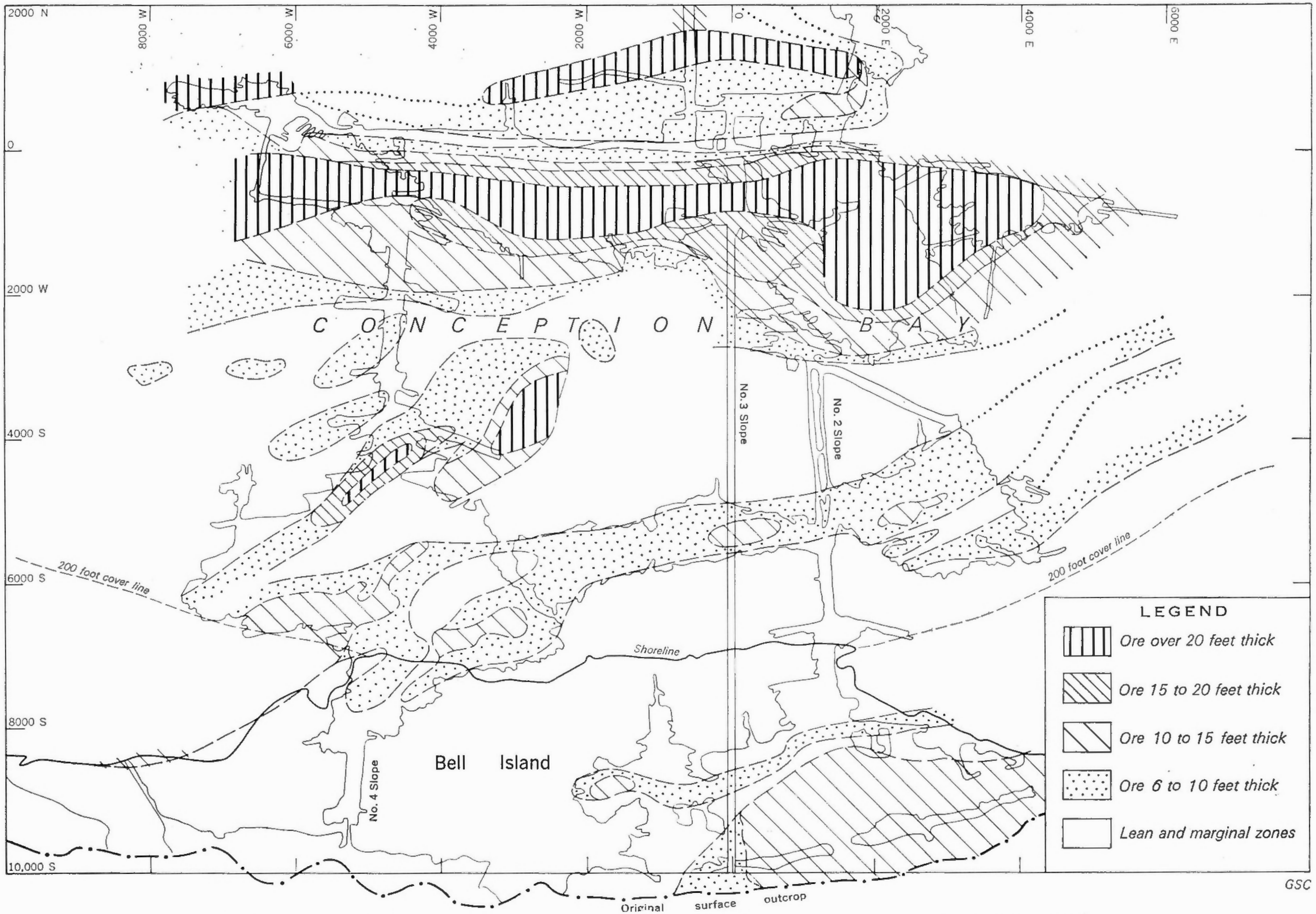

FIGURE 4. Plan showing ore trends and thicknesses, Lower bed, Wabana, Newfoundland (after Lyons, 1957).

bars of the oölitic hematite that form the Middle bed are elongated nearly parallel with the present northwest shoreline of the island, but the zone thins to a few feet about a mile from the shore. The composition of the "clean ore" ranges from 59.60 to 51.50 per cent Fe and 6.40 to 12.00 per cent SiO_2.

The 'Upper' Iron-Formation and Ore Zone

Located between 30 and 50 feet above the Middle zone, the Upper bed is characterized by a lensy erratic distribution of hematite-chamosite-siderite zones with sandy and shaly lenses, a lower iron content of the ore zones, and a greater amount of siderite. Siderite is present as a matrix to the oölites and also as thin wavy bands and ribbons along bedding planes. This zone, as explored so far, marks the upper limits of iron deposition in the basin. The composition of "clean ore" ranges from 51.8 to 48.60 per cent iron, and 8.20 to 10.50 SiO_2.

Structural Geology of the Ore Zones

Two prominent sets of faults and two sets of joints are developed in the east limb of the Conception Bay syncline as revealed in the mine workings. The two sets of joints, one striking N30°E and dipping 85°SE, and the other striking N70°W and dipping 85°SW, have an average spacing from 6 to 8 inches in the Lower bed and from 3 to 6 inches in the Middle bed. The ore breaks readily into rectangular fragments along these joints, but the joints are poorly developed in the shale beds. Two sets of faults are developed more or less parallel with the joint sets and may have been initiated along joints. Norris (1957) noted the corrugated surfaces of the faults because the dip steepens where faults cross competent ore beds or sandstone and flatten to 45 degrees where they cross shale. He also noted that faults with small stratigraphic throws had less slickensiding and attitudes nearly parallel with the one set of joints, whereas faults with greater stratigraphic throws and more slickensiding usually dip 10 to 20 degrees less steeply than joints striking parallel with them. Although movement in more than one direction has taken place on most faults and both strike-slip and dip-slip movement has occurred, it has been determined that northwest-trending faults have right-hand displacement and the northeast-trending faults have left-hand displacement. The northeast-trending faults appear to have developed somewhat later than the northwest faults but much of the movement along faults has involved adjustments of large blocks of ground with very little brecciation or contraction of adjacent beds. Vertical movements of up to 90 feet have been determined and the major faults pass through all three ore zones. One fault along which the Upper and Middle beds are brought into juxtaposition, on the east side of No. 6 mine, plays out in a shear zone in the Lower bed. Despite the joints and numerous faults, spalling of the nearly horizontal rock layers in the mines is not a problem. The major faults and general layout of the mine workings are shown in Figure 5 *after* Norris (1957).

Possible Extension of the Iron Ore Beds

Information on the possible distribution of the ore beds is limited because outcrops of Ordovician rocks are present only on the islands in Conception Bay

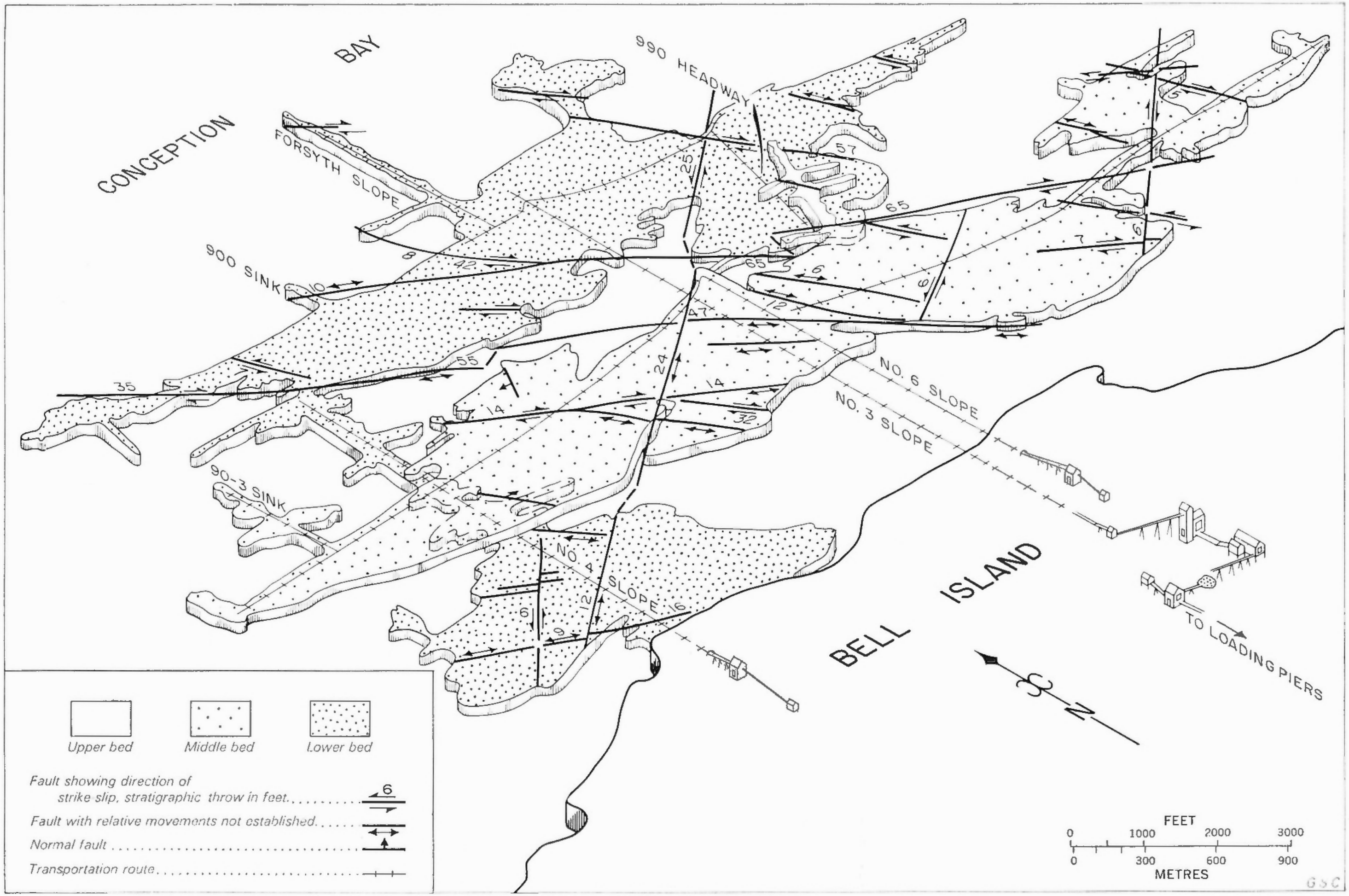

FIGURE 5. Schematic drawing of mine workings in the Lower, Middle, and Upper beds, Wabana, Newfoundland (*from* D. K. Norris, 1957, GSC; courtesy Dominion Wabana Ore Limited).

and most of the mine workings are under the sea. The Ordovician beds are structurally conformable with the Cambrian beds and are therefore thought to be present on the west limb of the Conception Bay syncline, but as they do not outcrop on the west shore of the bay this is not certain. A fault zone has been postulated by Hayes to extend northeast from Colliers Bay towards the east tip of land on Bay de Verde but McCartney (pers. com.) considers there is insufficient evidence for a major fault along this zone. The postulated fault zone lies close to the axis of the Conception Bay syncline, and as the Cambrian beds along the south shore of the bay are folded in the axial area with dips up to 35 degrees it is probable that Ordovician beds would also be folded. If the iron-formations do extend down dip to this zone they probably could not be mined because of the folding; this axis line would therefore be the western limit for mineable ore. The ore beds are terminated by their outcrop to the south and east and by the Topsail fault along the east side of the bay. They probably extend down dip to the north to beyond the economical depth for mining. With these limits, Lyons (1957) indicates an area of 50 square miles within a 5 mile radius of the outcrop that may be underlain by ore beds.

The iron-formations have a uniform dip of 8 degrees for the 2.7 miles they have been followed down dip from the outcrop, and it would be about this far again to the zone where folding and steep dips are thought to mark the western limit of ore. It is noted that the trend or strike lines of the thicker ore lenses or bars are more or less parallel with the strike of the beds and they may be offshore bars that formed parallel with the Ordovician coast-line. This being so, they may extend for considerable distances along strike but could terminate rather abruptly down dip or pass into a mineral facies not suitable for ore.

Origin of the Wabana Iron-Formations

A great deal has been written about Clinton type iron-formations, and their origin was discussed in Volume I (Gross, 1965, p. 123). One of the most comprehensive studies was that of Hayes (1915) on the Wabana deposits. His observations and conclusions from this work, quoted below, summarize many of the pertinent facts to be considered in dealing with the genesis of these beds.

> The oolitic iron ore with ferruginous shales and sandstones forms part of a series of sedimentary rocks of Lower Ordovician age.
>
> The ore beds are characterized by ripple-marked surfaces and crossbedded layers and contain remains of animals which lived in shallow water. The spherules of the ore vary in size from 0.1 to 0.5 millimetres and are composed of alternating concentric layers of hematite and chamosite. These spherules were pierced by living boring algae, hence the iron minerals forming them were precipitated near the surface of deposition, while the algae flourished on the sea bottom.
>
> Siderite occurs in smaller quantity than hematite and chamosite, but becomes locally abundant. It replaces chamosite and hematite and in some instances detrital quartz in the ore. The algae are found in all horizons in the ore beds and formed a very abundant marine plant life growing on the sea bottom. Tubules of the algae are preserved in the siderite and are frequently coated exteriorly with hematite. The siderite was chemically precipitated, probably under cover of overlying sediments where concentrations of ammonia and carbon dioxide resulted from decaying organic matter. Thus while hematite and chamosite were forming at the surface of deposition, the siderite was contemporaneously formed in the immediately underlying sediments.

> There is a total lack of limestone from the series, and igneous rocks are also absent. Practically all of the original calcium content of the ore, averaging about 2.5 per cent, is present in the form of fossil remains composed largely of calcium phosphate, or as calcium phosphate derived from such organic matter. The phosphorus of the ore is also derived from the remains of organic life preserved in it. No evidence of diagenetic transformation from an original oolitic limestone to an oolitic iron ore has been found and no concentration of iron has occurred since the deposition of these ferruginous sediments. They are primary bedded iron ore deposits, mined today in essentially the same condition except for induration, faulting, and the addition of small amounts of secondary calcite and quartz in fault cracks, as when they were laid down.
>
> Oolitic pyrite also occurs as part of the same series of sediments, but is characterized by a planktonic fauna indicative of open ocean currents and deeper water. The layers of pyrite show distinct stratification and are probably similar in origin to modern deposits of pyrite now forming in the Black Sea.
>
> The pyrite spherules are composed of concentric layers of pyrite, frequently alternating with layers of phosphatic material. Pyritized and unpyritized graptolites and brachiopod remains occur together in contact with the spherules, indicating that some mechanical mixing took place on the surface of deposition.

The position and nature of broad lenticular masses of iron-formation, which are interpreted to have formed as offshore bars and channel fillings, were not defined when Hayes did his study but most of the other shallow water features were recognized and he considered a good deal of palaeontological evidence in forming his conclusions. He believed that the algae that thrived in the muds and ocean bottom at the time of iron deposition may have contributed a good deal of oxygen to cause the oxidation of iron in chamosite to hematite. Although they no doubt did free considerable oxygen in their life process, it is believed that any hematite formed in this way is still detectable along the walls and surfaces of the algae borings. Without direct evidence for the source of the iron, Hayes inferred, as many other authors have, that the iron was derived by long continued weathering of earlier rocks and taken into solution and transported to the sea as inorganic and organic acid compounds.

It is evident that the formation of these beds involved complex chemical conditions that required a rather delicate adjustment of water depth, distribution of clastic material, and of Eh and pH conditions of the sea water. Chamosite appears to have formed in advance of the other iron-rich minerals. Because of the conspicuous increase in hematite in the outer parts of oölites, it may have formed in part by oxidation of chamosite or during a later stage of precipitation. Much of the siderite appears to have formed during diagenesis in the manner Hayes suggests. It is believed that ferrous iron in solution reacts with complexes of clay and colloidal clay particles to form chamosite on the surface of convenient nuclei and that the oölites are evidence of agitation and disturbance, possibly by wave or tidal action, in a shallow bay or shelf.

The hematite is considered to have formed on the chamosite spherules during fluctuation of water levels when iron was oxidized and precipitated in oxygenated water near the surface of the basin. Variations in depth of water may be brought about in a number of ways with the results showing as concentric layers of chamosite and hematite on the spherules or oölites.

The source of the iron in the beds at Wabana cannot be established with any degree of certainty until much more is known about the geochemistry, sedimentary environment, and geological setting at the time of deposition of the beds. As has been shown previously (Gross, 1965, pp. 108, 125), the iron in this type of deposit may have come from submarine volcanic emanations and have been carried by currents into this sedimentary basin, where it was oxidized and precipitated along the shore.

The Wabana Mines

The workings of the Wabana mines cover a 6-square-mile area, and their extent in the three major iron-formations is shown in Figure 5. The Nos. 3 and 4 slopes or shallow inclines serve the workings in the Lower bed and the No. 6 serves the Middle bed. The deepest workings are at a vertical depth of 1,850 feet below sea-level and are covered with 1,500 feet of rock. Mining is not carried out where rock cover is less than 200 feet, which means that no mining is carried out closer than 1,000 feet from the island.

Mining is by the room-and-pillar method with pillars ranging from 70 to 40 feet on a side and situated so that roof spans rarely exceed 27 feet. About 60 per cent of the ore is extracted by this method. After drilling and blasting, the ore is moved from the face in low trackless shuttle cars, which discharge to conveyors that take the ore to main levels where it is carried by mine cars to the first set of crushers. From the crushers it is transported to the surface by conveyor, some is passed through the sink-float plant and the products then moved by conveyor to the ore storage area at the docks on the east side of the island. The sink-float process removes low grade or non-ferruginous shaly fragments from the ore, and in so doing lowers the silica content by 1 to 2 per cent, with a corresponding increase in iron content.

Gillis Brook, Cape Breton County, Nova Scotia (18)

Weeks (*in* Stockwell, *et al.*, 1957, p. 194) noted that "Beds of iron-formation occur in Middle Cambrian strata on Gillis Brook at Grand Mira South, Cape Breton county. The occurrence was discovered many years ago, and in 1942 the Dominion Steel and Coal Corporation cleaned out several of the earlier pits and dug two shallow openings. The ore minerals occur in two narrow bands varying in width from 2 to 11 inches. Where both bands are present they are separated by about 2 feet of slate. Both hematite and magnetite were noted. The iron beds are considered to be primary sedimentary deposits and some of the iron has been altered to magnetite by nearby granite."

Grand Mira, Cape Breton County, Nova Scotia (18)

Ordovician beds of oölitic hematite grading into magnetite are interstratified with sandstone and shale near Grand Mira. According to Hayes (1919), the beds range in thickness from 4½ to 19 inches and are exposed at a number of localities between Grand Mira and Marion Bridge. They appear to be folded into a syncline in which the east limb is cut off by the White Granite Hills, and magnetite is present in beds near the granite. Although of no apparent economic importance, these beds are interesting because of their similarity to the Wabana iron-formation and their position in the regional tectonic framework.

Arisaig, Antigonish County, Nova Scotia (20)

According to Williams (1914), who described the geology of this area, the iron-formations are in the Browns Mountain Group of rocks of Lower Ordovician age and may be correlated with the iron beds on Bell Island, Newfoundland. The ferruginous beds are described as siliceous with iron impregnated in grit, the thinner beds being oölitic hematite and richer in iron. The iron beds were explored in 1910 by trenching and a tunnel 70 feet long. Williams (1914, p. 145) described the occurrences in two areas as follows:

> In an area about 1 mile northeast of Browns Mountain postoffice, ore has been exposed by prospect trenches at points about five-eighths of a mile apart. In the western prospects an ore zone more than 20 feet across has been uncovered. The "bed" dips nearly south at about 60 degrees and the contained ore consists of coarse grit impregnated with hematite. In the walls the grit is finer than in the ore. In the eastern exposure the "bed" strikes nearly north and south and is only about 5 feet across, and the ore is more compact and of higher grade. Possibly two "beds" are present here. Specimens are said to have assayed as high as 30 per cent metallic iron. The iron ore of this vicinity appears to belong to a lower horizon in the James River formation (the lower formation of the Browns Mountain Group) than that which contains the ore beds of Doctors brook.
>
> The most important ore belt of the district extends southwesterly for nearly 4 miles from a point about three-quarters of a mile southwest of Malignant cove. Many igneous intrusions have interrupted the ore leads in their northeastern extent, but between the East Branch of Doctors brook and the western brook flowing north from the Little Hollow, few intrusions are present.
>
> Numerous trenches and prospect pits have been dug and the ore zone is more extensively disclosed in this locality than elsewhere. However trenches for the most part cross the ore "leads" and the relation of ore to wall rock is frequently obscured. Three ore "beds" have been recognized with widths from 2 to 8 feet. From place to place the widths of individual leads vary and many small faults have been discovered which offset the ore 1, 2, or more feet. The beds strike in a northeast direction and are approximately vertical in dip.

The greatest distance along which a single bed has been traced is 6,750 feet, and the iron-formations are associated with greywacke and arenaceous beds. Williams (1914, p. 146) notes that the ore is free from sulphur but high in phosphorus, and he gives assays as follows for beds at Iron Brook west: A bed 5 feet thick of compact oölitic ore contained 46.2 to 48.17 per cent of metallic iron; a bed 4 feet thick of fine-grained ore contained 41.17 to 45.9 per cent metallic iron; and a bed 10 feet thick of grit impregnated with hematite contained 35.16 per cent metallic iron. The average of insoluble content ranges from 20.88 to 28.65 per cent.

Piedmont, Pictou County, Nova Scotia (22)

In the Piedmont locality near Egerton, Hayes (1919) mentioned an Ordovician bed of oölitic hematite and chamosite 7 feet thick that assayed Fe total, 42.50 per cent; SiO_2, 21.24 per cent; P, 0.704 per cent; and CaO, 6.46 per cent.

Arisaig and Ross Brooks, Antigonish County, Nova Scotia (19)

In this area, Williams (1914) reported oölitic hematite beds in Silurian rocks that may be correlated with the Clinton ores of the Appalachian region, and described the occurrence as follows:

> In Arisaig and Ross brooks a bed of hematite between 2 and 3 feet thick outcrops. Two exposures occur on Ross Brook, but there is evidence of faulting in the vicinity and the bed has probably been off-set along a fault zone. Wherever seen the strata stand nearly vertical. The wall rocks consist of shales and thin-bedded, arenaceous limestones and in places the surface of the wall rock is chloritized. It is probable that the ore bed is continuous or nearly so between Arisaig brook and Ross brook, but beyond these limits, particularly to the westward, the probability of disturbance is great.

The analysis of a sample shipment of ore is quoted as Fe, 52.93 per cent; SiO_2, 11.62 per cent; Al_2O_3, 7.46 per cent; P, 0.495 per cent.

Blanchard Brook, Pictou County, Nova Scotia (21)

Hayes (1919) mentioned an 18-inch bed of oölitic hematite and chamosite in a synclinal fold about 3 miles north of Sunnybrae. This is in the McAdam Formation, and is apparently of the same age as the iron-formation at Arisaig and Ross Brooks.

Nictaux-Torbrook Iron-Formations, Annapolis County, Nova Scotia (23)

Iron-formations that resemble Clinton type beds, though more highly metamorphosed than the Wabana iron-formations, are present in the Torbrook Formation of Lower Devonian age. The formation lies along two parallel zones, a northern zone extending southwest from Torbrook Mines to beyond Torbrook West for a distance of about 4 miles, and a southern zone that strikes southwest from a point about a mile east of Torbrook West for a distance of nearly 5 miles.

Mining was started from pits between Torbrook West and Torbrook Mines in about 1825 by the Annapolis Iron Company, Limited, and a smelter was erected at Moose River near Clementsport. Approximately 350,000 tons of ore was produced during sporadic working of the mines between that time and 1916 when World War I conditions curtailed shipment of ore to Europe.

The iron-formation zones occur on both limbs of the Torbrook syncline and are apparently part of the same bed. The Torbrook Formation is made up of a succession of dark grey to reddish shale, shaly siltstone, quartzite, and limestone that is over 6,000 feet thick. This formation is tightly folded into a syncline in which the beds are deformed by minor folds, faults, and shears, and intruded by gabbro and diorite dykes. They are cut off to the south by a large mass of granite. The beds strike southwest and dip steeply.

Iron-formation beds up to 10 feet thick are present on both limbs of the syncline. Smitheringale (1960) noted that two main beds that average about 5 feet thick, and several smaller beds, occur within a 200-foot-thick section on the northwest limb. Hayes (1919) described the beds as being composed of detrital quartz grains, argillaceous material, and calcareous fossil fragments associated with spherules of green iron silicate with concentric structures. Magnetite is present within the spherules and has partly replaced the silicate minerals; hematite is also present in minor amounts. Hematite is the main ore mineral in the beds to the northeast, and magnetite is more abundant to the southwest near the granite intrusions. Several hundred analyses quoted by Hayes indicate an average per cent composition for the Leckie iron-formation beds from the northern zone of Fe, 49.20; SiO_2, 15.09; Al_2O_3, 4.42; CaO, 4.94; MgO, 0.67; MnO_2, 0.74; P, 0.92; S, 0.077.

From the descriptions of the iron-formation and associated sedimentary rocks given by the authors mentioned, it is concluded that the Nictaux-Torbrook iron-formation was deposited as a shallow water, oölitic textured, hematite-chamosite-siderite iron-formation, which resembled the Wabana iron-formations in general features and habit. The iron-formations in the Torbrook area were apparently later metamorphosed by the adjacent granite mass and dykes, and much of the iron has been changed to magnetite at the expense of hematite, siderite, and some of the silicate minerals. At the same time the oölitic textures were altered and obliterated in places.

Occurrences of Clinton Type Iron-Formation

It is significant to note that iron-formations of this general type are found in rocks of Cambrian to Lower Devonian age. Although these formations are not known to occur elsewhere in the region with the thickness and areal extent found at Bell Island, they consistently occur in the same type of sedimentary environment and are associated with similar types of sediments. Even though the iron and major constituents vary considerably in content in different beds, formations of this type are relatively high in phosphorus and alumina compared with the siliceous iron-formations of other types.

Other Types of Iron-Formation

Thin-banded, magnetite-hematite-quartz iron-formations occur near Bathurst in the northern part of the highland belt that crosses central New Brunswick, and on the southeast coast of Burin Peninsula near St. Lawrence, Newfoundland. The iron-formations in both areas are Algoma type (Gross, 1965), and are associated with lavas, tuffs, greywackes, and argillaceous rocks of Ordovician and Middle Cambrian age. They are similar in lithology and mode of occurrence to many of the iron-formations extensively developed in the early Precambrian belts of central Canada.

Austin Brook Iron-Formations and the Bathurst Iron Mine, Gloucester County, New Brunswick (55)

Iron-formation has been mined in the Austin Brook area about 17 miles southwest of Bathurst, near to where Austin Brook flows into Nepisiguit River. Three main zones of iron-formation are present, one immediately south of the brook in which the mine is located and two north of the brook.

Discovery of the iron deposit in 1902 is credited to William Hussey of Bathurst. Between 1907 and 1913 a railway was built to the property, a mill and concentrator were erected, loading docks were built at Newcastle, and more than 180,000 tons of ore was shipped to Philadelphia by The Canada Iron Corporation, Limited.

