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ECONOMIC GEOLOGY
REPORT No. 22

GEOLOGY OF IRON DEPOSITS IN CANADA

Volume III
Iron Ranges of the Labrador Geosyncline

G. A. Gross

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1968

GEOLOGY OF IRON DEPOSITS IN CANADA

Volume III

Iron Ranges of the Labrador Geosyncline

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

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PLATE I. Ruth Lake mine, Labrador, Newfoundland, in foreground and Burnt Creek mine, Quebec, to far left, in the Knob Lake iron range. View northeastward, 1960.

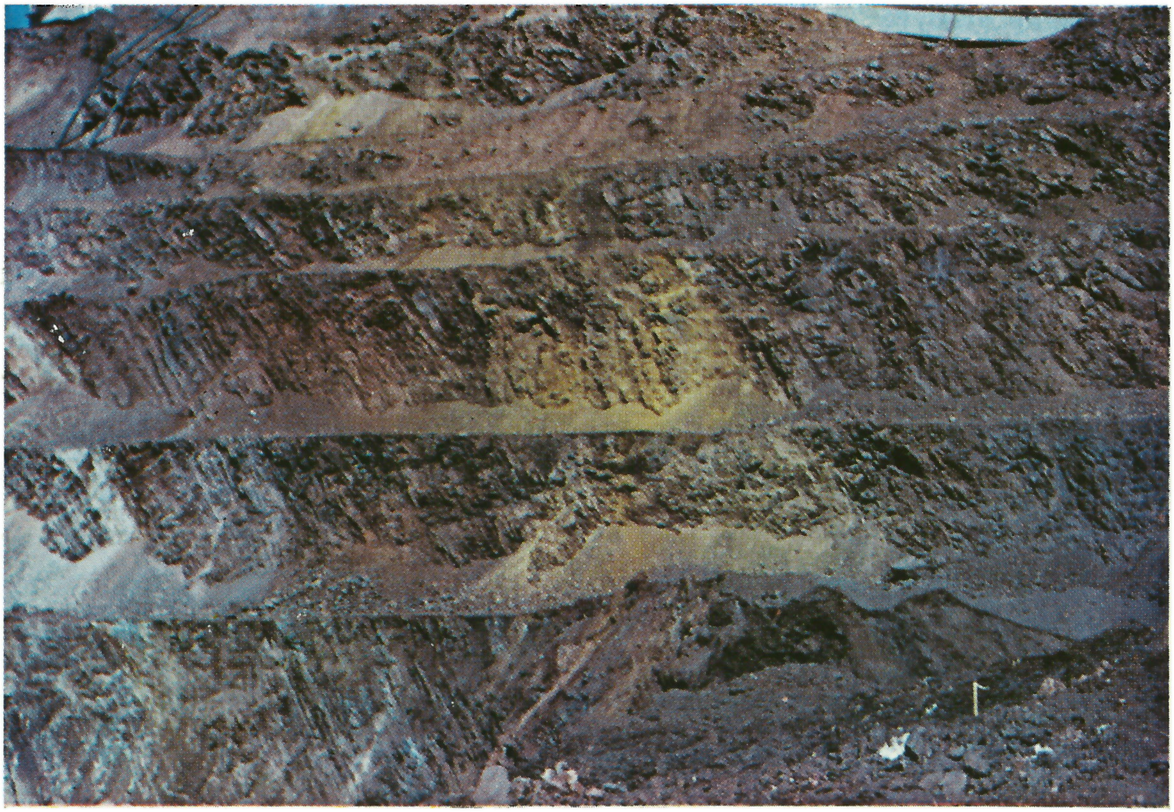

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PLATE II. Red, yellow, and blue types of hematite–goethite iron ore derived from slate, silicate–carbonate, and jasper oxide facies of iron-formation on the north side of French mine, Knob Lake iron range, 1962. Note the transition at left from red type ore to leached non-ferruginous slate.

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PREFACE

The iron ranges of Quebec and Labrador are part of one of the world's principal iron belts. Although production started in 1954, already more than 100 million tons of natural and concentrated ore has been shipped.

This report, the first publication to give a comprehensive account of the entire region, is therefore of particular interest and importance. Both the theoretical aspects of the nature and origin of the various types of deposit and the practical application of the conclusions to the discovery, evaluation, extraction, and beneficiation of the ore are considered.

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

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, April 30, 1965

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ДОКЛАД ОБ ЭКОНОМИЧЕСКОЙ ГЕОЛОГИИ

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Г. А. Гросс. Залежи железных руд Канады, том III: Пределы залежей железных руд Лабрадорской геосинклинали.

Научный труд описательного характера о типичных залежах железных руд разных сортов с упором на их геологию и происхождение.

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IRON RANGES OF THE LABRADOR GEOSYNCLINE

Abstract

The iron ore deposits, regional geology, and potential ore zones in the Quebec-Labrador iron belt are described in this third volume of the *Geology of Iron Deposits in Canada*. The iron ranges are part of a folded belt of Precambrian sedimentary, volcanic, and metamorphic rocks known as the Labrador geosyncline, which extends southeast for 700 miles from Ungava Bay to within 200 miles of the St. Lawrence River. Cherty iron-formation 200 to 800 feet thick and continental shelf-type sediments are highly folded and faulted and exposed continuously along the western part of the belt. Rocks in the central and western parts of the belt belong to the lower greenschist metamorphic facies, but north of Lac Bérard (formerly Finger Lake) and eastward metamorphism reached epidote amphibolite rank or higher. The southern part of the geosyncline lies within the Grenville Province of the Precambrian Shield where at least two ages of folding have taken place and all rocks are highly deformed and metamorphosed. Fault blocks along the northwest boundary of this province are separated by steeply dipping faults with reverse dip-slip movement, and the iron-formation occurs in isolated and complex structural segments.

Iron ore was first mined in 1954 from the Knob Lake iron range in the central part of the belt where more than 400 million tons of hematite–goethite ore occurs in 45 deposits within an area 12 miles wide and 65 miles long. Red, yellow, and blue types of direct shipping ore were developed from slate, silicate–carbonate, and iron oxide facies of Superior type cherty iron-formation. This was effected during Mesozoic time by descending groundwater leaching silica and oxidizing the iron beds.

The metamorphosed magnetite–hematite–quartz iron-formations west of Ungava Bay are a potential source of metataconite ore. More than two billion tons of crude ore carrying from 22 to 36 per cent iron with an average grade of more than 30 per cent recoverable iron has been proved by work to date, another two billion tons has been indicated, and considerably more is inferred in the region.

Ore concentrate was first shipped in 1961 from the large metataconite ore deposits in the southern part of the belt. Facilities are installed near Wabush Lake, Labrador, and at Lac Jeannine, Quebec, for treating magnetite–hematite–quartz iron-formation containing 30 to 38 per cent iron and producing annually 20 million tons of ore concentrate and pellets carrying 65 per cent iron. At least ten billion tons of metataconite ore containing four billion tons of ore concentrate has been indicated in this southern area and considerably more ore is inferred.

Résumé

L'auteur décrit les gisements de minerai de fer, la géologie régionale et les zones présumées ferrifères du Québec-Labrador dans ce troisème volume de *Geology of Iron Deposits in Canada*. Les massifs de fer font partie d'une zone plissée de roches sédimentaires, volcaniques et métamorphiques du Précambrien, connue sous le nom

de géosynclinal du Labrador, qui s'étend au sud-est sur une distance de 700 milles à partir de la baie d'Ungava jusqu'à moins de 200 milles du fleuve Saint-Laurent. Une formation ferrifère en couches siliceuses compactes d'une épaisseur de 200 à 800 pieds et des sédiments apparentés au plateau continental sont très plissés et faillés; ils affleurent tout le long de la partie ouest de la zone.

Les roches des parties centrale et occidentale de la zone appartiennent au faciès métamorphique inférieur de schiste vert, mais, au nord du lac Bérard (autrefois Finger Lake) et vers l'est le métamorphisme a atteint le stade d'amphibolite à épidote ou un stade plus avancé. La partie sud du géosynclinal s'étend à l'intérieur de la province de Grenville du bouclier Précambrien où au moins deux périodes de plissement ont eu lieu et toutes les roches sont considérablement déformées et métamorphisées. Les blocs de faille le long de la limite nord-ouest de cette province sont séparés par des failles à fort pendage avec mouvement opposé de plongement, et la formation ferrifère se trouve dans des segments de structure isolés et complexes.

Le minerai de fer a été extrait pour la première fois en 1954 dans le massif ferrifère du lac Knob au centre de la zone où 45 gîtes renferment plus de 400 millions de tonnes de minerai hématite–goethite dans une bande de terrain de 12 milles de largeur sur 65 de longueur. Il y a toute une gamme de minerais que l'on expédie à l'usine directement de la mine: des rouges, des jaunes et des bleus. Ils ont été extraits de formations contenant des ardoises, des carbonates et des silicates ainsi que des oxydes de fer dont le faciès s'apparente à celui du minerai de la région du lac Supérieur. Cela s'est accompli au cours de la période Mésozoïque par l'eau souterraine qui lessivait au passage la silice et oxydait les strates ferrifères.

Les formations de magnétite, d'hématite et de quartz métamorphosés à l'ouest de la baie d'Ungava sont une source potentielle de minerai de métataconite. Des réserves de plus de deux milliards de tonnes de minerai brut d'une teneur de 22 à 36 p. 100 en fer et une moyenne de plus de 30 p. 100 de métal récupérable ont été reconnues jusqu'à présent; on est certain d'en trouver deux autres milliards de tonnes et il est probable que la région en contient encore beaucoup plus.

Du minerai concentré a été expédié pour la première fois en 1961 à partir des vastes gisements de métataconite dans le sud de la zone. Des ateliers sont installés dans le voisinage du lac Wabush, au Labrador, et au lac Jeannine, au Québec, pour le traitement des formations de minerais ferrifères à base de magnétite, d'hématite et de quartz d'une teneur de 30 à 38 p. 100 en fer et produisant annuellement 20 millions de tonnes de concentré et des boulettes titrant 65 p. 100 de fer. Au moins dix milliards de tonnes de minerai de métataconite contenant quatre milliards de tonnes de concentré ont été supputées dans le sud de cette région et il y en a probablement beaucoup plus.

Chapter I

INTRODUCTION

The iron ranges along the western and central parts of the Labrador geosyncline form one of the major sedimentary iron belts of the world. They are exposed almost continuously in a narrow sinuous belt of Proterozoic rocks that extends for more than 750 miles from Hudson Strait through northeastern Quebec and western Labrador to near Pletipi Lake in central Quebec. The Labrador geosyncline is the longest continuous segment in a chain of Proterozoic rock belts containing iron-formations that borders a large craton in the eastern Precambrian Shield. This craton is bordered on the east and south by the Labrador geosyncline and the Lake Mistassini range, and on the north and west by the Cape Smith–Wakeham Bay belt, the Nastapoka and Belcher Islands, and the Sutton Lake iron ranges.

Exceptionally large reserves of low grade iron ore have been proven in the southwestern and far northern parts of the Labrador belt, and large reserves of high grade ore have been proven in the central part. During recent years, large-scale development and production of ore in this region has made the Labrador geosyncline one of the most important sources of iron ore in the world.

Although the existence of a major belt of iron-formation in this region was recognized as early as 1895 and deposits of high grade ore were discovered in 1929, the first iron ore shipped was in 1954 from the Knob Lake area in the central part of the belt. The possible size and extent of the metamorphosed iron-formations in the southwestern part of the geosyncline and their potential advantages as a source of low grade material for concentration were not generally appreciated until about 1952, and commercial concentrates were first shipped from the region in 1961. Most of the geosyncline has been covered by reconnaissance mapping since 1950, but only a small part of this major geological feature has been explored in detail. Because of these facts, the development of large ore reserves and the completion of the major construction projects required to bring them into production in this remote region constitute some of the outstanding pioneering achievements in Canada.

Iron is undoubtedly the most important mineral commodity in the region and probably will be for a long time, but deposits of a number of other minerals have been discovered. These have not, however, proved to be of commercial value. Nickel, copper, and zinc sulphides occur in the volcanic and intrusive rocks on the east side of the geosyncline and asbestos minerals are present in the ultrabasic rocks and in

MS. received August 1963. Report is based on information available prior to September 1962.

minor quantity in some of the iron-formation. Conditions are favourable in the southwestern part of the geosyncline for the occurrence of several types of metallic and especially non-metallic mineral deposits. Occurrences of manganese, graphite, cobalt, kyanite, and limestone are known, and there is a possibility of recovering mica, clay, silica, and other non-metallic materials as commercial by-products from the concentration of iron ore. Utilization of the huge potential hydro-electric power resources in the region for smelting the iron ore and processing other commodities is expected to lead to a more advanced stage of development and industrialization of this region in the future.

Acknowledgments

The author has made extensive use of published material and information from mining companies in his study of the Labrador geosyncline. Sources of information have been acknowledged directly throughout the report wherever possible. Private discussions with geologists and engineers have been of special benefit during the seven years of field work in various parts of this region.

The writer is particularly indebted to the mining companies who have permitted detailed examination of their properties, provided documentary information, and extended their hospitality. Special acknowledgment is given for assistance received from Labrador Mining and Exploration Company Limited, Iron Ore Company of Canada, Wabush Iron Co. Limited, Quebec Cartier Mining Company, Jones & Laughlin Steel Corporation, and Normanville Mining Company. The cooperation of the Geological Surveys Branch, Department of Natural Resources, Quebec, and the Department of Mines and Resources, Newfoundland, was greatly appreciated. Consultations during this study with company officials, colleagues in the Geological Survey of Canada, the Mines Branch, and the provincial mining departments are fully acknowledged.

Exploration and Development History

The coast of Labrador and Newfoundland was probably the first part of North America to be visited by Europeans, but the inland region between Hudson Bay and the Labrador coast remained relatively unknown until the early 1940's. The first expeditions by Europeans to this continent are believed to have been those of the Norsemen to Labrador and Newfoundland; these were followed by explorers sponsored in Spain, England, and France. Eventually Hudson travelled into the inland coastal regions of Hudson Bay in his search for a northwest passage to the Orient. Indications of the iron occurrences in the inland regions were recognized as early as 1870 by the missionary-explorer Father Pierre Babel, but A. P. Low of the Geological Survey of Canada was the first geologist to reconnoiter the Ungava Peninsula. During his remarkable exploration between 1893 and 1895 he recognized the Labrador geosyncline with its iron-formations as a major geological feature with particular economic potential.

Very little attention was given to the region for many years after Low's exploration, because of its remoteness and the arduous, time-consuming methods of travel.

When air travel became available, mining companies began to probe the interior of the peninsulas, and in 1929 a party directed by W. F. James and J. E. Gill, who were primarily interested in searching for gold, discovered the first material of ore quality near Knob Lake. In 1933 the iron-formations in the Wabush Lake area were also examined. The Labrador Mining and Exploration Company acquired a 20,000-square-mile concession covering the geosyncline belt in Labrador in 1936 and the Hollinger North Shore Exploration Company Limited acquired a large adjoining concession to the north, in Quebec, in 1941. In 1936 exploration was started by the Labrador Mining and Exploration Company on land now held by these companies, and in 1937 Mathieu André, a Montagnais trapper who knew the region, showed J. A. Retty the hard hematite deposit near Sawyer Lake. The following year Retty discovered potential iron ore in New Quebec north of the previous discovery in Labrador made by James and Gill.

Towards the close of World War II, with the rapid depletion of iron ore reserves in the Lake Superior region and the financial participation by the Hanna Coal and Ore Corporation with Labrador Mining and Exploration Company, exploration for iron in Quebec and Labrador received a new impetus. A large tract of land in the Mount Wright area in Quebec was investigated by the United Dominion Exploration Company Limited in 1947 and 1948, and a number of other concessions in the central geosyncline area north of Knob Lake were explored by iron companies in the late 1940's.

By 1949, more than 400 million tons of direct-shipping quality ore had been proven in the Knob Lake–Sunny Mountain ore zone and the Iron Ore Company of Canada, with financial participation by the Hollinger North Shore Exploration Company Limited, Labrador Mining and Exploration Company Limited, Hanna Coal and Ore Corporation of the United States, and five other American steel companies and Canadian and American insurance companies, was formed to develop the area and to operate the mines. The first ore was shipped on schedule in 1954 over 360 miles of newly constructed railroad to ore docks established on the natural harbour at Sept-Iles on the Gulf of St. Lawrence.

While this railroad construction was being carried out, a number of other companies began to explore the metamorphosed iron-formations in the southwestern and northern parts of the geosyncline, and Labrador Mining and Exploration Company began a more extensive investigation of the eastern part of their concession for base metal and other mineral deposits. Reconnaissance by this company in the southern part of their concession in 1949 and 1950 indicated the possible regional extent of the iron-formations around Wabush Lake. Exploration for iron ore at the southwest end of the belt around Matonipi Lake was started in 1951 under joint sponsorship by the W. S. Moore Company of Duluth, Minnesota, and by the Oliver Iron Mining Division of United States Steel Corporation. During the following years the United States Steel group examined a large part of the area between Matonipi Lake and Mount Wright guided by extensive airborne magnetometer surveys. They acquired and explored in detail several thousand claims with their largest holdings centred around Mount Reed, Lac Jeannine, and Mount Wright. Exploration by Quebec Cobalt around Bloom Lake in 1951 and by Bellechasse Mining Company northeast of Moiré Lake the following year, outlined other large areas of iron-formation which were acquired later by Jones & Laughlin Steel Corporation and other interests who have continued exploration in this area. Reconnaissance mapping by the Newfoundland and Labrador Corporation in 1953 revealed other large areas of iron-formation southeast of Wabush Lake; Canadian Javelin Limited investigated these deposits, completing some development work prior to their being taken over by Wabush Iron Company in 1957. This company was formed by Pickands Mather & Co. The Steel Company of Canada, Limited, and a number of other steel companies have since joined the group to participate in development of the deposits.