Another 7,688 tons of ore was shipped from the property during the next two years. Further mining was not carried out until 1942 when the Dominion Steel and Coal Corporation, Limited of Sydney, Nova Scotia obtained rights to operate the mine from the lease holder, Canada Iron Foundries, Limited of Montreal. A crushing plant was erected, facilities were reconditioned, and 127,734 tons of ore was shipped by rail from the No. 1 deposit to Sydney in 1943. When operations ceased practically all equipment was removed except the railway track, and the property reverted to the Crown. Since that time the land has been acquired by the Brunswick Mining and Smelting Corporation, Limited, and a large zinc-copper-lead sulphide deposit (Brunswick No. 6 orebody) has been discovered along the foot-wall of the iron-formation beds.

Geological Setting

The Tetagouche Group of Middle Ordovician rocks is a complex assemblage of slate, greywacke, quartzite, iron-formation, and limestone interbedded with acid and basic lavas, and pyroclastic rocks. This assemblage of sedimentary and volcanic rocks is intruded by Devonian biotite granite and granite porphyry stocks. The Tetagouche Group is tightly folded; bedding, schistosity, and axes of steep-plunging isoclinal folds trend northeast. This belt apparently forms the eastern part of a broad syncline, the axis of which trends northeast and lies some considerable distance west of Nepisiguit River.

Skinner (1952) noted that

> . . . the extrusive rocks comprise grey, porphyritic and non-porphyritic rhyolite, and altered, intermediate to basic lava (greenstone), together with minor, interbedded, grey to green slate, tuff, and greywacke, all of which are commonly schistose. Acid varieties predominate east of Bathurst Mines on Nepisiguit River, west as far as Nine Mile Brook, and along Nepisiguit Brook, Upper Portage River, and Tozer Brook. Greenstones predominate south and southeast of Bathurst Mines and west of Nine Mile Brook.
>
> The sedimentary rocks of the Tetagouche Group are grey and green, medium- to fine-grained greywacke; grey, green, red, and black slate; grey, green, and red siltstone; grey quartzite; and grey and green tuffs, and are interbedded with minor acidic to basic flows.

Iron-Formations

The first zone of iron-formation, with the mine pit in its north end, is situated about a quarter mile west of the mouth of Austin Brook and extends along strike for at least 2,000 feet, between Austin Brook and Nepisiguit River. The section exposed in the pit is about 140 feet wide, but the band tapers southward until it is 22 feet wide at Nepisiguit River. It strikes north, dips 50°W, and is dark grey and thinly banded to lensy or schistose in places and fine grained. Skinner (1956) described it as follows:

> The banding varies in degree from microscopic to a foot or so thick and is due to variations in concentration of the constituent minerals magnetite, specular hematite, quartz, siderite, sericite and chlorite. Magnetite is commonly the predominant iron mineral, but hematite is prominent in a zone about 50 feet thick which lies about 15 feet west of the foot-wall. Here it makes up about 40 per cent of the rock and magnetite about 25 per cent. Red jasper lenses and bands up to an inch thick are, on the whole sparsely intercalated with the iron-formation, but are more common in the hematite-rich type. Bands or lenses of magnetic chlorite schist up to 5 feet, but generally less than 2 feet thick occur here and there in the iron-formation.

A zone about 20 feet thick that is very rich in pyrite and sulphide minerals forms a conformable layer on the foot-wall or east side of the iron-formation. A narrow band of basic volcanic rocks, diabase, and some basic intrusive material is present along the west side of the iron-formation, and the whole zone of iron-formation and volcanic rocks is surrounded by schistose quartz-feldspar porphyry. Analyses quoted by Sidwell, 1951 (Table II) show the composition of the iron-formation as determined by a number of investigators.

Table II

Composition of Iron-Formation in the Bathurst Iron Mine

Analyses in %	I	II	III	IV
Iron	47.30	42.25	48.7	60.3
Ferrous oxide			18.1	23.8
Ferric oxide			49.4	59.7
Manganese	1.00	3.1	16.9	7.7
Silica	26.30	20.7		
Phosphorus	0.64	0.70	0.760	0.350
Sulphur	0.05	0.10	0.127	0.046

I A general sample taken by Lindeman across the whole width of No. 1 deposit, about 230 feet from its southern end.

II A representative sample collected by H. J. Rowley and K. O. J. Sidwell in 1950.

III An analysis of a 25 ton sample on which Timm conducted magnetic separation tests in 1923.

IV Analysis of concentrate made by Timm.

The second zone of iron-formation, exposed about 1,000 feet east of the open pit, extends north from Austin Brook for a strike length of at least 1,200 feet and apparently pinches and swells, forming at least three lenticular bodies up to 40 feet thick and dipping 60 to 80°W. The iron-formation in this zone resembles that in the southern one and, according to MacKenzie's map (1949), is surrounded by schistose rhyolite and rhyolite tuff.

A northern zone of iron-formation extends northward for nearly a mile from a point about 2,000 feet north of the old Bathurst mine. It consists of about ten lenses of iron-formation similar to that south of Austin Brook, the largest being about 1,000 feet long and up to 150 feet thick. Basalt and rhyolite bands occur with the iron-formation lenses in this zone, and quartz-feldspar porphyry is present along the eastern side. Skinner (1956) noted that grey to buff, fine-grained, siderite lenses are present in this zone of iron-formation, with magnetite and quartz disseminated in it or in associated bands. In places about 80 per cent of the iron-formation consists of banded siderite, and magnetite and quartz are present in quantities of 5 to 15 per cent. A sulphide body about 1,000 feet long and 200 to 300 feet thick lies along the foot-wall of this band and forms the Brunswick No. 6 zinc-copper-lead orebody developed by the Brunswick Mining and Smelting Corporation.

Development and Reserves

The results of exploration of the iron zones in this area are given by Sidwell (1951) and MacKenzie (1949); additional information gained during the recent exploration for base metal deposits has not yet been made available. Various attempts have been made to estimate the iron ore potential in these three zones; Lindeman suggested about 18 million tons to a depth of 500 feet, and others 7 million tons. With the development of base metal mines in the foot-wall of these iron-formation beds it may no longer be possible to mine them for iron ore.

Pabineau River Iron-Formations, Gloucester County, New Brunswick (54)

About 6 miles northwest of the Bathurst mine, along the east side of Pabineau River, is a belt with at least nine lenses of iron-formation. These lenses represent an uncommon facies present in some Algoma type iron-formations. Skinner (1956) concluded that they were derived from argillaceous ironstones that have since been metamorphosed, and described them as follows:

> The Pabineau River iron-formation is associated with banded, schistose, albite-magnetite-chlorite greenstones and moderately schistose albite chlorite-actinolite-epidote greenstones. A ground magnetometer survey of this area indicates that there are nine northerly-trending magnetic zones within a northerly-trending belt, 10,000 feet by 2,100 feet. The largest of these is about 200 feet wide and 1,200 feet long. Trenching across these anomalies shows that the iron-formation occurs in bands up to 10 feet thick, intercalated with schistose, banded, albite-magnetite-chlorite greenstone, and that commonly there is only one band per anomaly. The New Brunswick government assayed some of the rock underlying the highest anomaly. It contained 13.9 per cent iron.
>
> The iron-formation here, is a banded, grey and buff, magnetite-sericite-quartz schist. The magnetite-rich laminations are grey, aphanitic, and up to a quarter of an inch thick. They are intercalated with buff, aphanitic, sericite-quartz laminations up to half an inch thick. As seen under the microscope the magnetite occurs commonly as minute irregular grains that average about 0.004 millimeters across, but some of it has rhombic triangular and rectangular outlines up to 0.05 millimeters across. The average composition of specimens of the iron-formation is about 50 per cent sericite, 20 per cent magnetite, 15 per cent quartz, 10 per cent leucoxene, and 5 per cent chlorite.

Although this material contains less than 15 per cent iron and does not meet the definition of iron-formation adopted for this study, it is common in belts of volcanic rocks.

Other magnetite-rich lenses in spilitic rocks have been noted near Grants Brook and also in greywacke rocks in the region.

Mt. Calapoose Iron-Formation, Placentia West County, Newfoundland (3)

Magnetite-hematite iron-formation and ferruginous shales outcrop along the east shore of St. Lawrence Harbour southeast of Mt. Calapoose in Burin Peninsula. The iron-rich beds associated with black, grey, and multicoloured shales in the Little Lawn Formation are part of a succession of Middle Cambrian pillow basalts, flow breccia, tuff, chert, greywacke, shale, sandstone, and conglomerate.

The iron-formation is thin-banded, deep purple to red, aphanitic material composed of fine-grained magnetite and red hematite disseminated in cherty slate. Iron-rich layers are interbanded with greenish grey greywacke, argillite, and multi-coloured slate. Magnetite-rich beds are distributed throughout a section over a thickness of 100 feet but are most abundant over a part 25 feet thick, where the iron content is estimated to be about 40 per cent. The beds are highly crenulated and jointed; they strike N25°E, dip 35°NW, and folds plunge 35°W. The bed could not be examined down the cliff face to the edge of the water but was examined along strike for 150 feet to the northeast where argillaceous beds are more numerous. Very thin quartz veins in the formation bear specular hematite, and epidote is distributed along numerous seams and fracture surfaces.

An adit has been driven eastward across the lens for 30 feet, and a winze, now flooded, was sunk at the end of it to a depth of 35 feet.

The cherty magnetite-hematite layers in this band of iron-formation resemble the marginal zones along many bands of the oxide facies of Algoma type iron-formation.

Notre Dame Bay Area, Newfoundland (4, 5)

Within the succession of Ordovician volcanic rocks, greywacke, conglomerate, and shale that forms a broad syncline in the Notre Dame Bay area are numerous bands and lenses of grey and red ferruginous chert. They contain hematite, occasionally magnetite and pyrite, and in some places manganese oxide minerals. The amount of hematite present in some appears to be greater than it actually is because of secondary staining and fracture fillings of red hematite in chert. An attempt was made in the past to mine some of this material for iron ore but scarcely any of the beds contain enough iron to be classified as iron-formation. They may however be genetically related to Algoma type oxide facies.

Manganiferous Iron-Formations Near Woodstock, Carleton County, New Brunswick (56)

A number of bedded manganiferous iron deposits occur in a belt 30 miles long that extends southwest from Glassville to Campbell Corners and passes through the Jacksonville area about 4 miles northwest of Woodstock. Most of the exploration work has been on six zones of the belt, the first about a mile northwest of Jacksonville at Iron Ore Hill and the others continuing at intervals southwest to about a mile beyond Meduxnekeag River near Plymouth.

The deposits were discovered in 1836 and a small blast furnace was erected in 1848 on the west bank of Saint John River at the mouth of Lanes Creek, about a mile north of Woodstock. About 70,000 tons of ore was mined between 1848 and 1884 from the Iron Ore Hill and Moody Hill zones with the bulk of it coming from the first locality. The iron produced from the Woodstock furnaces was found to have exceptionally good physical qualities and was shipped to England for use by the Royal Navy for armour plating gun-boats. Except for cursory examinations of the deposits by Ells in 1874 and by Wright in 1931, little was done to investigate the deposits after the mines closed until World War II, when a few drill-holes were put down and Noranda Mines Limited carried out some flotation tests on the material.

Strategic Manganese Corporation, Limited, a subsidiary of Stratmat Ltd., acquired control of the deposits in 1953 and since that time has conducted gravimetric surveys and completed over 34,000 feet of drilling on six ore zones, with about half of this drilling being done on the Plymouth deposit immediately south of the Meduxnekeag River. Very extensive milling and smelting tests have been made on the potential ore.

Geology

The manganiferous iron-formation is present in a succession of thinly bedded Silurian, grey, grey-green, and red slate, sandstone, greywacke, and limestone. The bedded rocks are tightly folded and sheared in places. They strike northeast, dip steeply to the northwest, and the tightly compressed flexures plunge steeply to the southwest. Sidwell (1957) indicated that the iron and manganese minerals have been deposited in five conformable stratigraphic units described as follows:

> . . . silicified slates, manganiferous hematite, red to purplish ferruginous slates, green chlorite slates, and brown cherty slates. Of the five, the silicified slate and manganiferous hematite units contain the bulk of the iron and manganese. An idealized section would show the following succession: dark grey slates, (footwall), grey-green chlorite slates, silicified slates, manganiferous hematite, red ferruginous slates, grey green chlorite slates, and grey calcareous banded slates (hanging-wall). The brown cherty slates may occur anywhere within the sequence but generally occur with the silicified slates. The ore units may occur singly or combined as follows: silicified slates with minor interbedded green slates, red ferruginous slates with manganiferous hematite, and interbedded red and green slates with manganiferous hematite. Of these, the second is by far the most prevalent. The five units do not necessarily occur in the above listed order nor do they always occur together in any one lens. However, the red ferruginous slates thus far have been found to be present with either the manganiferous hematite or silicified slates, or, as shown in the majority of drill holes, with both. All five units have persistent and distinctive chemical characteristics.
>
> The manganiferous hematite, the highest grade unit, is a dark red to black, finely banded rock with, occasionally, alternating red and black or dark red laminae. It has a blocky fracture and is frequently replaced with quartz. It is believed that this quartz replacement is predominant on the crests or troughs of folds. The unit is also cut by narrow quartz stringers and veinlets of pink granular rhodochrosite and quartz which occasionally carry minute specks of chalcopyrite, galena, and sphalerite. Pyrite is a more prominent sulphide and is found particularly near the base of the unit. The unit is also cut by narrow, deep red, stringers of the manganese silicate piedmontite and contains occasional blebs of pale yellow to brown manganese-bearing axinite:. . .
>
> The predominant manganese mineral has been identified as braunite $(MnFe)_2O_3\ MnSiO_3$, which is intimately intergrown with the hematite. Apatite is commonly associated with the hematite. The principal gangue minerals are quartz, chlorite, and feldspar.

Table of analyses (Table III) from Sidwell (1957) gives an idea of the composition of some of this material.

Table III

Per cent	I Moody Hill	II Plymouth	III
Fe.	29.50	18.25	16.49
Mn.	12.30	16.71	13.52
CaO.	—	—	2.65
MgO.	—	—	5.57
SiO_2.	20.80	21.50	30.06
P.	0.98	0.65	0.61

I and II from Moody Hill and Plymouth deposits are from sections below the zone of weathering to illustrate differences of grade along the strike of the iron-formation.

III—a composite analyses of "ore" from one 326-foot intersection of the silicified slate unit.

Another table of analyses (Table IV) from Sidwell 1957 is instructive in showing the ranges in per cent composition of the iron and manganese in the five lithological units.

Table IV

Unit	Iron		Manganese		Fe Av. (EST)	Mn Av. (EST) noted
	Min.	Max.	Min.	Max.		
Manganiferous hematite.........	11	30	12	25	22	14-16
Silicified slates..................	10	25	9	20	16	12-14
Red ferruginous slates...........	5	9	1	6	6	2-3
Green slates......................	3	11	2	7	7	4
Brown cherty slates.............	2	12	2	9	8	6

The thicknesses of these units vary considerably; the first in Table IV ranges from 5 to 100 feet, the second up to a maximum of 470 feet, the third averages 250 to 350 feet, the fourth, at the margins of the zone, is undetermined, and the fifth is up to 10 feet thick.

Deposits

The deposits in the Jacksonville area would appear to be folded segments of the same bed and comprise the steeply plunging crestal parts of the folds. The beds are repeated and doubled up to form continuous blocks of iron-formation relatively free of barren zones. The six zones explored by Strategic Manganese Corporation, Limited were reported by Monture (1957) to have 214 million tons of potential ore. The estimates were based on ore depths to 500 feet with an average metal content of 13 per cent Fe and 9 per cent Mn. The amount of potential ore in the various deposits used for this estimate ranged from 8 to 70 million tons, and the deposits in order from south to north are the Plymouth, North Hartford, South Hartford, Moody Hill, Sharpe Farm, and Iron Ore Hill. Because of the folding, the potentially mineable mass of iron-formation thickens and thins within short distances along strike and the deposits listed average about half a mile long and up to 740 feet wide, the maximum being in the Plymouth orebody.

These deposits are regarded as a marginal type of potential ore because of their low grade and intimate mixtures of very fine grained iron and manganese minerals in slaty or cherty rocks. Utilization of this material as ore will depend on whether satisfactory metallurgical processes can be devised to treat economically low grade material of variable grade. Enough geological exploration appears to have been done to indicate that there is little possibility of finding higher grade primary beds of a mineral composition more amenable to concentration or where the iron to manganese ratio is more favourable. However, the 30-mile zone in which these deposits occur has not been completely explored.

It has been demonstrated that the material can be upgraded considerably by using a sink-float plant with a reasonably good recovery of manganese. Metallurgical investigations using the Strategic-Udy direct reduction process with further treatment in an electric furnace have shown that this type of material can be used as an ore for the production of iron and ferromanganese and the results from the research work are encouraging.

Sutton Iron-Formations, Missisquoi and Brome Counties, Quebec (86, 87)

Outcrops of clastic iron-formation were examined about a mile northeast of Little Pinnacle Mountain in Durham township, Missisquoi county on the south side of the road about 4.5 miles west of the highway intersection a mile south of the village of Sutton. The area is underlain by Cambro-Ordovician greywacke, sandstone, slate, tuff, and lavas, and the iron-rich beds are present in sandy greywacke facies that have a greenish cast. To the northeast, nearest the road, lensy beds up to 2 feet containing 15 per cent disseminated magnetite in blocky euhedral to rounded grains make up about 40 per cent of a 20-foot section. Individual magnetite-rich lenses are mostly less than 30 feet long, and crossbedding in the coarser sandy beds indicates that tops of the beds face northeast. About 40 feet northwest of the hilltop is an exposure of thin-banded, hematite-rich, greenish, sandy greywacke. The general strike of the rocks in the area is northeast and the dip 25°E, but the beds in this exposure are highly contorted and folded, which may in part be caused by penecontemporaneous deformation. The true width of iron-formation exposed is about 15 feet but the band may be considerably wider. Iron is present mainly as grey specular hematite distributed in $\frac{1}{4}$-to-1-inch bands, and constitutes more than 30 per cent of the rock. The steel-grey, thin laminae are similar in appearance on outcrops to medium-grained quartzitic or cherty iron-formations but they are interbedded with fine-grained clastic greywacke. Examination of thin sections shows that the iron is present in well-rounded to irregular-shaped hematite or magnetite grains ranging in size from 0.05 to 0.15 millimetre. A fair degree of sorting is noted and the coarser grains are most abundant. They are embedded in a fine-grained crystalline aggregate of quartz chlorite and sericite, which contains an abundance of subrounded zircon and titanite. Some of the titanite is intergrown with and possibly replaces opaque grains with a creamy brown surface that appears to be ilmenite partly altered to leucoxene.

The ferruginous beds have well-rounded grains, good sorting of the high gravity minerals, lensy distribution, crossbedding and penecontemporaneous deformation, all features common in beach deposits or sand bars. Because of their limited size and the presence of impurities, these beds are of little interest as potential iron ore deposits.

A number of similar occurrences of iron-formation were described by Logan (1848) in Sutton township, Brome county, in the area southeast along strike from the beds described above. A sample from a 7-foot bed on lot 9, range XI, mentioned by Waddington (1960) assayed 40.87 per cent iron and 27.20 per cent titanium dioxide.

Deslandes Township, Gaspé North County, Quebec (68)

Siderite occurrences are reported in the Madeline River area not far above the mouth of the north fork. The beds are at least 4 feet thick and are interbedded with

Ordovician slates and limestones. A lump sample that was assayed contained 40.30 per cent iron (Waddington, 1960).

Aldery Brook, Humber County, Newfoundland (2)

Frequent occurrences of clay ironstones in Carboniferous rocks are present in this area. One 35-foot bed on Aldery Brook near Grand Lake has been reported by Snelgrove and Baird (1953).

Both the Aldery Brook and Deslandes township occurrences are thought to be siderite iron-formations, but descriptions of their lithology are not available.

Residual Deposits

Londonderry Area, Colchester County, Nova Scotia (24)

Iron deposits in the Londonderry area lie in a narrow westerly trending belt about 12 miles long that extends from Totten Brook to Matheson Brook, along the southern slopes of Cobequid Hills. This famous area was one of the early scenes of mining activity in Canada and one of the first areas where iron and steel were produced in quantity. Some of the first experiments on a commercial scale using Dr. William Siemens direct process of making steel from molten iron were carried out in 1874-75 at Acadia mines. This process with further development became known as the open-hearth convertor, and is one of the principal methods used for making steel.

History

According to Lindeman and Bolton (1917), iron ore was known to occur in this area from the time the land was first settled, and mining was started in 1849 when six Catalan forges and a puddling furnace were erected on the east bank of Great Village River by the Acadia Iron Company. A charcoal blast furnace was operated intermittently between 1852 and 1875, and the first steel plant was erected in 1870. This was demolished in 1877 when the site was used for rolling mills. In 1886 The Steel Company of Canada, Limited, purchased the property from the Londonderry Iron Company but that Company went into liquidation in 1899. The Londonderry Iron and Mining Company, Limited, acquired the property, and the mines and furnaces were operated from 1904 to 1908. Over 2 million tons of ore was produced from the various mines during their time of operation.

Geology

Cobequid Hills are underlain by a complex group of sedimentary and volcanic rocks that are highly deformed by folding and faulting, and intruded by basic dykes and various Devonian intrusive masses of intermediate and granitic rock. The volcanic and sedimentary rocks are pre-Carboniferous, and consist of tuff, breccia, acid and basic flows, grey shale, and sandstone. Along the southern boundary of the Cobequid Hills area and the underlying group of pre-Carboniferous rocks, a strong, well-defined, westerly trending fault zone separates this group of rocks from a belt of Pennsylvanian sandstone and conglomerate to the south. A few outliers of Pennsylvanian conglomerate and sandstone rest on the pre-Carboniferous rocks in the area.

A zone with westerly striking lenses of ankerite and ferruginous carbonate lies about half a mile north of this boundary fault and continues parallel with it for more than 12 miles. The iron deposits are residual pockets of goethite and hematite that have formed in these carbonate lenses as a result of leaching and enrichment by surface waters.

Iron Deposits

The iron deposits consist of irregular masses of goethite, hematite, specular hematite, with minor siderite and ankerite. They occur entirely within the carbonate lenses, and reports indicate that all the deposits explored to depths below the zone of enrichment bottomed in fresh unaltered carbonate. In the lower parts of the ore masses the iron oxides grade over some distance into fresh carbonate. No ore, even as stringers or offshoots, extends into the rocks adjacent to the carbonate bodies.

The carbonate bodies, according to Weeks (1948), form a series of roughly parallel lenses that have irregular boundaries, contain some inclusions of country rock, lack banding or distinctive internal structures, are medium to coarse grained, and vary in width from narrow stringers to masses 50 to 100 feet thick. Five analyses listed of carbonate material and recalculated as separate carbonate constituents indicate that the amount of $CaCO_3$ ranges from 40 to 53.9 per cent, $MgCO_3$ from 18.9 to 25.2 per cent, $FeCO_3$ from 14.8 to 17.9 per cent, insolubles from 0.4 to 4.5 per cent, and limonite from 2.5 to 11.0 per cent.

Several varieties of ore are described by Lindeman and Bolton (1917), who note that the "paint ore" has been the chief productive ore of the area and that it is closely associated with and grades into ankerite or siderite. The botryoidal limonite ore, "bottle ore", was quantitatively of minor importance and consisted of hard brown masses that were present mainly near the surface or in cavities and openings in the "paint ore" or "brown ore." Table V from Lindeman and Bolton gives the composition of a number of varieties of ore.

Table V

Values in %

	I	II	III	IV
Iron	57.7	54.00	47.00	49.99
Silica	2.28	5.30	15.60	11.50
Alumina	0.38	7.41	4.11	1.08
Lime	0.16	0.49	0.87	0.75
Magnesia	0.14	0.57	0.12	1.064
Manganese	0.64	0.78	1.06	3.177
Sulphur	0.016	0.03	0.03	—
Phosphorus	0.097	0.08	0.057	0.143
Volatile matter	13.36	7.80	33.37	—

I Analysis of an average sample of "bottle ore"
II Earthy red hematite from Cumberland Brook
III Average of "brown ore" from Cumberland Brook
IV Brown ore from Old Mountain mines

A number of thin, $\frac{1}{2}$-inch-wide, specular hematite, vein-like masses are present in the ore and in the carbonate bodies, and other occurrences have been reported in rocks of the area. Although this mineral is resistant under weathering conditions, it is noted that much of the specular hematite in the ore masses has a brown streak and apparently has been partly decomposed. It was apparently present in the carbonate before the leaching and enrichment and was not fully decomposed, but its origin seems to have been quite different from that of the limonite–hematite masses.

The depth of ore and oxidation seems to be related to the drainage level in the country and extends to greater depths where the surface relief is more pronounced. Perhaps both ruggedness of topography and depth of oxidation depended on the amount of fracturing and jointing in local areas, and topography alone and the consequent depth of the water-table may have had little effect on the depth of oxidation.

Origin of Deposits

Weeks (1948) discussed the origin of these deposits in considerable detail and concluded that (a) a hypogene replacement origin is favoured for the carbonate lenses; (b) "the weathering of the carbonate bodies, the subsequent transportation downward of iron-rich solutions by percolating surface waters, and the later deposition in the carbonate bodies of various iron oxide minerals from these solutions, gave origin to lenses in the carbonate that could profitably be mined as ores of iron"; (c) carbonic acid and carbonated surface waters were the principal agents that dissolved the carbonate rock, transported the iron and precipitated it as oxides, and removed other constituents. In arriving at these conclusions he gave particular consideration to the facts that no diabase dykes cut the carbonate masses although they are present in the adjacent enclosing rocks; that the oxide masses are confined to the carbonate lenses and bottom in them, and the boundaries between iron oxide and carbonate are gradational and irregular; the depth of iron oxide enrichment seems to be related to the present topography and water-table; and the zone is well explored by underground workings and reports describing these corroborate the geological facts outlined.

Mine Development

Most of the mining in this area was done from adits driven into the hills to connect various levels, winzes, and stopes in the ore pockets. The workings are nearly all caved and could not be examined by Weeks at the time of his study 20 years ago. The West mines, between Cumberland and Martin Brooks, were exceptional in that the ore was mined from three vertical shafts. The workings extended along strike for more than 4,400 feet and to a depth of 100 feet below Cumberland Brook or a total vertical depth of 310 feet, and covered a breadth of 300 feet. The actual widths of the ore masses are not known.

The Old Mountain workings on the west side of Great Village Brook consisted of surface workings and four levels, and penetrated an area 2,100 feet long and 1,200 feet wide. The tunnels follow a sinuous course apparently to connect a number of ore pockets.

In the East mines, between Slack and Gory Brooks, surface and underground workings extend through an area 2,900 feet long and follow two zones of ore. These are about 400 feet apart in the west and converge to one at Gory Brook. Productive workings are also located around Weatherby Brook east of Gory Brook. Other workings include the Coolan and Sky prospects in the west near Matheson Brook, the Derry north of Old Mountain mine, and the Pine Brook and Totten Brook prospects east of East mine. Because of the size and grade of these occurrences and because the zone was extensively worked over an 80-year period and thoroughly prospected, it is unlikely that any appreciable amount of material now exists that could meet modern ore specifications.

Other Occurrences

None of the other residual deposits reported in the Appalachian belt appears to be of economic significance. Bog iron deposits are indicated near Tracadie and Fredericton in New Brunswick, in the Eastern Townships of Quebec, and along the shore of Terra Nova Lake in Newfoundland, and many other similar small deposits doubtless occur. Beach sands or placer deposits with appreciable iron content have not been reported.