The Geological Survey of Canada started reconnaissance mapping in 1949 in the Knob Lake area and in the following ten years covered most of the geosyncline area between latitude 52 and 58 degrees. Since 1955 Geological Survey parties of the Quebec Department of Mines have mapped a large area north of latitude 58 degrees and other areas in the vicinity of Mount Wright and Mount Reed.

About 1946 or later mining companies were granted a number of concessions that covered most of the geosyncline between the Hollinger North Shore Exploration Company concession north of Schefferville, and Fort-Chimo, Quebec. These, in order from south to north in 1948, were Norancon Exploration (Quebec) Limited, Fort Chimo Mines Limited, Quebec Labrador Development Company, Limited, and Fenimore Iron Mines Limited. Although no commercial deposits of iron were discovered, a number of prospects examined indicated conditions similar to those at Knob Lake where commercial deposits were being explored. A number of sulphide deposits in the eastern part of the belt were also examined.

Claims covering iron-formation were staked in 1951 near Ford Lake, west of Hopes Advance Bay on Ungava Bay, by Ross Toms and much of the iron-formation from there north was staked by this prospector during the next few years. Concessions in the area south of Payne Bay were granted to Oceanic Iron Ore of Canada Limited in 1953 and for a small area near Nagvaraaluk[1] Lake to Quebec Explorers Limited in 1956. With the interest of Cyrus Eaton of Cleveland, Atlantic Iron Ores Limited and International Iron Ores Limited were formed in 1952 and they carried out extensive investigation of the area around Ford Lake, Roberts Lake, and Payne Bay during the next five years.

A major iron range was discovered in the southwest region in the Seignelay River area in 1958 by C. C. Houston and Associates under direction of Pickands Mather & Co., and has been investigated in considerable detail. Active exploration has been maintained throughout this southwest region by a number of companies since the initial stages of exploration, and many ore deposits that contain very large tonnages of potential low grade ore are known.

Quebec Cartier Mining Company, a subsidiary of United States Steel Corporation, began large-scale development in 1958 to bring the Lac Jeannine deposit into production and to ship as much as eight million tons of ore concentrate a year. This project involved the excavation of a deep harbour at Port Cartier, the construction of a 193-mile railroad, the building of a concentration plant, a hydro-electric power dam and plant, two towns, and the preparation of the Jeannine deposit for open-pit mining.

[1]Formerly Armand Lake

The first shipment of ore concentrates from this mine in 1961 marked the beginning of a new phase in iron ore production in Canada with the utilization of coarse-grained, metamorphosed iron-formation on a large scale. Iron Ore Company of Canada started production of iron ore concentrate at the rate of six to seven million tons a year from mines in the Wabush Lake area in 1962, and Wabush Iron Company began to ship a similar amount of concentrate from their property in that area, commencing in 1965. It is remarkable that major facilities for producing high grade ore concentrates have been established in this region within 10 years of recognition of the potential of the metamorphosed iron-formations and initiation of intensive exploration of the region.

Chapter II

GENERAL GEOLOGY

Geological Setting of the Labrador Geosyncline

The chain of Proterozoic rock belts distributed around a large part of the Superior Province of the Canadian Shield in western Quebec is considered by Stockwell (1957, 1961) to be part of the Churchill Province, as defined on the basis of structure and isotopic ages. These belts of folded rocks lie unconformably on the granite and metamorphic rock complexes of the Superior Province but are in fault contact with, or are transitional through zones of increasing metamorphic rank to, the metamorphic and igneous rocks of the Churchill Province.

The general geology of the Labrador geosyncline—or Ungava fold belt as it is referred to by Stockwell—is shown on Figure 1 (*in pocket*). The geosyncline is a sinuous to arcuate belt of sedimentary, volcanic, and intrusive rocks more than 750 miles long and up to 60 miles wide. Rocks of this folded belt lie unconformably above older Precambrian granite, granodiorite, and gneisses along the west side of the geosyncline, north of Sawbill Lake, in the north part of the region north of Hopes Advance Bay, and on the east side between Snelgrove Lake and Ashuanipi River. Along the east side of the belt, rock groups recognized as part of the geosyncline appear to be in fault contact with granite gneisses, hypersthene granites, and amphibolites in the border zone between André Lake in the south and Hérodier Lake in the north. The eastern border between Hérodier Lake and Hopes Advance Bay is less well defined; highly metamorphosed rocks of the geosyncline are difficult to distinguish from granitic gneisses and amphibolite of uncertain origin that are in part at least derived from geosyncline rocks. The border of the geosyncline is not defined clearly in the southeast between Snelgrove Lake and Ashuanipi River. Wynne-Edwards (1960) noted that "although the passage from clastic sediments to granitic gneiss is abrupt both are mineralogically similar and the former are sheared and recrystallized to a point where they closely resemble gneisses."

Southwest of Sawbill Lake, the rank of metamorphism increases to the upper epidote-amphibolite facies and two ages of folding are recognized. There, distinctive rocks such as iron-formation, quartzite, or dolomite, which can be recognized as part of the geosynclinal assemblage, are broken up into complex structural segments associated with granitic gneisses, foliated amphibolites, or gabbro intrusions of the Grenville Province.

Geology of the Geosyncline North of Wabush Lake

The first systematic study of the stratigraphy of the geosynclinal rocks to be reported in detail was that of Harrison (1952) in the Knob Lake area. The names used by him for rock groups and many formations in that area have been generally adopted and their use has since been extended throughout the part of the belt where satisfactory correlations with his type section can be made.

The Proterozoic rocks are commonly referred to as the Kaniapiskau Supergroup, subdivided locally into groups and formations (Frarey and Duffell, 1964). At Attikamagen Lake, for example, the Knob Lake and Doublet Groups of sediments and volcanic rocks have been defined. The regional distribution of major lithological units only are shown on Figure 1. These are discussed first, before reviewing the stratigraphy in the principal parts of the belt. Because of uncertain correlations of the rock units north and south of Wabush Lake, the stratigraphy of each part is discussed separately.

A few formations such as the Wishart, Ruth (middle slate), Sokoman, and Menihek (upper slate) are found in this order of succession from bottom to top throughout the western part of the belt, but in most localities other lithologically similar members as well as a number of other distinctive formations are present below and above this succession. These formations thicken considerably in some areas and where they thicken other lenticular stratigraphic members may be present, suggesting that deposition took place on an undulating surface and that deposition of some types of material was practically restricted to deeper basins. The sedimentary and volcanic materials composing this rock belt apparently came from two major source areas. The quartzite, dolomite, and arkosic rocks on the west side of the belt were contributed from a source area to the west and form a rather typical miogeosynclinal, shallow-water succession, which is typical of deposits formed on the shelves of continents. Similar rock types in the lower part of the succession in the southeast part of the belt south of the main group of volcanic rocks were derived from a source area lying to the east. The other principal source of material was a belt of volcanism to the east which contributed considerable tuff, the extraneous clastic material in the argillites and greywackes, and the extrusive and intrusive rocks. This belt probably was the source of much of the silica and iron deposited in the cherty sediments. Because of these different sources there is a marked change in the rock succession from west to east in all parts of the geosyncline with interfingering of the two major types of material near the centre.

Typical stratigraphic successions in nine parts of the geosyncline are summarized in Tables IA and IB (*in pocket*) and the location of the sections shown in Figure 2. An attempt is made to correlate some of the major stratigraphic units, but the lack of distinctive horizon markers, separation of members along major faults, and lack of sufficient detailed information in many areas make correlation between minor units difficult.

The iron-formation is a satisfactory horizon marker for regional correlation because of its distinctive lithological characteristics, its continuity in the western part of the belt (as shown by mapping), and its consistent position in the stratigraphic succession relative to other major lithological units. The first three sections (1-3) in the

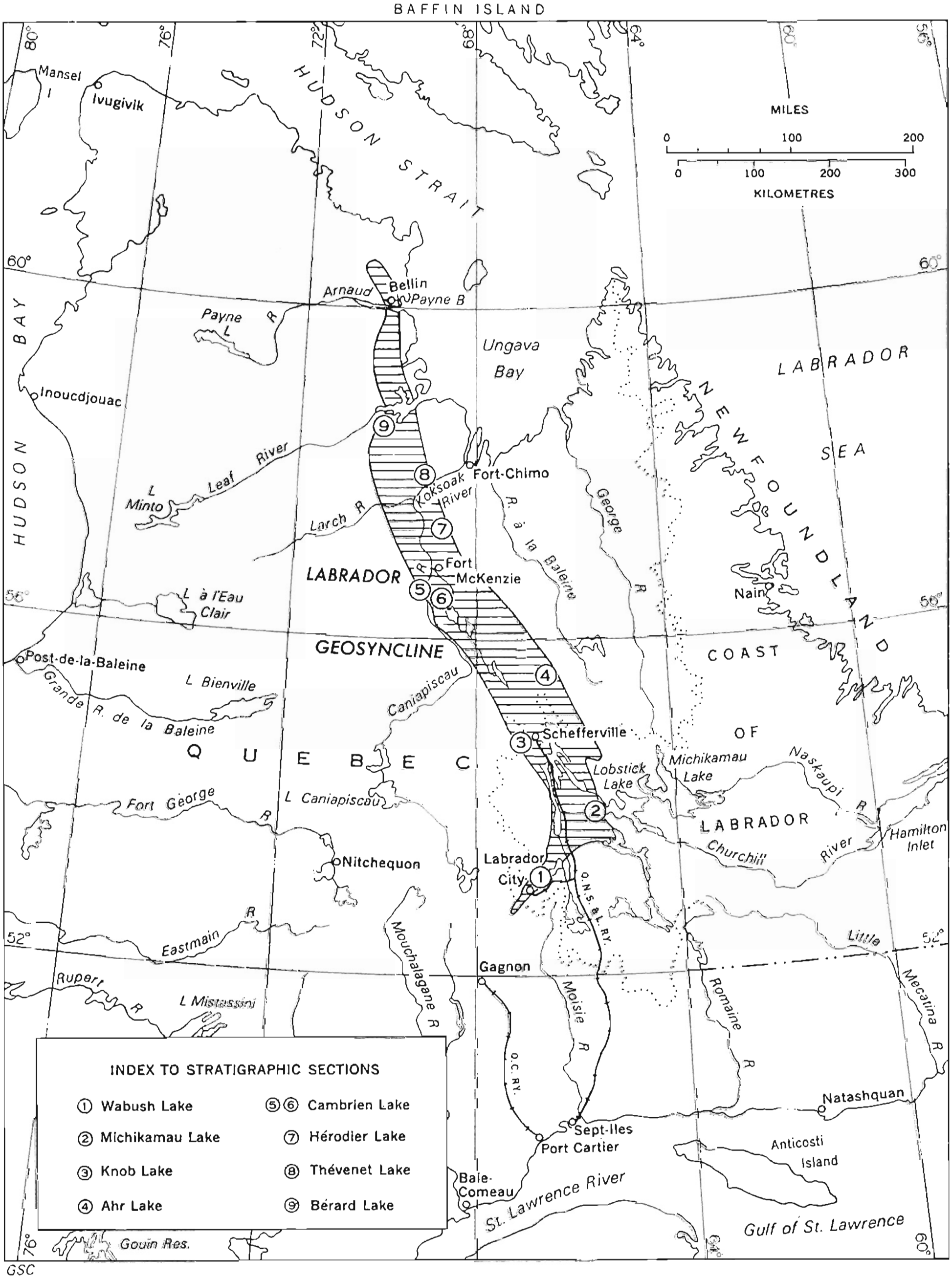


FIGURE 2. Locations of stratigraphic sections (see Table I).

central and southern parts of the belt indicate a consistent correlation for major formations from the Menihek down to the granite-gneiss complex. They suggest fairly uniform sedimentary conditions in this broad area except for the Fleming Formation at Knob Lake and the volcanic rocks in the iron-formation east of Astray Lake. This is not the succession found with the iron-formation in the region southwest of Wabush Lake. The Ahr Lake succession (4) farther to the northeast has considerably more volcanic material and the great thickness of interbedded greywacke and pyroclastic rocks obscures the relation of quartzite and dolomite formations there to the shelf rocks in the west. The section at Ahr Lake above the iron-formation corresponds to the eastern and upper part of the Knob Lake section. The Cambrien and Hérodier Lakes sections (5-7) differ from those in the southern region mainly by the presence of a major group of argillites, quartzites, and conglomerates below the iron-formation, and dolomite apparently above it, particularly in the eastern part. The stratigraphic succession up to the top of the iron-formation (Jones, 1948) near Hematite Lake east of Cambrien Lake is very similar in detail to that in the Knob Lake area and the main members of the iron-formation occur in the same order in both areas. In the Lac Bérard[1] area only thin quartzite and slate formations are present below the iron-formations; a distinctive dolomite formation lies above it, and lavas are present very near the western margin of the belt. The Lac Bérard succession is typical of that found all through the remaining northern part of the belt, except for part of the eastern area which is illustrated by the Thévenet Lake succession (8).

Sedimentary Rocks

The succession quartzite–slate–iron-formation–slate persists throughout the belt north of Wabush Lake and these rocks form a marker unit to which the other lithological units may be referred (*see* Tables IA and IB). At the western edge of the belt, quartzite with some arkose and conglomerate overlies early Precambrian gneisses and granite with angular unconformity. This relationship is observed west of Stakit and Menihek Lakes and in most parts of the western border, except west of Wakuach Lake where iron-formation is thrust faulted over the gneisses and west of Cambrien Lake where the main quartzite–iron-formation beds are underlain by a thick group of argillite, quartzite, and dolomite, which is in turn underlain by 5,000 feet of feldspathic quartzite, arkose, and conglomerate in westerly trending belts. The quartzite unit below the iron-formation, known as the Wishart Formation in the Knob Lake area, is less than 100 feet thick near the western margin of the belt but may increase to twice this thickness near the centre.

The maroon to grey-black slate beds above the Wishart quartzite and below the iron-formation are present everywhere but vary in thickness from less than 10 feet to more than 100. Fine clastic carbon-bearing layers are interbedded with thin ferruginous chert layers in the upper part of the formation and there is a transition from clastic slate to silicate–carbonate–chert–iron-formation. This ferruginous rock, called the Ruth Formation at Knob Lake, apparently marks the beginning of abundant iron deposition throughout the region.

One major iron-formation that varies considerably in thickness appears to under-

[1]Formerly Finger Lake

lie the greater part of the geosyncline. The thickness and order in which the silicate–carbonate and oxide facies occur within it may vary from place to place, but as far as is known a member rich in iron silicate and iron carbonate is present throughout at the base of the formation. This is overlain by an oxide facies possibly alternating with various other facies in the upper parts of the unit. North of Fort McKenzie the iron-formation can commonly be divided into a lower member composed of silicate–carbonate and oxide facies and an upper member composed of siderite, ferruginous dolomite, iron silicates, and quartz. This stratigraphic unit is more than 550 feet thick in the Knob Lake area where it is known as the Sokoman Formation. It is rarely less than 100 feet thick on the western margin and in most places thickens considerably eastward, towards the central part of the belt, before thinning and apparently pinching out beyond there. Structural deformation makes it impossible to define its eastern limits by mapping. The formation is composed of thin-banded ferruginous chert layers with an oölitic or granular texture, or the metamorphic equivalent of such material. Oxide facies composed of hematite, magnetite, and chert are the most abundant, but iron silicate facies composed of minnesotaite, stilpnomelane, and occasionally greenalite in chert and siderite, occur persistently. Although mapping shows one main band of iron-formation, other thin bands occur in ferruginous slate east of Gerido Lake, in the slates below the main band near Cambrien Lake, and in the succession of volcanic rocks east of Murdoch Lake.

A very fine grained, thinly laminated black slate, containing considerable carbon and in some places pyrite, immediately overlies the main iron-formation. It is conformable with the iron-formation; in some places cherty iron-formation beds interbanded with black slate form a transition zone between the two stratigraphic units. In some areas dolomite lenses occur in the slate unit. This unit marks the beginning of a thick succession of argillites and greywackes that increase in abundance to the east where they are interlayed with lava flows and gabbro sills. This succession is known as the Menihek Formation in the Knob Lake area but lithologically similar rocks are found above the iron-formation in nearly all parts of the geosyncline. Sediments east of Knob Lake interlayered with gabbro sills and volcanic rocks are considered to be stratigraphically equivalent to the Menihek rocks.

In some parts of the belt another thick slate or greywacke–argillite formation below the quartzite–iron-formation zone forms the main basal unit in the succession. This lower slate–argillite formation is very like the Menihek slate in composition and character, except that carbon-rich beds are not so abundant and most of the formation is light greenish grey, although part is maroon, brown, yellowish, or black. In the Knob Lake area the Attikamagen Formation is the best known part of this lower stratigraphic succession, and there slates thicken from 100 feet near the western margin of the belt to more than 1,200 feet in the central part. Near the exposed unconformity on the west similar rocks are found at some localities only, but throughout the central part of the belt slates are widespread. They continue eastward, but become interlayered with volcanic rocks and basic sills and lose their identity where they may be interfolded and faulted with the upper argillites and slates. Thin beds of dolomite, quartzite, conglomerate, chert, and some tuff occur in this succession in the southern part of the area and much of the fine-grained angular clastic material may be of volcanic origin.

In the belt, a number of dolomite members are found both below and above the quartzite–iron-formation zone. The Denault dolomite of the Knob Lake area and the dolomite member in the Wabush Lake area lie above the lower slate–argillite formation (Attikamagen). Three dolomite members may be present in the Wakuach Lake area: one below the lower slate, one below the main quartzite unit, and one above the iron-formation. North of Koksoak River a thick dolomite formation (the Abner) occurs in the succession of argillite rocks above the iron-formation, and south of this river a dolomite unit is considered to lie stratigraphically above the iron-formation. Dolomite beds of uncertain stratigraphic position are present in the succession at a number of places along the eastern margin of the belt. In the central-eastern part however some lie below the iron-formation.

At Knob Lake, a chert breccia of the Fleming Formation lies above the Denault dolomite and below the Wishart quartzite. The lower part, directly overlying the dolomite, is composed of angular laminated grey chert fragments and brecciated dolomite embedded in a carbonate matrix. This grades upwards, through a facies with a colloform to dense chert matrix, to the main upper part in which chert fragments are embedded in quartzite. This unit is lenticular and up to 300 feet thick northwest of Knob Lake, but thins in all directions away from this area. Chert breccia also occurs with the iron-formation, and thin beds are found with dolomite in other parts of the belt.

Quartzite, grit, and jasper conglomerate, in part crossbedded and nearly flat lying, form prominent hills in the south part of the belt near Sims Lake. They are younger than the Kaniapiskau rocks and are intruded by gabbro dykes and sills. The succession in the Otish Mountains is composed of red to white sandstone, arkosic sandstone, and quartzite with minor pebble-conglomerate, boulder-conglomerate, and red mudstone associated with gabbro sills. Its relationship to rocks of the Kaniapiskau Supergroup, or to the overlying sandstone, conglomerate group near Sims Lake, is not known.

Middle to Upper Ordovician limestone is present on Akpatok Island in the north and deformed outliers intruded by diabase dykes occur around Mouchalagane and Manicouagan Lakes. Lacustrine clays and redeposited iron-formation rubble containing Upper Cretaceous fossil plants fill deep depressions and crevices in many of the hematite–goethite ore deposits in the Knob Lake area (Blais, 1959).

Volcanic Rocks

The broad regional distribution of volcanic rocks in the central and eastern parts of the belt is shown on Figure 1, but a discussion of details of this extensive suite of rocks is beyond the scope of this study, except for those that may have had an effect on the origin of the iron-formation. A considerable amount of clastic material of volcanic origin is present in the argillites and greywackes far beyond the centres of volcanism recognized by the thick accumulations of lava and pyroclastic rocks.

Volcanic rocks in the south-central part of the belt appear to have come from a centre in the Dyke Lake area. Basic lavas lie between the quartzite and the iron-formation a few miles southeast of Knob Lake and in the upper part of the iron-formation east of Astray Lake. They occur within the iron-formation between Dyke Lake and Snelgrove Lake, and extend south from there into the Sims Lake area, with some occurrences as far south as Ossokmanuan Lake. Basalt flows, pillow lavas, pyroclastic rocks, and flows containing jasper pebbles are interbedded with other sedimentary rocks throughout that part of the area.

The Doublet Group of volcanic and sedimentary rocks lies along the eastern side of the belt. The Murdoch Formation is composed mainly of basic pyroclastic rocks interlayered with basalt flows and greywacke, quartzite, slate, and conglomerate. This formation is about 2,000 feet thick in the area east of Attikamagen Lake, but thickens farther north in the Murdoch Lake area where it includes a thin iron-formation. The formation extends north along the east edge of the geosyncline belt to near Hérodier Lake. In the south where it is separated from other units by faults, it is known as the Murdoch Formation, but west of Ahr Lake and the main fault zone, rocks of this formation overlie Menihek rocks. Conglomerates within it contain boulders from the sedimentary succession to the west as well as material from the orogenic belt to the east.

The second main volcanic formation is present on the southeast edge of the belt where it is known as the Willbob Lake Formation. It consists mainly of basalt flows and pillow lavas, minor pyroclastic rocks interlayered with fine-grained black slate, greywacke, and quartzite. The volcanic rocks in the central part of the belt north of Otelnuk Lake are like those of the Doublet Group and are considered to be its northern extension.

The Thompson Lake Formation composed mainly of quartzite, greywacke, shale, argillite and conglomerate intercalated with basalt lies between the Murdoch and Willbob Lake Formations and in some places is more than 2,000 feet thick.

Intrusive Rocks

Much of the central and eastern parts of the belt is underlain by a multitude of thin gabbro sills that are conformable with the sedimentary and volcanic rocks. They are considered to be the intrusive equivalents of the latter. According to Baragar (1960), the extrusive basalts of the area represent the original magmas from which the normal gabbro sills were derived. The normal gabbros (tholeiites) show a trend in differentiation towards extreme enrichment in iron with negligible alkali enrichment and characteristically a low potassium and strontium content. Many of the sills differentiated in situ and have olivine-bearing lower parts and pegmatitic upper parts rich in sodic plagioclase.

A number of steeply dipping, north-trending diabase dykes cut the sedimentary succession in the Knob Lake area, and these post-date the main period of deformation. The gabbro, meta-gabbro, and derived amphibolites in the south around Wabush Lake and Ossokmanuan Lake are recognized as a separate group of rocks that were intruded near the end of the Grenville orogeny and are considerably younger than the sills in the eastern part of the belt.

Small rhyolite and syenite intrusive masses cut the volcanic-sedimentary complex east of Attikamagen Lake.

Some narrow serpentinized peridotite intrusions are present within or near the belts of volcanic rocks along the east and north-central part of the belt.

Metamorphism

Rocks in the central part of the belt between Sawbill Lake and Lac Bérard belong to the lower part of the greenschist metamorphic facies, and most primary textural features are preserved despite incipient recrystallization. There is a gradual increase in metamorphism towards the eastern boundary of the belt with an abrupt change from the greenschist facies to rocks of higher metamorphic rank, including amphibolites, granulites, and migmatites, across the shear zones and faults along the eastern margin of the belt. In the south the biotite isograd lies north of Wabush Lake and extends northeast along the southern margin of the sedimentary belt with an appreciable increase in metamorphism in the Kaniapiskau rocks to the south of it. The distribution of geosynclinal rocks south of this line is difficult to define because extensive recrystallization in the epidote amphibolite and amphibolite facies has obscured the original nature of much of the rock and little can still be recognized except the iron-formation, quartzite, and dolomite.

The biotite isograd in the northern part of the area extends from Thévenet Lake to the north end of Lac Bérard and regional metamorphism increases progressively north and east from this line, epidote amphibolite facies rocks being present around Hopes Advance Bay and Payne Bay, and garnet, biotite, hornblende, and staurolite schists and sillimanite-bearing gneisses around Hérodier Lake and Thévenet Lake. A gradual decrease in metamorphism is evident north of Payne Bay.

Structure

The persistent northwest strike of the folded rocks stands out on the regional map and is strongly reflected in the valley and ridge topography so characteristic of this belt. Rocks along the western margin dip gently east along Menihek Lakes, west of Otelnuk Lake, and north of the Koksoak River, and are relatively undisturbed in these areas. A number of major fold structures control, to a great extent, the complex fold patterns that show up on more detailed maps. The southern part of the main belt, between Sawbill Lake and Lac le Fer, may be divided into four main structural units consisting of two major synclines and two uplifted highly folded and faulted belts. Both synclines have narrow triangular surface patterns that narrow northward to their apex areas in Howells River valley and south of Lac le Fer. These are designated as the Ashuanipi–Sims and the Petitsikapau Lake synclines. The rocks along their broad southern bases strike northeast and dip northwest forming a southern enclosure to the major structures. The highly folded and faulted belt extending from Sims Lake to Astray Lake and north beyond Knob Lake separates these two synclines and contains the main zones in which high grade ore deposits have been discovered. The second folded and faulted belt lies east of Lake Petitsikapau and is a tightly folded structure imbricated by numerous thrust faults.

A broad asymmetric syncline that extends from west of Fort McKenzie north to Lac Bérard has low easterly dipping beds on its west limb and steeper dipping more highly deformed beds on its east limb. The southern part of this structure is outlined east of Cambrien Lake by iron-formation repeated many times by tight folding within a north-plunging syncline.

Isoclinal folds and thrust faults are the predominant structures between the Koksoak River and Leaf Bay. An asymmetric syncline north of Payne Bay with a gently dipping west limb and a steeply dipping to overturned east limb, and a small basin structure at Nagvaraaluk Lake mark the northern extension of the main belt, although other outliers of Kaniapiskau rocks are found farther north.

The predominant small-scale structures imposed on these major structural elements throughout the belt consist of doubly plunging isoclinal folds with steep easterly dipping limbs. These folds are cut by numerous thrust faults that strike northwest and dip east, which commonly parallel the attitude of the folded beds. Displacement along most of them is a few hundred feet. There is a gradual change from nearly flat lying beds on the west to asymmetric and tight isoclinal folds in the central Astray Lake–Knob Lake deformed belt and broad drag-folded and homoclinal structures are prominent in the eastern parts.

A number of major thrust faults that dip gently to the east occur in the area west of Lac le Fer. Broad sheet-like blocks of strata have been thrust westward along these faults. In some places iron-formation rests directly on the pre-Kaniapiskau gneiss and granite complex and the lower part of the stratigraphic succession is absent below these fault planes. Similar low angle thrusts are present in the Payne Bay area, where the upper parts of the stratigraphic succession have been thrust west for a considerable distance over the lower part. In one area the iron-formation is repeated three times by thrusting on low angle faults and north of Payne Bay the stratigraphic succession above one such fault is completely overturned.

Fault zones, strongly sheared and brecciated, strike northwest in places along the eastern border of the geosyncline belt, as outlined on the map. The western border of the belt is offset in places by faults that strike west to northwest, and a number of steep-dipping cross-faults occur in the Knob Lake–Sunny Lake ore zone and in many other parts of the belt. Northeast-trending faults are present across the south end of the belt south of Sawbill, caused by the Grenville orogenic disturbance, and some gabbro masses were intruded along these zones of weakness.

Movement occurred along some of the thrust faults in the Knob Lake area in Cretaceous or later time and Schwellnus (1957) suggested that some of the cross-faults and folds may have developed during this period.

Historical Geology

Enough information is available to outline in general the succession of events in the history of the Labrador geosyncline, and more details can be inferred in local areas. Considerably more stratigraphic and tectonic study is, however, required before all the stratigraphic units and geological events recognized in local areas can be correlated.

The first event was the deposition of Kaniapiskau sediments along the western side of the belt on a surface of low topographic relief. In the Cambrien Lake area, however, there must have been a series of deep east-trending valleys. A number of broad basins or depressions apparently existed on this old terrain and these became centres for the accumulation of the thicker stratigraphic members in Wabush Lake, Knob Lake, Cambrien Lake, and other areas. The granite, gneiss, and amphibolites of this early terrain are part of the Superior Province; the isotopic ages of these rocks are between 2,550 and 2,400 million years. Rocks directly below the unconformity west of Stakit Lake are crumbly and decomposed.

Sedimentation began with the deposition of fine-grained argillaceous muds in a long trough-like depression. Sandstone, arkose, calcareous and arenaceous shale, carbonates, and some of the cherty material eroded from the landmass to the west were deposited in shallow water in a continental shelf-like environment in this basin. Sandstone and shale, and, intermittently, calcareous rocks were deposited across the western part of the basin. Most members of this group thicken eastward from the present western margin of the belt to near the central part and then thin, pinch out, or become intercalated with volcanic rocks. The original western limit of the belt apparently lay near to and parallel with its present margin, but the original eastern margin is not clearly defined. Quartzite, slate, and greywacke in the lower part of the succession in the southeastern marginal area, south of the main group of volcanic rocks, were formed of material derived from a source area to the east. Except for some volcanic activity producing lava and pyroclastic rocks, conditions of sedimentation during the initial stages in this local area were similar to those along the west margin.

Volcanic activity started during the early part of this period of sedimentation, particularly in the southern part of the trough, and contributed pyroclastic material and lava flows that are interbedded with the shelf-type sediments. The principal zone of volcanism lay along the eastern margin of the belt and produced a thick succession of basic lavas and pyroclastic material that was mixed with fine-grained sedimentary material. Volcanic activity seems to have culminated after the main period of sedimentation from western sources. Volcanic rocks predominate in the upper part of the rock succession and are much more abundant in the east. The great intrusion of gabbro sills, similar in composition to the lavas, appears to have taken place near the end of the cycle of volcanic events. Considerable deformation by folding and thrust faulting had already taken place but these sills were emplaced before this main period of deformation was complete. The ultrabasic masses were probably intruded near the close of the period of volcanism and prior to the main period of gabbro intrusion.

The iron-formations appear to have been deposited near the middle of the main period of sedimentation but during the early stages of volcanism. The water in the basin was apparently rather shallow throughout the sedimentation history, as shown by crossbedding and stromatolith structures in the dolomites, numerous shallow-water features in the quartzites, scour-and-fill structures, and diastem breccia zones or local disconformities at many stages in the rock succession. Black slates, rich in carbon, occur locally with the fine-grained clastic members and carbonate rocks. These are indicative of an euxinic environment that was low in oxygen, and of rather poor circulation and stagnant water conditions. Deposition of the iron-formation was preceded by very extensive euxinic conditions, as indicated by the widespread distribution of the high carbon, iron-rich Ruth Slate or its stratigraphic equivalent which is transitional upward through ferruginous cherty zones to silicate–carbonate facies of iron-formation. The lower part of the slate formation overlying the iron-formation—the Menihek Formation or its equivalent—is also rich in carbon, which indicates that strong euxinic conditions persisted for some time after deposition of the iron and silica ceased. The oxide facies of the iron-formation, consisting mainly of hematite, magnetite, and chert, is present in the middle part of the Sokoman Formation. As it was deposited in shallow oxygenated water, depositional conditions must have changed periodically from deeper water, reducing euxinic conditions to shallow-water oxidizing conditions. The cycle from silicate–carbonate to oxide iron-formation is repeated as many as three times. In the area west of Wabush Lake oxide facies iron-formation overlaps and extends west of the silicate–carbonate facies, where it was evidently deposited in shallow water near the old shoreline. This overlap to the west of oxide facies iron-formation over silicate–carbonate facies was probably a prominent feature at one time along the entire western margin of the geosyncline belt. The oxide facies was probably deposited at that time over the entire region but was later stripped from the central parts of the area where lower deeper water facies were exposed.

There is abundant evidence of transgressions and regressions of the shoreline, which caused interfingering of various sedimentary facies and numerous erosional disconformities. Pebbles of iron-formation occur in conglomerates in the lower part of the succession in many parts of the area. These pebbles may well have been derived from beds formed within basins that were eroded during one of these minor periods of uplift. Westward transgression of the sea is indicated by the deposition of deeper water shales and argillites over the iron-formation and some of the shelf rocks. Kavanaugh (1954) showed that sediments derived from volcanic, plutonic, and metamorphic rocks lie unconformably above deformed beds of the early sedimentation period in some localities in the eastern part of the belt. It is evident that there was local warping and intermittent sinking of this sedimentary basin, accompanied by marked changes in the depth of water, during deposition of these rocks, but the nature and order in which these changes occurred are still not well understood. These epeirogenic movements affecting the geosynclinal belt caused at least 3,000 feet of subsidence in the central–western part and considerably more in the eastern part, as indicated by the thickness of the sedimentary–volcanic rock succession.

A major orogenic disturbance followed the period of subsidence and sedimentation, which caused intense stresses to be directed from the northeast, and these produced the isoclinal folds and thrust faults that dominate the structural pattern. Deformation caused by this orogeny extended to the western margin of the belt but was much more pronounced in the east, where rocks of the geosyncline range from schists to gneisses and lose their identity in the granite-gneiss terrain that extends to the Labrador coast. Isotopic ages determined for the geosynclinal rocks and eastern gneisses range from 1,400 to 1,900 million years, indicating that this Labrador orogeny lasted for a considerable time. It is believed that the sediments were deposited between 2,400 and 1,900 million years ago.

Sandstones and conglomerates that rest unconformably on folded Kaniapiskau rocks near Sims Lake mark the next major event in the region. Pebbles of iron-formation and other rock types in the conglomerate indicate that these rocks were derived from the Kaniapiskau Supergroup, and crossbedding shows that the material was transported to the northwest. They are thought to have been derived from a highland belt to the south that was uplifted and folded during the Grenville orogeny; similar rocks in the Otish Mountain area may have come from the same belt and have a similar history.

The southern part of the region was structurally deformed and metamorphosed during the great Grenville orogeny, which according to isotopic dating took place between 1,200 and 800 million years ago. This orogenic belt trends northeast, truncating the prominent northwest trend of the geosyncline belt. Many fold structures in the southern region, developed during the Labrador orogeny, were refolded during the Grenville orogeny along westerly or northwesterly trending axes. Extensive intrusion of gabbro and gabbroic anorthosite took place along the northwest side of the Grenville orogenic belt especially in the Wabush-Ossokmanuan Lakes area.

Much of the eastern part of the continent may have been submerged during early Palaeozoic time as suggested by the wide distribution of outliers of early Palaeozoic rocks. Subsidence of this region is believed to have been caused by broad epeirogenic movement and warping of the earth's crust, but folded Ordovician rocks on Mouchalagane Lake and Manicouagan Lake, associated with volcanic rocks indicate at least some local orogenic disturbances.

Most of the region is believed to have been a landmass by Mesozoic time and probably was uplifted during the late Palaeozoic. Depressions and crevices in the orebodies near Knob Lake contain several hundred feet of lacustrine clay and argillites with Cretaceous fossil plants. These deposits confirm the presence of a landmass, at least in the east, but it may have been of limited regional extent as marine Cretaceous sediments are preserved south of James Bay. Some structural disturbance took place in late Cretaceous or post-Cretaceous time around Knob Lake, with minor movement on existing faults and the development of some cross-faults. The eastern part of the continent was apparently of much the same shape during Cenozoic time as now, and there are numerous occurrences of rocks that had been deeply weathered before Pleistocene glaciation. The topography and drainage pattern that developed during the later part of the Cenozoic was considerably modified by this recent glaciation and most of the bedrock surfaces were eroded down to fresh unweathered material before being covered by glacial deposits.