Iron Deposits Associated With Anorthositic Rocks

Sheep Brook Area, St. George's–Port au Port County, Newfoundland (8)

The only anorthosite mass of any appreciable size in the Appalachian region is in southwestern Newfoundland, east of St. George's Bay. A few small titaniferous magnetite deposits occur within the eastern part of this mass in the vicinity of Flat Bay Brook near the headwaters of Sheep Brook. The presence of this occurrence was first predicted by A. Murray in 1873 after finding boulders of magnetite in the rivers that flow westward from the highlands, and the two largest occurrences were staked by C. R. Bishop in 1888. Aside from reconnaissance trips by a number of geologists, little detailed work was done in the area until Baird (1954) made a study of the deposits in 1942. A considerable amount of work was carried out during 1957 on these deposits by Brinex Exploration Company of St. John's, Newfoundland. The writer is grateful to Mr. Hugh Lilly, who directed this field work, for accompanying him during his investigation of the deposits in June 1957.

The largest deposits on the Bishop Claim (approximate lat. 48°24′, long. 58°20′) are about 2 miles northeast of the junction of Hells Gulch Brook and Flat Bay Brook, 7.5 miles southeast of the village of St. George's on the east coast of St. George's Bay. The easiest access to the area is by the road from St. George's to Flat Bay Brook and along the north bank of this stream to the trail leading north along Hells Gulch Brook.

General Geology

The iron occurrences are near the southwestern side of an anorthosite mass that forms a highland 25 miles long between Bottom Brook on the north and

Fischells Brook on the south, and about 12 miles wide where it continues eastward from a point 4 miles east of St. George's. The age of this mass is not well defined, as it is in fault contact with Mississippian rocks on the east and undifferentiated early Palaeozoic metamorphic rocks on the west. Baird (1954) recognized four types of anorthosite in this mass: (1) The Cairn Mountain type, dark grey, coarse grained and composed of 90 per cent feldspar of basic andesine to labradorite composition; (2) Eastern border facies, medium to fine grained, and composed almost entirely of white or very pale pink feldspar with intimate mixture of bands of altered green mafic minerals and grey gneiss; (3) pink and brown varieties, common along Flat Bay Brook, which vary from light pink to dark red-brown and are intermediate in appearance between Cairn Mountain type and the gabbroic type; and (4) a gabbroic type, common along Flat Bay Brook in which the mafic minerals, mainly pyroxene and magnetite, increase to 30 per cent.

While on a traverse up Hells Gulch Brook to the Bishop Claim, the following observations were made by the writer. Along the upper northeast side of Hells Gulch, grey to dark brownish grey, coarse-grained (crystal size up to $\frac{1}{2}$ inch), massive anorthosite is exposed, which contains up to 10 per cent magnetite evenly distributed in 3 to 5 mm crystals or in clusters of crystals. Magnetite is present in the anorthosite over most of this area together with a few per cent of mafic constituents that are mostly pyroxene and hornblende. Jointing is prevalent and there is evidence of shearing and some northeast-trending structural alignment along shear zones. Near the top of the ravine coarser grained facies of anorthosite were found, and a few pegmatitic zones (measured in tens of feet) consist of dark grey, purplish plagioclase crystals up to a foot across with 3-to-4-inch amphibole and pyroxene crystals and magnetite grains in large clot-like masses of similar dimension. Much of the plagioclase has protoclastic texture. Magnetite is distributed at random in grain clusters; the coarser grained magnetite is present in stringers that follow shears or is emplaced in crushed zones in the plagioclase.

Between Hells Gulch and Bishop Claim the anorthosite texture and composition is variable. Some of it bears disseminated medium-grained magnetite and the grain size varies from 5 mm to several inches in zones of coarse pegmatitic material. The mafic content is usually under 5 per cent. Towards the Bishop Claim area the anorthosite becomes coarser grained with an average grain size of 1 inch and the magnetite is segregated in coarse clusters with many of these in small structural breaks. Zones of brownish, finer grained anorthosite have a distinct protoclastic texture.

Joints are well developed and belong to two sets, one striking east to northeast and the other northwest. The joints and minor faults are exposed by narrow, steep-walled valleys and ravines which meet nearly at right angles. The more continuous valleys follow the northwest-striking joints.

A medium- to fine-grained diabase dyke is exposed at the northeast end of Bishop North prospect.

Bishop North Deposit

This deposit, on the southwest side of a steep bluff, forms a massive body 45 to 50 feet wide. It is exposed for a length of 300 feet, and is probably 500 feet long. This lenticular body of magnetite strikes northeast and dips 65°NW.

The contacts of this magnetite body against the anorthosite are very sharp but irregular; no difference in grain size of the magnetite near the contacts was noted. The magnetite is coarse (1 inch) grained and is very uniform in size. It is bluish black to grey brownish black, massive aggregate and individual crystals have well-developed octahedral parting. Minute plates and needles of ilmenite parallel with the parting in the magnetite are visible on etched or polished surfaces. The anorthosite along the borders of the magnetite lens is coarser grained and in places pegmatitic with pyroxene, amphibole, and magnetite clusters. Some fine-grained, pink garnet is developed at the contact between magnetite and mafic minerals. In places along the border or within tens of feet of the border the anorthosite is lighter grey to white or leached, and in some of these lighter zones near the deposit magnetite is absent.

Bishop South Deposit

This magnetite deposit is about 2,000 feet southwest along strike from the Bishop North deposit and extends southwest from a small pond for about 400 feet. It is reported (Baird, 1954) to be about 70 feet wide and to strike N30°E and dip 60°W. This deposit is similar in most respects to the Bishop North occurrence but contains some green spinel mixed with the magnetite.

Bishop III Deposit

This occurrence is about 1,700 feet along strike southwest from the Bishop South deposit and is about 20 feet by 10 feet in area. It appears to belong to the same zone as the other Bishop deposits.

Hayes Prospect

The Hayes prospect lies half a mile north of Flat Bay Brook and can be reached by following a trail that leads north from Flat Bay Brook road about half a mile east of Surveyors Brook. It consists of a number of narrow lenses of magnetite, up to 6 feet wide and 100 feet long, distributed along a narrow zone about 500 feet long, which strikes northeast and is in line with the Bishop deposits. Except for a greater abundance of amphibole and pyroxene, it is similar to the other deposits and is apparently emplaced along the same structural belt.

Other prospects in this area include the Hudson, south of Flat Bay Brook, and a few other minor occurrences on the east side of Hells Gulch.

Baird (1954) gives the composition of magnetite material from some of these deposits. Iron content is not reported, but he noted that the titanium content varies but averages about 6 per cent in Bishop North and South and about 5 per cent in the Hayes occurrence. Silica is less than one per cent, and sulphur averages about 0.30 per cent. The phosphorus content is low and vanadium, found in all samples, averaged 0.20 per cent.

Origin of Deposits

The distribution of magnetite in coarse-grained clusters or clots and as an accessory constituent throughout the anorthosite indicates a genetic relationship between the anorthosite rock and the iron and titanium oxides. The large masses of magnetite have obviously been emplaced at a late stage in the cooling history of the anorthosite after it was sufficiently crystalline and rigid to be deformed by fracturing and shearing. It is deduced that, because the magnetite lenses show no chilling or decrease in grain size at their borders, the anorthosite was still at a high temperature when the massive magnetite was introduced. On the other hand, it was probably little affected by the increased temperature associated with the magnetite emplacements. Indeed the alteration of the anorthosite and some of the garnet and skarn that developed may have been caused by later stage hydrothermal activity that took place after the anorthosite at this level was fully lithified. The magnetite is considered to have separated from the feldspar of the anorthositic material in the deeper parts of the anorthositic mass and then been injected into the higher levels as a mobile, rather fluid melt when they were rigid enough to fracture. It is especially interesting and significant that most of the magnetite masses follow one northeast-trending fracture zone.

Iron Deposits in Rocks of Intermediate to Granitic Composition

Indian Head Area, St. George's–Port au Port County, Newfoundland (9)

The Indian Head area is particularly interesting because of the great range in composition and variety of igneous rocks in it, and the heterogeneous assemblage of iron deposits associated with these rocks. It forms a rough rocky ridge of high relief from a mile to 3 miles wide that extends northeast for nearly 10 miles from the headland it forms at the east end of St. George's Bay. The iron deposits are distributed along the central and western part of this highland for a distance of 3 miles inland from Indian Head.

The area was first prospected by trenching and diamond drilling about 1923 by the Reid Newfoundland Company Limited and examined by a number of geological parties in the 1930's. A prospecting program was begun in 1941 by Dominion Steel and Coal Corporation, Limited, who mined a small amount of iron ore from the Indian Head mine and the Cliff mine between 1941 and the early part of 1943. Considerable exploration was done by test pitting, and in 1942 the Newfoundland Geological Survey carried out an investigation that included geological mapping, dip-needle surveys, test pitting, and diamond drilling. A detailed description of the prospects and this work is given by Heyl and Ronan (1954) from which much of the following information is summarized. Most of the area where the iron deposits occur is now within a military reserve, and the writer was able to make only a cursory examination in 1957.

General Geology

The Indian Head area is underlain by a complex suite of igneous rocks that are certainly of pre-Carboniferous age and generally regarded as Precambrian. The types described from the area are: hypersthene diorite–gneiss, hornblende plagioclase gneiss, granoblastic norite–gneiss, hypersthene pyroxenite, anorthosite, soda granite–gneiss, microcline biotite granite–gneiss, hornblende microperthite granite–gneiss, granite pegmatite, peridotite, and doleritic basalt dykes. These rock types are thought to have been emplaced in the order given, from oldest to youngest. The iron deposits occur mainly in the granoblastic norite–gneiss and in the soda granite–gneiss, and a few in hypersthene pyroxenite. The general structure of the area has been interpreted as a broad dome with shallow-dipping limbs that plunges 15 to 30°NE, the southwestern part of which is considered to underlie St. George's Bay. The domal structure is disrupted by a number of faults that strike north to northeast and a north-dipping thrust fault, which appears to mark the northern limit of the area with iron deposits, cuts across the high ridge north of Long Gull Pond.

The Iron Deposits

There are more than thirty iron occurrences in this area all of which are small and, with a few exceptions, are thin sheet-like masses and disseminations lying conformable with the foliation in the gneissic rocks. The mineralized zones range from a fraction of an inch to 10 feet thick, but average about 2 feet, and are as much as several hundred feet long.

The deposits fall into three groups. Those of the southern group lie south of Labrador Pond near Indian Head. They comprise disseminations, small veins, and masses of magnetite in hypersthene pyroxenite, and contain about 25 per cent iron, 0.48 to 3.21 per cent titanium, and 0.02 to 0.14 per cent vanadium, and have a low sulphur and phosphorus content. Deposits of the next group, located south of the Stephenville road, consist of thin bands and lenses of magnetite in norite gneiss. The Indian Head mine is one of about eight occurrences in this group. About eight occurrences of the northern group were investigated north of Stephenville road near Gull Pond and Oxback Pond. The iron is present mainly as magnetite with minor specular hematite in layers, veinlets, bands, and some disseminated zones in soda granite–gneiss. Magnetite from Upper Drill Brook prospect assayed 64.4 per cent iron, 2.99 per cent titanium, 0.23 per cent vanadium, 0.07 per cent sulphur, and phosphorus nil. Most of the drill-core samples from holes between Upper and Lower Drill Brook prospects contain about 5.5 per cent titanium where the iron is between 55 and 60 per cent, and 0.47 to nil phosphorus. Representative samples of Lower Drill Brook mines 'ore' assayed 60.5 to 64.05 per cent iron, 3.48 to 4.32 per cent titanium, 0.07 to 0.38 per cent vanadium, 3.8 to 0.44 per cent sulphur, nil phosphorus, and 0.47 per cent silica, according to Heyl and Ronan. Pyrite, chalcopyrite, and molybdenite are reported as accessories in this material.

The deposits north of Gull Pond, which include the Cliff mine, consist mainly of banded specular hematite in soda granite–gneiss. Two parallel bands of hematite in the Cliff mine are separated by about 10 feet of gneiss and dip 15 to 20°N. The lower band is about 8 feet thick and the upper band from 1 foot to 3 feet. Samples of rich specular hematite material from prospects in this area contain from 59.18 to 70.2 per cent iron, from 0.63 to 0.08 per cent titanium, vanadium traces to nil, sulphur low, and phosphorus nil to 0.22 per cent.

The ratios of titanium and vanadium to iron vary considerably even between nearby deposits, but there are not enough data to tell if this variation is due to differences in the composition of the enclosing rock. The titanium, vanadium, and phosphorus content is much lower in the specular hematite bands in the northern part of the area.

Although the deposits in this area are extremely interesting because of their relationships to such a diverse group of rocks, exploration work to date has not suggested the likelihood of there being large commercial deposits. The area is, however, worth re-examining to determine its potential for material amenable to concentration.

Other Types of Iron Deposits and Their Distribution

A great many small occurrences in the Appalachian region, on which limited investigations have been carried out, are mentioned in the literature.

Small occurrences of magnetite both disseminated and in veins are recorded in the large Triassic intrusive mass of basalt and diabase south of the Bay of Fundy. Small amounts of magnetite are also associated with the ultrabasic rocks in the Eastern Townships of Quebec, and in western Newfoundland. Very few magnetite deposits of the contact metasomatic and replacement type are reported, but the small Millstream deposit on Rocky Brook about 9 miles north of Bathurst is thought to be of this type. Disseminated and replacement occurrences of magnetite deposited under structural control are of interest in the Tilt Cove area, Notre Dame Bay, Newfoundland where they are associated with, and form part of, the gangue of the copper and base metal sulphide ores. A few other small disseminated magnetite occurrences are mentioned in reports.

As indicated on Figure 1, vein type deposits are widely distributed throughout the Appalachian region in rock of all ages. A number of veins in the East River area of Pictou county, Nova Scotia, now considered to be exhausted, were mined in the early part of the last century. Less than 100,000 tons of botryoidal goethite and hematite was mined from five different deposits and averaged 40 to 48 per cent iron, 14 to 30 per cent silica, 0.03 to 0.075 per cent phosphorus, and 0.02 to 0.08 per cent sulphur. Very good quality direct shipping specular hematite ore was mined from several veins in the Guysborough area around 1876. The vein deposits there apparently were not more than 12 feet wide and were in Devonian rocks. A number of other vein deposits, some of which were mined up to 40 years ago, are described by Lindeman and Bolton (1917) in Colchester and Cape Breton counties in Nova Scotia. Some of these are specular hematite deposits, and others are red hematite and goethite, and nearly all are in Carboniferous rocks.

A number of hematite–goethite vein occurrences were examined along the west coast of Conception Bay, Newfoundland. The largest and best known of these is at Workington near Lower Island Cove. Elaborate transportation and dock facilities were prepared there in 1898, and a number of prospect shafts were sunk. The shafts are flooded but fragments on the dumps indicate that hard lumpy mixtures of goethite and hematite make up the interesting part of the vein fillings. The following analysis given by Snelgrove and Baird (1953) is considered to be typical of the material seen on the dumps: 60.37 per cent iron, 0.17 per cent manganese, 0.028 per cent phosphorus, 0.02 per cent sulphur, and 6.72 per cent silica. The steeply dipping veins are reported to be 5 to 7 feet thick and apparently follow a well-defined fault or structural break in grey slates and argillaceous sediments and schists. The botryoidal and colloform structure of the goethite is indicative of open space fillings and the vein deposits probably do not extend to very great depths. They may constitute a series of lenses, and irregular pods along the fault zone, but seem to be too small to be of economic interest.

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PART II

IRON DEPOSITS OF THE GRENVILLE AND LABRADOR COAST REGIONS

Introduction

The Grenville Province forms a belt about 200 miles wide that lies northwest of the St. Lawrence River, and extends from Lake Huron to the Labrador Coast, a distance of 1,200 miles (*see* Fig. 6, *in pocket*). A smaller part of this province, about 10,000 square miles, lies east of Lake Ontario in the Adirondack region of New York State and is connected with the main part of the province along the Frontenac axis in the Kingston–Brockville area of Ontario. Rocks in the Grenville Province were involved in a major orogeny near the end of the Precambrian era. Isotopic ratios indicate that this period of rock deformation, igneous intrusion, and mountain building took place between 800 and 1,000 million years ago. Rocks as young as early Proterozoic were affected, but the earlier geological record is obscure because of intense metamorphism.

The northwest boundary of this province is not precisely defined, but the border zone extends from the north end of Georgian Bay northeast to Chibougamau Lake, along Temiscamie River south of Lake Albanel, north of Wabush and Gabbro Lakes, and follows this northeast trend to the Labrador Coast. The region north of this boundary between the Labrador geosyncline and the coast is probably part of a different and older province, as isotopic ratios indicate ages ranging from 1,150 to 1,800 million years for these rocks. The northwest regional trend of this coastal rock belt appears to be truncated by the northeast-trending Grenville structures. Available field data and age determinations are not sufficient to define the boundaries of the Grenville Province in this coastal region.

Rocks are highly metamorphosed and deformed, and correlation of rock groups within the province or with groups in adjacent areas is extremely difficult. This province is defined as the region deformed by the Grenville orogeny. The age of this orogeny is indicated by isotopic ratios, which are believed to date the last major period of rock deformation and recrystallization. The age of the metasedimentary and metavolcanic rocks themselves is obviously older than this orogeny, and no doubt these rocks originally formed many distinctive stratigraphic units. The southern part of the Grenville Province was populated almost as early as any other part of Canada, but much of the geology has not been mapped in sufficient detail to show its highly complex structural and petrological features.

A great variety of mineral commodities is mined in the Grenville Province. Iron ore was one of the first mineral products to be recovered from the part south of the Ottawa River, but gold, copper, lead, zinc, and uranium are also mined. Very large deposits of ilmenite and titaniferous magnetite are associated with anorthosite and gabbroic anorthosite. The province is probably most famous for the numerous deposits (distributed mainly in its southwestern parts) of non-metallic minerals and occurrences of rare and exotic minerals. Limestone, dolomite, mica, feldspar, nepheline, beryl, apatite, lithium minerals, and rare earths are all important commodities. In the northeast the iron-formations of the Labrador geosyncline extend southwest into the Grenville orogenic belt where they are highly metamorphosed. They form enormous reserves of low grade iron ore from which concentrates are now being produced. As these iron-formations are part of the stratigraphic succession that forms the Labrador geosyncline, they will be described in a later volume.

The Grenville Province is drained by streams that have their headwaters along its northwest boundary and flow south into the St. Lawrence River or Gulf of St. Lawrence. Topographic relief over much of this region is low but rugged; rounded, oval-shaped hills and hummocks were sculptured by glacial action. Most of these hills are bare or covered only with thin patches of glacial till and overburden; rocks are generally well exposed. The topography is very rugged in the area east of Saguenay River and for 100 miles north of the St. Lawrence River. Major streams pass through vertical-walled canyons up to 1,000 feet deep, and the country is deeply incised by steep-walled valleys. North of this jagged range of hills, isolated hills and narrow plateaux rise 500 feet above the rolling Shield topography. Lakes are numerous, and the drainage pattern is very erratic.

General Geology

The geology is complex because of the intense metamorphism and structural deformation. Thick successions of metasedimentary and associated volcanic rocks have been recognized in various parts of the region. These are now gneisses and schists that were derived from sandstone, arkose, conglomerate, shale, limestone, iron-formation, lava, and various volcanic rocks. The metasedimentary gneiss and schist are intruded by a great variety of granites, syenites, and pegmatites. Large areas are underlain by granite or granodiorite-gneisses, which are generally considered to be the product of extensive granitization. One of the most distinctive rock groups in the province is comprised of the anorthosites, gabbros, and related intrusions that contain deposits of iron, titanium, and ferride elements.

The general geology is shown on Figure 6, together with some of the major rock groups of adjacent provinces. No attempt is made to differentiate rock units within metasedimentary belts or to correlate between belts. Anorthosite and gabbro masses and various other intermediate to basic rocks are shown in a general way together with the iron and titanium deposits.

Table VI

Table of Formations, Grenville Province

Era	Period	Epoch	Description
CENOZOIC	Quaternary	Recent Pleistocene	Sand, clay, marl, peat Glacial drift
Unconformity			
	Age uncertain		Lavas in Mushalagan Lake area
Unconformity			
PALAEOZOIC	Ordovician	Trenton and Black River	Mainly limestone
		Chazy	Mainly limestone and shale
		Beekmantown	Mainly dolomite
	Cambro–Ordovician	Potsdam–Nepean	Sandstone, arkose, and conglomerate
Unconformity			
PRECAMBRIAN		Buckingham Series	Trap, diabase, fine-grained gabbro Pegmatites Granite, syenite, aplite dykes Nepheline syenite, fine-grained gabbro, gabbro anorthosite
			Syenite–granite Diorite Gabbro Gabbro anorthosite a suite of related intrusions with magnetite and titaniferous magnetite
			Anorthosite
		Intrusive contact	
	Many series of metasedimentary and volcanic rocks in various stages of metamorphism, relative ages of deposition not determined		
		Hasting Series	Metasediments, blue-grey limestone, buff weathering dolomite, conglomerate with granite, crystalline limestone, volcanic rock, "Eozoan", and quartzite pebbles

Table VI (cont'd)

Unconformity			
PRECAMBRIAN		Grenville Series	Metasediments, crystalline limestone, quartzite, amphibolite, gneisses, schist. Metavolcanics and iron-formation probably belong to an older series of metamorphosed Keewatin rocks
	Relationship uncertain		
		Wabush Lake Mount Wright	Metasediments, quartzite, iron-formation, meta-dolomite, schists, gneisses–metamorphosed Labrador geosyncline rocks
		Beetz Lake Forget Lake	Quartzites, calcareous quartzites, biotite hornblende schists and gneisses, graphite schists.
		Seal and Croteau Groups	Greywacke, shale, quartzite, argillite, acid and basic volcanic rocks, sandstone, conglomerate

Stratigraphic Groups of the Grenville Province

Grenville Series

The metasedimentary rocks along Ottawa River and north of St. Lawrence River were investigated in the early part of the nineteenth century. Specific attention was first given to this series by Sir William Logan, and the term Grenville Series was used by him in descriptions of the crystalline limestones, quartzites, gneiss, and other metasediments around the village of Grenville, Quebec, north of Ottawa River. This term was used for other lithologically similar rocks in adjacent areas and was soon applied to large areas of metasedimentary rocks in southeastern Ontario and southern Quebec. It has also been applied in many isolated areas within the province underlain by highly deformed metasedimentary rocks, especially where the successions contain crystalline limestone or dolomite. In the classical southeastern part of the province the Grenville Series is composed of coarsely crystalline gneisses, marbles, and amphibolite masses derived from sandstone, arkose, shale, limestone, and small amounts of lava and volcanic rocks. The period of deposition for this series is of course uncertain, but it is now considered by many to be Proterozoic. In the Madoc-Marmora area, magnetite-specular hematite-quartz iron-formation is interbanded with basic volcanic rocks of the Grenville Series (Wilson, 1933).

Hastings Series

This series of metasedimentary rocks is recognized in Hastings county and adjacent parts of southeastern Ontario. These rocks overlie the Grenville Series unconformably, but there is very little structural discordance between the two series. Bluish grey weathering limestone, conglomerate, and schist of the Hastings Series are not generally as highly metamorphosed as rocks of the Grenville Series. Both acid and basic volcanic rocks are interbanded with conglomerate in some places where the Hastings and Grenville rocks have not been differentiated. Numerous other amphibolite bands are present that may have been derived from volcanic rocks.

Killarney Area Metasediments

Rocks east of Killarney on Georgian Bay were described in the classic work of Quirke and Collins (1930). They found small masses of quartzite, argillite, and limestone, lithologically similar to beds in the adjacent Bruce Series of the Huronian, surrounded by pink and grey gneisses and massive granite. They also found that the Huronian rocks north of Georgian Bay formed a succession over 20,000 feet thick, which terminated abruptly along a line that extended northeast from Killarney. East of this line, which is accepted as the boundary of the Grenville Province, the rocks consist of gneisses, granite, and syenite and some recognizable metasediments. Huronian quartzites along this boundary line grade eastward into red porphyritic granite over a distance of 50 feet, and farther east the granite porphyry grades into gneiss. Partly digested inclusions of sediments in the granite, and transitions between sediments and granite or gneiss led Quirke and Collins to conclude that Huronian sediments were transformed into granitic gneisses and became part of the rock assemblage of the Grenville Province.

Wabush Lake and Mount Wright Area Metasediments

In the boundary area of eastern Quebec and Labrador, rocks of the Kaniapiskau Supergroup of the Labrador geosyncline extend southwest into the Grenville orogenic province. The succession of quartzite, dolomite, iron-formation, argillaceous beds, and greywacke of the Kaniapiskau Supergroup has been followed almost continuously as far south as Wabush Lake. Similar metasedimentary beds are distributed intermittently with the gneisses southwest of Wabush Lake for a distance of 150 miles. Their metamorphic rank changes near the boundary of the Grenville Province from the lower greenschist facies to the north to the epidote-amphibolite facies in the Wabush Lake area to the south. The biotite isograd, where located by Fahrig (1960) north of Wabush Lake, follows a northeast-trending line. Features of the Grenville orogeny, such as intense structural deformation and intrusions of granite and gabbro, extend north of this line for at least 5 miles. The rocks south of the border zone are much coarser grained and are deformed by a second stage of folding and regional deformation. The regional distribution of these deformed metasediments in the Grenville Province is indicated by the iron-formations plotted on Figure 6. Further detail on this region will be given in volume III of this series devoted to the geology of the Labrador geosyncline.

Beetz Lake — Forget Lake Area Metasediments

A large area east of Romaine River and north of Anticosti Island is underlain by a thick succession of metasedimentary rocks of undetermined age. This group of rocks is made up of various massive, grey, calcareous, argillaceous, or hematite-rutile rich quartzites, quartz-mica schists, hornblende and biotite schists, and graphitic schists. Fold axes in this tightly folded belt trend north, and the general structure of the region consists of broad anticlines and synclines. Large gabbro sills, mostly concordant with the structure of the metasediments, are intruded throughout the belt.

Other Groups of Metasediments

A large number of smaller areas underlain by metasedimentary and possibly metavolcanic rocks are not mentioned or shown on Figure 6. Rocks in most of these areas consist of gneisses derived from sediments, crystalline limestone and quartzite, and of amphibolites derived from basic intrusions, extrusions, or calcareous sediments. Furthermore, much of the Grenville Province has not even been mapped.

Stratigraphic Groups, Labrador Coast Area

Seal and Croteau Groups

These groups in the Seal and Snegamook Lakes area were described by Fahrig, 1959. They are generally regarded as of Proterozoic age but have not been correlated directly with rocks of the Labrador geosyncline. Effects of the Grenville orogeny have not been clearly established in this region. It is thought that the east-trending faults along the south margin of this younger rock belt may be part of the structural deformation that marks the northwest boundary of the Grenville Province. Perhaps the Grenville orogenic belt swings north in this area to include the deformed rocks along the Labrador coast, or perhaps this deformation was caused by an earlier orogeny. The Seal–Croteau rocks unconformably overlie granitoid rocks intruded by anorthosite and are separated from similar rocks to the south by well-defined thrust faults. The Croteau Group, considered to be mainly older than the Seal Group, is composed of greywacke, dolomite, shale, quartzite and pyritic carbonaceous shale, basic to acidic volcanic rocks, sandstone, and conglomerate. The Seal Group consists largely of arkose, quartzite, red, grey or black shale and argillite, and basic volcanic rocks. Numerous gabbro sills are present throughout the area, and a few small bodies of peridotite have been found. The Croteau Group to the east of the belt forms a monoclinal structure, whereas the Seal Group to the west forms a large syncline truncated along the south by thrust faults.