With this brief historical background some conclusions may be reached regarding the possible period of leaching and enrichment that produced the soft orebodies at Knob Lake. The orebodies, for reasons given later, are considered to have been formed by processes of deep weathering, oxidation, and the action of groundwater. The uplift of the area and surface exposure of the rocks for a considerable time was therefore a requirement for ore development. Fragments of leached or enriched material have not been found in any of the Precambrian conglomerates (although fragments of fresh iron-formation are abundant), and there is a general lack of evidence to indicate that alteration to ore took place during the Precambrian. Undoubtedly from structural evidence, the ore formed after the rocks were folded and faulted during the main orogenic disturbance although it has been involved in minor late stage faulting. If the area was submerged during most of the Palaeozoic, then ore formation could not have started until possibly late in the Palaeozoic or during the Mesozoic. The deep crevices and depressions in the orebodies that contain rubble and debris of ore grade mixed with Cretaceous plants, and the nature and position of these deposits show that much of the leaching of silica and the enrichment of iron had taken place by late Cretaceous time. It would appear then that suitable conditions may have prevailed during the Mesozoic for weathering and enrichment of the iron-formation. Much more information about the nature of this terrain during the Palaeozoic is needed to confirm this conclusion.

Principal Subdivisions of the Geosyncline

The Labrador geosyncline can be divided, naturally, into three geological divisions. The southern division, southwest of Sawbill Lake, is composed of highly metamorphosed rocks within the Grenville orogenic belt. The central division, which extends from Sawbill Lake to Lac Bérard, contains high grade hematite-goethite ore deposits in relatively unmetamorphosed iron-formation. The northern division, north of Lac Bérard, is made up of more highly metamorphosed rocks much like those of the southern division.

Chapter III

GEOLOGY AND ORE DEPOSITS OF THE CENTRAL DIVISION OF THE LABRADOR GEOSYNCLINE

The Knob Lake Iron Range

At least forty-five hematite-goethite ore deposits have been investigated in an area 12 miles wide that extends 65 miles northwest of Astray Lake, referred to as the Knob Lake iron range, which consists of tightly folded and faulted iron-formation exposed along the height of land that forms the boundary between Quebec and the Coast of Labrador, Newfoundland. The iron deposits occur within deformed segments of iron-formation, and the ore content of single deposits varies from a million to more than 50 million tons. Since 1954, seven open-pit mines have been operated within a 5-mile radius of Knob Lake and the town of Schefferville, and up to the end of 1961 nearly 75 million tons of ore containing about 52.306 per cent iron, 0.075 per cent phosphorus, 1.591 per cent manganese, 6.30 per cent silica, 1.25 per cent alumina, and 10.38 per cent moisture was shipped. About 420 million tons of ore was proven in the Knob Lake range before development and production in the area started. More ore has been found in some of the orebodies during detailed development and mine operation than was previously estimated.

Geological conditions throughout the central division of the geosyncline are generally similar to those in the Knob Lake range, and the whole region is regarded as favourable for the occurrence of hematite-goethite ore. To date, however, no orebodies of this type of mineable size and grade have been found outside the Knob Lake range, even though a number of leached and enriched zones have been explored on the surface.

The following detailed description of the geology of the Knob Lake range will serve to illustrate geological features throughout the central division of the geosyncline.

Stratigraphy

The general stratigraphy for the Knob Lake area (*see* Table IA, section 3, and revised nomenclature) has been described by Harrison (1952). This succession is representative of most of the range, except that the Denault dolomite and Fleming Formation are not uniformly distributed; thicknesses of other formations vary

TABLE II | *Chemical Analyses of Knob Lake Range Rocks and Iron Ores*

Dry analyses in % / Constituent	Denault Dolomite				Fleming Chert	Wishart	Attikamagen		Ruth and Ore		
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	17.01	91.28	28.1	0.5	95.60	47.95	66.79	68.50	53.69	47.35	7.18
TiO_2	?	?	0.1	0.0	?	?	0.60	0.40	1.14	?	?
Al_2O_3	0.94	1.70	4.0	0.4	0.50	?	16.58	14.30	11.11	9.34	2.44
Fe_2O_3	0.92	1.83	0.2	0.2	1.16	10.87	2.78	0.70	13.26	32.88	79.51
FeO	1.50	0.01	1.5	0.17	0.41	0.01	2.13	5.91	5.75	0.21	0.02
MnO	0.19	1.64	0.0	0.0	0.13	26.14	nil	—	?	1.94	3.60
MgO	15.53	0.04	13.7	21.0	0.01	0.02	1.56	2.10	0.89	0.04	0.02
CaO	24.78	0.23	18.9	29.6	0.27	0.22	nil	0.20	0.43	0.12	0.14
Na_2O	0.16	?	0.1	0.1	?	?	1.41	1.50	0.72	?	0.05
K_2O	1.24	?	1.6	0.1	?	?	4.65	1.50	3.81	?	0.13
H_2O + 105°C	?	?	0.53	0.18	0.22	4.88	3.68	3.38	5.92	4.05	4.91
CO_2	37.19	1.93	30.20	46.30	?	?	nil	—	nil		
P_2O_5	0.03	0.04	0.0	0.0	?	0.13	tr	—	0.18	0.27	0.32
C	?	?	0.0	0.22	?	?	nil	1.46	1.98	?	?
S	tr	tr	?		tr	?	—	—	?	0.003	0.001
Total	98.59	98.70	98.9	98.8	98.30	90.22	100.18	99.9	99.88	96.20	98.32

SOURCE OF DATA

1. Average analysis of 6 samples of unaltered Denault dolomite, from various parts of the area (Stubbins, *et al.*, 1961)
2. Average analysis of 5 samples of highly leached Denault dolomite, from operating mines (Stubbins, *et al.*, 1961)
3. Laminated siliceous dolomite, Marion Lake area (Donaldson, 1960)
4. Stromatolitic dolomite, Marion Lake area (Donaldson, 1960)
5. Partly altered Fleming Chert Breccia, from Gagnon mine (Stubbins, *et al.*, 1961)
6. Leached and enriched Wishart quartzite, from Gagnon mine (Stubbins, *et al.*, 1961)
7. Average analysis of 2 samples of Attikamagen slate (Gross, 1951)
8. Black Attikamagen slate, Marion Lake area (Donaldson, 1960)
9. Average analysis of 2 samples of unaltered Ruth slate (Gross, 1951)
10. Slightly altered Ruth slate, from Fleming area (Stubbins, *et al.*, 1961)
11. Average analysis of many representative samples of Ruth slate ore, from operating mines (Stubbins, *et al.*, 1961)
12. Average analysis of 2 samples of unaltered Menihek slate (Gross, 1951)

throughout the range; and details of the stratigraphy of the iron-formation may vary locally.

Attikamagen Formation

This formation is exposed in folded and faulted segments of the stratigraphic succession where it varies in thickness from 100 feet near the western margin of the belt to more than 1,200 feet near Knob Lake. The lower part of the formation has not been observed in these faulted segments so that the nature of the succession and

TABLE II

Menihek			Redmond		S.C.I.F. and Ore			Metallic I.F. and Ore			Ore	Constituent
12	13	14	15	16	17	18	19	20	21	22	23	
69.64	53.9	66.34	16.08	47.37	49.97	27.94	6.53	55.03	34.14	9.00	8.25	SiO_2
0.65	2.3	?	nil	nil	?	?	?	?	?	?	?	TiO_2
13.68	14.9	17.13	15.43	33.23	0.92	0.28	1.16	0.17	0.15	0.79	0.89	Al_2O_3
1.68	9.0	4.49	63.45	11.67	10.45	62.26	80.62	39.09	62.26	84.91	83.18	Fe_2O_3
2.27	4.57	0.13	0.13	0.20	28.57	0.31	2.72	1.04	0.50	0.65	0.62	FeO
?	0.1	0.15	0.05	0.09	0.64	0.31	1.70	0.27	0.35	0.79	1.61	MnO
1.96	4.3	0.17	0.04	0.03	3.12	0.01	0.01	0.36	0.01	0.01	0.05	MgO
0.47	1.3	0.23	0.05	0.12	0.18	0.06	0.05	0.30	0.15	0.13	0.10	CaO
0.97	2.1	0.03	?	?	0.01	?	?	0.01	0.05	?	?	Na_2O
3.51	2.8	0.91	?	?	0.11	?	?	0.01	0.07	?	?	K_2O
2.41	3.66	5.42	7.96	12.79	2.62	8.69	6.08	0.66	0.87	1.52	4.54	H_2O + 105°C
nil	nil	nil										CO_2
0.11	0.20	0.10	0.22	0.27	0.02	0.04	0.28	0.06	0.01	0.10	0.14	P_2O_5
2.57	—	?	?	?	?	?	?	?	?	?	?	C
?	?	0.001	?	?	0.001	0.013	0.003	0.015	0.002	0.016	0.013	S
99.92	99.1	95.10	103.41	105.77	96.61	99.91	99.15	97.02	98.56	97.92	99.39	Total

13. Lower part of Menihek Formation, Marion Lake area (Donaldson, 1960)
14. Altered Menihek slate, from French mine (Stubbins, *et al.*, 1961)
15. Fossiliferous Redmond argillite, from Redmond mine (Stubbins, *et al.*, 1961)
16. Average analysis of 3 representative samples of Redmond clay, from Redmond mine (Stubbins, *et al.*, 1961)
17. Unaltered silicate-carbonate iron-formation from Ferriman area (Stubbins, *et al.*, 1961)
18. Enriched silicate-carbonate iron-formation, from Gagnon mine (Stubbins, *et al.*, 1961)
19. Average analysis of many representative samples of ore in silicate-carbonate iron-formation from operating mines (Stubbins, *et al.*, 1961)
20. Average analysis of 3 composite samples of fresh metallic iron-formation, Knob Lake range (Stubbins, *et al.*, 1961)
21. Average analysis of several representative samples of leached and enriched metallic iron-formation, Knob Lake range (Stubbins, *et al.*, 1961)
22. Average analysis of many representative samples of ore in metallic iron-formation, from operating mines (Stubbins, *et al.*, 1961)
23. Weighted analysis of all ore (Stubbins, *et al.*, 1961)

of the unconformity with the granites beneath is not known. It consists of argillaceous material that is thinly bedded (2 to 3 mm), fine grained (0.02 to 0.05 mm), greyish green, dark grey to black, or reddish grey. Calcareous or arenaceous lenses as much as a foot thick occur locally interbedded with the argillite and slate, and lenses of chert are common. The formation grades upwards into Denault dolomite, or into Wishart quartzite in areas where dolomite is absent. Beds are intricately drag-folded, and cleavage is well developed parallel with axial planes, perpendicular to axial lines of folds, and parallel with bedding planes.

The coarser parts of beds, composed largely of angular to acicular almost needle-like quartz grains and a few albitic plagioclase grains, grade into a dense intergrowth of secondary white mica and chlorite. Most of the fine material is white mica containing potassium. Some beds are rich in carbon, which accounts for their dark grey or black colour. In general the texture of the coarse slate beds resembles that of tuffaceous greywacke from other Precambrian areas, with poor sorting of grains in thicker beds and graded bedding in the thinner layers. The composition of two samples of Attikamagen slate is given in Table II.

Denault Formation

This formation is interbedded with the slates of the Attikamagen Formation at its base and grades upwards into the chert breccia or quartzite of the Fleming Formation. The Denault consists primarily of dolomite, which weathers buff-grey to brown. Mostly it occurs in fairly massive beds that vary in thickness from a few inches to several feet, some of which are composed of aggregates of dolomite fragments that vary in size from several inches to microscopic particles. Crossbedding in the thinner beds is not uncommon, but most of the beds are very fine textured, massive, and competent. Lenses and nodules of grey chert a few inches thick are distributed along the bedding planes of the dolomite. Here and there shale and arenaceous beds are interbedded with the dolomite and graded bedding can be used for top determinations. Concentric conical forms and various other shapes of stromatolite-like structures are present in some of the beds. Near Knob Lake, this formation probably has a maximum thickness of about 600 feet, but in many other places it forms discontinuous lenses that are, at most, about 100 feet thick. Leached and altered beds near the iron deposits are rubbly, brown or cream coloured and contain an abundance of chert or quartz fragments in a soft white siliceous matrix. According to Howell (1954), the carbonate in this formation consists of granular mixtures of dolomite and ankerite, and specimens examined contained up to 43 per cent calcium-iron carbonate mixed with calcium-magnesium dolomite.

Howell also described a cherty argillite member that is present locally near or at the top of the Denault Formation. This is similar in some respects to the Attikamagen slate but contains more chert and in places ferrous silicate minerals. This member is rich in apatite, which is distributed as minute crystals along bedding planes or in lenses, rounded clastic grains, and allotriomorphic masses. He concluded that the phosphorus may have been concentrated by algae or other organisms and that it, as well as fluorine present, may have originated from a contemporary volcanic source. This slate member at the top of the dolomite formation may mark a long period of time when very little normal sedimentation took place but when significant amounts of minor elements accumulated in fine clastic muds through adsorption and the action of organisms. Brecciated dolomite, with large angular fragments cemented by fine-grained carbonate of a similar composition, indicates that erosion and deformation of the upper part of the formation took place in local areas.

Fleming Formation

The Fleming Formation, which occurs a few miles southwest of Knob Lake and only above dolomite beds of the Denault Formation, has a maximum thickness of about 300 feet. It consists of rectangular 1- to 1½-inch fragments of chert and quartz. The fragments consist of fine colloform bands of coarse and fine grey chert alternating with bands of radiating needles of quartz resembling chalcedony. As much as 75 per cent of the rock may be composed of angular fragments that are cemented in a fine chert matrix. In the lower parts of the formation the matrix is mostly dolomite grading upwards into chert and siliceous material. As the chert breccia grades upwards to the quartzite of the Wishart Formation, the amount of clastic quartz in the chert matrix increases and the number of coarse fragments of chert decreases. Light coloured shaly beds occur at the top of the formation. Where leached and altered near the mines, the breccia becomes chalky white with high content of white siliceous clay.

Because of the peculiar character of this breccia, various suggestions have been made regarding its origin. Company geologists have suggested that it may be a residual accumulation of chert fragments derived by weathering of the underlying dolomite. Howell (1954) showed that much of the chert in the upper part of the Denault Formation formed as a replacement of carbonate and slate beds and as open space fillings in solution cavities in the carbonate. He suggested a similar origin for the chert breccia, with wave action and subaqueous slump causing further deformation of the brittle chert layers and lenses before final induration and silicification. The writer agrees that much of the silicification in the Denault dolomite was epigenetic but considers much of the silicification in the Fleming to be penecontemporaneous. There is evidence of considerable epigenetic silicification in the Fleming Formation as well, but the bulk of this rock is believed to have been precipitated as thinly laminated horizontal chert beds in shallow water. These appear to have been disturbed and broken up periodically by strong wave or current action during occasional stormy periods or at times of strong tidal action. Precipitation of silica in quiet water following a disturbance would take place in horizontal layers over these brecciated beds and form a matrix around existing fragments. With the next storm or disturbance solidified layers would be broken up and the accumulation of the chert breccia continued. The presence of carbon in black chert layers and in some of the fine clastic material associated with this breccia suggests that algae or organisms may have been abundant and played an active role in the precipitation of the chert.

Wishart Formation

Quartzite and arkose of the Wishart Formation form one of the most persistent units in the Kaniapiskau Supergroup. Thick beds of massive quartzite are composed of well-rounded fragments of glassy quartz and 10 to 30 per cent rounded fragments of pink and grey feldspar mostly ½ to 1 mm in size, well cemented by quartz and minor amounts of hematite and other iron oxides. Most of the rock with 10 to 25 per cent feldspar is arkosic quartzite but arkose beds are common.

Fresh surfaces of the rock are medium grey to pink or red, depending on the amount of hematite, and weathering produces little change of colour. Feldspar grains weather readily to light grey clay material leaving a pitted surface on the rock. Lenses of grit with rounded up to ¼-inch quartz grains are common, but most of the beds are composed of well-sorted quartz grains.

The thickness of the beds varies from a few inches to several feet but exposures of massive quartzite with no apparent bedding occur most frequently. Crossbedding is common and in a few places large symmetrical ripple-marks of high ratio of length to amplitude are present. According to Harrison (1952), where the Wishart rests directly on the gneisses, pebbles of chert are common in feldspathic quartzite with a chert cement. Where it rests on Attikamagen or Denault rocks the contact is gradational through a zone in which the two rock types are interbedded.

Thin sections of the quartzite consist of well-rounded quartz grains of fairly uniform size (average 0.4 mm) enlarged by later quartz to weld the whole into a very compact rock. Feldspars consist predominantly of microcline and orthoclase with numerous fragments of albitic plagioclase. A little chlorite is present, and hematite and brown iron oxides are distributed around the sutured boundaries of enlarged quartz grains. The borders of the original rounded sand grains are marked by fine dusty iron oxide.

A band of pink to grey massive chert, from a few feet to 30 feet thick, overlies the quartzites in many localities. It is commonly rubbly and altered, with numerous open spaces and vugs that contain secondary iron and manganese oxides.

Ruth Formation

The Wishart Formation is overlain by black, grey-green, or maroon ferruginous slate, 10 to 120 feet thick. This thinly banded, fissile material contains lenses of black chert and various amounts of iron oxides. It is composed of angular fragments of quartz with potassium feldspar sparsely distributed through a very fine mass of chlorite, white mica, iron oxides, and abundant finely disseminated carbon and opaque material. Much of the slate contains more than 20 per cent iron, and where the slate grades upwards to silicate-carbonate iron-formation, laminae of black clastic material are interbedded with dark cherty beds rich in minnesotaite, stilpnomelane, nontronite, goethite, lepidocrocite, siderite, and carbon. The total iron content increases in the upper part of the formation and fresh material is olive-green to khaki or brown, and deep red when oxidized. Many of the hydrated iron oxides disseminated in the formation appear to have formed after the fine-grained platy silicate minerals crystallized with a dense felty texture. The sharp angular to blocky nature of coarser quartz and feldspar grains and the wide distribution but small thickness of this formation are features characteristic of some tuffaceous rocks. Nonetheless, the high percentage of potassium feldspar with quartz suggests a source like that for the underlying quartzite. The silica to alumina ratio for the clastic beds (*see* Table II) is similar to that for the Attikamagen and Menihek Formations. However, the increase in carbon, mainly of organic origin (Harrison, 1952), and the increase in chert, ferrous silicate, and carbonate is typical of a deeper neritic environment of deposition where organic remains are preserved and chemical precipitation predominates over clastic sedimentation.

In the southern part of the main ore zone the Ruth slate grades upwards into brown slaty iron-formation that is predominantly chert but weathers a deep chocolate-brown. In the northern part of the main ore zone, in the Goodwood area, the slate is covered with several feet of grey vuggy leached chert.

Sokoman Formation

More than 80 per cent of the ore in the Knob Lake range occurs within this formation. The main lithological types and their positions in the stratigraphic succession are described in the following general outline, and much of the descriptive detail from company reports and the writer's investigations are summarized in Table III. Chemical analyses and petrographic descriptions of typical facies of the iron-formation in a section north of French mine (Fig. 6, *in pocket*) are given in Tables IV and V. Lithologically the iron-formation varies in detail in different parts of the range and the thickness of individual members is not consistent.

A thinly bedded, slaty facies at the base of the formation consists largely of fine chert with an abundance of iron silicates, mostly minnesotaite, and disseminated magnetite and siderite. Fresh surfaces are grey to olive-green and weathered surfaces brownish yellow to bright orange where minnesotaite is abundant. A minor component consists of clusters of radiating crystals of minnesotaite distributed through a fine cherty mass, with numerous euhedral magnetite grains and disseminated siderite. This 'silicate-carbonate facies' (Gross, 1965, p. 87) is usually thin banded to slaty, but massive beds 2 or 3 feet thick occasionally occur.

Thin-banded oxide facies of iron-formation occurs above the silicate-carbonate facies in nearly all parts of the area. The jasper bands, which are half an inch or less wide and deep red, or in a few places greenish yellow to grey, are interbanded with hard, blue layers of fine-grained hematite and a little magnetite. The red of the jasper bands is due to finely disseminated hematite distributed around particles of chert. The iron-oxide bands consist of aggregates of blocky and wedge-shaped grains of hematite, martite, and magnetite. Patches or lenses of fine euhedral crystals of carbonate are distributed along the banding of the rock, and clusters of minnesotaite needles occur around iron-oxide grains. Oval-shaped granules and oölites of fine chert, ½ mm along their greatest dimension, make up most of the jasper bands.

The thin-banded jasper beds grade upwards into thick massive beds of grey to pinkish chert and beds that are very rich in blue and black iron oxides. These massive beds are commonly referred to as 'cherty metallic' iron-formation and make up most of the Sokoman Formation. The iron oxides are usually concentrated in layers a few inches thick interbanded with leaner cherty beds. In many places iron-rich layers and lenses contain more than 50 per cent hematite and magnetite. The cherty beds are composed of oval-shaped granules and oölites of one millimetre or less that have concentric rings of chert and crystalline iron oxide. The granular forms are cemented by coarser textured chert. Fine needles of iron-silicate minerals, mainly minnesotaite, occur around hematite and magnetite in some beds that are partly altered to brown iron oxides.

The cherty metallic iron-formation grades upwards to pinkish and then to grey or brownish grey beds, but lenses of jasper are dispersed throughout this part of the formation. Carbonates may occur in lenses or patches at any or all horizons of this unit and are readily removed by weathering, leaving conspicuous pits or grooves.

The upper part of the Sokoman Formation comprises beds of dull green to grey or black massive chert that contain considerable siderite or other ferruginous carbonate. Bedding is discontinuous and the rock as a whole contains much less iron than the

TABLE III | *Iron-Formation Facies and Derived Ore*

	Silicate–Carbonate Iron-Formation		Oxide Facies of
	S.C.I.F.	Lower Red Cherty (L.R.C.)	PinkChertyandGreyCherty(P.andG.C.)
Thickness	20-100 feet	30-60 feet	80-160 feet combined
Weathered surface	Dark olive-brown to yellow-brown, minnesotaite beds often deep orange. Decomposes to fissile slate, flaky	Purple red to deep red, high iron beds are bluish black. Decomposes to granular sandy quartz–blue-hematite and martite aggregate	Less intense colour than in red cherty facies. Chert pinkish grey interbedded with grey chert layers with transition to predominant grey chert facies in upper parts. Decomposes as to L.R.C. with greater development of goethite, brown colour more conspicuous. Differential weathering between beds more pronounced with light and dark layers
Fresh surface	Olive-green to brownish grey. Subtle colour variation between thin beds	As above, with some mottly red and blue beds in red jasper and beds of strong metallic lustre	As above, pink to grey colour variation between beds and laminae, some lensy distribution of iron-rich layers
Bedding	Thick continuous beds and laminae usually less than 5 mm, rarely over 1 foot, thick	Well bedded, vary from thin 5 mm beds to thicker massive beds from a few inches to 2 feet. Lensy to nodular development common. Good segregation of iron-rich and chert beds in places	Well-defined, thin, wavy in places, crossbedding noted, lenticular to streaky distribution of iron oxides within layers and along bedding planes. Thicker in upper parts
Composition	Chert matrix with minnesotaite, siderite, magnetite, minor amounts of stilpnomelane, carbon. Occasional thin dark clastic beds. Usually less than 30% Fe. Most chert beds in upper parts	Jasper chert matrix with chert and hematite-magnetite-martite granules and oölites. Minor minnesotaite, stilpnomelane, ferruginous carbonate, hydrous iron oxide. 30-70% iron oxide, 30-40% Fe. Apparent decrease in iron content upward	Uniform, generally as to L.R.C. in mineralogy. 30% Fe or less in many parts
Texture	Very fine grained, felty intergrowth of silicates, granules of silicate, carbonate, and magnetite in chert	Medium to fine grained granular or oölitic with coarser cherty matrix. Iron concentrated mainly in peripheral parts of granules	Fine-grained chert matrix with smaller granules and oölites prevalent. Grain size variable but generally fine dense chert
Granules	Larger and more abundant in upper beds	0.1 to 0.5 mm in size, occasionally larger, mostly granular with oölitic concentric rings on edges, some composite granules and oölites	As to L.R.C. iron oxides concentrated in granule peripheries
Cleavage and jointing	Bedding plane cleavage well developed, closely spaced, highly fractured	Widely spaced, not conspicuous. Mostly perpendicular and along beds	Generally as to L.R.C. more closely spaced
Deformation	Small folds and crenulations	Drag-folds, small isolated crenulation folds by fracturing and brecciation	As to L.R.C.
Alteration	In preferential order—siderite to goethite, minnesotaite to goethite, magnetite to martite and goethite. Chert is leached mainly to brown and yellow earthy iron-hydroxides	Magnetite alters to martite, reconstitution of blue and red hematite, silicates and carbonates to goethite. Fine-grained chert leaches most readily, leaving fine granular to powdery siliceous clay with disseminated nodules and granules of hematite. Marked increase in porosity with major textural and structural aspects preserved, becomes friable. Mainly oxidation and removal of silica	As to L.R.C. finer chert leaves less distinct segregation of iron oxides and silica on leaching. Distinct powdery, porous, pink and grey chert layers with oxide stringers and red to brown iron oxide mixtures. Alters to porous friable bedded ore
Amenability to ore	Alters readily to earthy powdery yellow and brown ores. Richer chert zones less favourable for ore	Major protore because of high primary iron content and fine chert matrix that leaches readily. Strong joint pattern contributes to permeability. Minimum alteration required to make ore	Generally as to L.R.C. but lower iron content and dense chert leaves it less amenable to ore development. Differential leaching leaves hard and soft material, difficult to concentrate
Derived ore Leached ore	Porous powdery, light yellow-brown. Remaining silica intimately mixed in iron hydroxides, relic bedding prevalent, highly decomposed. High moisture content	Porous, blue-black to deep red, banded to massive granules and nodules of dense hematite in relic protore. Texture with most of silica in fine discrete grains. Colour darkens to black with spotty increase in disseminated manganese oxides	Leached ore bluish grey to grey-brown, banding distinct with grey cherty or pink layers
Enriched ore	Darker brown, rubbly, crude banding, denser but coarser fragments, coarse porosity, more permeable, manganese in pores, joints and vugs. High moisture contents	Dark blue to red or brown with goethite enrichment, coarser nodules to lumpy, coarser porosity to vuggy. Higher density, lower moisture content greater percentage of lump ore, less content of fines. Goethite enrichment by filling of pores and fractures and by replacement or accretion on granules	Most prevalent with goethite cement and enrichment of granular mass. Brownish black, often massive to rubbly
		FIRST CYCLE OF SEDIMENTATION	

Iron-Formation		Upper Iron-Formation (U.I.F.) Lean Cherts			
Brown Cherty (B.C.)	Upper Red Cherty (U.R.C.)	Grey	Yellow	Red	Lean Chert
50-80 feet, less in some areas	80-150 feet	10-50 feet	20-60 feet	0-50 feet	60-80 feet
Brown to yellow or grey-brown. Banding accentuated by grey and brown alteration of chert and iron-rich bands. Texture and grain sizes accentuated. Decomposes to sandy cherts with much brown coloration	Deep red, purple red, blue metallic layers. Much lensy and nodular jasper. Decomposes to granular sandy quartz and blue hematite as to L.R.C. Upper beds strongly pitted	Dull grey speckled with grey chert, pitted	Resembles S.C.I.F. but lighter yellow-brown	Spotted jasper in pink to red jasper and hematite beds	Dull green-grey scattered coarse pits
Brown to grey or greenish grey beds. Interbedded bluish and brownish iron-rich beds	Thick lensy red jasper and blue-black hematite-rich beds. Coarse granular to nodular and lensy. Red jasper most abundant in lower parts	Massive, pinkish grey, spotted	Like S.C.I.F. light greenish grey		Dense lean massive chert
Well-defined, less uniform lensy, variations in thickness locally, thin-bedded to slaty in lower parts. Thicker to more massive in upper parts	Well-defined, thick and massive in upper parts, good segregation of red jasper and hematite-rich layers. Thinner near base	Thick, irregular, cross-bedding. Poor segregation of components	Thin bedded to slaty	Thin, irregular cross-bedding	Thick, massive
Less uniform, mainly hematite-magnetite with spotty siderite in grey to greenish chert. Slaty beds composed of minnesotaite and carbonate in grey-green chert matrix. 30% Fe or less, ferrous iron more abundant. Fe silicates and carbonate more abundant especially along bedding surfaces	Similar to L.R.C. decrease in Fe towards top, carbonate in spots and disseminated towards top. Iron distribution in hematite–magnetite-rich granules. Manganese in rhodocrosite increases towards top. 30-45% Fe	Iron oxides in granules, spotty carbonate. Low in iron.	Blotchy carbonate and minnesotaite with minor Fe oxides. Much light porcelaneous chert	Iron-oxide granules in red jasper and grey cherts mostly low in iron	Low iron in streaky carbonates, silicates and goethite
Variable from grey, fine to medium cherts with oxide-rich granules to cherty S.C.I.F. facies.	Coarse granular jasper, much speckled red jasper, blue hematite in coarse granules and stubby lenses, nodes, layers. Most granules about 1-2 mm. Some 3-5 mm in jasper matrix	Dense, fine-grained granules, present, speckled	Coarse granules in dense chert	Granules of iron oxide and jasper in dense fine-grained chert	Dense fine grained, strongly granular to oölitic in places
Prominent with considerable variation in size. Mainly cherty, some carbonate	Prominent medium to coarse, oölitic growths around cherty granules and oölitic fragments. Mainly red chert with hematite and magnetite, some siderite, larger granules flattened to nodular	Coarse to medium, vary greatly in size	Some coarse	Mainly as above, some coarse white granules	Large carbonate granules, chert granules and oölites
Closely spaced, well developed parallel to bedding. Slaty to blocky	Widely spaced, blocky	Blocky	As to S.C.I.F.		Widely spaced
Crenulation, fracturing and brecciation	Fracturing				Fractures
Prominent carbonate-silicate alteration to goethite, martitization. Leaching of silica but less uniform to give granular to earthy layers. Much brown and yellow stain and secondary goethite. Oxidation commonly precedes silica leaching	Leaching of matrix cherts to give porous sandy friable bedded ore. Generally as to L.R.C. Coarse granules, sandy chert nodules in granular hematite	Dull grey pits and rough surface with carbonate leaching, blotchy to mottled	As to S.C.I.F. lighter ocherous yellow	As to L.R.C.	Carbonate spots give coarse deep pits and vugs
Generally fair to good, silica tends to remain high	Highly amenable with high primary iron content and silica leaches readily	Poor, low iron	Fair, siliceous	Fair to poor	Poor to nil
Brown, friable, porous, thin banded, much variation between bands in silica content, goethite enrichment almost essential	Bluish red, porous, conspicuous banding, red chert bands and nodules. Marked manganese staining. Silica in discrete grains mixed with iron-rich granules	Leaches to give hydrous iron oxides with high silica	As to S.C.I.F. Siliceous	As to L.R.C.	
Dark brown, yellow streaks and interbanding. Mottly goethite limonite distribution, less uniform. Hard and soft bands	Marked by goethite alteration of granules and goethite enrichment by cementation and filling of pores. Generally as to L.R.C.	Locally enriched to make ore	As to S.C.I.F.	As to L.R.C.	Secondary manganese veins
SECOND CYCLE OF SEDIMENTATION		THIRD CYCLE OF SEDIMENTATION			

TABLE IV | *Chemical Analyses (%) of Chip Samples of Iron-Formation Facies, French Mine (For descriptions see Table V; for location see Fig. 6)*

Sample No.	B523	B524	B525	B526	B527	B528	B529
SiO_2	49.41	41.42	48.16	51.24	43.77	49.01	56.49
Al_2O_3	0.68	0.79	0.53	0.42	0.42	0.37	0.37
Fe_2O_3	16.34	54.49	46.96	41.97	49.85	44.50	38.10
FeO	24.19	1.35	1.50	3.25	2.27	3.65	1.99
CaO	0.02	0.00	0.01	0.00	0.00	0.00	0.00
MgO	2.95	0.37	0.31	0.62	0.37	0.19	0.00
Na_2O	0.03	0.08	0.03	0.02	0.02	0.03	0.02
K_2O	0.07	0.01	0.01	0.01	0.01	0.01	0.01
H_2O+	5.20	0.98	2.04	2.10	2.54	1.94	2.42
H_2O-	0.38	0.06	0.04	0.05	0.05	0.02	0.03
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.08	0.04	0.04	0.03	0.04	0.05	0.04
MnO	0.65	0.02	0.02	0.02	0.03	0.03	0.03
CO_2	0.22	0.02	0.02	0.06	0.02	0.04	0.04
S	0.05	0.05	0.03	0.00	0.00	0.00	0.00
C	0.15	0.12	0.10	0.08	0.13	0.04	0.03
Total	100.42	99.80	99.80	99.87	99.52	99.88	99.57

Analyst G. A. Bender, Geological Survey of Canada
SPECTROGRAPHIC ANALYSES. Composition of all samples within these ranges.
Co-0.1-1.0%, Ni- < 0.01, Ti- $< 0.01\%$, Cr-0.01-0.1%, Cu-0.01%, Ba- $< 0.01\%$
B - not detected

Analyst W. F. White, GSC
B523 - Silicate-carbonate facies
B524 - Lower red cherty facies
B525 - Pink cherty facies
B526 - Grey cherty facies
B527 - Brown cherty facies
B528 - Upper red cherty facies
B529 - Grey upper cherty facies

lower part of the formation. Clusters of carbonate crystals weather out leaving pitted porous surfaces with powdery brown iron oxide in the cavities. Beds several feet thick composed mainly of iron-silicate minerals and carbonate are interbedded with the grey and green cherts in the upper part of the formation. Thin beds are conspicuous throughout the formation although massive beds several feet thick are not uncommon. The thin beds are mostly lenticular and discontinuous, and commonly consist of many thin laminae that vary in composition and texture. Nodules of jasper or grey chert, two or three times as long as they are thick, may be distributed along some beds. Wavy banding, crenulations, and brecciated laminae cemented by chert appear to be primary and penecontemporaneous deformational features. Crossbedding and ripple-marks are seen occasionally. Syneresis cracks have been observed in some granules, and some flattened nodules up to 8 inches long have a well-developed polygonal pattern of contraction cracks filled with coarse-grained white quartz. These contraction features are typical of material that has crystallized from gelatinous silica.

The iron-formation is fine grained and cherty throughout, but most of it has evidently been recrystallized since diagenetic and induration processes were completed. Accessory minerals are stilpnomelane, chlorite, graphite, tourmaline, and manganese oxides. Greenalite and chamosite have been identified by Perrault (1955). Crocidolite and riebeckite occur in later veins and fractures.

Menihek Formation

Thin-banded, fissile, grey to black argillaceous Menihek slate conformably overlies the Sokoman Formation in the Knob Lake area. Total thickness is not known, as the slate is found only in faulted blocks in the main ore zone. East or south of Knob Lake the Menihek Formation is more than 1,000 feet thick but tight folding and lack of exposure prevent determination of its true thickness even there. The contact with the Sokoman Formation is abrupt in the southern part of the area, the transition from thin banded cherty rocks to slate being across a zone a few feet thick. Harrison (1952) reported that about 75 miles north of Knob Lake, Menihek slate successively overlies Sokoman, Ruth, and Wishart Formations, and gneisses, indicating a progressive overlap by the younger formation. It is believed that differential uplift and warping of the depositional basin has in some places led to minor erosion of the sediments below the Menihek, but that a continuous sedimentary succession has been preserved in most of the basin.