Ramah and Mugford Series

These rocks, which are distributed along the Labrador Coast between Nutak and Nachvak Fiord, are considered by Christie (1952) to be Proterozoic, but their relation to rocks in the Grenville orogenic belt is not known. Granitoid gneisses, crystalline limestone, and conglomerate intruded by masses of related diorite, gabbro, and anorthosite are unconformably overlain by gently dipping quartzite, argillite, ferruginous quartzite, dolomite, and volcanic rocks of the Mugford Series, and by quartzite, argillite, slate, ferruginous quartzite, dolomite, chert, graphitic schist, and volcanic rocks of the Ramah Series. These younger rocks are relatively fresh and unaltered and probably extend inland and southward for a considerable distance.

Post-Grenville Rocks

The various outliers of Palaeozoic beds suggest that the entire region was once covered by Palaeozoic sediments. Most of the Palaeozoic beds are nearly flat lying and, as in the Ottawa Valley area, are downfaulted blocks, but small occurrences around Mushalagan Lake are highly deformed. Volcanic rocks of post-Ordovician age indicate a late period of orogeny in the Mushalagan Lake area.

Anorthosites and Basic Intrusions of the Grenville Province

Anorthosite–Gabbro–Diorite Complexes

The very large masses of anorthosite and gabbroic anorthosite are prominent and distinctive features of the Grenville Province. Their general distribution is shown on Figure 6, and the gabbroic and dioritic phases are indicated where possible. These masses intrude highly deformed, medium to coarsely crystalline gneisses and metasedimentary rocks. They appear to be dome shaped and to have regular, well-defined borders. In a few areas, as near Seal Lake in Labrador, gneisses intruded by anorthosite are overlain by a younger succession of rocks. There is a consistent association of anorthosite and highly metamorphosed rocks, suggesting that high temperatures and probably a plutonic environment were required for their formation. The relative ages of the different masses are not known, but these masses are believed to have been emplaced during the early part of the Grenville orogeny. Dykes and offshoots from these masses cut crystalline gneisses or sediments and have produced metamorphic effects and alterations in the host rocks.

Most of the anorthosite masses are composed of 90 per cent or more plagioclase, which varies from medium to very coarse grained and ranges in composition from oligoclase and andesine to labradorite. The mafic constituents are usually hypersthene and augite; the amount of titaniferous magnetite, ilmenite, and other titanium–iron oxide minerals disseminated with the plagioclase varies. Internal structures vary from massive, banded, and layered to gneissic. Other large masses have a protoclastic texture believed to have been caused by regional deformation that took place after the anorthosite was fully consolidated.

The marginal parts of many anorthosite bodies grade to norite gabbro and pyroxene diorite. Masses of more soda-rich anorthosite may intrude more calcium-rich phases and gabbro, diorite, and even syenitic masses may intrude anorthosite bodies. Syenites and pyroxene granites are present in the border phases or as separate intrusions near the borders of many masses. These may be products of the magmatic differentiation that produced the anorthosite but some may have formed through partial assimilation of wall-rock material.

The anorthosite–gabbro complexes are of particular interest because of the ilmenite and titanium-bearing magnetite or hematite always associated with them. In some areas these oxide minerals are disseminated through the plagioclase, commonly forming distinctive layered rocks, whereas in other areas the iron-titanium oxides may form irregular clots or distinct intrusive masses in the anorthosites. The ilmenite–hematite complexes occur more frequently in the cores of anorthosite masses; titaniferous magnetite is more common in gabbroic anorthosite or in norite gabbro. The gabbroic phases in most areas contain much more iron and titanium oxide than the anorthosite phases.

Figure 6 gives some indication of regional distribution of the main phases. Information is sketchy in many parts of the area and Figure 6 is highly generalized, but anorthosite masses appear to be larger and more abundant and underlie many more square miles of territory than gabbroic phases. Furthermore, gabbroic phases are apparently less abundant and less conspicuous in the region extending from the Labrador Coast to near the Saguenay River. From there south, the anorthosite forms smaller but distinct masses, like the Morin body, and gabbroic anorthosite, gabbro, and dioritic phases are more abundant. It is possible that gabbroic material was peripheral to the upper parts of large masses, and where these are deeply eroded only the lower anorthosite phases are preserved. On the other hand, many of the small diorite and gabbro bodies in the southern part of the province may be offshoots from deep seated magmatic bodies, the anorthosite phases of which are not exposed.

Other Basic and Ultrabasic Intrusions

These rocks form a heterogeneous group, and their age and interrelationship pose major problems. Many bands and discordant bodies of amphibolite with metamorphic texture, derived from widespread basic intrusions, are present. Besides the main group of these intrusions, which are related to the anorthosite bodies, there are many other distinct groups of basic intrusions; ultrabasic masses (*see* Fig. 6) are found in many areas.

A suite of gabbro, diabase, and olivine diabase dykes is the youngest Precambrian rock recognized in the southern part of the region, but dyke rocks of comparable composition were intruded at several different periods. An interesting suite of gabbroic rocks was intruded in the south part of the Labrador geosyncline area near the end of the Grenville orogeny. These rocks range from thin concordant sill-like masses emplaced between bands of folded metasediments, to stocks and discordant masses up to 100 square miles in area. In the Mount Wright area (Gross, 1955) they consist of sills and lenticular masses that have been recrystallized under stress to form foliated hornblende-plagioclase-biotite-garnet amphibolites. The central parts of the thicker masses are composed of sub-ophitic textured, massive, olivine–pyroxene gabbro with all stages in the transition from gabbro to amphibolite discernible. Farther east, near Wabush Lake, metamorphic aureoles are present in iron-formation adjacent to similar gabbro masses. The relationship of this suite to the nearby anorthosite–gabbro masses or to the basic intrusions farther northeast in the Labrador Trough or in the Seal Lake area is not known. Similar sill-like masses are present in the Beetz Lake-Forget Lake area, and Claveau (1949a, b) thought that the gabbro suite was genetically related to the anorthosite intrusions. Other large gabbroic bodies in the eastern part of the Grenville Province (Fig. 6) may also be related to the anorthosite suite.

Granites, Syenites, and Monzonites of the Grenville Province

The granitoid gneisses so prevalent throughout this region have already been mentioned. Some can be positively recognized as metasedimentary rocks, but large areas are underlain by both massive and foliated more or less acidic rocks. It is beyond the scope of this summary to attempt a review of the extensive literature on these granitic rocks. Apparently an early period of granite emplacement produced the rocks now found as pebbled in some of the conglomerates of the Grenville metasediments. Furthermore, some occurrences of granite, syenite, and monzonite are closely related to rocks of the anorthosite, gabbro–diorite suite, which predates the main period of granite emplacement near the end of the Grenville orogeny. The emplacement of granitic rocks was an important phase of the Grenville orogeny and, except for a suite of diabase dykes, these granites and syenites are among the youngest Precambrian rocks. For further description of the granitic rocks the reader is referred to the work of Hewitt (1956), Wynne-Edwards (1957), Buddington (1939), and to reports of the Geological Survey of Canada, the Ontario Department of Mines, and the Quebec Department of Mines. Rocks of this province that have received particular attention are the nepheline syenites in the Bancroft area and the pegmatite dykes with their diverse mineral assemblages.

A distinctive group of charnockite rocks has been mapped along the border of the Grenville belt north of Mount Wright and similar rocks are known to underlie large areas in several other parts of the province. This suite of rocks is composed of dark bluish grey, granitic and dioritic hypersthene-biotite gneiss and massive rocks of equivalent composition. They have a greasy luster and coarse granular texture. The age of these rocks relative to other rocks in the province is uncertain. Charnockites belong to the granulite metamorphic facies and are considered to have formed in a deep seated or plutonic environment where very high temperatures and pressure prevailed but where the content of volatile constituents was low. Iron-formations north of Mount Wright at the border of the charnockite belt are not so highly metamorphosed as those farther south and do not show the textural features typical of the granulite facies. For this reason the charnockite suite, in this area at least, is thought to have formed before the Grenville orogeny, probably much earlier. Charnockitic rocks are also distributed north and west of the Labrador geosyncline where isotopic ratios show ages older than 2,000 million years.

Major Structural and Tectonic Features

The rocks of the Grenville Province are considered to be the roots of a late Precambrian mountain system that may have extended for some considerable distance to the southwest through the region now covered by Palaeozoic rocks. At one stage this mountain system was comparable to the present Appalachian system and orogenic disturbances of the Grenville system probably lasted over a period of time similar to that required for the evolution of the Appalachian Mountains. The boundary between the Appalachian and Grenville systems is a major structural break known as Logan's Line.

The nature of the northwest boundary of the Grenville Province has been the subject of much investigation, and although the tectonic map of Canada shows this boundary as a fairly distinct and well-defined line marked by faults, more detailed information reveals a broad zone with several complex features. The correlation of rock groups across this boundary in the Killarney and Wabush Lakes areas has been mentioned. Faults have been emphasized in most descriptions but the continuation of major fault systems along the full length of the boundary has not been demonstrated. Bedding plane foliation is characteristic of rocks in the Grenville belt whereas axial plane cleavage and schistosity are features of the less metamorphosed rocks to the north. Granite and gabbro intrusions are present in the border zone between the two Precambrian provinces; the geological record of earlier events is obscure. However, in some places Grenville rocks appear to be uplifted and thrust northwest along structural breaks that mark the boundary. The biotite isograd trends northwest parallel with the boundary zone.

Structures such as the Clare River syncline or Mayo anticline in the southern part of the province have been defined in detail in many parts of the Grenville Province, but regional structural patterns are uncertain because large granite or gabbro masses separate the metasedimentary belts. In the northeast, the structure of the metasedimentary group containing iron-formation is extremely complex because of two stages of folding and several stages of faulting. In general, foliation in the gneisses trends northeast but there are many local divergencies from this trend, especially near anorthosite masses where regional trends in the gneisses are usually distorted.

Northeast-trending faults paralleling the boundaries of the Grenville belt are present in many places (*see* Hewitt, 1956), and other sets of northwest-trending faults parallel the Ottawa and Saguenay River valleys.

Distribution of Iron Deposits in Relation to Regional Geology

The four major types of iron deposits in the Grenville Province are: highly metamorphosed iron-formations; titaniferous magnetite and ilmenite deposits associated with gabbro, anorthosite, and diorite; contact metasomatic, skarn, and vein deposits; and magnetite-rich sand deposits. The iron-formations between Wabush Lake and Pletipi Lake constitute one of the principal iron ore reserves on the continent and will be described in volume III of this series. Except for the iron-formations and magnetite sand occurrences, practically all other iron deposits occur within or near anorthosite and gabbro. It is evident from Figure 6 that nearly all these deposits contain more than one per cent titanium. A few non-titaniferous magnetite deposits are associated with ultrabasic or serpentine rocks and a large number of non-titaniferous contact metasomatic and vein type deposits occur in eastern Ontario and along Ottawa River, but nonetheless there is a consistent relationship throughout the Grenville belt between occurrences of titaniferous magnetite and ilmenite and the anorthosite-gabbro suite of rocks. So far, except for the iron-formations, only titaniferous iron deposits have been discovered in the northeastern part of the Grenville Province.

Distribution of Iron Deposits Northeast of Ottawa River

The distribution pattern of iron deposits northeast of Ottawa River is indicated by the data summarized on Figure 6. Exploration and investigation of the regional geology and mineral occurrences have been very limited in this region, but the available published data seem to indicate a general pattern. Although the relationship between iron-titanium occurrences and petrological variations in the anorthosite–gabbro rocks has been studied in only a few small intrusive masses, it is evident that a relationship exists between the kind of deposit and the rock phase in which it occurs. Such relationships have been shown in the Morin anorthosite where titaniferous magnetite occurs in the peripheral gabbroic anorthosite phase and ilmenite–hematite in the central anorthosite core (Osborne, 1936; Rose, 1960). Similar relationships may be found in other intrusive masses, but information on most of these is still sketchy.

One of the first trends to be seen is that the major ilmenite occurrences lie along the south and east margins of the Grenville Province. They are clustered in the Allard Lake–Magpie River area, the St. Urbain area, and the Morin anorthosite north of Montreal. Other occurrences are reported near the Labrador coast, where their position in respect to structural and tectonic features is not clear. Titaniferous magnetite occurrences in this southern marginal zone are in peripheral parts of the anorthosite-gabbro masses and the smaller gabbroic anorthosite intrusions.

Deposits in the central and western part of the province are of titaniferous magnetite containing more than one per cent titanium. Occurrences with less titanium are found in the area near Ottawa River and are more numerous in the southwest where other local trends are evident. It may be that titaniferous magnetite occurs in zones peripheral to central areas where ilmenite deposits occur, rather than being distributed along northeast trends indicated by structural and tectonic features. The distribution of smaller gabbro-diorite intrusions may also follow a similar zonal pattern about central anorthosite masses, as suggested in the area around the Morin intrusion.

Several interesting local and regional trends (*see* Fig. 7) are shown by the iron-titanium ratios (Fe:Ti) of magnetite and ilmenite samples from various occurrences. Deposits in the Allard Lake-Magpie River anorthosite consist predominantly of ilmenite with minor exsolved hematite and most have Fe:Ti ratios of 1.8 to 2.3 compared to a ratio of 1.16 for pure ilmenite. Deposits in the west part of the mass

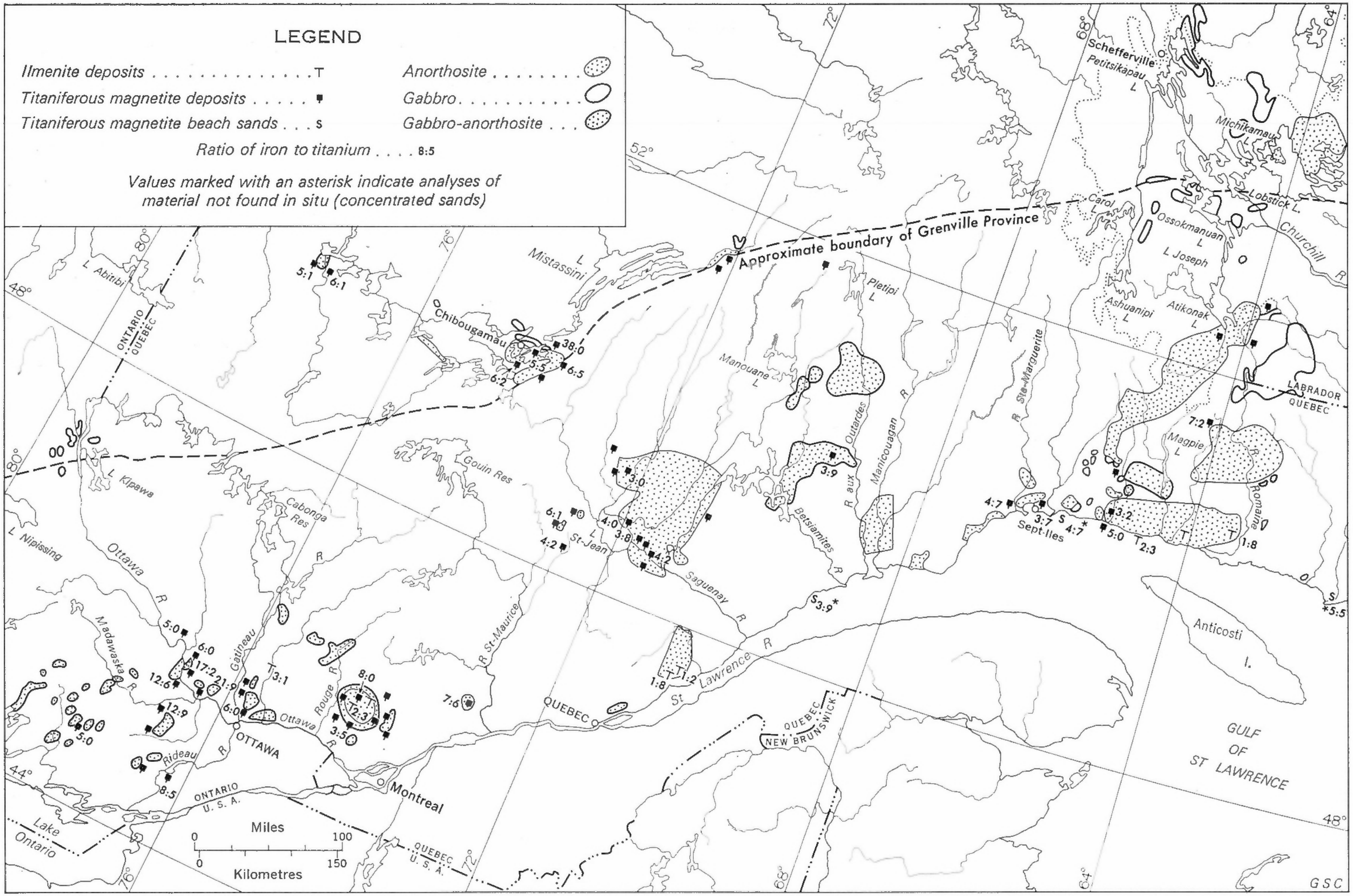

FIGURE 7. Iron/titanium ratios of titaniferous magnetite and ilmenite deposits of the Grenville Province.

have ratios of 5.0 to 3.2. One deposit on the northern margin of this body has a ratio of 4.3, about the same as deposits on the western margin, all are about the same distance from Allard Lake group of ilmenite deposits. Deposits associated with the gabbro anorthosite around Seven Islands Bay have Fe:Ti ratios of 3.7 to 4.7. A conspicuous trend in ratios from about 1.8, to 3.8, to 7.0 appears in deposits at St. Urbain, the Lake St. John area, and the Chibougamau area respectively. At St. Urbain Fe:Ti ratios for most of the ilmenite deposits are 1.8 and one has a ratio of 1.2. In the Lake St. John intrusion most of the ratios for titaniferous deposits are 3.8 with one deposit on the south edge having a ratio of 4.0 and one on the northwest having a ratio of 2.9. In a small body of gabbroic anorthosite southwest of Lake St. John, ratios vary between 5.74 and 6.2. In the Chibougamau intrusion information on titaniferous magnetite deposits indicates that they are much richer in iron, with a Fe:Ti ratio of about 7.0.

Deposits in the Morin anorthosite north of Montreal, consisting mainly of ilmenite, have Fe:Ti ratios of about 2.3 whereas ratios in the titaniferous magnetite deposits in the bordering gabbroic phases are about 7.7. A few magnetite occurrences in granite gneisses and metasediments near the Morin anorthosite, contain less than one per cent titanium but may be genetically related to this anorthosite–gabbro complex.

Iron-titanium ratios of deposits along Ottawa River and in eastern Ontario within or near gabbroic anorthosite–diorite intrusions range from 5.0 to 36.4 with most between 5.0 and 17.2. A great many skarn contact metasomatic or replacement occurrences are present which are thought to be genetically related to the anorthosite-gabbro suite of rocks and contain less than one per cent titanium.

Data are too sparse to draw conclusions about trends in Fe:Ti ratios in a northeast direction, except to note that from the Morin anorthosite southwest the ratios are generally higher than those northeast of it. These higher ratios coincide with areas of intrusions in which gabbroic and dioritic phases are much more abundant than anorthosite phases. The significance of these trends in the distribution of iron-titanium ratios is based on very limited data, and can be properly appraised only when more petrographic and analytical data are available.

Distribution of Iron Deposits along Ottawa River and in Eastern Ontario

The iron deposits in this area can be divided into two categories: titaniferous magnetite disseminated in or closely associated with gabbroic anorthosite and related dioritic intrusions, and magnetite deposits either as replacements associated with amphibole-pyroxene-epidote-garnet skarn zones or in veins in various host rocks. The trend or pattern of distribution of the deposits in the area north of Ottawa River is not so evident as that south of it, but the deposits are of similar type and follow the same geological controls. The distribution of deposits south of Ottawa River is shown on Figure 8 (*in pocket*), classification being based mainly on data given by Rose (1958). Many smaller occurrences not shown appear to follow the same distribution patterns.

Deposits appear to be grouped in two narrow belts elongated in a north-south direction. The first belt extends from Calumet Island to Kingston and is bounded on the east by Palaeozoic rocks. About thirty-five deposits occur along 15 miles of this belt. The second belt is mainly in Hastings county and extends from Bancroft to and under the Palaeozoic rocks in the south. About thirty-five occurrences in this belt are shown, and records indicate the existence of at least a similar number of smaller occurrences that have not been shown. A third belt with fewer deposits near the south boundary of Haliburton county follows the neartheast trend of the metasediments. Although the major deposits are found to lie in north-south trending belts, clusters of deposits within these belts occur in northeast-trending zones or zones that are coincident with structural lineaments.

The iron deposits occur in areas in which small intrusions of gabbroic anorthosite and diorite are also most abundant. Most are in areas underlain by metasedimentary or metavolcanic rocks and are rare in areas underlain by granite. Most of these deposits occur within crystalline limestone, or are closely associated with it. More specific detail on associated rock types and the nature of the occurrences is summarized in Table VII (*in pocket*) and Figure 8.

Rose (1958) concluded from his study of the distribution of minor elements in these deposits that the average amounts of these elements in the ores compared more closely with their distribution in gabbros than with that in granites. He suggested that the magnetite deposits were derived by differentiation from a magma perhaps slightly less mafic than gabbro, and he found that the distribution of ferride elements in both titanium-rich and titanium-poor deposits and in pyrite deposits supported this view. Probably many of the magnetite deposits were derived from the same magma source that produced the gabbro, anorthosite, diorite, and syenite bodies.

The chemical characteristics of deposits and their location would depend to a great extent on the distance from the source magma and the stage or degree to which differentiation had progressed. The position of final emplacement of this oxide material would depend on the chemical environment in the host rocks and on the presence of suitable structural channels or traps. It has also been noted that deposits farther away from basic intrusions have less titanium than deposits near to or within these rocks. The spatial relationship between iron deposits and gabbroic rocks in this area is well established and suggests a genetic relationship between the two. A small number of deposits may be produced by the differentiation of acidic phases of this same igneous suite. A few other deposits may be genetically related to other granite intrusions. Giblin (1960) has questioned the conclusion that skarn deposits are genetically related to the suite of gabbro-diorite intrusions and has presented good evidence for believing that deposits in Mayo township, including the Rankin, Childs, and Bessemer, are genetically related to a large tonalite body. The tonalite may, however, be itself part of the gabbro-diorite-syenite suite.

In conclusion then, most of the magnetite deposits are of the skarn type and are abundant near gabbroic intrusions. They appear to be more numerous in amphibole-chlorite schists or gneisses high in mafic constituents than in granitic rocks. Magnetite-ilmenite deposits occur mainly in gabbroic anorthosite and consist of layered zones containing disseminated magnetite and ilmenite, massive dykes, and injection bodies.

Description of Iron Deposits

Iron Deposits Associated Directly with Plutonic Rocks

Except for the iron-formations, the iron-titanium deposits of this group constitute the largest concentrations of iron in the Grenville Province, but because of their composition and texture they have not yet been successfully worked for iron ore. They are however mined and processed in Canada as ores of titanium oxide and titanium, and appreciable metallic iron is recovered as a by-product. Deposits of this association have titanium intimately mixed with the iron oxides and are therefore unsuitable as a source of ore for normal blast furnace operation. Processes have now been developed, however, that may enable this type of material to be smelted economically for the recovery of iron, and a number of titaniferous magnetite occurrences can therefore be regarded as potential iron ore. A few of the larger and better known deposits are described briefly.

Allard Lake Ilmenite Deposits, Saguenay County, Quebec (*8*)[1]

At least six ilmenite deposits ranging in size from one million to 100 million tons and numerous smaller occurrences lie in a 5-to-10-mile area between Allard Lake and Puyjalon Lake in Saguenay county, Quebec. The largest of these deposits, the Lac Tio, is about 25 miles north of Havre–St-Pierre, on the north shore of the Gulf of St. Lawrence, and is considered to be the largest deposit of its kind in the world.

Ilmenite occurrences in this area were first examined by Retty (1944) in the course of reconnaissance in 1941 for the Quebec Department of Mines. Subsequently claims were staked by private interests and optioned by Kennco Explorations, Limited, who carried out an exploration program in the area in 1946. The Lac Tio and several other large deposits were discovered in the course of this work, and drilling and development were started immediately. Exploration consisted of systematic traversing across the anorthosite mass at quarter-mile intervals to record geological information, and dip-needle readings were obtained as a routine part of the exploration. An airborne magnetometer survey was made in 1947 over a 1,000-square-mile area but, even though the ilmenite bodies gave strong negative anomalies, it did not reveal any new deposits. Known occurrences and some geological boundaries were however clearly indicated. The Quebec Iron and Titanium Corporation, owned by Kennecott Copper Corporation and The New Jersey Zinc Company, was formed to operate the mine, and the smelter was established at Sorel, Quebec. Construction of a railway from the docksite at the village of Havre–St-Pierre to the mine was started in 1948 and the first ore was shipped to Sorel in 1950.

Production has been more or less continuous since that time with periodic closures for various reasons. The ore is smelted in electric furnaces at Sorel, and titanium dioxide and several grades of pig iron are produced. More than 217,000 tons of titanium slag and 145,000 tons of iron were produced in 1959, and facilities

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[1] Numbers in brackets after deposit names refer to locations on Figures 6 and 8 and to lists of deposits Appendix III.

are being enlarged to increase annual production to more than 400,000 tons of titanium oxide slag and 200,000 tons of iron.

Geological Setting

The ilmenite deposits of the Allard Lake area occur within a large oval-shaped anorthosite intrusion, 2 to 15 miles from its east border. This intrusion underlies a 2,000-square-mile area, and extends west of Romaine River for about 100 miles. The anorthosite is composed of several rock types ranging from almost pure plagioclase anorthosite to gabbroic anorthosite, norite, ilmenite-rich anorthosite, and gabbro.

Anorthosite with less than 5 per cent mafic minerals is the most abundant variety; it is medium to coarse grained, porphyritic in places, and varies from light to dark grey, pinkish to brown, or even greenish brown. Most of it is massive but banding or foliation occurs in some places. Protoclastic texture is present in much of the rock. The coarse plagioclase crystals show evidence of strain, of being bent or distorted and granulated around their borders, and are surrounded by finer grained feldspar and mafic minerals that have recrystallized after the coarse plagioclase. The texture indicates that the rock was crushed or subjected to stress during the late stages of its crystallization, before all of the material was crystalline, or that it was deformed subsequent to consolidation and the matrix material only recrystallized. The composition of the plagioclase ranges from An_{40} to An_{52} and the mafic minerals consist mainly of hypersthene with minor augite, ilmenite, amphibole, and biotite.

Noritic and mafic phases appear to be more common in the eastern parts of the intrusive mass. They are commonly banded or foliated and some form dykes or sills that intrude the anorthosite. Gabbro and diorite dykes cut gneisses and granitic rocks adjacent to anorthosite.

The border zones between anorthosite and the host gneisses consist of a group of hypersthene-bearing hybrid rocks, which include altered phases of anorthosite as well as various dykes of syenite, granite, and pegmatite. These dykes cut the gabbro and anorthosite but pegmatite dykes, some of which are zones, cut anorthosite, massive ilmenite, and granite and appear therefore to be the youngest intrusions in the region.

The *ilmenite-magnetite norite* phase of the anorthosite complex appears in elongated to lenticular sheets which dip steeply east and have fairly sharp contacts with the anorthosite. Discordant features suggest that the norite was intruded during a late stage in the consolidation of the anorthosite mass. Norite bodies up to half a mile wide and several miles long occur east of Lac Ellen, a mile east of the railroad at mile 18, along the eastern shore of Allard Lake, and in other parts of the area. Medium-grained granular norite near Lac Ellen is composed of plagioclase and 50 to 60 per cent mafic material made up of hypersthene, apatite, ilmenite, and magnetite. The iron titanium oxides are interstitial to the other minerals and make up 30 per cent of the rock. Most of the noritic phases are banded or gneissic, and oxides are more abundant in the lower parts of the bands than in the upper. The composition and texture is highly variable. Grain size ranges from 1 to 20 mm, and banding is formed by differences in relative proportions of major constituents.

Hargraves (1962) described this rock in some detail and noted that ilmenite is the predominant oxide but that magnetite may be present in nearly equal proportions in some parts. Both minerals occur as clusters of discrete grains. The ilmenite grains contain exsolved lamellae of hematite but magnetite grains appear to be homogeneous. Hargraves determined that the magnetite contained 0.75 to 3.3 per cent TiO_2 in solid solution. In general, where the magnetite content decreases the hematite content increases, and this relationship is considered to reflect variations in oxygen partial pressure during cooling of the magma. About 8 to 10 per cent of fluorapatite is present with the oxide portions and the amount appears to be independent of variations in the amounts of the other minerals.

Faults. Numerous north- to northeast-striking, steeply dipping or vertical normal faults occur throughout the region.

Description of Ilmenite Deposits

Ilmenite deposits clustered in the eastern part of the anorthosite complex occur as massive, medium- to coarse-grained dykes, sills, lenses, or irregular bodies. The largest and best known deposit, the Lac Tio, illustrates many typical features.

The Lac Tio deposit. The main deposit is an irregular tabular mass, 3,600 feet long, 3,400 feet wide, and up to 300 feet thick. Topographic relief over this deposit exceeds 400 feet. A north-trending valley divides the deposit and follows a major fault zone that dips steeply and strikes north. The eastern part of the ore deposit is down faulted about 300 feet relative to the western part (Pl. III). Hammond (1952) stated that:

> . . . west of the fault, the ore occurs as a thin, flat-lying body, from 25 to 200 feet thick, with a flat dip west. Near the top of the hills the ilmenite dips flatly under a ridge of anorthosite. Again, 1,200 feet farther west, and at the same elevation, ilmenite outcrops are exposed over a length of 2,600 feet and a width varying from 25 to 350 feet. It would appear that this deposit represents a flat-lying western extension of the main orebody.
>
> East of the fault separating the east and west sections of the main orebody, diamond drilling results suggest a basin-like or synclinal attitude, with the deepest ore occurring below the low ground where the bottom of the orebody has not yet been established.

Gross, 2-6-57

PLATE III. Southeast part of Lac Tio ilmenite deposit and open-cut mine at Allard Lake, Saguenay county, Quebec.

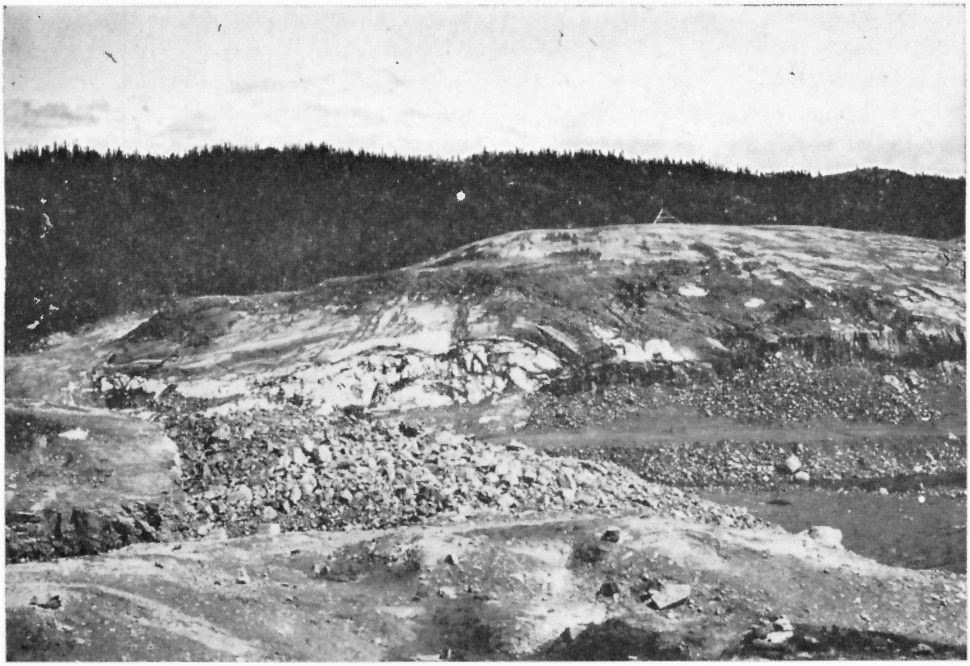

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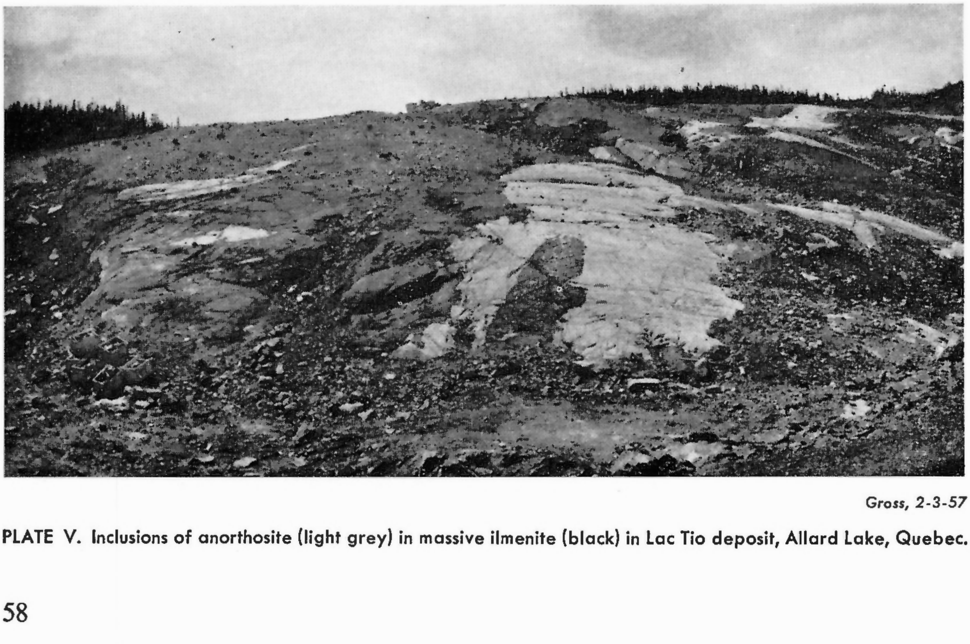
PLATE IV. Irregular dyke of ilmenite (black) in anorthosite, northeast side of Lac Tio deposit, Allard Lake, Quebec.



Gross, 2-3-57

PLATE V. Inclusions of anorthosite (light grey) in massive ilmenite (black) in Lac Tio deposit, Allard Lake, Quebec.

PLATE VI

Massive and disseminated ilmenite (black) in anorthosite.

112341

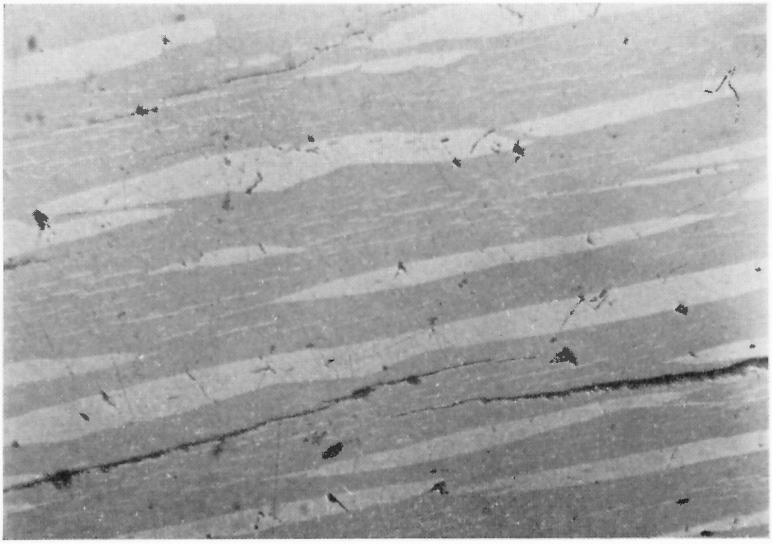
PLATE VII

Coarse-grained ilmenite, Lac Tio deposit, Allard Lake, Quebec.

Gross, 2-7-57

PLATE VIII

Photomicrograph showing hematite (light grey) exsolved from ilmenite (dark grey) Lac Tio deposit, Allard Lake, Quebec.



Inclusions or xenoliths of anorthosite, ranging from a single feldspar crystal to angular and irregular masses tens of feet in size, are common and are more numerous near the borders of the deposit (Pl. V). Surface examination creates the impression that the orebody consists of a complex interconnected maze of sills and dykes of ilmenite. Vertical or nearly vertical boundaries of the massive ore are usually very sharp and well defined but horizontal boundaries are more commonly irregular and indistinct. Massive ore grades to crudely banded disseminated ore and this to anorthosite along many ore boundaries (Pl. VI). Small stringers and dykes of massive ilmenite extend from the main body through the marginal zone and into the anorthosite (Pl. IV).

Massive ilmenite ore consists of 88 to 97 per cent combined iron and titanium oxide. It is coarse grained, dull black to brownish black, and has a glistening jet black surface where freshly broken. Ilmenite crystals are fairly uniform in size in local patchy areas measuring tens of feet in diameter but the grain size in various parts of the deposit ranges from $\frac{1}{4}$ to $\frac{3}{4}$ inch (Pl. VII). The ore breaks with a knobby irregular surface, and individual grains can be crumbled from the surface in many parts of the deposit. The ore close to fault zones in other parts of the deposit is dense, finer grained, and extremely hard. The ore minerals are remarkably uniform in composition. The ilmenite grains contain microscopic blades of exsolved hematite, which constitutes about 15 per cent of the ore (Pl. VIII). A very small amount of magnetite has been reported, and pyrite, pyrrhotite, and chalcopyrite form veins or interstitial fillings around oxide mineral grains.

The ore averages 32 per cent TiO_2 and 36 per cent Fe, and the iron titanium ratio throughout the orebody is remarkably uniform. Because of this the grade of ore can be estimated to within 2 per cent from its specific gravity, which ranges from 4.46 to 4.9. Analyses reported by Hammond (1949) are given in Table VIII.

Table VIII

Analyses of Allard Lake Ilmenite
(25-foot sections of drill-core)

TiO_2	Fe	S	P_2O_5	Cu	V	Mn	Ni	Co
34.1	41.1	0.99	0.004	0.037	0.21	0.09	0.03	0.013
34.8	38.8	0.36	0.010	0.12	0.22	0.08	0.03	0.014
36.0	42.8	0.40	0.012	0.14	0.21	0.08	0.01	0.013
34.4	39.1	0.39		0.07	0.21	0.10	0.02	0.019

Hatch and Cuke (1956) give the following analysis for typical ilmenite-hematite ore:

	Per cent		Per cent
TiO_2	35.0	MnO	0.17
Fe	40.2	V_2O_5	0.30
FeO	28.3	Na_2O	0.30
Fe_2O_3	26.2	Cr_2O_3	0.10
CaO	0.8	S	0.28
MgO	3.2	P_2O_5	0.015
Al_2O_3	3.1	Cu	0.02
SiO_2	3.7	Ni	0.03

The Cliff deposit. This deposit, west of Lac Tio, is elliptical, about 1,240 feet long and 740 feet wide, and averages 200 feet in thickness. The bottom of the orebody dips east and has a uniform sharp contact with anorthosite at the base. The orebody is reported (Hammond, 1949) to thin and pinch out to the west under anorthosite, and to contain approximately 12 million short tons of ore of approximately the same grade as the Lac Tio orebody.

Lac Ellen deposit. The band of low grade ilmenite-magnetite norite 2 miles long that extends south from the east side of Lac Ellen has already been described.

A massive high grade ilmenite deposit at the north end of Lac Ellen was examined and is of interest because of its funnel shape and excellent vertical exposure. A cross-section of the deposit may be seen on a south-facing cliff about 150 feet high. The sides of the deposit are in sharp contact with anorthosite and both dip about 70 degrees, the west side dipping east and the east side dipping west. The deposit is about 100 feet wide at the top of the cliff and extends north for at least 200 feet. It is cut off by a fault at the cliff face. Anorthosite is exposed in the creek bed to the northeast at the base of the cliff, and the cliff, lake shore, and valley form a strong east-trending lineament that marks the fault zone that cuts the ilmenite body. This deposit is mineralogically and physically like the Lac Tio deposit.

Grader deposit. About 150,000 tons of ilmenite was mined from this deposit in 1950 during the early stages of development in the area. It is 25.5 miles north of Havre–St-Pierre on the east side of the railroad, and exposures indicate that it is at least 200 feet wide and 400 feet long. It is an injected mass in sharp contact with anorthosite and is similar in mineralogy and grade to the Lac Tio deposit. A finer grained anorthosite dyke, one inch thick, cuts the massive ilmenite, which indicates that there are late stage intrusions of anorthosite in the complex succession of igneous events related to these occurrences.

Origin of the Ilmenite Deposits

Massive ilmenite bodies are obviously intruded into the anorthosite and gabbro in many places. In other places, especially in the banded phases, discordant relationships are not apparent but entire masses of gabbro and iron-titanium oxide may be intrusions. The consistent association throughout the world of ilmenite-magnetite-hematite masses with gabbro or gabbroic anorthosite and the occurrence of iron-titanium oxides in all stages of concentration, ranging from interstitial to layered to injected masses, in a single deposit leave no doubt about the genetic relationship of the anorthosite and iron-titanium oxides (*see* Gross, 1965, vol. I, pp. 59-63). The plagioclase evidently crystallized first and as this took place mafic material accumulated in the remaining magma. Iron-magnesium silicates would be expected to crystallize when the eutectic point was reached in the magma and a late stage melt rich in iron and titanium oxide would be left. This oxide melt is believed to have been separated from the anorthosite material by downward settling due to its greater specific gravity. Any structural deformation that took place at this stage would cause further concentration by filter pressing and injection of the oxide melt into fractures or lower pressure areas in surrounding crystalline anorthosite or country rocks.

Hargraves (1962) points out that isolated massive ilmenite deposits occur below sheets of norite rich in oxides or are in circumstances that suggest that they were once covered by norite. He also notes that the Fe:Ti ratio is the same in the disseminated oxides in the norite as in the injected isolated masses. These features are to be expected if the above concept of genesis is correct.

St. Urbain Ilmenite Deposits, Charlevoix County, Quebec (35)

Ilmenite deposits were discovered in this area as early as 1666 and an attempt was made between 1872 and 1874 to produce pig iron by smelting with charcoal. Prior to the development of the Allard Lake deposits most of Canada's ilmenite came from this area. Production has been more or less continuous since 1908 and, since that date, Continental Iron and Titanium Mining Limited (now Continental Titanium Corp.) which was incorporated in 1955, has acquired most of the interesting land in the St. Urbain area. They have carried out a large diamond-drilling and development program since 1955 and have completed considerable metallurgical test work. The company has indicated that about 20 million tons of ore has been proven in the five main deposits, the Furnace, General Electric, Coulombe East, Coulombe West, and Bignell, which averages 40 to 45 per cent titanium dioxide and 35 to 40 per cent iron.

Seven deposits of ilmenite lie within a half mile radius of a point situated about 1½ miles southwest of the village of St. Urbain and about 7 miles north of the village of Baie-St-Paul, on the north shore of the St. Lawrence River about 60 miles northeast of Quebec City.

Geology

The main group of deposits is about 3 miles from the southwest border of an oval-shaped anorthosite-diorite mass 20 miles long and about 10 miles wide. The core of this mass consists of labradorite–anorthosite and underlies an area 4 by 7 miles. A few small ilmenite occurrences in its central part lie east of Lake Ontario. The remainder of the anorthosite mass is composed of andesine–anorthosite and contains the main group of deposits. The anorthosite is bordered almost completely by intrusive masses, 2 to 3 miles wide, which range in composition from diorite and quartz-diorite to syenite and granite. Mawdsley (1927) indicated that these rocks are most probably genetically related to the anorthositic phases but that lack of critical exposure has prevented direct examination of their relationships.

Description of Ilmenite Deposits

Some ilmenite deposits, like the Coulombe orebody, are east-trending dyke-like masses up to 100 feet wide, others are nearly flat-lying lenticular masses like the Furnace deposit. The General Electric deposit contains about 5 million tons of ilmenite and is very similar in character to the Allard Lake deposits. The massive black dykes and lenses of ore are composed of ilmenite that contains 15 to 20 per cent hematite, in the form of exsolved blades up to 0.2 mm wide. Karpoff (1953) reported analyses of two 3,000-ton composite ore samples from this area (*see* Table IX), and quoted a third analysis from work by C. H. Warren.

Table IX
Analyses of Ilmenite Ore from the St. Urbain Deposits, Quebec

	I	II		III	
TiO_2	41.95	38.70		40.00	
Fe_2O_3	18.64	18.64		20.35	
FeO	29.30	28.66		29.57	
SiO_2	2.56	4.27		1.91	
Al_2O_3	2.70	4.00	9.96 to 13.57	4.00	10.08
MgO	4.30	4.80		3.17	
CaO	0.40	0.50		1.00	
MnO_2	0.10	0.12			
Na_2O	0.01	0.05			
P_2O_5	—	—			
V_2O_5	0.18	0.16			
Cr_2O_5	0.20	0.08			
NiO_3	0.10	0.10			
MnO	—	—			
ZnO	—	—			
B_2O_3	Tr	Tr			
CuO	0.01	0.04			
SnO_2	—	—			
BaO	0.001	0.01			
Pb	—	—			
Sb_2O_5	0.002	0.002			
	100.453	100.132			

Samples I and II each 3,000-ton composite sample of ilmenite; III analyses quoted from Warren (Karpoff, 1953).

A zone about 2 feet wide that contains 5 to 20 per cent rutile in ilmenite forms a vein-like mass in the General Electric deposit. Rutile was also seen in small veins that cut the adjacent anorthosite. The rutile is present in one millimetre or finer grains, and the ilmenite in 3 to 5 mm grains. According to a company report, the TiO_2 content of the vein zone ranges from 42.49 to 51.59 per cent, the iron ranges from 28.43 to 35.64 per cent, and the rutile from 2.80 to 18.64 per cent. Karpoff (1953) noted that up to 10 per cent by volume of rutile is present locally in some of the ilmenite deposits. Calcite veins a few inches thick cut some deposits.

Ilmenite and Titaniferous Magnetite Deposits in the Morin Anorthosite, Terrebonne County, Quebec

A large number of deposits composed of ilmenite-hematite, ilmenite-magnetite, and other titaniferous magnetite complexes are associated with this anorthosite body. A small amount of ilmenite has been shipped from a deposit near Ivry and a great deal of exploration and metallurgical test work has been carried out to evaluate the deposits as both iron and titanium ores.

Geology

The Morin anorthosite complex underlies a circular area about 30 miles in diameter centred near the town of Ste-Agathe-des-Monts, 50 miles northeast of Montreal. Another crescent-shaped anorthositic intrusion 5 to 6 miles wide and more than 25 miles long lies about 5 miles east of the main circular mass. The Morin mass is composed of an interrelated complex suite of anorthosite, gabbroic anorthosite, quartz monzonite, syenite, and granitic rocks, all considered to be derived from a single parent source. The central part is composed of anorthosite surrounded by a border of gabbroic anorthosite 2 miles wide. Several other large bodies of gabbroic anorthosite occur within the central and eastern part of the central anorthosite mass. Large masses of monzonite, syenite, and granite are present on the borders of this gabbroic anorthosite ring, which in places appear to grade into gabbro, which in turn grades into anorthosite. All the related rocks of this unit are intruded into gneisses, schists, quartzites, meta-limestones, and other metasediments of the Grenville Series.

Description of Iron-Titanium Deposits

Rose (1960) summarized the distribution of major rock types and of the various types of iron-titanium deposits that occur within them, and gave brief descriptions of the deposits. Nearly all the deposits of ilmenite with exsolved hematite occur in the anorthosite phase. Titaniferous magnetite deposits, composed of magnetite with exsolved ilmenite and aggregates of discrete grains of ilmenite, and titanium bearing magnetite, are present exclusively in the gabbroic phases. A magnetite deposit in the quartz monzonite contains a very small amount of titanium, and other magnetite deposits in the area that may be genetically related to the anorthosite-gabbro-syenite suite but are in metasediments are practically free of titanium.

There is a decidedly greater concentration of iron and titanium oxide minerals in the gabbroic phases than in other phases of this suite. These are distributed both as disseminated grains in the gabbro, where in places they make up more than 20 per cent of the rock, and as small dykes and injections of massive magnetite or ilmenite. The iron-titanium ratio is much lower in deposits in anorthosite, where ilmenite is the principal mineral, and is considerably higher in magnetite-ilmenite deposits in the gabbroic phases. Deposits in this massif are similar in most of their characteristics to deposits already described at Allard Lake but, as is to be expected with greater amounts of gabbro present, titaniferous magnetite deposits predominate. Small amounts of sulphide minerals, mainly pyrite, chalcopyrite, or nickeliferous pyrrhotite, are present with the iron-titanium oxide minerals. Large zones consisting of discrete ilmenite grains mixed with titaniferous magnetite permit separation of the bulk of the titanium from the ore by fine grinding and high intensity magnetic methods. Less than one per cent TiO_2 remains in some of the magnetite concentrate. Information from Rose (1960) and McGerrigle (1959) is summarized for a few occurrences.

Wexford Township (47). A zone 2 to 3 miles wide composed predominantly of gabbroic anorthosite, extends north from the village of St. Hippolyte for about 7 miles to the edge of Lake Masson. Ilmenite-hematite occurrences with disseminated titaniferous magnetite are present in a narrower belt of foliated medium-grained gabbroic anorthosite about 1,000 feet wide and 6 miles long. The ilmenite-hematite occurrences consist of numerous massive lenses a few inches wide that dip steeply and strike north. Laurentian Titanium Mines Ltd. has located one zone, beginning about 1,000 feet north of Lac Pin Rouge, that is reported to contain 15 million tons of ilmenite-hematite that averages 19.9 per cent TiO_2 and 27.6 per cent iron to a depth of 225 feet. Two other lower grade zones in this belt were drilled by this company, one north of Lac Pin Rouge and one south of it. The average analysis for the hole in the northern zone showed 18.62 per cent iron and 6.26 per cent TiO_2, and this information together with surface sampling indicated more than 28 million tons of potential ore averaging 20.11 per cent iron and 6.95 per cent TiO_2. A drill-hole in the south area that showed an average of 24.07 per cent iron and 9.08 per cent titanium oxide and surface samples indicated another potential ore deposit of more than 17 million tons averaging 23.52 per cent iron and 7.59 per cent TiO_2.

Tamara Mining Ltd. and Drummond Copper Corporation Ltd. hold ground in the northern part of this belt southwest of Thomson Lake where occurrences of titaniferous magnetite in gabbroic anorthosite are stated to have 230 million tons of potential ore averaging 20 to 23 per cent iron and 6 per cent TiO_2.

Concentrates containing 67 per cent iron, with less than one per cent titanium and 2.8 per cent silica, have been produced from this low grade material in Wexford township by grinding the crude ore to −150 mesh and removing ilmenite by magnetic separation.

***Beresford Township, Ivry Deposit* (45).** This deposit of massive, coarse-grained ilmenite is about 1½ miles west of Ivry station on lots 36 and 39 of range V. It forms a dyke at least 60 feet wide and over 750 feet long, which cuts dark coloured anorthosite. A trench 50 feet wide, 130 feet long, and 45 feet deep has been cut into the deposit. Numerous inclusions of anorthosite are present in this lens-shaped dyke that strikes northwest. Hematite blades are exsolved in the ilmenite grains and ilmenite grains are intergrown with dark green spinel, plagioclase, pyroxene, amphibole, mica, and apatite. This mineral aggregate is cut by veinlets of pyrite, pyrrhotite, and chalcopyrite. Analyses of Ivry ilmenite are given below, I from Robinson (1922), and II from Waddington (1960):

I		II	
Ti	19.84	TiO_2	33.23
Fe	42.98	Fe	42.75
SiO_2	—	SiO_2	7.54
P	0.076	—	0.036
S	0.144	—	0.010
V_2O_3	0.04	—	—
Cr_2O_3	0.08	—	—
Ni	Nil	—	—

***Desgrosbois Township* (45).** A large zone rich in titaniferous magnetite and ilmenite is present in gabbro-anorthosite about a mile north of the Ivry deposit and west of Desgrosbois railway station. The gabbroic anorthosite shows some banding and is crushed and mixed with anorthosite. The oxide minerals, mixed with pyroxene and apatite, are largely present in the groundmass around the breccia fragments.