The Menihek slate is mostly dark grey or jet black. It has a dull sooty appearance but weathers light grey or becomes buff where leached. Bedding is less distinct than in the slates of other slate formations but thin laminae or beds are visible in thin sections. The slate is composed of very fine, angular to acicular fragments of quartz, 0.04 mm in greatest dimension, distributed in a fine mass of white mica, chlorite, and platy minerals. Iron oxides are present in minor amounts. Abundant fine dusty carbon makes many laminae opaque in thin sections, and in others it is disseminated or is distributed in wavy bands along bedding planes. Except for the abundance of carbon, the Menihek slate is very like the Attikamagen slate and those varieties with acicular quartz grains, albitic plagioclase, and graded bedding resemble the fine-grained greywacke rocks in many other Precambrian areas.

Environment During Deposition of the Sokoman Formation and Associated Rocks

The marked differences in lithological facies indicate that conditions varied considerably during deposition of these sediments. Following the accumulation in shallow water of the relatively coarse clastic material of the Wishart Formation, fine-grained clastic muds (now the Ruth slate) were deposited in deeper quiet water. Sedimentation took place in a strongly reducing environment enabling preservation of considerable carbon of organic origin (Harrison, 1952) and the formation of ferrous iron silicates and siderite. The predominance of fine clastic material in graded beds shows that sedimentation took place below the effective depth of wave action, but small scour-and-fill structures in places indicate minor reworking of clastic material by currents.

A transition from predominantly clastic sedimentation to chemical precipitation of silica and iron is shown by the interbanding of clastic and iron-rich cherty beds in

TABLE V

Description of Iron-Formation Facies, French Mine
(For Chemical Analyses see Table IV)

	B523 Silicate–Carbonate	B524 Lower Red Cherty	B525 Pink Cherty
Location	One mile northwest of French Mine on northwest slope of Pete Signal Hill	250 feet north of ore loading station north side of French Mine	350 feet northeast of loading station north of French Mine
Thickness sampled	50 feet	40 feet	25 feet
Megascopic description	Mainly thin bedded (¾″ to 2″) with beds composed of laminae ¼″ or less thick. Dull olive-green to grey with khaki or brown cast. Deep orange-red to orange-brown on weathered surface. Very fine grained, some beds strongly magnetic. Very rich in iron-silicate minerals. Few cherty beds. Uniform section	Lensy banded red jasper and grey-blue hematite chert, stubby lenses, laminae and nodules ¼″ to 1″ thick give rock a thin-bedded appearance, fractures and breaks in slabs 4″ to 6″ thick, medium-sized chert granules in finer grained matrix, some in grey to brownish red blotches and patches. Hematite is dense blue-black in iron-rich beds, and where disseminated in chert bands gives a pink to brown colour. Some fine grained specular hematite	Fairly uniform thin-banded pinkish chert with disseminated blue hematite interbanded with blue-grey hematite-rich bands. Beds and slabby fragments ¾″ to 2″ thick composed of wavy laminae, laminae less distinct than in lower red facies, some beds of brownish chert. Differs mainly from lower red in colour. Some ¼″ thick laminae composed of coarse granules
Microscopic description	A thin-banded, dense, felty mass of minnesotaite, a few secondary veins of minnesotaite. Granular texture preserved in some bands, granules sheared and distorted in others. Considerable brown stain. Very little free quartz or carbonate in sections examined	Composed almost exclusively of hematite and chert. Granular to oölitic texture. Jasper is fine-grained chert with disseminated dusty red hematite. Chert granules rimmed by coarser grained hematite that is re-crystallized. Some patches of coarser grained quartz in matrix to granules and centres of many granules selectively recrystallized to coarser quartz.	Coarse granular or oölitic to nodular texture. Small oölites not abundant. Cherty texture over large areas interrupted by patches of coarse-grained quartz and crystalline hematite, minor brown iron oxide

the upper part of the Ruth Formation. The cherty silicate-carbonate member at the base of the Sokoman Formation is mainly a chemical sediment, precipitated in a reducing environment in neutral to alkaline water. The presence of granules composed of chert, iron silicate, and carbonate, or mixtures of these minerals would suggest agitation of the water during the development of these beds. However, thin layers

TABLE V

B526 Grey Cherty	B527 Brown Cherty	B528 Upper Red Cherty	B529 Grey Upper Cherty
400 feet northeast of loading station, French Mine	500 feet northeast of loading station, French Mine	550 feet northeast of loading station, French Mine	500 feet east of loading station, French Mine
50 feet	20 feet	60 feet	67 feet
Bands and zones vary in colour from pinkish grey to grey to brown. Predominantly thin banded (¼″), but much is crudely laminated to lensy or forms thicker 2″ to 6″ massive beds. Some wavy to lenticular banded iron-rich and leaner cherty beds are fairly well differentiated. Weakly magnetic in places	Lenticular thin banding 3″ to 4″, of brownish grey to pinkish jasper iron-formation. Considerable variation in high ferruginous bands from blue to brown laminae and lenses. Coarse granular texture in most beds with nodes and stubby lenses ½″ thick of pink and brown jasper	Thick massive beds prevalent up to 1 foot thick with gradational patches of blue to grey-pink iron-rich beds interspersed with banded, lenticular and nodular jasper, ½″ to 1″ thick. Magnetite- and hematite-rich lenses abundant in jasper. Some coarse granular to nodular material. Generally pinkish blue to dark grey with abundant red jasper	Grey-green magnetite carbonate chert with blue to brown hematite-goethite-rich beds. Spotty distribution of carbonate in grey chert and iron oxide beds. Blue hematite beds with metallic lustre and granular textured jasper beds dispersed in the lower part of the member. Considerable blue and brown iron oxide uniformly disseminated in grey-green chert. Magnetite-rich beds in places
Much medium-grained quartz with numerous fine-grained cherty granules. Granular to oölitic texture present in some beds. Considerable hematite crystallized in fine discrete grains, much goethite present in grains. Secondary bands or stringers, and as brown stain	Fairly pure oxide facies of hematite goethite, and chert. Jasper nodules consist of fine chert with minor hematite dust. Ferruginous beds have coarser recrystallized hematite and quartz and secondary goethite. Similar to grey cherty facies	Granular textured chert hematite and magnetite, with some goethite, minor minnesotaite. About half of silica recrystallized to coarse chert, remainder is fine-grained chert. Much of coarser chert in centres of granules. Minnesotaite in cherty patches. Some hematite altered to goethite	Predominantly hematite and goethite in coarse chert. Fine chert in centres of granules in matrix of coarse chert. Grains of hematite border granules with some disseminated in the matrix. Brown iron oxide replaces some hematite grains and much is derived from siderite. Minor iron-silicate content distributed in grey-green chert

of clastic material with graded bedding interbedded with layers of granular chert were evidently deposited in quiet water. This apparently anomalous association might be explained by postulating conditions of alternately agitated and quiet water, if successive beds were indurated before the overlying layers were deposited. Such conditions appear unlikely, as fine muds submerged in water are unlikely to be indurated until deeply buried. Furthermore, if the siliceous granules formed as solid pellets in agitated water they would be mixed with clastic material in single beds. Another possible explanation is that the siliceous granules remain suspended in water until they reach a certain size before settling to form a sedimentary layer. The fact that the size of granules is fairly uniform may be significant. If the granules formed in suspension as hydrous gelatinous globules of silica, sufficient silica could be coagulated before settling to form granules of the size found. If the silica globules, however, were soft and gelatinous when they settled they should be flattened and lens-shaped instead of round or oval. A third possibility is that the granules formed in place in quiet water. Contraction in gelatinous silica might then account for their development or they may have formed by accretion around nuclei. The role played by organisms in depositing silica is not well understood, but it is possible that these granular forms may have been developed by small algae colonies, similar in some respects to osagia (Twenhofel, 1919), which caused accretion of silica in rounded or granule-shaped forms.

The silicate-carbonate facies grades upwards into the cherty metallic part of the iron-formation. This part, composed of red to grey jasper with hematite and magnetite, marks a change in sedimentation conditions to an oxidizing environment in neutral to alkaline waters. The predominance of ferric oxides, both disseminated as fine dust in the jasper, and in granules, oölites, and discrete grains, suggests that sedimentation took place in shallow oxygenated water. The presence of crossbedding, ripple-marks, and lenticular banding, and the abundance of granules, oölites, and a coarse nodular to pisolitic texture in the cherty beds, all indicate agitated water with strong wave and current action and, in general, deposition in shallow water. Slight changes in the depth of water and the amount of available oxygen could account for the changes in colour in the cherty beds from red to grey or brown. A number of factors may have contributed to the variation in thickness of the beds, such as the rate of contribution of silica and iron, changes in the rate of deposition of the silica due to variation in dielectric properties of the sea water, non-uniform periods of agitation of the water in the basin, or possible variations in rate of growth of algae or other organisms.

The cycle of sedimentation from silicate-carbonate facies formed in a reducing environment, to jasper-hematites formed in an oxidizing environment, to oxide facies of lower iron content formed in a less oxidizing environment, has been repeated in many areas with the upper cycle in most places being less well defined and the succession of beds in it generally much thinner than that in the first cycle. Schwellnus (1957) suggested three cycles of silica-iron sedimentation in the French mine area, where the possible third cycle is composed of a thin succession of lenticular beds. It can be seen from Table III that iron-formation facies of the first cycle are generally more uniformly bedded with smaller granules. In the second cycle more beds are lenticular with less uniform thickness, granules and nodular structures are larger, and crossbedding is more common. The beds of the uppermost cycle are even less uniform in thickness and distribution, granules and nodules of chert are generally coarse but vary greatly in size, and crossbedding is common; the iron content is low and clastic material, although not plentiful, is more abundant than in the middle cycle. The increase in amount of crossbedding and the less uniform and coarser nature of granules in the upper cycles suggest that the water was shallower, and more disturbed and agitated than during deposition of the first cycle. Chemical sedimentation of silica and iron practically ceased with the deposition of the fine clastic muds that make up the Menihek slates. These muds, with an abundance of preserved carbon, are typical of deposits formed in deeper quiet water in a strongly reducing environment.

It is deduced that sedimentation of the Sokoman iron-formation and associated slates took place in a broad shallow marine basin where clastic sedimentation was of relatively little importance and chemical sedimentation predominated. The depth of water in this basin may have fluctuated considerably to permit the deposition of muds with graded bedding and cherty facies in shallow agitated water. The alternation of beds formed in a strong reducing environment with those formed in a strong oxidizing environment suggests that circulation was poor in this basin and that fluctuation in depth of water may have been a major factor in determining the type of facies precipitated. Conditions present in a restricted lagoonal type of environment could account for most of the sedimentary features. Such a shallow basin may have been bounded on the east by an uplifted linear belt where volcanic activity was centred. Much of the fine clastic material may have originated as tuff from this volcanic source. A large part of the silica and iron may have been contributed to the basin waters by thermal springs and emanations that were a product of the volcanic activity along this eastern belt.

Structural Geology of the Knob Lake Iron Range

The general distribution of stratigraphic and structural units around the operating mines in the area is shown on Figure 3 (*in pocket*) and some of the major structural features are shown on the accompanying cross-section.

The structure of this belt is similar to that of the foothills region of many prominent mountain systems. Major folds and faults have resulted from stresses directed from the northeast where the main orogenic belt was apparently situated. It is evident that detailed stratigraphic information and reliable determinations of the tops of beds are essential if this type of structure is to be satisfactorily interpreted. Indeed, cross-sections in the vicinity of ore deposits being mined show that the structure is much more complex in detail than that depicted on Figure 3.

Crossbedding or grain gradations, particularly the former, were the principal primary structures used to determine bedding tops. Grain gradations in beds in the slate formations are difficult to recognize in the field but are seen distinctly in thin sections; crossbedding is common in the quartzites and dolomites. The gradation from carbonate to quartzite matrix in the Fleming chert breccia has been used in a few places.

Secondary structures, mainly drag-folds, are extensively developed in all thin-bedded parts of formations, and appear to be congruent with major folds except for those directly associated with major fault zones. To satisfactorily interpret the field data it is necessary to distinguish between variations in the thickness of formations due to primary deposition and those caused by folding.

Folds

Folds with persistent northwest-trending axes are a predominant structural feature. The overall pattern of folding is that of a corrugated mass with doubly plunging anticlines and synclines dying out along strike. To the east where deformation is greatest the folds are isoclinal and overturned to the southwest, but to the west where deformation is not so great open asymmetric folds predominate. Apparently, because of the difference in competency, the thick-bedded to massive shelf-type sediments in the western part of the belt were less deformed than the incompetent, thinly bedded, sedimentary and volcanic rocks to the east. Although most folds are broken by later faults, the wave length of major folds is about 1,000 feet.

Extensive drag-folding, congruent with major folds, has further deformed beds and complicated the structure. Size of drag-folds ranges from crenulations visible in hand specimens to large structures that can only be defined by mapping. In some places, flanks of major folds are further deformed by cross-folds of relatively small closure that produced broad dome structures. In a few places where major folds plunge steeply the combined effect of drag-folds and cross-folds shows up on the surface as fan-folds. Cross-folds are thought to be of later age than the major folds and related drag-folds.

Near some of the iron deposits an additional stage of folding is recognized, which probably took place during Cretaceous or later time and may coincide with the late stage of faulting mentioned below.

Faults

Faulting of two ages has been recognized in the area. During the earlier period, strike faults were produced that are continuous over great distances and are on an average spaced about 1,000 feet. As a result of this faulting the rock is cut into a series of slices that parallel in strike the trend of the major folds and further emphasize the main northwest regional trend. These faults strike northwest, dip steeply to the east, and reverse dip-slip movement on them has led to upthrusting and transport of fault slices to the west. The strike faults when related in position to the major folds are mostly front limb thrusts that formed towards the close of the main period of folding, final adjustment to the deforming stresses taking place on these major breaks. As a result of these faults being imposed on the overturned fold pattern, there is considerable repetition of stratigraphic successions at the present erosion surface.

Many faults that cause displacement of at least several hundred feet are narrow, clean breaks with little brecciation. Other fault zones are marked on the surface by depressions tens of feet wide underlain by highly contorted and brecciated beds cut by numerous parallel shear planes. Some major fault zones are composed of numerous sinuous fault planes that separate narrow lenses of sediments.

A second set of faults strike east to northeast, and are roughly normal to the set described above. These cross-faults have a vertical displacement of as much as 50 feet and in places possibly more, and have very little horizontal displacement. Schwellnus (1957) described these as pivotal faults. They developed later than the first set and some movement apparently took place very late in the history of the area.

Many fault zones of the first set were reactivated during Cretaceous or later time, further thrusting from the northeast causing brecciation in some pockets of ore and overlapping of Cretaceous clay and gravel or rubble ore by fresh unaltered members of the stratigraphic succession.

Joints

At least three sets of joints were recognized. Of these, one set is perpendicular to the axis of folds, one parallel or nearly parallel with the bedding, and a third parallel with the axial planes of folds in some areas. Joints are more clearly defined in massive beds, and the important role they played in increasing permeability and hence leaching and oxidation of iron-formation needs further study.

Iron Deposits of the Knob Lake–Sunny Lake Ore Zone

Distribution

The locations of all known iron deposits of commercial size in the Knob Lake–Sunny Lake ore zone are shown on Figure 4 (*in pocket*), except for the Eclipse deposit which lies 20 miles northwest of the area shown. The deposits lie in two main groups, thirty-three of them being in the 25-mile-long zone centred on Knob Lake, and eleven of them in a 12-mile-long zone centred on Sunny Lake 25 miles to the north. Ore reserves in the southern group exceed 250 million tons of direct shipping ore, and in the northern group about 100 million tons, with another 36 million tons in the Eclipse deposit. The individual orebodies vary greatly in size, about ten contain between 15 and 45 million tons, about fourteen contain between 5 and 15 million tons, and the remainder contain between 1 and 5 million tons. Besides the deposits shown, a large number of zones are known with leached and partly enriched iron-formation. Also, there are many small occurrences of no economic interest.

General Description and Character of the Deposits

The iron deposits consist principally of residual masses of hematite and goethite derived from iron-formation. The structural setting and relative proportions of different types of ore naturally vary greatly from deposit to deposit but the major ore controls and the physical and chemical characteristics of the various ore types are similar throughout the range. Descriptions of forty-five deposits are summarized in Table VI (*in pocket*) and more detailed geology is given in the discussion of individual mines.

Relation to Topography

The ore deposits lie close to the height of land that forms the main watershed between streams flowing southeast to the Atlantic and those flowing north to Ungava Bay. The high hills and ridges of this belt are formed of the resistant iron-formation and quartzitic rocks that dip steeply in the tightly folded and faulted crestal part of a broad uplifted anticlinorium. All known deposits occur at the top of hills or on the upper slopes. Much less iron-formation is exposed in the lower ground and alteration is also less common where iron-formation has been explored in these areas. The ore deposits are elongated parallel with the strong northwest topographical and structural trend and consistently follow the configuration of individual beds of iron-formation.

As seen from Table VI, there is no particular relationship between the occurrence of deposits and the presence of special landforms, unless it is that most deposits are preserved on the upper slopes of hills. Material of ore grade as well as leached or enriched zones extends downwards from the bedrock surface but there is no consistency in the elevation of the upper surfaces of ore zones (*see* Fig. 4). Nor do either these elevations or the depths reached by deposits seem to be related directly to heights on the present watershed profile. The Knob Lake group of deposits, on the whole, lies below the 2,400-foot level and extends to greater depths than the Sunny Lake group, most of which lies above the 2,400-foot level.

Stubbins and Blais (1961) emphasized the fact that all ore zones reach the bedrock surface or are connected to it by altered leached zones. They also pointed out that the ore tonnage per vertical foot decreases with depth and that the amount of lean ore increases with depth. The water-table, according to their studies, is generally less than 100 feet below the present surface and follows its general configuration, sloping in the direction of the surface drainage. Most of the ore lies below the present water-table.