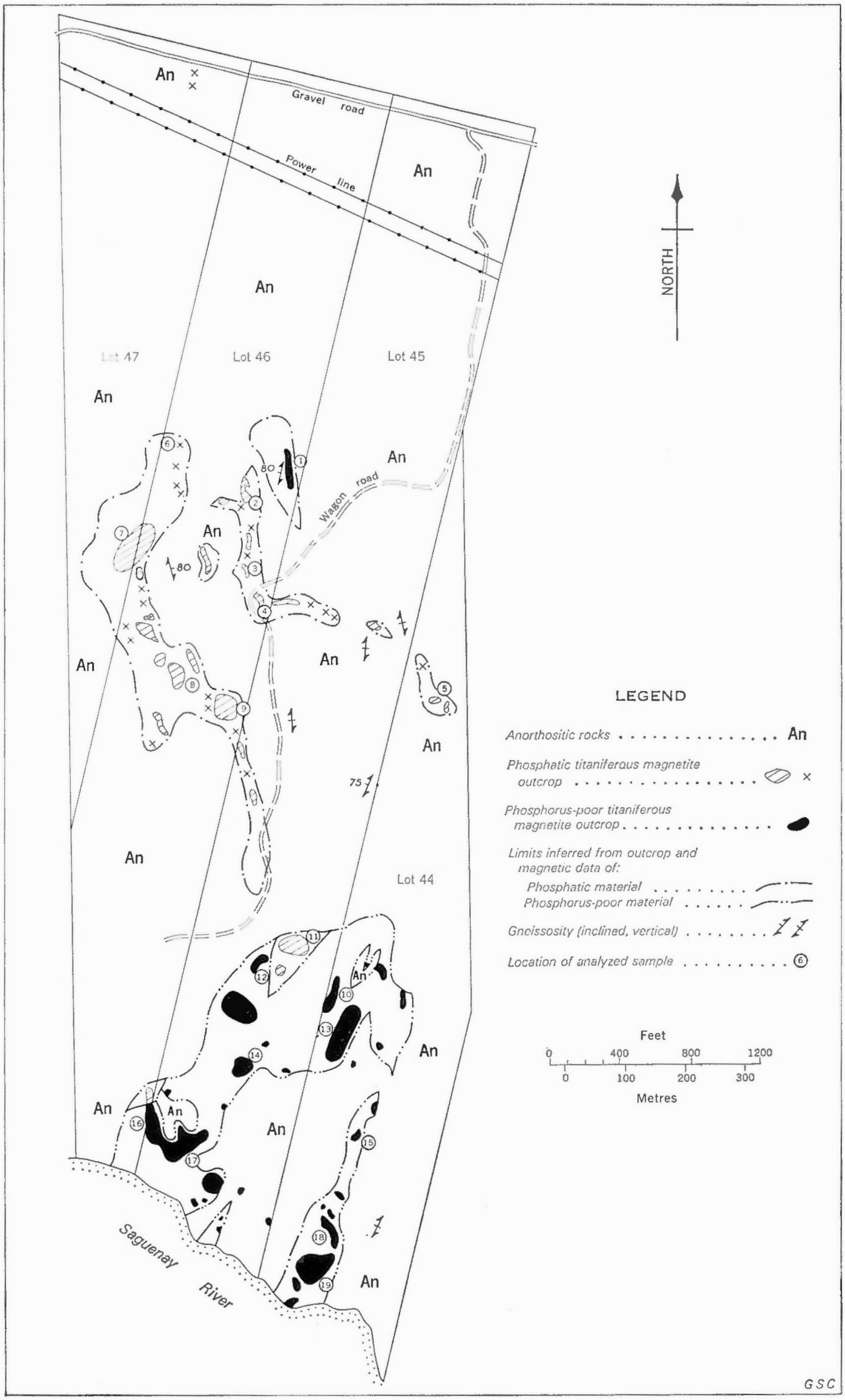


FIGURE 9. St. Charles titaniferous magnetite deposits and distribution of phosphatic and phosphorus-poor material in anorthositic rocks, Bourget township, Quebec (data from R. F. Jooste, 1958).

Wolfe Township (*48*). Rose (1960) reported a zone more than 1,200 feet long and 200 feet wide of gabbroic anorthosite with disseminated ilmenite exposed in the road about a mile south of St. Faustin.

Abercromby Township (*49*). A zone in quartz monzonite, 2½ miles west of St. Jérome, is reported to be about 15 feet wide and 1,100 feet long and contains numerous veins and lenses of magnetite up to 3 feet thick. Analyses of two channel samples showed respectively: 61.29 and 55.43 per cent iron, 0.33 and 0.58 per cent titanium, and 0.02 and 0.02 per cent vanadium (McGerrigle, 1950).

Titaniferous Magnetite Deposits in the Saguenay and Lake St. John Anorthosite

Titaniferous magnetite deposits are associated with a very large composite mass of anorthosite, gabbro, and related rocks that underlies an area of 5,000 square miles and extends northeast from Lake St. John and the Saguenay River for more than 100 miles. This mass is composed of a great variety of igneous rocks that are considered to be genetically related but form a composite of many separate intrusive bodies. Anorthosite and gabbroic anorthosite are the most abundant, and different phases of these rocks are gradational in local areas. The gabbro-anorthosite group is intruded by pyroxene diorite and anorthositic troctolite, and younger intrusions including syenite-monzonite, quartz syenite, and granite, cut these in turn. Much of the area has been covered by reconnaissance mapping only, and the distribution of the various rock types in this composite intrusion is imperfectly known. Most of the titaniferous magnetite deposits discovered so far occur in the southern part of this intrusive complex, but other parts of it have not been fully explored.

Saint Charles Titaniferous Magnetite Deposits, Bourget Township, Chicoutimi County (19)

The Saint Charles deposit consists of a number of lenticular and dyke-like masses of titaniferous magnetite on the north shore of Saguenay River 15 miles downstream from Lake St. John. The oxide masses range from 100 to more than 1,000 feet in length and trend north parallel with the banding in the enclosing gabbroic-anorthosite. The anorthosite varies from massive, coarse-grained varieties to medium-grained, gabbroic material rich in oxides, olivine, pyroxene, hornblende, and biotite. The anorthosite rocks are cut by fine-grained, dark grey gabbro-diorite dykes, composed of 55 per cent plagioclase (An_{48}), 30 per cent pyroxene, 10 per cent hornblende, and 5 per cent opaque grains. Inclusions of these dyke rocks are found in the titaniferous magnetite dykes, and Robinson (1926) noted that the magnetite in the dyke rocks is almost non-titaniferous. Three analyses given by Robinson are of interest:

	Fe	Ti	P
Coarse-grained magnetite	48.18	13.45	0.404
Fine-grained impure magnetite	33.77	7.44	3.85
Dyke rock	19.25	0.30	0.027

Pink granodiorite dykes are present in the area, and pegmatite dykes cut the magnetite masses.

Table X

Analyses of Saint Charles Titaniferous Magnetites

Locality	1*	2†	3†	4†	5†	6†	7†	8†	9†	10†	11†	12*	13*	14*	14‡*	15*	16*	17*	18*	19*
Fe	40.23	38.40	33.32	37.60	45.43	37.15	35.38	33.27	35.30	43.94	33.95	41.29	39.81	47.45	49.37	52.17	47.57	48.13	47.20	46.75
TiO_2	13.35	17.14	13.38	16.29	20.72	15.19	14.40	12.30	12.29	18.74	11.94	17.92	13.35	20.90		21.87	22.04	20.04	18.57	17.95
SiO_2	13.06	1.91	15.11	5.15	2.11	6.80	4.27	7.19	6.31	4.88					2.12					
Al_2O_3	6.37	10.25	7.56	6.14	4.60	2.52	4.40	4.67	5.32	7.03					5.91					
CaO	0.21	7.65	6.71	7.55	3.39	9.51	13.31	13.76	12.14	3.23					0.16					
MgO	11.35	2.35	6.84	4.48	4.73	7.51	5.24	6.88	5.59	4.07					3.26					
P	0.03	3.12	2.06	3.19	1.31	3.35	4.45	4.43	4.54	1.00	1.45	0.00	0.00	0.02	0.13	0.00	0.09	0.005	0.00	0.03
S	0.05	0.07	0.04	0.07	0.07	0.11	0.18	0.08	0.06	0.03										
V	0.11	0.10	0.09	0.09	0.14	0.09	0.08	0.06	0.07	0.03	0.23	0.25	0.27	0.26	0.22	0.25	0.25	0.25	0.22	0.24
F		0.32	0.16	0.29	0.00	0.19	0.33	0.46	0.37											
Cl		0.04	0.03	0.01	0.02	0.04	0.04	0.02	0.04											
Fe/Ti	5.07	3.74	4.15	3.86	3.66	4.08	4.09	4.51	4.79	3.90	4.74	3.84	4.97	3.79	—	3.96	3.59	4.00	4.24	4.35

Sample locations shown on Figure 4

* Phosphorus — Poor

† Phosphatic

‡ Bulk Sample (600 lbs)

Data from Jooste, 1958

Waddington (1960) described the area of the Saint Charles deposit as follows:

> Lenticular bodies of titaniferous magnetite are irregularly distributed in medium-grained anorthosite, mainly over an area 6,000 feet long by 1,200 feet wide in lots 44 to 47. The average tenor of 56 samples, from 21 different localities in this zone, is 42.78 per cent iron and 16.47 per cent titanium dioxide. The largest outcrop has an area of 13,000 square feet, with no contacts exposed. Its average tenor is 40.23 per cent iron, 13.35 per cent titanium dioxide, 13.06 per cent silica, 6.37 per cent alumina, 0.21 per cent lime, 11.35 per cent magnesia, 0.03 per cent phosphorus and 0.05 per cent sulphur. Two types of magnetite, phosphatic and phosphorus poor, were noted. The phosphatic type contains 5 to 30 per cent apatite by volume, whereas the phosphorus poor type contains less than 5 per cent apatite.

The phosphorus-poor types of magnetite are generally coarser grained and are distributed mainly in the southern part of the area. Osborne (1944) stated that the mineralogy and texture of the oxide rich masses vary considerably even within individual masses, and noted that spinel is everywhere present with ilmenite and magnetite. Ilmenite is present in amounts up to 10 per cent in discrete grains as well as in exsolved blades of very different sizes in magnetite. Iron-rich olivine (40 per cent Fe_2SiO_4), pyroxene, hornblende, and biotite are present, and colourless to greenish apatite may be present in amounts up to 30 per cent by volume in 5 mm or finer grains. The general distribution of the phosphorus-rich and phosphorus-poor titaniferous magnetite occurrences is shown in Figure 9 together with the location of samples for which analyses are given in Table X (data from Jooste, 1958). Other deposits in this area are mainly small, dyke-like masses but similar in most respects to the masses in the Saint Charles deposit.

Kenogami Township, Chicoutimi County (20)

A number of small dykes of massive titaniferous magnetite and several zones of disseminated magnetite were examined in this area. Waddington mentioned one zone on lot 46, a sample from which assayed 44.08 per cent iron, 16.73 per cent titanium dioxide, 9.07 per cent silica, 6.05 per cent alumina, 0.19 per cent lime, 0.05 per cent phosphorus, and 0.10 per cent sulphur.

Three hundred tons of ore was reported to have been shipped in 1901 from an exposure area between the highway and the railway track on lots 32 to 33, range IV, 9 miles west of Jonquière. Samples from one zone about 35 feet wide and 1,000 feet long, composed of numerous veins and stringers of magnetite in anorthosite, assayed 39.99 per cent Fe and 18.38 per cent TiO_2. Another zone, about 75 feet to the north contains massive magnetite over a width of 8 feet, which is bounded by disseminated magnetite in anorthosite. Chip samples from this zone were reported to contain 9.81 per cent iron and 4.41 per cent TiO_2 for a width of 15 feet on one side, 24.55 per cent iron and 11.93 per cent TiO_2 for the central 8 feet, and 11.10 per cent iron and 5.32 per cent TiO_2 for the adjacent 10 feet (Dept. Mines, Que., PR No. 330).

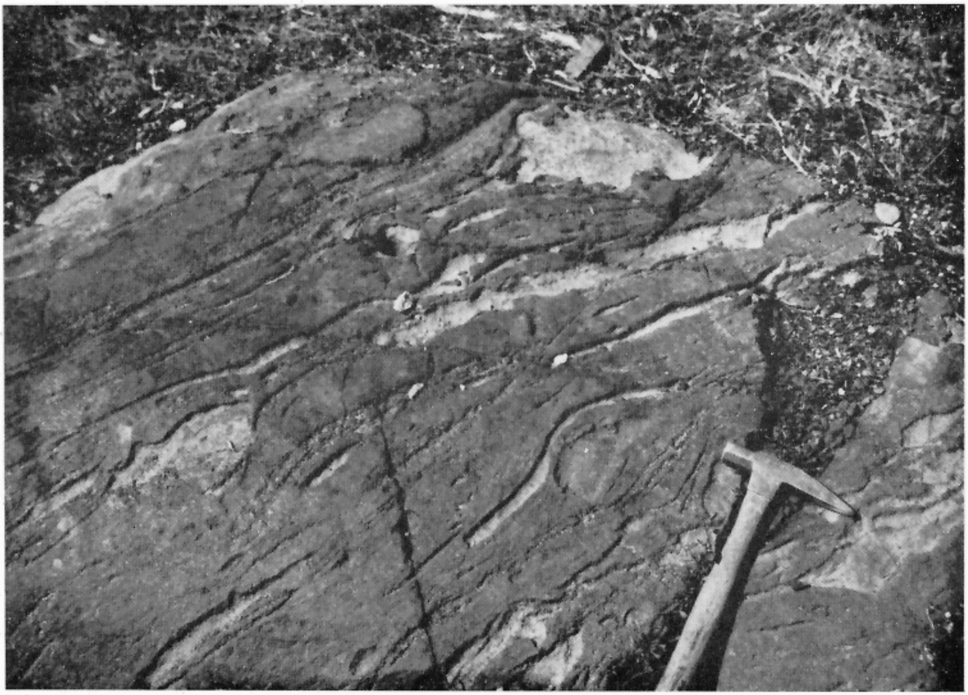
Grey to mauve-grey, coarse-grained anorthosite with blue feldspar phenocrysts up to 8 inches across bears numerous small veins and clots of titaniferous magnetite where it is exposed in a road-cut. Plagioclase grains in the anorthosite are crushed in places, shear zones were noted and dark grey to green, fine-grained dykes up to 10 feet wide with chilled borders cut the anorthosite. Magnetite is emplaced along some fracture zones together with garnet, rutile, and apatite. Clusters of apatite grains up to 2 inches across are present with magnetite in the anorthosite.

Hubert Township, Roberval County (31)

A zone with magnetite disseminated in medium- to coarse-grained diorite, a representative sample of which assayed 24.80 per cent iron and 5.82 per cent TiO_2 is of interest because of the Fe:Ti ratio in this diorite rock.

Lyonne Township, Roberval County (27)

This property is about 42 miles west of Roberval and extends southwest from near the southwest boundary of Lyonne township. It is accessible by gravel road from Roberval or St. Félicien on Lake St. John. At least five zones of titaniferous magnetite in gabbroic anorthosite were explored by Roberval Mining Corporation between 1957 and 1959 by geophysical methods, geological mapping, and by diamond drilling. Further exploration and metallurgical tests were completed by Oglebay, Norton and Co. of Cleveland, Ohio, before they gave up their option in 1960. More than 110 million tons of crude ore measured to a depth of 500 feet was



Gross, 2-8-58

PLATE IX. Irregular lensy bands of anorthositic gabbro with disseminated magnetite, Lyonne township, Roberval county, Quebec.

indicated. This contained 22 to 23 per cent iron and 6 to 6.8 per cent titanium. Metallurgical tests showed that this crude ore could be treated to provide a concentrate carrying 69.72 per cent iron and 0.51 per cent titanium.

The zones rich in magnetite occur in a belt of banded to crudely foliated gabbro and gabbroic anorthosite about a quarter mile wide and more than 2 miles long. This is a medium- to coarse-grained (3-10 mm), dark grey rock, with sub-ophitic to hypidiomorphic texture and has considerable bluish plagioclase mixed with grey or mauve plagioclase, pyroxenes, hornblende biotite, magnetite, and ilmenite. Lenticular banding is distinctive because of the segregation and marked differences in the proportions of mafic silicates and iron or titanium oxides (Pl. IX). Numerous dykes and masses of pink to grey porphyritic syenite have finer grained border zones and cut the gabbro. Medium- to coarse-grained biotite-feldspar granite, porphyritic in places, cuts the gabbroic and syenitic rocks. One pegmatite dyke in the gabbro is composed of pink feldspar, biotite, and one-inch crystals of magnetite. The syenitic and granitic rocks all appear to be younger than the banded gabbro and anorthosite, but they may be genetically related. The gabbro-anorthosite belt is surrounded by porphyritic granite-gneiss, pegmatite granite, and some syenite.

The magnetite-rich zones within the gabbroic anorthosite are elongated parallel with the north strike of banding in the gabbro, and the lenses or layers dip steeply or vertical. The magnetite and dark metallic oxides may form irregular masses up to a few inches long or narrow massive lenses an inch thick in which the magnetite grains may be 2 to 3 mm in size. Most of the magnetite is disseminated in the mafic bands in grains less than ½ mm. Magnetite grains contain small amounts of exsolved ilmenite in fine blades and lamellae, but some ilmenite is also present as discrete grains.

Most of the magnetite-rich zones occur within a zone in the gabbro belt about a mile long. Waddington (1960) reported that "Five zones of titaniferous magnetite have been found in a band of anorthositic gabbro. Zone A is 2,400 feet long by 600 feet wide. Indicated reserves in zone A to a depth of 500 feet are reported to be 90,000,000 tons averaging 23.6 per cent iron and 6.8 per cent titanium dioxide. Zone B is 1,800 feet long by 500 feet wide, and indicated reserves to a depth of 500 feet are reported to be 34,000,000 tons averaging 22.6 per cent iron and 6.2 per cent titanium dioxide". Other zones include C with surface dimensions of 900 by 150 feet, and D which measures 600 by 200 to 500 feet.

Titaniferous Magnetite Deposits in the Chibougamau Gabbro-Anorthosite (83)

A number of banded iron deposits are present within gabbroic anorthosite phases of the Chibougamau anorthosite complex. This intrusive body is about half a mile west of the boundary line between the Grenville and Superior Provinces, and is similar to intrusions within the Grenville Province. It may have been emplaced at the same time as smaller anorthosite bodies within the Grenville Province nearby, and the iron deposits associated with them are also considered here.

The anorthosite body is one of the predominant geological features of the area. It has a U-shaped outline on the surface and is about 40 miles long and 25 miles wide. The body is composed mainly of anorthosite with plagioclase ranging from An_{52} to An_{70} in composition but grades in places to feldspar-rich hornblende gabbro and hornblende diorite. The centre of this U-shaped area is underlain by a biotite–hornblende granite which may be contemporaneous with and genetically related to the anorthosite. The gabbroic anorthosite is banded or layered and the layers dip steeply north on the north arm and south on the south arm, suggesting that this mass may form an anticline that plunges steeply to the northeast.

The anorthosite is intruded into a succession of andesitic lavas, sediments, hornblende schist, and garnet–mica schist. Gradational zones between hornblende schist and gabbroic anorthosite are present in many of the contact areas. A zone a few miles wide that extends along the north side of the anorthosite massive is underlain by a complex group of intrusions ranging from pyroxenite and serpentinized ultrabasic rocks to gabbro, diorite, diabase, and some serpentinized diorite. Magnetite is interstitial to coarser mineral grains and may form 20 per cent of some parts of this altered diorite. Langley (1958) showed a definite boundary line on his map between the lava and hornblende schist group and the biotite–hornblende gneisses of the Grenville Province. However, some schist zones are present in the gneisses.

A number of iron occurrences are reported to lie within a band of gabbroic anorthosite, one quarter to one half mile wide, that extends along the north border of the anorthosite intrusion. Banded gabbroic anorthosite, rich in titaniferous magnetite, occurs on both the north and south side of Portage Island in Roy township, where 200 feet of drill-core from the north band assayed 30.22 per cent iron and 1.37 per cent titanium dioxide. Drill-holes in the southern band intersected 335 feet of rock that assayed 24.76 per cent iron and 1.26 per cent titanium dioxide, and another hole intersected 165 feet of material that assayed 29.20 per cent iron and 1.14 per cent titanium dioxide.

The same band of gabbroic anorthosite is exposed on the south end of Marguerite Island and contains 30 to 70 per cent titaniferous magnetite.

A marginal zone about 1,000 feet wide between anorthosite and serpentinized material north of Magnetite Bay contains magnetite in the form of veins and pods. Analyses of a number of drill-cores average 20 per cent iron and 1.07 per cent titanium dioxide.

Magnetite is disseminated in gabbro about half a mile north of Nepton Bay and a sample from this area assayed 31.89 per cent iron, 1.63 per cent titanium dioxide, 19.74 per cent silica, 0.02 per cent phosphorus, and 0.02 per cent sulphur (Waddington, 1960).

Another band of gabbroic anorthosite is present in the south arm of the anorthosite mass that contains zones rich in titaniferous magnetite. The layering or banding in this area dips 70°SE and magnetite is present as massive bands up to 2 feet thick as well as being disseminated in layers. Assad (1957) described a zone 7,200 feet long extending across the border between Lemoine and Rinfret townships where, "... a typical cross section from northwest to southeast may include a band of gabbro anorthosite 300 feet wide containing local bands 5 feet wide rich in magnetite; a major zone of magnetite of high tenor, 180 feet wide, containing local traces of pyrrhotite and chalcopyrite; a band of gabbro anorthosite 125 feet wide and a band of magnetite formation, 60 feet wide, similar to the major zone." A bulk sample of this material is reported to show an average tenor of 43.4 per cent soluble iron, 12.3 per cent TiO_2, 23.5 per cent SiO_2, 0.01 per cent P, and 0.04 per cent S.

Magpie Mountain Titaniferous Magnetite Deposit, Township 1770, Saguenay County (15)

One of the largest massive titaniferous magnetite deposits known is located 2 miles west of St. Jean River, about 75 miles north of Mingan or 130 miles northeast of Sept-Iles. Steeply dipping bodies of magnetite form the crests of ridges that rise 600 to 1,000 feet above the surrounding plain. The magnetite bodies are surrounded by anorthosite zones up to 100 feet thick, and the composite mass is in granite and granite-gneiss. Four separate deposits or zones are known and are intersected by two major thrust faults along which vertical displacement is predominant. The magnetite is medium to coarse grained and contains ilmenite in very fine exsolved blades. The tabular masses consist mainly of magnetite with 15 per cent plagioclase and pyroxene. The largest of the four deposits is 11,600 feet long, 1,000 feet wide, and is reported to contain 725 million tons of material that averages 45.71 per cent iron, 10.8 per cent TiO_2, and 7.45 per cent silica. Reserves of potential ore in the four deposits are estimated to be greater than 1½ billion tons mineable in open pits. The deposits are held jointly by Halmon Mining & Processing Limited, and Strategic Materials Corporation.

Magnetite Occurrences near Manitou Lake, Saguenay County (14)

A number of magnetite-rich zones with low titanium content were examined in this area by Hollinger (Quebec) Exploration Company Limited, and results reported by Waddington (1960) are summarized here.

These occurrences form conformable zones in granite–gneiss and amphibolite, and their high iron–titanium ratio is typical for this type of occurrence in the Grenville Province.

Three zones southwest of Marmont Lake average 20 feet in width but may be up to 100 feet wide, and are 1,000 to 1,600 feet long. Systematic sampling shows 52 per cent iron, less than 2.2 per cent TiO_2, and 20 per cent silica.

Another zone in the Gad Lake area in granite–gneiss is 4,000 feet long and 600 feet wide. Lenses and veins of massive magnetite occur in this zone, the largest being 1,200 by 10 to 50 feet in dimension, and the average grade 61.5 per cent iron, 1.52 per cent titanium dioxide, 7.86 per cent silica, 0.111 per cent phosphorus, and 0.075 per cent sulphur.

A sample from small magnetite layers in granite–gneiss exposed in a stream bed and cliff face 1¼ miles west of Manitou River assayed 53.50 per cent iron, 1.53 per cent titanium dioxide, 2.40 per cent phosphorus, and 0.20 per cent sulphur.

Titaniferous Magnetite Deposits at Newboro Lake, South Crosby Township, Leeds County, Ontario (95)

Two of the best known deposits of titaniferous magnetite in southern Ontario occur on the west shore of Newboro Lake about 4 miles southeast of the town of Westport. Iron ore was mined from these deposits between 1858 and 1871 and shipped down the Rideau Canal to Kingston and from there to markets in the United States. The Chaffey mine workings consist of three trenches on a small island in the lake, and the Matthews or Yankee mine consists of an open pit on the mainland about half a mile north of the Chaffey pits. An investigation of these deposits was started in 1957 by New Mylamaque Explorations Limited (now New Mylamaque Mining & Smelting Limited) who made magnetometer and geological surveys over the deposits, completed nearly 30,000 feet of diamond drilling, and sponsored extensive metallurgical studies. Feasibility studies have been made with plans to produce a metallic iron product by using a pyrometallurgical process for reducing the ore. The company reports that 53 million tons of open pit potential ore with an average grade of 26.7 per cent iron and about 6 per cent titanium dioxide has been indicated to a depth of 350 feet by drilling. A concentrate carrying 51 per cent iron has been produced from ore ground to 28 mesh, and 80 per cent of the iron was recovered from the crude. The ratio of crude ore to concentrate was 2.4:1. It is estimated that only one ton of waste rock will have to be removed for every 20 tons of ore mined.

Geological Setting

The titaniferous iron deposits of this area occur within a body of gabbroic anorthosite about a mile long and half a mile wide that extends northwest from the shore of Newboro Lake. The banded gabbroic body is almost surrounded by monzonite, which intrudes the gabbro in some places but grades into it in others. This body is in contact on the east side with migmatite and intermixed granitic rock and schist. The Newboro gabbroic anorthosite is typical of a number of other gabbroic bodies in the area that are surrounded by monzonite and quartz monzonite intrusions. These bodies contain appreciable amounts of titaniferous magnetite. Small dykes of monzonite cut the gabbro; diabase dykes are the youngest intrusions in the area.

The gabbro-anorthosite is dark grey to green and coarse grained with a sub-ophitic texture. Andesine and labradorite grains are surrounded by augite and ferroaugite, hornblende, biotite, variable amounts of titaniferous magnetite and ilmenite, and accessory apatite. Distinct banding is present along the eastern side of this mass where the minerals are segregated into mafic and plagioclase-rich layers (Pl. X). Diorite phases are present locally in many parts of the intrusion. Near the Matthews pit the bands or layers strike north and dip 70° to 80° W, but south of there they strike northeast, dip steeply, and appear to be curved or to form an arcuate pattern around the south and east sides of the intrusion. The magnetite- and ilmenite-rich zones and layers that form the potential ore are a part of this banded arcuate structure.

Gross, 5-1-58

PLATE X. Banded anorthositic gabbro with disseminated magnetite near Newboro Lake, Ontario.

Potential Ore Deposits

The main magnetite-rich zone is at least 300 feet wide and more than 3,000 feet long. It is composed of subsidiary zones and layers in which the magnetite-ilmenite content varies from 80 per cent to no more than a few per cent. The oxide material is mainly magnetite, which in some layers is practically free of inclusions but in others has ilmenite exsolved along octahedral planes, and pleonaste (Mg-Fe spinel) exsolved along cubic planes. Ilmenite with exsolution lamellae of hematite occurs in discrete grains intermixed with the magnetite. Sphene associated with calcite has been found in narrow restricted parts of the magnetite-rich zone and along fracture zones in the gabbro. A small amount of pyrite is disseminated with oxides in a number of layers. An analysis of ore from the Chaffey mine shows:

	Per cent
Iron	50.23
Silica	7.10
Sulphur	1.52
Phosphorus	0.085
Alumina	5.65
Titanium dioxide	9.80

This analysis may be representative of higher grade material as the bulk of material now considered as potential ore is fairly uniform, with about 30 per cent iron and 7 per cent titanium dioxide. The sulphur content rises slightly in the higher grade material but phosphorus, being largely disseminated with the silicate minerals, is fairly uniformly distributed. Traces of vanadium and chromium are reported.

The layers rich in iron and titanium oxides and mafic minerals appear to have consolidated at the same time as the plagioclase layers, and gradations from one type of layer to another are common. Aggregates of mafic minerals surround or even enclose plagioclase grains and are interstitial to the plagioclase grains in the lighter bands. Krogh (1961) concluded from his study of the deposit that "Field and petrological evidence indicate that the body is a magmatic intrusive which was emplaced after the metamorphism of the sediments was completed. The oxide-rich zone within the body is the result of injection of late magmatic fluid into closely spaced arcuate concentric planes of dilatancy that resulted from movement of the deep magma core after the crystal mesh was solid enough to yield by rupture." He also found that the amount of TiO_2 dissolved in magnetite coexisting with ilmenite indicates a temperature of formation for the body of at least 800°C, which is higher than the temperature indicated for the metamorphism of the paragneiss.

Other Titaniferous Deposits Associated with Plutonic Rocks

The locations of a number of other ilmenite occurrences are shown on Figure 7, but very little information is available concerning the occurrences. Numerous titaniferous magnetite occurrences are reported in this area all within or closely associated with gabbroic anorthosite or rocks genetically related to anorthosite. Of these, the occurrences at La Blache and Schmoo Lakes in township 745, Quebec, are probably the largest known with over 25 million tons of massive titaniferous magnetite with an average tenor of 49 per cent iron and 21 per cent titanium dioxide (Waddington, 1960). Most other occurrences are small and many have appreciable amounts of apatite associated with them. Small amounts of iron ore were mined around the turn of the century from several of these deposits located close to transportation routes.

Skarn, Contact Metasomatic, Veins, and Structurally Controlled Replacement Deposits

More than 150 iron occurrences of this general type are present in the southwest part of the Grenville Province. Iron ore was produced from many of these deposits during the last part of the nineteenth century, and ore is now being produced from two deposits that have been worked since 1955. All the known iron occurrences in this area are relatively small, probably only a few could provide more than 15 million tons of ore concentrate, and most contain less than one per cent titanium dioxide. Nearly all are in the southern part of the province; a few are reported in the northern Labrador coast area.

The distribution of the larger occurrences in eastern Ontario and southern Quebec is shown on Figure 8, and a summary of some of their major geological features is given in Table VII. The occurrences are classified on this figure according to their mineral composition and the major types of host rock. Host rocks include skarn—composed of pyroxene, amphiboles, epidote, garnet, biotite, and chlorite—, crystalline limestone, dolomite, granitic gneiss, granite, and pegmatite. The main mineralogical types include titaniferous magnetite, magnetite, and hematite deposits. These deposits were studied by Rose (1958) and only a few are described here to illustrate their general characteristics.

The Hilton Mine, Bristol Township, Pontiac County, Quebec (*71*)

The Hilton mine (Pl. I)—previously known as the Bristol mine or deposit—is about 3 miles north of Ottawa River, between Shawville and Quyon on lots 21 and 22, range II of Bristol township. More than 16,000 tons of iron ore was mined between 1872 and 1894 from a few small surface pits and underground workings that extended to a depth of 150 feet. The ore was roasted in two furnaces of 50-ton-per-day capacity to remove a small amount of pyrite. The property was acquired in 1950 by the W. S. Moore Company of Duluth, Minnesota, and an ore zone suitable for open pit mining was indicated by diamond drilling in 1951. The Steel Company of Canada, Limited, Jones & Laughlin Steel Corporation, and Pickands Mather and Company became joint owners of the property and carried out further diamond drilling and evaluation studies. They eventually formed an operating company known as Hilton Mines Ltd. In 1956 this company began developing the property for open pit mining, concentrating, and pelletizing of the ore. Production of 600,000 tons of pellets per year was planned, and ore was shipped from the property early in 1958 (Pl. XI). Production in 1959 amounted to 584,000 tons of pellets, and an expansion program was started late in that year to enable production to be raised to 800,000 tons of pellets a year. Operations on the property in 1959

Gross, 1-3-58

PLATE XI. Hilton mine, near Shawville, Quebec, in 1958. Compare Plate I showing same area after operating the mine for 5 years.

involved the mining and handling of 2,262,204 tons of crude ore and 1,819,415 tons of waste rock, and 1,111,163 tons of cobbed ore was treated in the mill to produce about 584,000 tons of furnace product containing between 65 and 66 per cent iron.

Geological Setting

The geology of this area was mapped and described in considerable detail by Wilson (1924) and further regional studies were made by Sabourin (1955). The Bristol deposit lies within a belt of Grenville metasediments composed of crystalline limestone and dolomite, impure quartzite, and biotite–hornblende granite–gneiss. This belt strikes northwest and dips 55° to 60°N. A group of rhyolite, andesite, diorite, and amphibolite rocks is associated with the metasediments. Rocks in this belt are intruded by pyroxene syenite, pyroxene diorite, gabbro, and anorthosite of the Buckingham Series. These intrusions resemble some of the rocks in the gabbro–anorthosite suites in other parts of the Grenville Province. A green to white granular rock consisting mainly of white to pale green diopside is described by Wilson (1924). It is closely associated with crystalline limestone and was probably formed by emanations from an igneous source reacting with limestone. This metamorphic pyroxenite also contains other lime silicate minerals, phlogopite, scapolite, and apatite, and pegmatitic phases in it contain tourmaline, zeolites, fluorite, and sulphides. Metamorphic pyroxenites are associated with granite and syenite and with rocks of the Buckingham Series, but Wilson concluded that they are probably related in origin to the intrusions of the Buckingham Series because in the Quyon area they are cut by granite dykes like those that also cut Buckingham rocks. The ages of syenite, aplite, and large masses of granite are included in a younger group of intrusions and these rocks are cut by late stage diabase dykes. The Bristol deposit consists of a number of steeply dipping tabular sheets and disseminated zones of magnetite in metasediments and skarn rock which are cut by numerous small granite dykes.

Description of Bristol Deposit

The ore zone is about 500 feet wide and 2,500 feet long and appears to be conformable with the enclosing metasedimentary rocks. It strikes northwest, dips 55°NE and is bounded on the hanging-wall side by an impure quartzite rock that is interbanded with thin calcareous and argillaceous beds and mica schists. Banded crystalline limestone is present along the foot-wall of the ore zone. It contains considerable light grey and green amphibole, bands of amphibolite, and chlorite mica schist. Biotite–hornblende–feldspar gneisses are closely associated with the metasediments. A mass of pyroxene diorite considered to be part of the Buckingham Series is exposed north of the quartzite band.

The ore consists of a heterogeneous mixture of magnetite shoots and stringers, masses of skarn, and a complex group of metasedimentary rocks and granite. Much of the ore consists of dark green amphibolite and skarn composed of green amphiboles, pyroxene, biotite, chlorite, epidote, and feldspar. Magnetite is disseminated in the skarn and some is distributed in grain clusters 5 to 10 mm across. Most of the magnetite occurs in massive tabular sheets or pods that are conformable with the layers in the banded skarn and vary in thickness from a few inches to tens of feet. Amphibole minerals occur in coarse acicular grains and radiating grain clusters. The amphibolite is closely associated with crystalline limestone beds and is evidently derived from limestone by alteration and replacement. Most of it is banded in conformity with the metasediments, although numerous offshoots of amphibolite skarn appear to have formed by replacement along fracture systems in the sediments. The whole complex of metasediments, skarn, and magnetite is intruded by a great number of narrow dykes and irregular bodies of grey to pinkish, medium-grained granite.

There is considerable evidence that the skarn and magnetite formed along an early fault or fracture zone and that emplacement of the swarm of granite dykes was also controlled by this major structure.

The ore zone is strongly shattered and fractured along a number of shear or fault zones that cut both granite and skarn. One fault zone at the southwest end of the pit strikes northwest and dips steeply southwest. The southwest side has moved east and up relative to the northeast side. Other strong zones of shearing strike west to northwest and dip 50°NE, and north to northeast and dip 60°NW.

Because of the erratic manner in which the magnetite is distributed in the ore zone, the intrusion of irregular masses of granite, and the dislocation of sections of the ore zone along shears and faults, it has been virtually impossible to establish a detailed geological pattern that would indicate the distribution of ore zones of different grade. In practice the whole mass of material in the ore zone is mined and the waste material is removed at several stages in the concentrating plant by using magnetic cobbers and separators. Much of the magnetite although appearing to be medium grained is intimately mixed with silicate minerals, and about 70 per cent of the final ore product must be ground to −325 mesh to meet requirements for pelletizing and to enable a satisfactory separation and concentration of the magnetite. Small amounts of pyrite and other sulphides are present but are of no serious concern as either they are removed by the magnetic separators or the sulphur is eliminated when the pellets are roasted. The pellets are very low in silica and contain no appreciable amount of deleterious constituents.

Most of the mineral constituents in the upper 35 feet of this ore zone were oxidized. The magnetite was altered to martite, and Rose (1958) noted that martite was found to a depth of 264 feet. The sulphides were oxidized to red hematite and hematite was abundant in the upper parts of the orebody. Many deposits of this type in the area have oxidized zones and it is evident in several places that this alteration took place prior to Palaeozoic time. A large part of the Bristol deposit was covered by 30 to 40 feet of grey, thin-bedded marine clay and thin layers of sand and glacial till.

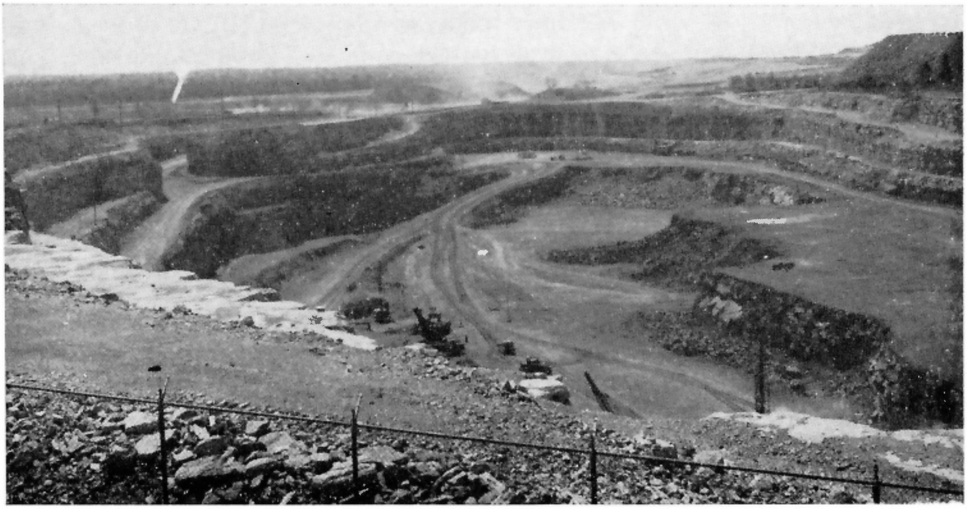
Origin of the Deposit

Wilson (1924) suggested that the ore may have originally formed beds that were interstratified with the crystalline limestone and that the whole mass was subsequently broken up and deformed. Since this suggestion was made the deposit has been opened up and mined to a depth greater than 100 feet. It is evident now that skarn formed as an alteration and replacement of limestone and associated beds and that the magnetite in turn replaces skarn minerals. The magnetite–skarn replacement occurred after the metasediments were highly metamorphosed and before the last major period of granite intrusion. Intrusion of rocks of the Buckingham Series also took place during this interval of time. It is believed that magnetite and skarn mineral zones were formed at a late stage in the succession of igneous events that produced the Buckingham Series rocks. If this is so, the magnetite and skarn may be closely related genetically to the metamorphic pyroxenite rocks mentioned above, if not perhaps part of the same phenomenon.

The Marmora Mine, Marmora Township, Hastings County, Ontario (118)

The Marmora magnetite deposit was first indicated by a small, well-defined, oval-shaped anomaly recorded by an aeromagnetic survey carried out in 1949 by the Geological Survey of Canada and the Ontario Department of Mines. The anomalous zone over the deposit is about a mile long and three-quarters of a mile wide, and the central part of the deposit is about 1½ miles southeast of the village of Marmora.

The deposit area was acquired by Bethlehem Steel Corporation, and exploration by diamond drilling in 1950 and 1951 indicated more than 20 million tons of ore carrying 35 to 37 per cent iron within the economic limits of open pit mining. The deposit was covered by about 125 feet of Palaeozoic limestone (Pl. XII) and was probably one of the first to be discovered by an aeromagnetic survey. A number of small magnetite occurrences in Precambrian rocks exposed a few miles north of this deposit were an indication of possible mineral potential in the area.



Gross, 1-8-58

PLATE XII. Marmora mine, looking southeast, Marmora, Ontario, 1958.

Marmoraton Mining Company Ltd., a wholly owned subsidiary of the Bethlehem Mines Corporation, was formed to develop and operate the mine. The stripping off of 100 to 125 feet of limestone and construction of a concentrating and pelletizing plant were started in 1952, and dock facilities were built at Picton to accommodate the first shipment of pellets in 1955. About 20 million tons of limestone was removed in order to expose the ore, and it is expected that the deposit will be mined by open pit methods to a depth of 450 feet below the base of the Palaeozoic rocks. In a normal year production from this deposit amounts to about 500,000 tons of pellets. About 1,126,000 tons of waste rock was removed in 1959, and 313,259 tons of concentrate containing 66.25 per cent iron was obtained from 762,785 tons of ore treated in the mill.

The ore is mined and hoisted up an inclined ramp and then transferred to the mill where it is concentrated and pelletized. A high proportion of it is ground to —325 mesh to provide suitable material for pelletizing and to liberate the fine-grained magnetite for concentration by magnetic methods.

The Marmora deposit lies within a belt of Grenville metasediments composed of crystalline limestone, amphibolites, granite-gneiss, and quartzitic gneisses, which are intruded by rocks of the gabbro-anorthosite-diorite group, by later granite and syenite, and finally by diabase dykes. Rocks of the gabbro-diorite group are exposed within a mile of the deposit at the edge of the limestone capping and may be present much closer to it.

The metasedimentary rocks exposed in the pit strike north to northwest and dip 60°W. Crystalline limestone is predominant on the east side of the deposit, but considerable impure meta-quartzite interbanded with the limestone is distributed throughout the magnetite skarn zone of the deposit. A large mass of grey syenite and dioritic rock is present on the southwest side of the ore zone. A number of diabase dykes cut both syenite and ore zones.

The ore deposit consists of a number of long, thin, sinuous, magnetite-rich zones, 50 to 100 feet wide, composed of skarn rock impregnated with magnetite. These zones or lenses are roughly parallel with the strike and dip of the metasediments and form tabular to lenticular masses up to 400 feet thick and 2,500 feet long. A cross-section of the deposit given by Rose (1958), based on drill-hole information, indicates that the ore zone extends at least to a depth of 750 feet below the base of the Palaeozoic strata. Most of the skarn rock, especially in the eastern part of the deposit, consists of medium- to fine-grained, dark green pyroxene and amphibole and variable amounts of epidote, garnet, chlorite, and talc. Epidote–garnet–pyroxene skarn seems to be more prevalent and coarser grained in the western part of the deposit, near the grey to pink syenite mass. Crude banding in the skarn rocks is parallel with banding in the metasediments and partly altered beds show that the skarn is derived largely from the bedded rocks (Pl. XIII). The magnetite is mainly fine to medium grained and either is disseminated with the skarn minerals or forms thin lenses, shoots, or stringers in the skarn zones. Pyrite and traces of chalcopyrite may constitute up to 5 per cent of the ore and are most abundant in the western part of the ore zone. A large proportion of the sulphide minerals occurs as fracture fillings and appears to have been introduced after the magnetite.

Gross, 1-7-58

PLATE XIII. Banded magnetite ore with amphibole, pyroxene, garnet, and epidote gangue minerals, Marmora deposit, Ontario.

Some of the epidote-rich skarn is related to the syenite, and epidote and magnetite are present along fractures in the syenite. Quartz and calcite veins containing pyrite and pyrrhotite are present in both the magnetite-bearing skarn zones and in the syenite, suggesting that much of the sulphide material was introduced late in the history of the deposit.

The ore zone has been deformed by fracturing and shearing, and some parts show brecciation. One shear that strikes northeast and dips 25°W cuts the magnetite-bearing skarn rocks and the syenite.

The Marmora deposit is similar in many respects to the Bristol deposit and is thought to have been formed under similar circumstances and probably at the same stage in a succession of geological events that were similar in the two areas.

The Hull Iron Mine, Hull Township, Gatineau County, Quebec (58)

The Hull iron mine, 2 miles west of Ironside in lots 11 and 12, range VII, Hull township, has recently been developed on the site of the old Forsyth mine. The property, previously held by Hull Iron Mines Limited and now taken over by Jubilee Iron Corporation, covers the old Forsyth, Baldwin, and Lawless mines. These occurrences of magnetite have been known since before 1830 and about 13,000 tons of ore was mined between 1854 and 1858 for export to Pittsburgh, Pennsylvania. A blast furnace was erected on the property in 1867 and operated during the summer of 1868. Over 17,000 feet of diamond drilling was completed during 1958 and 1959, and underground development included driving an inclined adit for over 1,000 feet, sinking a vertical shaft to a depth of 750 feet, and drifting on several levels. According to published information, this work has indicated more than 4,250,000 tons of potential ore to a depth of 600 feet that carries 50 per cent or more iron, 5 to 13 per cent silica, 0.65 per cent sulphur, and 0.35 per cent titanium dioxide.

The iron deposits on this property form veins, pods, and lenticular masses of magnetite mixed with amphibole and pyroxene skarn. They lie along a 6,800-foot westerly trending zone in crystalline limestone. The old Forsyth mine workings at the eastern end of this zone and nearest to Hull consisted of a steep-walled open cut, 735 feet long, 10 to 80 feet wide, and 25 to 50 feet deep with deeper underground workings of unknown size. The recent underground and drill-hole development work shows that this vein zone strikes west and dips 75°N at the surface, but that the dip reverses at depth and the walls remain steep but sinuous. The width of this vein zone varies from about 20 feet near the west end to more than 100 feet in places, the average being between 80 and 90 feet. A section of the vein was examined in a cross-cut near its east end about 150 feet below surface. In this working the vein zone is about 97 feet wide and has sharp walls or boundaries with the crystalline limestone. Magnetite is mixed with amphibole, pyroxene, biotite, garnet, and chlorite, as well as forming small massive shoots, stringers, and bands. The zone, which is crudely banded, sheared, and schistose in part, contains inclusions of limestone or masses of coarse calcite; graphite is present on some slip surfaces. The silicate skarn minerals appear to have been derived mainly from the crystalline limestone, but shearing after the development of the magnetite and skarn minerals has disrupted much of the banding and primary structure. Some of the magnetite shoots appear to have been introduced after the main mass of silicate minerals had formed. The vein zone forms a broad lens or shoot that plunges east and is cut off at the east end by a fault and a pegmatite dyke. It pinches out to the west. Recent work has shown that the composition of a large part of the ore is:

	Per cent
Fe	47
SiO_2	13.5
CaO	4.0
Al_2O_3	2.9
MgO	1.8
S	0.65
P	0.03
C	3.2
TiO_2	0.3 to 0.4

The old Baldwin mine on lot 13, range VI, consists of a number of small pits west of the old Forsyth trench. A vein of massive magnetite that strikes west and dips steeply north is exposed in this pit. It is about 12 feet wide and lies between limestone on the north and garnet-amphibole-biotite skarn on the south. A small amount of pyrite is present in the magnetite.

The Lawless mine on lot 14, range VII, west of the Baldwin, consists of several pits exposing small veins of magnetite in limestone. Little or no skarn material is associated with the magnetite. These veins have been introduced along fault or shear zones in limestone and some shearing has taken place since their emplacement. The skarn minerals associated with the magnetite and the character of the vein masses in general are very similar to those of the ore at the Hilton and Marmora mines. It is believed that these deposits like many others in the southern Grenville Province have a similar mode of origin and are probably all genetically related to the gabbro-anorthosite-diorite intrusive suite. The Hull deposits, like many that occur within crystalline limestone, are well-defined zones with sharp contacts and consist of massive magnetite with a minimum of disseminated magnetite ore. No doubt structural features controlled the location of the occurrences but the limestone may have been important in neutralizing acid solutions that probably transported the iron, and in causing deposition of the magnetite close to or within structural openings.

Iron-Formation in Southern Grenville Province and Labrador Coast Areas

A number of small bodies of iron-formation have been recognized in the southern part of the Grenville Province but none is as thick or has the regional extent of those in the southwest part of the Labrador geosyncline, which is within the Grenville tectonic belt. Reports of iron-formation in the Grenville Province (Engel and Engel, 1953) have been discredited by some in the past but the controversial ferruginous bands are now recognized as sedimentary iron-formation, although none found so far has proved to be large enough for economic development.

Belmont Iron-Formation, Belmont Township, Peterborough County (149)

A band of magnetite–specular hematite–quartz iron-formation was examined about a quarter mile west of the north end of Belmont Lake. The band strikes north to northeast, dips steeply to the southeast, and is conformable with the enclosing mica-chlorite schists, greywacke-quartzite, and metavolcanic rocks. It is probably not more than 60 feet thick and was followed for about a quarter mile along strike. Roger Young, a prospector in the area, reported that it has been traced to the north along the east side of Cordova Lake and east from there to the northwest end of Twin Sister Lakes. It is also exposed east of the bridge that crosses Deer River, where it is much thinner and associated with crystalline limestone.

The iron-formation is thin bedded, bluish grey to pinkish grey, and is composed of layers rich in magnetite and specular hematite that alternate with grey sugary quartz layers or reddish jasper layers. Dark green amphibole grains are present in some layers and garnet, mica, and amphibole-rich bands are present near its borders. Thin sections show that the rock is composed of an equigranular mosaic of quartz grains about 0.25 mm in size with iron oxide grains ranging from 0.01 to 1.0 mm. It is interesting to find iron oxide as grains in oval-shaped rings about 1 mm long, and as oval-shaped dusty patches. These structures are identical to metamorphosed granules and oölites preserved in many of the highly metamorphosed Proterozoic iron-formations in other areas. The presence of these structures in the Belmont iron-formation and their similarity to those found in Proterozoic or younger iron-formations suggest that perhaps the Grenville sediments were also deposited in Proterozoic or later time.

Miller and Knight (1913) who first described this iron-formation gave an analysis that shows 24.06 per cent iron, 0.024 per cent sulphur, and 0.126 per cent phosphorus.

Houdet Township Iron-Formation, Pontiac County, Quebec (75)

Magnetite-quartz iron-formation is exposed at a number of places along a narrow zone that extends west for 2½ miles from the south end of Cuff Lake. Claims were acquired in 1956 by O'Leary-Malartic Mines Limited who carried out exploration work. Holannah Mines Limited optioned the property in 1957 and completed 5,000 feet of drilling in 17 holes.

The bedding in the iron-formation is conformable with the banding in the adjacent quartz-biotite-feldspar gneiss, the garnet-hornblende-biotite-chlorite schist, and the amphibolite gneiss. These rocks strike west and dip 40 to 75°S in most outcrops but 30°N in others. The beds are folded and contorted, and it is not certain whether the various zones of iron-formation represent one bed repeated by folding and faulting, or several lenses along one horizon. The actual thickness of the iron-formation could not be determined from the outcrops, but dip-needle readings along a few lines indicate that it may be less than 100 feet.

The iron-formation is uniform and continuous and consists of alternating magnetite-rich and quartz-rich layers that range from ¾ to less than ¼ inch thick but average about ½ inch. Brownish green amphibole grains are present in some layers, especially near the borders of bands, and the beds are transitional across a few feet to garnet-biotite-amphibole gneiss. The magnetite-quartz layers are medium grained and have a sugary to equigranular texture with an average grain size of 0.5 mm in many beds. Relic granules have been recognized in a few thin sections. The iron-formation was estimated in the field to contain about 35 per cent iron and Laurin (1958) reported that picked samples range from 30.25 to 42.00 per cent iron, 43.36 to 29.54 per cent silica, 0.0 to 0.003 per cent sulphur, and 0.004 to 0.02 per cent titanium oxide.

Byrd Lake Iron-Formation

Another band of iron-formation is reported by Wahl and Osborne (1950) in the Cawatose map-area. It is exposed about 8 miles east of Cuff Lake and may be a segment of the bed in Houdet township. They describe the occurrence as follows:

> An exposure with Grenville type limestone and quartzite was found within pink granite orthogneiss on the east shore of Canica Lake. . . .The exposure is approximately 20 feet wide and 30 feet long . . . The quartzite passes abruptly upward through a zone less than an inch wide of fine grained quartz, biotite and garnet, into a garnetiferous biotite schist. . . .The garnetiferous schist is three feet thick and is red brown, coarse grained and slightly schistose. . . . The limestone is in sharp contact, on its east side, with magnetite-garnet gneiss.

> The magnetite-garnet gneiss is a three foot layer of massive rusty-brown weathering paragneiss. The rock consists of alternating bands up to half an inch thick, of clear, red brown glassy quartz, and fine grained layers of magnetite and garnet. . . .This rock may be either metamorphosed iron formation, or a contact metamorphic product of the pink granite gneiss and an impure quartzose sedimentary rock. . . .

Parkman Township, Nipissing District, Ontario (153)

A band of iron-formation along Opemika Creek, in the central part of Parkman township about 40 miles north of North Bay and 2 miles west of McLaren Bay on Lake Timiskaming, has been described by Fern Dubuc of Jalore Mining Company, Limited. The surface width is reported to be 50 to 60 feet. The band was traced along strike for more than a mile and, according to magnetic data, may be 3 miles long. The iron-formation is conformable in a succession of Grenville rocks which in ascending order consist of garnetiferous hornblende gneiss with thin, rich magnetite beds, iron silicate magnetite-quartz iron-formation, quartz-mica gneiss, and crystalline limestone. The beds strike N30°E and dip 40°NW.

The iron-formation is made up of alternating lenticular layers of quartz, quartz and magnetite, and silicate-rich bands containing some magnetite. The layers vary in thickness from $\frac{1}{4}$ to 1 inch, and the size of quartz and magnetite grains is $\frac{1}{2}$ mm, grains of silicate minerals being up to an inch in size. The iron-formation is estimated to contain 30 to 35 per cent iron in the magnetite.

Iron-Formations in the Hebron and Saglek Fiord Area of the Labrador Coast

Magnetite gneiss is mentioned by Norancon Exploration Limited in a report for 1946 on a concession area. The magnetite gneiss occurs on an island, about $1\frac{1}{2}$ miles in diameter, that is 4 miles north of Hebron and about $\frac{1}{4}$ mile off the mainland. The Newfoundland-Labrador Exploration Syndicate sent an expedition headed by Ross Toms to the area in 1958. Reports indicate that a large, low grade iron deposit was found near a good harbour site and that a number of other prospects were examined within a 100-square-mile area.

The iron occurrences south of Saglek Fiord are reported to consist of beds of quartzite with varying amounts of magnetite (20 to 40 per cent iron), the description of which suggests a metamorphosed iron-formation, and numerous veins and lenticular bodies of massive magnetite. The bands of iron-formation are associated with banded gneiss, quartzite, and metasedimentary rocks. The main band ranges from 10 to 500 feet wide and was traced for a strike distance of more than 5 miles. A large number of iron-formation bands were found in gneiss in the general area and the iron rich beds at Hebron are reported to be similar to those described from farther north.

Residual Magnetite Sand Deposits

Extensive accumulations of sand rich in magnetite occur along the north shore of the St. Lawrence River where tributaries enter from the north. Exploration work on these deposits has been described as early as 1863 by Logan and 1870 by Hunt, in their reports for the Geological Survey of Canada. Extensive investigations were made later, between 1900 and 1915, and considerable exploration by drilling and bulk testing has been done in recent years.

The magnetite is concentrated near the shore by wave and tidal action in the deltas of the major rivers. Practically all the magnetite contains titanium in the form of exsolved ilmenite, but the high gravity concentrates also contain considerable ilmenite in separate grains. Concentrates from some of the occurrences that contain 70 per cent iron may however contain as little as 1.45 per cent titanium dioxide. A very large tonnage of low grade crude material has been reported and as these deposits can be mined by dredges and the ore concentrated by inexpensive methods they constitute a potential source of iron ore. Many of the concentrates, however, contain too much titanium to be accepted as ore for use in standard blast furnaces.