Some of the ore is in permanently frozen ground, particularly that on very high hills, and permafrost may extend downwards for more than 200 feet.

Relation to Structure

There is no consistent structural pattern in the orebodies, and structure appears to be only one of a number of complex interrelated factors that contributed to the formation of ore. Most deposits occur in synclinal and homoclinal folds cut by steeply dipping thrust faults with reverse dip-slip movement (*see* Table VI). Many are in broad gently plunging synclines. The importance of this type of structure may lie in the fact that permeability in the rocks is increased by slipping between beds and the development of joints during folding rather than in the shape of the fold itself. It is recognized however, that the trough or basin-like shape of the permeable zones created by this type of flexure, formed favourable impounding structures or served to guide and channel the flow of the circulating groundwater that leached and oxidized the iron-formation. The homoclinal structures with superimposed drag-folds and variations in dip may be regarded as flanks of major folds that have been separated from the main flexure by thrust faults.

Ore is commonly associated with thrust faults and these appear to be one of the major controlling factors in the location of ore. Their influence is attributed to the increase in permeability caused in the rocks by the fracturing and shearing associated with them. Schwellnus (1957) concluded from statistical studies of the structure in the mine areas that overlapping strike faults were particularly important. Stubbins and Blais (1961) considered the *en échelon* pattern of strike faults and elaborated on this point, stating:

> Although the movement along the regional strike faults is primarily dip-slip, it becomes oblique in areas of fault overlap due to the development of strike slip component. This results in a stress couple in these areas, producing rotation of most fractures and creating new shear fractures. The net effect is believed to be the development of areas of dilatancy containing a multitude of fractures amenable to penetration by circulating waters.

The distribution of orebodies in relation to the major folds and faults near Knob Lake is shown on Figure 3. There is no evident correlation between the occurrence of ore and the type of folds or the spacing of the regional strike faults. No unique elements have been encountered in the structures enclosing ore to suggest that they differ in form from any other non-ore-bearing structures, and it is concluded that although certain structures may contribute to ore control in the area, they do not dominate as localizing factors.

Structural features that gave rise to permeability in the iron-formation or any permeable zones exposed at the bedrock surface were most important. Ore is probably present in many plunging structures, because these highly fractured and permeable zones connected, up plunge, to the erosion surface at the time of ore formation and served to channel the flow of oxidizing groundwater. Unfortunately the spacing of fractures and the permeability of different rock types in various kinds of structures that have not yet been studied may have affected ore formation.

Reactivation and movement on thrust faults during late Cretaceous or more recent time may have been an important factor in preserving many of the orebodies from erosion. If ore was formed at or near the surface by weathering and groundwater leaching, residual deposits should have formed in any permeable iron-formation exposed. The present distribution of deposits suggests that only the deeper parts of these are preserved. In the upper parts of some of the deposits, however, pockets several hundred feet thick of rubble ore and freshwater clays are preserved. These were evidently deposited on the surface or in crevices and ravines open to the surface. Movement on these faults and down warping late in the last period of disturbance thrust some fault slices over the fault blocks to the west, in some places partly overriding them. Ore deposits on the foot-wall side of these thrust faults were thus protected from erosion until the adjacent ridges were worn down. The amount and pattern of movement on these late faults in the area have not been determined, but some local evidence suggests that as much as several hundred feet of displacement may have taken place. In the Ruth 3 deposit, fossil wood and rubble ore occurs to a depth of over 800 feet and Schwellnus (1957) indicated that this material has been deeply buried by rotation of a section of the orebody between two faults during this late stage of deformation. Blais (1959) gives further evidence for the deformation of rubble ore and fault blocks by late movement on faults in the Redmond deposit. The full significance of late stage fault movement, subsidence, down warping and folding as well as faulting, were important factors in the preservation of rubble ore.

The tendency for some groups of deposits to be distributed along lines perpendicular to the regional structural trend, as are the deposits at French mine or some of the Fleming deposits, might suggest that they are closely related to cross-faults. Detailed structural studies show however that both ore structures and ore formed prior to movement on these cross-faults, or that cross-faults are absent or do not coincide with the cross-trend of deposits. There is no obvious explanation for these cross-trends, but they may coincide with valleys or strong surface features in an earlier erosion surface.

Relation to Stratigraphy

The location, size, shape, and physical and chemical characteristics of the ore are directly related to characteristics of the protore iron-formation, and to a large extent controlled by them. The ore consists of residual masses within beds and facies of the iron-formation, and traces of bedding and primary textural features are recognizable to some extent in practically all the ore. Some transportation and redistribution of iron have evidently taken place during the later stages in the history of ore development both within the iron-formation and to a much lesser extent in the adjacent low iron sediments. Examples are numerous of ore development having selectively followed one stratigraphic unit of the iron-formation to considerable depth whereas adjacent units are relatively fresh and unaltered. In most deposits the grade of ore is more uniform along the beds than across them, boundaries between zones of different grade coinciding with the bedding. In some other deposits, however, material of ore grade is restricted to part of the iron-formation succession but cuts across the bedding within it. Where any appreciable amount of ore is present it is always in the iron-formation or the upper part of the Ruth slate where the primary iron content was relatively high.

Ore is more abundant and generally of higher grade in beds that originally had a high iron content. Considering the residual nature of the ore this is to be expected, as much less silica need be removed to raise to ore grade the composition of a bed that initially contained 40 per cent iron than one that contained 30 per cent. It is understandable, therefore, why much of the ore is found in the lower and upper cherty metallic iron-formation (*see* Table VII) and that this ore is largely of the high grade blue type (*see* Table VII).

The physical-chemical characteristics of the different types of ore are directly related to and controlled by variations in texture, mineral content, and composition of the protore iron-formation from which the ore is derived. Recognition of this has enabled classification of the ore into three major types—red, yellow, and blue—which are related to slate, iron silicate, and cherty iron-oxide iron-formation respectively (Pl. II). The final properties of these ores may be modified by the introduction and redistribution of iron-oxide minerals, the deposition of secondary manganese oxides, the degree to which silica is leached from the chert or the iron-silicate minerals, and by the amount to which late structural disturbance may have destroyed the relic bedding and textural forms distinctive of the protore.

The amenability of the various lithological facies of iron-formation to ore development and some of the features of the ore formed in these facies are given in Table III. The classification of ore types on the basis of stratigraphy is particularly useful in estimating and controlling the grade of ore mined and in appraising its properties. This classification is also essential if the properties and distribution of the ore types are to be understood and the method of concentration determined. It is also most helpful in determining the type of treatment that might improve the physical structure of the ore.

Principal Types of Ore

Blue ore is derived mainly from cherty-metallic or oxide facies of iron-formation.

It is composed of fine-grained, blue to dark grey-black, hematite with lesser amounts of red hematite, martite, and brown goethite. It has a distinctly porous granular texture with primary oval granules or oölites of iron oxide replaced by later hematite or goethite or simply enlarged by overgrowths of iron oxide. The blue ore may be friable and crumbly to nodular, or may even form hard, coherent, lumpy ore where a high proportion of iron oxide has been introduced. Silica remaining in the ore is mostly very fine grained, less than 100 mesh size, and sugary to equigranular. Beds that were originally rich in iron may remain hard, and the ore has a distinct blue metallic luster. Commonly the ore has a red to pink or grey cast, depending on the predominant colour of the chert layers in the original beds. Much of the blue hematite and goethite shows under the microscope a vermicular to irregular intergrowth and some hematite and martite, a strong euhedral, fine-grained habit. The equigranular mineral habit in this type of ore generally results in well segregated silica and iron-oxide grains, and many lean or marginal leached bodies of iron-formation can be beneficiated by simple washing and gravity processes.

The *yellow to brown ore*, often referred to as SCIF ore, is derived from the silicate-carbonate facies, and is composed mainly of goethite or hydrous iron oxides and dark brown martite. This ore is generally earthy to ocherous in appearance and has a high proportion of very fine grained material. Textures vary from fine colloform intergrowths of brown or yellow goethite, to crudely banded fragments with patchy, needle-like, or radial intergrowths of iron oxide pseudomorphous after iron-silicate and carbonate-chert textures. The silica, in the form of chert or iron-silicate minerals, is much more intimately mixed with iron oxides in yellow ore and some of it has a definite soft spongy to clay-like cohesion when squeezed in the hand. Porosity, although high, is in the form of fine openings and there is a high moisture content due to strong adsorption in this fine earthy material. The minnesotaite-carbonate-chert beds from which this ore is derived are readily leached and oxidized by natural processes, as silica dissolves readily from the very fine grained, felty textured silicates and siderite easily breaks down. The yellow ore is, however, more difficult to beneficiate than the blue.

Red ore is composed mainly of earthy red hematite, goethite, soft aluminous silicates, and finely divided chert or quartz. It is derived from the upper, iron-rich part of the Ruth slate or from other black slaty facies in the iron-formation. Individual layers may consist of dense earthy hematite or nodular to colloform hematite intergrowths. Much of it is soft, spongy, and clay-like and has high porosity with finely divided pore spaces and a high moisture content. Banding is generally distinct with conspicuous red, blue, or blood-red laminae. Beds originally consisting of fine black clastic material may stand out in the ore as punky soft saprolitic clay layers where they are leached of silica, calcium and magnesium, and lack iron enrichment. They commonly vary from white to pink or deep red and are known as 'paint rock'. The intimate intergrowths of iron oxide and aluminous clay or silica make these ores difficult to beneficiate.

Rubble ores overlie some of the bedded residual ore deposits. They consist of irregular masses and pockets of clastic ore fragments, bedded clay, and rock debris or gravel containing fossil wood and plants Plate III A. Three major types of rubble ore are recognized, iron sands and gravel, talus, and breccias. These grade into one another in some mines and are considered to be contemporaneous in formation. They represent reworked parts of the earlier formed orebodies and contain fossil wood and leaves believed to be of early Upper Cretaceous age (Dorf, 1959). The properties of this ore material are described by Stubbins and Blais (1961) as follows:

> The rubble ores are nearly all high grade, except where the iron sands and gravels are interlayered with quartz sands or where the talus contains large blocks of lean iron-formation, altered slate or quartzite. The rubble ores commonly show uniform grades and several vertical drill holes have intersected high grade rubble ore down to depths of 400 feet without variations of more than 5 per cent in iron and silica. In general, the rubble ores are Non Bessemer as they are rich in goethite and have a high phosphorus content. Local accumulations of ore fragments derived from the MIF (oxide facies of iron-formation) yield Bessemer grade. Manganese-filled fractures in breccia ores may produce manganiferous grade.

Sand and gravel ores in the upper part of the deposits are mainly unconsolidated, well-sorted, bedded sediments. They consist of subangular fragments of ore, as much as 10 inches in size but mainly less than 3 inches, in a matrix of fine sandy ore and quartz grains or cherty fragments. Stratification and crossbeds dip towards the centre of the pockets or basin and the deposits may be as much as 350 feet thick. These ores are overlain by glacial drift and do not appear to have any distinctive topographic expression.

The sand and gravel ore in some places grades downwards into talus ore, which is poorly sorted and consists of angular to subangular blocks of bedded ore and sediments of up to 10 feet embedded in fine-grained ore. The talus ore appears to be ore material from various parts of the iron-formation succession that has slumped into crevices and fissures or fallen from fault scarps or valley walls.

The breccia ores are developed mainly near fault zones and are composed of broken, bedded ores with randomly oriented angular masses ranging in size from less than an inch to tens of feet. They are characterized by fragments of ore of one type or from strata of different types surrounded by secondary iron and manganese oxides with impressive colloform or stalactitic texture and structure filling voids and openings in the breccia. These breccia ores appear to be the product of late stage deformation along faults that broke up masses of bedded ore and produced increased permeability and open spaces for secondary iron and manganese enrichment.

Physical and Chemical Properties of the Ore

The properties of the main types of ore in the mines near Knob Lake have been summarized by Stubbins, Blais, and Zajac (1961) from information obtained after 5 years of mining. The following description is based mainly on data from their paper. The compositions and physical properties typical of the various ores are summarized in Table VII.

The important relationship of silica leaching and porosity and the resultant development of the residual ores are illustrated by Figure 5. Pore spaces in the ore and partly altered iron-formation are small in diameter and poorly connected and appear to result from removal of silica around the borders of chert gains and granules. Coarse cavities and open vugs in the ore, ranging in size from less than one inch to more than a foot, may be lined with secondary goethite or manganese oxides with colloform to botryoidal textures.

It has been found during dewatering of the mines that fresh rocks are more permeable than altered rocks and ore. The explanation for this seems to be that, even

TABLE VII | *Physical and Chemical Properties of Typical Ores*

Type of Ore	Blue	Yellow	Red
Relative abundance in mine areas	66%	20%	14%
Average composition from natural analyses in %			
Fe	54.5	50.0	48.0
P	0.038	0.103	0.123
Mn	0.56	1.13	2.41
SiO_2	8.2	5.6	6.2
Al_2O_3	0.72	1.00	2.10
Moisture	8.9	14.2	13.7
Critical moisture	9-11	15-16	15-18
Porosity in % of volume	10-44	19-49	7-47
Average porosity	31	36	30
Permeability	Medium	Low	Low
Specific gravity	3.2	2.6	2.8
Tonnage factor, cu. ft. per long ton	11.3	14.1	12.7
Typical sieve analysis, dry screening, in %			
+ 1 inch	19	22	20
+ 6 Mesh	26	35	34
+ 35 Mesh	20	25	26
+ 100 Mesh	15	9	9
− 100 Mesh	20	9	11
Essential ore minerals	Blue hematite, martite, goethite, magnetite	Goethite, limonite	Earthy red hematite
Amenability to concentration by washing	Medium to high	Very low	Very low

Data from Stubbins, *et al.*, 1961

though porosity is much greater in ore and leached rocks, groundwater permeates more easily along joint, fracture, or fault systems than through porous leached rock. There is abundant evidence that leaching and alteration of the iron-formation took place along fractures and joints. In advanced stages of decomposition of the rock the fracture walls apparently broke down and the finely divided silica, iron oxide, and clay material tended to agglomerate and close off the intricate circulation channels in the rock. Because of the variations in texture of the ores, the yellow and red ores hold up to 35 per cent moisture by volume with less than 10 per cent of the moisture of saturation being drained out during mine dewatering. The blue ore on the other hand holds up to 25 per cent moisture by volume but of this 10 to 20 per cent will drain out.

Ores containing more than a certain critical amount of moisture will stick and become compacted in some types of railway cars under certain transportation conditions. This critical amount is generally well below the saturation limit and varies with the permeability and other physical characteristics of the ore.

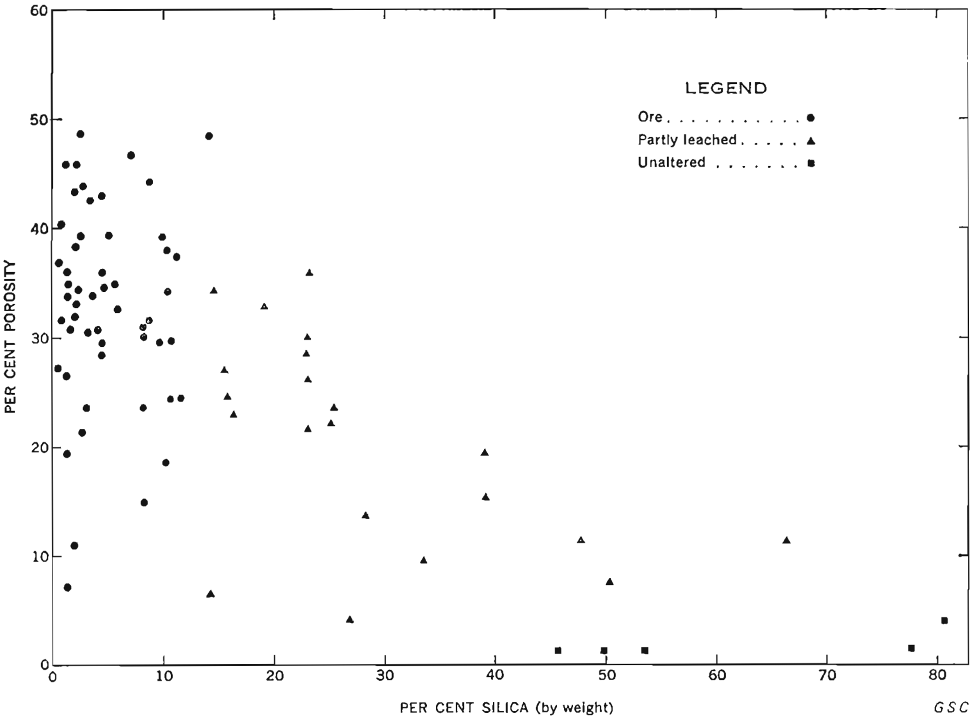


FIGURE 5. Graph showing relation between measured porosity vs. silica content (from Stubbins and Blais, 1961).

The average volume occupied by a long ton of ore is 12.2 cubic feet but ranges from 10 to 17 cubic feet, depending on the type of ore. There is little difference in density between unaltered iron-formation and ore because of the high porosity of the ore even though the iron oxides have a high specific gravity.

Oxidation is an important part of the ore-forming process, so that practically all magnetite in or near orebodies has been altered to martite or hydrated ferric iron oxides. There is sufficient magnetite in most of the iron-formation to produce positive magnetic anomalies but leached or altered zones, if they produce any noticeable effect, give anomalously low magnetometer readings.

Redistribution of Iron

The importance of the leaching of silica from the iron-formation so as to leave residual hematite and goethite as the main ore constituents must be emphasized. Nonetheless there is considerable evidence in the mines to indicate that some of the iron oxide is in secondary fillings of pores and openings and, although none has probably been transported far it has certainly been redistributed and redeposited within the ore zone. It is very difficult to determine how much of the iron oxide is secondary and how much is residual from the protore. Examination of the data on porosity and density of the ore (summarized in Table VII) shows that ore formation is not a simple leaching process but that some iron is secondary or else the porosity of the ore has been changed by compaction.