Magnetite Sand Deposits at the Mouth of the Natashquan River (4)

Probably the largest of these magnetite sand deposits occurs near the mouth of the Natashquan River. Iron-rich sand is present both north and south of the river along the last 12 miles of its course and overlies Pleistocene marine clay. It forms a large sand plain with an elevation of 25 to 50 feet broken by sand dunes 5 to 25 feet high. The sands are well bedded with prevalent crossbedding, and magnetite is concentrated in layers up to several inches thick.

Reports from drill-holes and tests carried out by Aconic Mining Corporation indicate that more than 1.5 billion tons of sand containing 3.7 per cent iron occurs in a 13.7-square-mile area. Estimates are based on samples from drill-holes with an average depth of 94.5 feet. This work indicated that magnetite concentrates could be produced that would carry 65 per cent iron, about 3 per cent titanium dioxide, and a low phosphorus and sulphur content. The test work outlined a 5.47-square-mile area within the tract of land where the iron content is 4 per cent.

Other Magnetite Sand Deposits

The locations of some of these deposits along the St. Lawrence River are shown on Figure 7. Others on the shores of inland lakes are also shown. Very little is known about the size of these occurrences; they are of doubtful economic value as most of the magnetite is titaniferous.

Residual Iron Deposits

A number of deposits in the Grenville belt consist of red hematite and goethite or goethite which are thought to be residual concentrations of iron on the Precambrian erosion surface. A few of these in eastern Ontario consist of pockets of red hematite in Precambrian crystalline limestone and dolomite below Palaeozoic limestone cappings. Others not covered by Palaeozoic rocks appear nonetheless to be related to the pre-Palaeozoic surface and do not extend far below the present surface. Many of these occurrences of red hematite are cut by quartz and calcite veins and contain grains of specular hematite. Vugs in the red hematite lined with crystals of quartz, calcite, specular hematite, and magnetite obviously formed under different conditions than the red hematite. Martite is found with the red hematite and in the vugs.

These deposits are believed to have formed by the weathering of ferruginous carbonate rocks, and magnetite- or pyrite-rich zones. They apparently formed on the Precambrian erosion surface prior to the deposition of the Palaeozoic rocks as fragments of hematite and considerable goethite are found in conglomerate and clastic beds at the base of the Palaeozoic succession and martite and hematite are common in the upper part of many magnetite deposits. Martite is found to depths greater than 200 feet in many deposits but is more abundant near the surface. Highly leached and altered saprolitic rocks occur below the glacial deposits in many parts of the eastern shield. Some of this alteration may have taken place in Precambrian time.

Small goethite veins and irregular masses of goethite and hematite in Hincks township, Gatineau county, Quebec, described by Tanton (1944) may be examples of residual occurrences although he suggested another mode of origin. They occur in gneiss that is highly decomposed and altered to kaolinite near the hematite deposits. The hematite-goethite samples contained 68 per cent Fe_2O_3, 4 to 13 per cent SiO_2, and 6.46 to 0.75 per cent P_2O_5.

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APPENDICES I TO III

Appendix I

GROUP	CLASSIFICATION OF IRON DEPOSITS

I HEMATITE-GOETHITE DEPOSITS IN IRON-FORMATION[1]. Direct shipping ores and wash ores formed in iron-formation by leaching of silica and concentration of iron by natural processes.

- *Type A*) i) Lake Superior type in Minnesota, and Knob Lake type in Quebec and Labrador. Concentrations of hematite, goethite, and other iron minerals in cherty iron-formation. Cherty iron silicate, carbonate, and cherty iron oxide iron-formations are the common kinds of protore for this type.
  - ii) Semitaconites, partly leached iron-formations associated with Type A) i) that provide "wash ore". These are considered as a special subtype in this group.
- *Type B*) The Old Helen mine deposit, Michipicoten district, Ontario. Concentrations of hematite and goethite of direct shipping quality in siderite beds.

II IRON-FORMATIONS. Various kinds or types of iron-formation that may be utilized without concentration or beneficiation, or that are suitable for beneficiation.

- *Type A*) Clinton type of iron-formation, Wabana deposits, Newfoundland. Hematite-siderite-chamosite beds with distinctive oölitic texture.
- *Type B*) Minette or Lorraine oölitic siderite-chamosite iron-formations, mined in the Northampton district of England.
- *Type C*) Helen mine and Sir James mine, Michipicoten district, Ontario. Siderite iron-formation consisting of stratigraphic units of fairly massive siderite.
- *Type D*) Taconite iron-formation, Moose Mountain mine, Ontario, and Mesabi Range taconites in Minnesota. Included here are all iron-formation that must be ground finer than 100 mesh to be concentrated. Common types include iron oxide, iron-silicate, iron-carbonate, and iron silicate-iron oxide types with a banded cherty matrix.
- *Type E*) Metataconite iron-formation, Wabush Lake, Labrador, Newfoundland, and Lac Jeannine, Quebec, or the itabirite deposits in Minas Gerais, Brazil. Included here are metamorphosed iron-formations that have undergone extensive recrystallization and can be concentrated without grinding finer than 100 mesh.
- *Type F*) Pyrite-rich iron-formations of potential ore value.
- *Type G*) Other types of iron-formation of distinctive character found in local areas.

III RESIDUAL DEPOSITS, AND CHEMICALLY AND MECHANICALLY TRANSPORTED SURFACE DEPOSITS.

- *Type A*) Steep Rock Lake type, Steep Rock Range, Ontario. Buried residual accumulations of iron minerals on regoliths, with subsequent alteration of iron minerals and redistribution of iron. Mainly massive to crudely banded red and brown hard rubbly hematite and goethite ores of direct shipping quality.
- *Type B*) Residual deposits, Londonderry area, Nova Scotia; Bilbao, Spain.
- *Type C*) Laterite deposits developed by surficial oxidation and supergene enrichment of rocks other than iron-formation, Conakry, French Guinea.
- *Type D*) Bog Iron deposits, St. Maurice, Quebec. Iron is transported chemically and precipitated near or on the surface.
- *Type E*) Placer deposits and deposits formed by mechanical concentration of iron minerals. Iron sands of the North Shore of the St. Lawrence River, or the Charleson hematite gravel deposit south of Steep Rock Lake.

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[1] For definition of iron-formation see Chap. V, Vol. I, Gross, 1965

IV DEPOSITS DIRECTLY ASSOCIATED WITH PLUTONIC ROCKS

Type A) The St. Charles deposit, Bourget township, Quebec; or Chaffey mine at Newboro Lake, Ontario. Layered, disseminated, interstitial, and injected magnetite with minor hematite and ilmenite in basic and ultrabasic rocks.

Type B) Allard Lake deposits, Quebec; or Taberg type of deposit in Sweden. Layered, disseminated, interstitial, and injected ilmenite with magnetite and hematite in anorthosite rocks.

Type C) Stephenville, Newfoundland. Deposits in acid intermediate rocks or in alkalic rocks. Massive and disseminated ores in these rock types. Further subdivision may be based on types of host rock.

V SKARN, CONTACT METASOMATIC, VEINS, AND STRUCTURALLY CONTROLLED EMPLACEMENTS OF IRON MINERALS.

Type A) Texada Island, British Columbia; Marmora deposit, Ontario. Skarn, contact metasomatic deposits or high temperature replacement deposits.

Type B) Forsyth deposit, near Hull, Quebec. Veins with minor replacement, deposited under structural control.

Type C) Disseminated magnetite, iron oxides, and iron minerals that are probably of replacement origin and deposited under structural control in shear zones and other structural features.

Type D) Noranda deposits, Quebec. Massive and disseminated iron sulphide bodies, may contain base metals and other ore minerals.

VI OTHER TYPES OF DEPOSITS

Appendix II

Properties in Maritime Provinces, Eastern Townships, and Gaspé

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		Newfoundland		
1	II A	Wabana	47°45′	52°55′
2	II C	Aldery Brook near Grand Lake	49°98′	57°02′
3	II D	Mt. Calapoose-St. Lawrence Harbour	46°52′	55°20′
4	II D	Ming's Bight-White Bay	49°55′	56°00′
5	II F	Lock Port pyrite mine, Notre Dame Bay	49°30′	55°17′
6	III D	Terra Nova, Bonavista south	48°27′	54°20′
7	IV C	Skinner prospect and Mountain ore prospect, Port au Port-Stephenville area	48°30′	58°25′
8	IV C	Flat Bay Brook, St. George's-Port au Port	48°20′	58°20′
9	V A	31 occurrences, Stephenville-Indian Head-Gull Pond area	48°30′	58°25′
10	V A	Southwest Brook, St. George's-Port au Port	48°26′	57°52′
11	V B	Sop's Arm, White Bay	49°43′	56°54′
12	V B	Snook's Arm, Green Bay, Notre Dame Bay	49°48′	55°56′
13	V B	Cook's iron mine, Fortune Harbour, Notre Dame Bay	49°30′	55°17′
14	V B	Hickey's Pond, northwest end of Placentia Bay	47°48′	54°15′
15	V B	Bay de Verde, Conception Bay	47°45′	52°55′
16	V B	Snow's Pond, Port de Grave, Conception Bay	47°30′	53°25′
17	V C	Tilt Cove, Green Bay north	49°49′	55°42′
		Nova Scotia		
18	II A	Grand Mira south, Cape Breton county	45°52′	60°18′
19	II A	Antigonish-Arisaig area	45°50′	62°08′
20	II A	Arisaig	45°45′	62°08′
21	II A	Merigomish area, Pictou county	45°38′	62°32′
22	II A	Sutherland-Meiklefield, Pictou county	45°28′	62°32′
23	II A	Nictaux-Torbrook, Annapolis county	44°55′	65°00′
24	III B	Londonderry area (East Mines, Old Mountain workings, West Mines)	45°30′	63°40′
25	V A	Boisdale-McPherson mine	46°10′	60°25′
26	V A	Upper Glencoe, Inverness county	46°00′	61°10′
27	V A	Bass River, Colchester county	45°28′	63°45′
28	V A	Gerrish Mountain, Colchester county	45°25′	64°00′
29	V A	Scott's Bay Village, Kings county	45°18′	64°25′
30	V A	Northwest of Kentville, Kings county	45°10′	64°35′
31	V B	Coxheath Hills, Cape Breton county	46°08′	60°25′
32	V B	Curry Mine and Ingraham Mine, Boisdale, Cape Breton county	46°10′	60°25′
33	V B	East of Louisburg, Cape Breton county	45°55′	59°40′
34	V B	Marion Bridge, Cape Breton county	45°58′	60°15′
35	V B	East Bay, Cape Breton county	45°55′	60°25′
36	V B	Loch Lomond, Cape Breton county	45°50′	60°32′
37	V B	Morrison Head, Richmond county	45°40′	60°35′
38	V B	Whycocomagh area, Inverness county	46°00′	61°05′
39	V B	Arichat, Isle Madame	45°50′	61°00′
40	V B	Moose Point, Guysborough county	45°24′	61°31′
41	V B	Burns mine, Erinville area, Guysborough county	45°23′	61°50′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
42	V B	Roman Valley area, Guysborough county	45°30′	61°50′
43	V B	Numerous small veins, southern Antigonish county	45°30′	62°00′
44	V B	Brown's Mountain, Antigonish county	45°40′	62°06′
45	V B	Clifton Mine, Colchester county	45°22′	63°23′
46	V B	Brookfield (Chambers and Pearson mines), Colchester county	45°15′	63°18′
47	V B	Clementsport, Annapolis county (Potter, Milner, and Milbury mines)	44°35′	65°40′
48	VI	East River area, Pictou county	45°27′	62°35′
49	VI	Maitland, Hants county	45°20′	63°35′
50	VI	Goshen area, Hants county (Laner, Goshen, Tomlinson mines)	45°10′	64°10′
51	VI	Upper Economy River, Colchester county	45°31′	63°58′
52	VI	Lower Five Islands, Colchester county	45°25′	64°05′
53	VI	Wheelock and Martin mines, Torbrook area, Annapolis county	45°01′	64°43′
		New Brunswick		
54	II D	Pabineau River Iron-formation, Gloucester county	47°26′	65°55′
55	II E	Bathurst mines, Gloucester county	47°24′	65°48′
56	II G	Woodstock Fe-Mn formations, Carleton county	46°10′	67°30′
57	III D	Tracadie bog iron, Gloucester county	47°30′	64°55′
58	III D	Miramichi (Oak Mountain), York county	45°55′	66°40′
59	V A	Millstream magnetite, Gloucester county	47°40′	65°53′
60	V A	Deer Island, Charlotte county	44°55′	67°00′
61	V B	Cape St. Vincent to Black River, Saint John county	44°10′	65°50′
62	V B	Musquash Harbour, Saint John county	45°08′	66°13′
63	V B	St. George, Charlotte county	45°08′	66°50′
64	V C	Lepreau, Charlotte county	45°08′	66°30′
65	VI	Maugerville, Sunbury county	45°45′	66°35′
66	VI	Clarendon Road, Queen's county	45°22′	66°24′
67	VI	Grand Manan Island	44°40′	66°50′
		Eastern Townships and Gaspé		
68	II C	Deslandes tp., Gaspé-Nord county	48°55′	65°50′
69	II D	Bolton tp., Brome county	45°15′	72°20′
70	III D	Ireland tp., Megantic county	46°05′	71°25′
71	IV A	Beauceville, Beauce county	46°15′	70°50′
72	IV A	Ham—Sud tp., Wolfe county	45°45′	71°30′
73	IV A	Yamaska Mountain, Ste. Hyacinthe county	45°27′	72°52′
74	IV A	Sutton tp., Brome county	45°05′	72°40′
75	V B	Baie-de-Gaspé, Nord county	48°55′	64°25′
76	V B	Inverness tp., Megantic county	46°15′	71°35′
77	V B	Dunham tp., Missisquoi county	45°05′	72°50′
78	V C	Leeds iron mine, Megantic county	46°15′	71°05′
79	V C	Smith and Belvedere mines, Ascot tp., Sherbrooke county	45°30′	71°55′
80	VI	Seigneurie de Pabos, Gaspé sud	48°25′	64°40′
81	IV	Newport, Gaspé sud	48°15′	64°50′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
82	VI	Cranbourne tp., Dorchester county	46°20′	70°35′
83	VI	Spaulding tp., Frontenac county	45°40′	70°45′
84	VI	Chester tp., Arthabaska county	46°05′	71°45′
85	VI	Cleveland tp., Richmond county	45°40′	72°05′
86	VI	Sutton tp., Brome county	45°15′	72°20′
87	VI	St. Armand East, Missisquoi county	45°05′	72°52′

Appendix III

Properties in Eastern Ontario and Southeastern Quebec

See Figures 7 and 8

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		Quebec		
		SAGUENAY COUNTY		
		Iron-rich (magnetite sands)		
1	III E	Moisie tidal and terrace sands	50°15′	66°00′
2	III E	St. Jean River to Mingan (between Long Point and St. Jean River)	50°18′	64°12′
3	III E	Mingan magnetite sands	50°18′	64°00′
4	III E	Natashquan	50°05′	61°45′
5	III E	Manicouagan Peninsula (near Baie Comeau)	49°10′	68°12′
6	III E	Betsiamites (between Betsiamites and Papinachois Rivers)	48°58′	68°40′
7	III E	Laval tp.	48°45′	69°02′
		Ilmenite Deposits		
8	IV B	Allard Lake and vicinity	50°30′	63°30′
		(a) Lac Tio		
		(b) Cliff		
		(c) Lac Ellen		
		(d) Grader		
		(e) Between Ilmenite Bay and Froide Bay		
		(f) South tip of Isle Ste. Helene		
		(g) 20 feet north of (f)		
		(h) West side of Allard Lake		
		(i) Rouge Point-NE Allard Lake		
		(j) Petit Pas Lake-east of (i)		
		(k) Puyjalon Lac (east side)		
9	IV B	St. Jean River	50°25′	64°11′
10	IV B	Thunder River (Rivière au Tonnerre)	50°20′N	64°43′W
		Titaniferous Magnetite Deposits		
11	IV	Letellier (9)	50°23′	66°26′
12	IV A	Chaloupe—Cap Rond (Rivière aux Graine)	50°20′	65°15′
13	IV A	Bailloquet tp.	50°23′	65°15′
14	IV A	Gad Lake-south end of Manitou Lake	50°50′	65°20′
15	IV A	Magpie property	51°27′	64°04′
16	IV A	Clarke City (Ste. Marguerite River)	50°17′	66°40′
17	IV A	Lac de la Blanche—Hervieux Lake area	50°00′	69°30′
18	IV A	Matonipis area	51°50′	69°40′
		CHICOUTIMI COUNTY		
		Titaniferous Magnetite		
19	IV A	Bourget tp.	48°31′	71°28′
		St. Charles mine and nearby occurrences — Saguenay River area		
		Range I, lots 34, 35		
		lots 44-47		
		(St. Charles)		
		II, lot 49		
		III, lots 45-47		

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
20	IV A	Kenogami tp.	48°25′	71°30′
21	IV A	Taché tp.	48°35′	71°30′
22	IV A	Pambrum Lake	51°42′	70°40′
23	IV A	Lac au Poivre	49°04′	70°50′
		Others—types occurrences		
	VI	Float Boulders—Kenogami tp.	48°25′	71°30′
		St. Jean County		
		Titaniferous Magnetite		
25	IV A	Ile d'Alma	48°35′	71°45′
26	IV A	Taillon tp. Peribonka River	48°45′	71°55′
		Roberval County		
		Titaniferous Magnetite Occurrences		
27	IV A	Lyonne tp.	48°28′	72°42′
28	IV A	Rinfret tp., Chibougamau	49°55′	73°55′
29	IV A	La Trappe tp.	49°10′	72°14′
30	IV A	Antoine tp.	49°07′	72°25′
31	IV A	Hubert tp.	49°15′	72°35′
32	IV A	Ashuapmouchouan tp.	48°35′	72°35′
33	IV A	Des Soers Lake, Chabanel tp.	48°15′	72°30′
		Superior Type		
34	VI	Lorne-Avaugour area (only float)	49°25′	73°30′
		Charlevoix County		
35	IV B	Ilmenite Deposits	47°32′	70°34′
		St. Urbain Area		
		Glen Prospects—lot 312		
		Joseph Bouchard prospect—lot 622		
		Coulombe orebody—lot 319		
		Two General Electric orebodies—lots 321 and 325		
		Bignell orebody—lot 608		
		Furnace or Courneau mine—lot 363		
36	IV B	Brassard deposit near Ste. Agnes	47°40′	70°30′
		Portneuf County		
37	VI	Chavigny-Dulac prospect	46°55′	72°20′
		Champlain and Laviolette Counties		
		Laviolette county		
38	III E	Normand tp.–Wakaumekonke Lake-sands	47°05′	73°25′
		Champlain county		
39	III E	Champlain and Batiscan magnetic sands	46°29′	72°20′
40	III D	Bog iron near St. Maurice	46°28′	72°20′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		ST. MAURICE COUNTY *Titaniferous Magnetite*		
41	IV A	St. Boniface-Grondin or Shawinigan mine	46°32′	72°50′
		MONTCALM COUNTY		
42	IV A	Chilton tp.	46°15′	74°05′
43	IV A	Rawdon tp. S. of St. Theodore near St. Julienne	45°55′	73°42′
44	IV B	Beresford tp.-Ivry mine	46°09′	74°20′
45	IV B	Beresford tp.–Desgrosbois	46°10′	74°23′
46	IV B	St. Hippolyte-Wexford tp.	45°56′	74°02′
47	IV B	Wexford tp.	45°58′	74°04′
48	IV B	Wolfe tp.-St. Faustin	46°08′	74°32′
49	V C	Abercrombie tp.-St. Jerome	45°46′	74°04′
50	IV B	St. Theodore	46°04′	73°52′
		ARGENTEUIL COUNTY		
51	V A	Grenville-magnetite	45°40′	74°32′
52	IV A	Arundel-Harrington east	45°54′	74°40′
53	V A	Wentworth-magnetite	45°45′	74°25′
54	IV A	Morin Heights	45°56′	74°20′
		LABELLE COUNTY		
55	III D	B-Marchand ochre-along Rouge River near L'Annonciation	46°25′	74°58′
56	V A	Montigny-magnetite near Lac Montjoie	46°25′	75°08′
		PAPINEAU COUNTY		
57	VI	Templeton-Haycock mine area	45°40′	75°40′
		GATINEAU COUNTY		
58	V A	Hull iron range-ranges VI and VII, Baldwin mine Forsyth mine Lawless mine	45°30′	75°48′
59	IV A	Hull	45°38′	75°45′
60	IV A	Wakefield tp.	45°45′	75°50′
61	IV A	Denholm tp.	45°49′	75°53′
62	VI	Hincks tp.	46°01′	75°54′
63	V A	Blake tp.	46°02′	75°48′
64	V A	Cameron tp.	46°12′	75°57′
		PONTIAC COUNTY *Titaniferous Magnetite*		
65	IV A	Calumet Falls	45°40′	76°42′
66	IV A	Litchfield	45°46′	76°38′
67	IV A	Clarendon	45°38′	76°35′
68	IV A	Bristol	45°29′	76°22′
69	IV A	Waltham	45°55′	76°58′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		Magnetite		
70	V A	Calumet	45°45′	76°40′
71	V A	Hilton mine formerly Bristol deposit	45°30′	76°22′
72	V A	Leslie tp.-Otter Lake	45°51′	76°21′
73	V A	Hainaut tp.-Altud Lake	46°47′	76°38′
74	V A	Hainut-Lac de Renzy	46°48′	76°42′
		Algoma		
75	II D	Houdet tp.-Cuff Lake	47°02′	77°08′
		Vein Type		
76	V B	Calumet	45°47′	76°40′
		Miscellaneous		
77	II F	Iron pyrite-Clarendon tp.	45°35′	76°40′
78	VI	Clarendon tp.	45°35′	76°40′
		TEMISCAMINGUE COUNTY		
79	V B	Gendreau tp., Kipawa Lake	46°52′	79°00′
80	V A	Guillet tp.	47°12′	78°25′
		ABITIBI EAST		
81	IV A	Comporte tp.–Shallow Lake	49°40′	77°30′
82	IV A	Isle-Dieu tp.-Bell River	49°40′	77°40′
83	IV A	Roy tp.-Chibougamau Lake (several deposits)	49°55′	74°05′
		Eastern Ontario		
		LANARK COUNTY		
		Magnetite Deposits		
84	V A	Radenhurst and Caldwell mines, Lavant tp.	45°10′	76°39′
85	V A	Yuill mine, Darling tp.	45°13′	76°34′
86	V C	Wilbur mine, Lavant tp.	45°02′	76°40′
87	VI	Foley mine, Bathurst tp.	44°54′	76°26′
88	VI	Maberly (2 along railroad), Sherbrooke tp.	44°50′	76°32′
89	V A	Christie Lake, S. Sherbrooke tp.	44°49′	76°26′
90	VI A	Silver Lake, S. Sherbrooke tp.	44°48′	76°28′
91	VI A	Fournier mine, S. Sherbrooke tp.	44°46′	76°29′
92	V A	Bygrove mine, S. Sherbrooke tp.	44°44′	76°30′
		Hematite		
93	III B	Dalhousie or Playfair mine	44°59′	76°24′
94	V B	White Lake-Darling tp. scattered occurrences	45°16′	76°29′
		LEEDS COUNTY		
		Titaniferous Magnetite		
95	IV A	Matthew's mine	44°38½′	76°21′
96	IV A	Chaffey mine	44°38′	76°20′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		Renfrew County		
		Magnetite		
97	V A	Williams mine, Bagot tp.	45°18	76°45′
98	VI	Martel mine, Bagot tp.	45°17′	76°40′
99	V A	Culhane mine, Bagot tp.	45°20′	76°42′
100	V A	Bluff Point, Bagot tp.	45°17½′	76°40′
101	V A	Calabogie deposit, Campbell and Caldwell mines, Bagot tp.	45°18′	76°40′
102	V A	Dacre and vicinity, Brougham tp.	45°22′	76°59′
103	V A	Radnor mine and vicinity, Grattan tp.	45°26′	77°01′
		Hematite		
104	V B	McNab mine–Arnprior, McNab tp.	45°26′	76°22′
		Titaniferous Magnetite		
105	IV A	Horton tp. (along Otter River)	45°34′	77°40′
106	IV A	Blythfield	45°15′	77°43′
		Frontenac County		
		Magnetite Occurrences		
107	V C	Black Lake	44°37′	76°37′
108	V C	Glendower workings, Zainesville Iron Co.	44°36′	76°38′
109	II D	Wolfe Lake	44°40′	76°30′
110	V A	Mary and Robertsville mines	44°54′	76°40′
		Titaniferous Magnetite Occurrences		
111	IV A	Eagle Lake, Blessington mine	44°42′	76°40′
		Hastings County		
		Magnetite		
112	V C	Mount Pleasant, Tyendinaga tp.	44°15′	77°03′
113	V C	Banker's Lake, Madoc tp. Dominion mines	44°30′	77°32′
114	VI	Seymour mine, Madoc tp.	44°32′	77°33′
115	V A	Hobson mine, Madoc tp.	44°35′	77°35′
116	V A	Nelson mine, Madoc tp.	44°34′	77°35½′
117	V A	Knob mine, Madoc tp.	44°35′	77°34½′
118	V A	Marmoraton mine and	44°28′	77°40′
119	V A	Maloney mine, Marmora tp.	44°43′	77°48′
120	V A	MacDonald-St. Charles mine, Tudor tp.	44°46′	77°38′
121	V A	Lee mine, Tudor tp.	44°49′	77°40′
122	V A	Baker mine, Tudor tp.	44°49½′	77°40′
123	V A	Emily mine, Tudor tp.	44°50′	77°38′
124	VI	Ridge area, Wollaston tp.-includes series of small maps Ridge, Eagle Lake, John Lake, Snow Lake, McMurray Lake, and Vader Lake	44°49′	77°50′
125	V A	Jenkins mine, Wollaston tp.	44°51′	77°52′
126	V A	Coehill mine, Wollaston tp.	44°52′	77°51′
127	V A	Childs mine, Mayo tp.	45°06′	77°35′
128	VI	Rankin mine, Mayo tp.	45°05′	77°36′
129	V A	Bessemer mine, Mayo tp.	45°03′	77°38′
130	V A	Quarry Lake anomaly, Dungannon tp.	45°02′	77°49′
131	V A	Carfrae anomaly, Faraday tp.	45°02′	77°52′
132	V A	Bow Lake deposits, Faraday tp.	45°01′	77°57′
133	V A	Boulter occurrences, Faraday tp.	45°12′	77°40′

Map No.	Type	Deposit	Location (approx.)	
			Lat.	Long.
		Titaniferous Magnetite		
134	IV A	Ricketts mine, Lake tp.	44°43′	77°42′
135	IV C	Orton (Horton) occurrences, Tudor tp.	44°44′	77°40′
		Hematite Occurrences		
136	III B	Wallbridge mine, Madoc tp.	44°35′	77°32′
137	VI	St. Charles mine, Madoc tp.	44°31′	77°28′
138	III B	Eldorado Copper mine, Madoc tp.	44°36′	77°32′
139	VI	Brennan mine, Madoc tp.	44°32′	77°29′
		Miscellaneous		
140	II D	Iron-formation, Ormsby Junction, Limerick tp.	44°52′	77°42′
		HALIBURTON COUNTY		
		Magnetite Deposits		
41	V A	Paxton mine, Lutterworth tp.	44°50′	78°37′
142	V A	Victoria mine, Snowdon tp.	44°50′	78°34′
143	V A	Howland mines-Irondale occurrence, Snowdon tp.	44°51′	78°32′
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