If it is assumed, for example, that blue type ore is derived by simple leaching of silica from a bed that originally contained 40 per cent iron as hematite and the remainder quartz, with negligible porosity, then leaching to form this into a residual ore containing 8 per cent silica and 64.4 per cent iron as hematite must leave a porosity of 53 per cent of the total volume. Allowing for 8 to 9 per cent moisture, as indicated in Table VII, the maximum porosity to be expected is 44 per cent. But the minimum porosity actually measured is 10 per cent and the average is about 31 per cent. As much of the ore contains 6 to 8 per cent silica and the iron content averages 54.5 per cent with some ore containing as much as 60 per cent iron and less than 5 per cent silica, it is unlikely that the ore formed by leaching alone. The porosity in ore is 10 per cent or greater but less than the amount derived from leaching, and the amount of silica and insoluble material is also much less. The specific gravity measured is higher than the calculated figure. Much of the iron-formation has a primary iron content of about 35 per cent, so that the porosity should be even greater than that actually present. If, however, the iron were converted to goethite during leaching, the discrepancy between calculated and measured porosity would be much less and the conditions present could be produced without secondary iron element enrichment or slumping.

The discrepancy between the calculated and measured porosity may also be accounted for by redistribution of the iron oxide and its deposition in the pores and openings in the ore or if the porosity is diminished by slumping or compaction. There is considerable evidence of slumping in the nearly flat lying bedded ores on the Mesabi range but slump and collapse structures are much more difficult to distinguish in the steeply dipping and tightly folded beds in the Knob Lake range. Very little evidence for slumping has been noted in these ores and thickness of individual beds followed from ore through lean ore to unaltered iron-formation does not vary. Much intricately folded bedding is preserved in ore (Pl. III B). Slumpage therefore is considered to be limited in extent and to have had an insignificant effect in changing porosity and other properties at Knob Lake. Furthermore, brecciation and deformation would tend to increase the overall porosity and open spaces in the ore. Considerable compaction may have taken place, but this would be difficult to detect.

There is textural evidence that secondary iron oxides were deposited, and this could account for the ore properties measured. If this secondary enrichment took place while the silica was being leached, the main primary structures would be preserved without the collapse and obliteration of the bedding. The source of this secondary iron is assumed to be within the iron-formation, as the ore occurs almost exclusively there. Even where the adjacent quartzite or dolomite is highly leached and friable very little iron is found in fractures or veins. This indicates very little migration of iron from the iron-formation. Much of the secondary iron may have been transported down-dip from the part of iron-formation now eroded away. The facts that ore grade diminishes with depth, that ore deposits pass downward into fresh unaltered iron-formation, that they bottom along the base of bands of iron-formation, that oxidation is uniform and complete to depth, and that all deposits connect to surface suggest that the iron was redistributed within the formation by circulating surface waters rather than by solutions from a deep seated source.

Ore Grade and Composition

The ores are graded for commercial purposes into three main types, based on their chemical composition. The average analyses of each type of ore shipped from Knob Lake during the first five years of operation are given in Table VIII. All material with 50 per cent or more iron and less than 20 per cent silica, dry analyses, is classified as ore for estimating reserves but material containing more than 55 per cent iron and less than 10 per cent silica is now classified as 'direct ore' and the remainder as 'lean ore'. Material below the standard grade of ore, consisting of partly leached iron-formation, is stockpiled if mining operations require its removal or classified in the mine as 'treat rock' for future beneficiation. Some ore zones have up to 65 per cent iron and as low as 1 per cent silica.

TABLE VIII *Average Composition of Knob Lake Ores Shipped in the First 5 Years*

						Natural Analysis					
	Tons	Iron	Phos-phorus	Manga-nese	Silica	Alumi-num	*Lime	*Mag-nesia	*Sul-phur	Mois-ture	Loss on Ignition
Bessemer	4,818,487	55.5	0.033	0.39	6.29	0.96	0.13	0.02	0.007	8.96	4.03
Non-Bessemer	43,576,504	52.7	0.081	1.08	6.05	1.24	0.15	0.02	0.005	10.57	5.12
Manganiferous	6,592,973	46.9	0.118	5.26	6.69	1.52	0.12	0.02	0.005	10.68	5.97
Total	54,987,964										
Average		52.23	0.081	1.52	6.15	1.25	0.14	0.02	0.005	10.44	5.12

(*From* Stubbins and Blais, 1961)
*1959 shipments only

The average grade and range in grade for 418 million tons of ore in all deposits as determined prior to mining are shown in Table IX. In general the Knob Lake ores are low in sulphur but relatively high in manganese. The content of other trace elements is well below the maximum permitted in ore specifications.

Composition of Ore Mined

The composition of the ore mined in various deposits in 1959 is given in Table X. The grades shown do not correspond directly with the grades from single parts of deposits, but represent the material taken from various pit faces and mixed to make up the commercial ore types listed.

Bessemer ore must be low in phosphorus and manganese, and much of the blue ore meets these specifications. Very little yellow or red ore is of Bessemer quality. The bulk of the ore is of non-Bessemer grade with medium phosphorus and manganese

TABLE IX *Average Grade of Ore Reserves by Types, Knob Lake Range Computed before Mining*

	Bessemer			Non-Bessemer			Combined Bessemer and Non-Bessemer	Manganiferous		
	Minimum	Maximum	Weighted Average	Minimum	Maximum	Weighted Average	Weighted Average	Minimum	Maximum	Weighted Average
Fe	50.0%	67.1%	60.73%	53.8%	61.6%	57.53%	59.53%	44.5%	54.4%	50.17%
Mn	0.08	1.04	0.29	0.06	1.29	0.57	0.40	3.14	11.70	7.64
P	0.014	0.043	0.027	0.048	0.211	0.118	0.061	0.012	0.196	0.109
SiO_2	2.26	18.24	8.71	3.19	13.33	8.07	8.47	3.25	17.50	7.92
CaO	0.05	0.25	0.09	0.05	0.24	0.11	0.11	0.04	0.20	0.10
MgO	0.04	0.11	0.05	0.04	0.10	0.06	0.06	0.04	0.09	0.06
Al_2O_3	0.13	2.53	0.59	0.25	3.60	1.47	0.92	0.26	2.20	1.32
S	0.009	0.023	0.012	0.008	0.034	0.014	0.013	0.005	0.040	0.012
Loss on Ignition	0.27	9.55	2.88	2.00	10.29	6.34	4.18	1.13	10.25	6.65

From Gustafson and Moss, 1953

content in the range shown in Table IX. Most of the manganiferous ore, which contains more than 3 per cent manganese, occurs in the natural yellow and red type zones. There the manganese content may in places be as high as 30 per cent, although it is commonly closer to 8 per cent. A manganese content between 1 and 3 per cent is undesirable in most commercial specifications and the amount of this element must be carefully controlled in the mixing and blending of ore for shipment. Material suitable for sale as manganese ore does not occur, as the iron-manganese ratio is too high even in the zones with most manganese.

The lime and magnesia content of these ores is very low, as would be expected from the small amount in iron-formation (*see* Table IV). The alumina content is greatest in the red ore, which is derived from slate. Work by Schwellnus (1957) on 165 composite samples of ore shows: up to 15 ppm of Cr, Mo, Ni, and Ge; from 15 to 30 ppm of V and Co; up to 130 ppm of B; and about 230 ppm of Ti. The trace element content is lowest in the blue ore and highest in the red ore but, except for germanium which is fairly uniform, varies from deposit to deposit. He also found that the phosphorus content increases with the amount of secondary goethite. The trace element content is generally lower in fault zones and is somewhat higher in the ore than in the corresponding protore. This suggests some residual enrichment of these constituents and possibly leaching of them along fault zones as a later process.

Mineralogy of the Ore

Iron oxides. The general mineral composition of the ore and the iron-formation from which the ore is derived are given in Table III and in the descriptive section of the

TABLE X | *Iron Ore Company of Canada, Mine Production, 1959*

		Natural Analysis					
Mine	Long Tons	Iron	Phosphorus	Mang.	Silica	Alum.	Moist.
GAGNON							
Bessemer	775,079.92	56.474	0.026	0.345	5.09	1.20	8.90
Non-Bessemer	2,865,049.08	50.175	0.072	0.765	6.51	1.97	12.79
Manganiferous	420,227.53	45.948	0.097	5.148	6.35	1.94	11.61
TOTAL GAGNON MINE	4,060,356.53	50.940	0.066	1.138	6.22	1.82	11.92
FRENCH							
Bessemer	322,061.08	57.360	0.025	0.366	7.18	.64	7.73
Non-Bessemer	2,056,512.16	53.403	0.054	1.278	7.66	1.09	9.82
Manganiferous	555,756.25	48.211	0.084	4.700	7.25	1.08	10.53
TOTAL FRENCH MINE	2,934,329.49	52.854	0.057	1.826	7.53	1.04	9.73
FERRIMAN							
Bessemer	845,146.65	54.257	0.027	0.273	8.03	0.61	8.91
Non-Bessemer	819,450.36	50.694	0.044	1.167	8.68	1.00	11.36
Manganiferous	41,636.25	45.268	0.055	4.198	9.67	1.46	11.81
TOTAL FERRIMAN MINE	1,706,233.26	52.326	0.036	.798	8.39	0.82	10.16
RUTH LAKE							
Bessemer	47,292.74	58.253	0.035	0.398	3.64	0.60	9.28
Non-Bessemer	2,685,771.18	51.370	0.125	1.203	5.43	1.40	12.23
Manganiferous	419,127.69	46.951	0.155	4.321	5.19	1.62	12.76
TOTAL RUTH LAKE MINE	3,152,191.61	50.886	0.127	1.606	5.37	1.41	12.2
BURNT CREEK							
Bessemer	1,523.71	56.441	0.036	0.222	4.17	1.01	10.87
Non-Bessemer	752,350.85	51.900	0.098	1.498	5.42	1.21	12.46
Manganiferous	14,271.20	47.817	0.134	3.287	4.83	1.48	14.23
TOTAL BURNT CREEK	768,145.76	51.833	0.098	1.529	5.41	1.21	12.49
GRAND TOTAL							
Bessemer	1,991,104.10	55.718	0.026	0.319	6.64	0.84	8.73
Non-Bessemer	9,179,133.63	51.436	0.083	1.104	6.55	1.46	11.81
Manganiferous	1,451,018.92	47.103	0.108	4.692	6.44	1.50	11.56
TOTAL ALL MINES	12,621,256.65	51.613	0.077	1.393	6.56	1.36	11.29

From Mineral Inf. Bull. MR45, Dept. Mines and Technical Surveys, Canada

ore types. Only a limited amount of microscopic study has been reported, and the paragenesis in the intimate intergrowths of iron oxide have not been described in detail from enough localities to permit formation of many general conclusions.

Several varieties of hematite occur, including dark blue metallic, specular, earthy red, and martite. Much of the granular blue-grey hematite present in granules in the cherty metallic iron-formation has maintained the same crystal habit and texture in the ore as in the unaltered protore. Early formed hematite shows later overgrowths of grey hematite and specular hematite in blocky to platy euhedral grains may ring granules, be dispersed in early hematite intergrowths, or be present in the matrix of the granules. Some earthy hematite is present in late veins and intergrowths in the blue ore but it is a major constituent in the red ore. Martite is extensively developed in all the ores and the crystal form of magnetite is well preserved and some magnetite remnants are enclosed in red or grey hematite.

Magnetite or martite pseudomorphs of magnetite are widely distributed in all ore types. Some of the coarser crystals cut across textures in the iron-formation and are present as veins cutting the bedding. They appear to have formed during an early metamorphic stage prior to ore development. However, there is much fine-grained, dusty magnetite in oölite rings or disseminated in chert or silicate minerals that is considered to be primary.

Goethite is abundant in all the ores and ubiquitous in its many forms and modes of occurrence. It is the principal ore mineral in the yellow ore and consistently forms as an alteration product of carbonate and iron silicates wherever these minerals occur. Goethite has formed predominantly as a late stage ore mineral cementing other mineral aggregates and extensively replacing early varieties of hematite. It forms irregular overgrowths on hematite or chert-hematite granules, and forms vermicular textured grain aggregates and colloform incrustations in pores, vugs, and open spaces in the ore. It is extensively developed in many beds and zones of iron-formation where it replaces the earlier magnetite, hematite, and other rock minerals and appears to have formed as a result of oxidation and hydration in the rock without any appreciable leaching of silica.

Manganese oxides. Practically all the manganese is present as manganese oxide and hydroxide minerals and most of it was deposited after the iron minerals had formed. Most of the manganese oxides form colloform or botryoidal masses distributed in fractures, veins, vugs, or in the cementing matrix in the ores. It is most abundant in the red ores and in the transition zone between Ruth slate and silicate-carbonate iron-formation, probably because the fresh silicate-carbonate facies is high in manganese and the thin bedding and fractures in this ore have maintained permeable channels. In other ore types it is distributed along late faults or permeable zones. Some of the botryoidal coatings in cavities are covered with radiating steel-grey, needle-like crystals of pyrolusite but the main colloform masses are composed of psilomelane or hollandite. Many other varieties of manganese minerals may be present in these dense mineral intergrowths. Manganese in some zones in blue ore is finely disseminated with the dark hematite and gives the ore a dense earthy black appearance. Manganese minerals form nodular intergrowths with goethite in yellow ore and are responsible for some of the deep purple patches in red ore. Manganese oxides filling fractures and veins are widely distributed in all rocks in this area and are particularly conspicuous in some of the fractured quartzite, chert, and dolomite beds adjacent to orebodies.

Description of Principal Properties

The structural configuration and distribution of the different types of ore in the deposits are interpreted from surface maps, extensive drilling, and detailed mapping of the ore faces in the mines, together with ore analyses from both the development and production stages of drilling and from the grades of material mined. Mine excavations show that very accurate and concise structural interpretations are possible when the local stratigraphy of the iron-formation is known in detail. The stratigraphic types of ore are not shown on the figures but can be inferred from the types of iron-formation present. The distribution of the metallurgical ore types is more difficult to predict because iron and manganese are considerably redistributed and an ore mass of a single type may frequently cross stratigraphic boundaries.

French Mine

Burnt Creek Deposits 1, 3, and 6

Three deposits, Burnt Creek 6, 1, and 3, in that order from west to east, are being mined in one large open pit known as French mine (Pl. IV). The general geology is shown in Figure 3, and the shape of the deposits and the distribution of the various metallurgical types of ore in relation to stratigraphy are illustrated in Figure 6.

The *west deposit* 6 lies within a syncline in iron-formation in which most of the east limb has been truncated by a steep east-dipping thrust fault. The other two deposits lie in homoclinal structures formed by the repetition of the iron-formation by thrust faults. The structure of the west deposit is modified by a large drag-fold on the west limb of the syncline and the north and south sides of the deposit are bounded by steeply dipping cross-faults. Stratigraphic information shows that movement on these cross-faults has caused the orebody to be moved down relative to the adjacent iron-formation beds, thus forming a separate fault block. There is further dislocation of the stratigraphic succession along thrust faults in the middle and east deposits and a drag-fold in the east homocline has formed a local basin structure that appears to have influenced ore development.

The quartzite and slate forming the foot-wall of the west deposit is highly leached and decomposed to depth. The ore bottoms in the middle of the Ruth slate and the base of the ore follows this central horizon consistently, suggesting that only the upper part of the slate, which was originally rich in iron, is converted to ore. All members of the iron-formation are converted to ore. The ultimate depth of ore on the east side of this deposit has not been determined by drilling but the base of the ore is assumed to follow the slate boundary.

Ore is developed in the *middle deposit* in all members of the stratigraphic succession from the top of the Ruth slate to the red upper iron-formation (Pl. II). In the section shown the ore boundary along the foot-wall is concordant with stratigraphy, but is discordant along the hanging-wall. The plan, however, shows marked discordance at the north end of this deposit as well as at the south end where the boundary is irregular with large lean inclusions and a narrow band of ore follows along a fault zone.

Ore is present in the *east deposit* in all units, from the Ruth slate to the upper red cherty iron-formation, but the base of the deposit is irregular and cuts across the bedding. The north end of this deposit is particularly discordant and cuts sharply across the bedding in the iron-formation. At the south end several long narrow tongues of ore extend south along fault zones. The abrupt termination of the north end of the middle and east deposits suggests that cross-faults are present and may be a factor in controlling ore location. There is no dislocation of beds or direct evidence for fault displacement. The iron-formation north of these orebodies is relatively fresh and unaltered as if the access of groundwater to permeable structures in the area was controlled by some other northeast-trending feature, perhaps a steep valley wall on an earlier erosion surface.

The distribution of metallurgical types of ore in the French mine is irregular and the grade is much less uniform and predictable than in other mines. Because of this, haphazard distribution operation of the mine has been particularly difficult.

A large part of the *west deposit* is covered by rubble ore which extends to a depth of about 150 feet. The overlap of this rubble by quartzite and slate on the east side of the deposit is a result of late thrust faulting. Most of the ore is non-Bessemer grade, except for a uniform band of manganiferous ore in Ruth slate on the west side of the deposit and a uniform band of Bessemer ore, about 100 feet thick, distributed concordantly in the grey and brown cherty member and lower part of the upper red cherty member. A prominent feature in the *middle deposit* is the distribution of Bessemer ore in the upper red cherty member but extending into the grey and brown cherty members, and grey upper member. Small pockets of manganiferous ore are also present. Much of the ore in the *east deposit* is of the manganiferous type and is mostly in the lower parts of the deposit. Other ore types occur in smaller irregular masses.

According to figures quoted by Choubersky (1957), the deposits in the French mine have a combined ore reserve of 23 million tons.

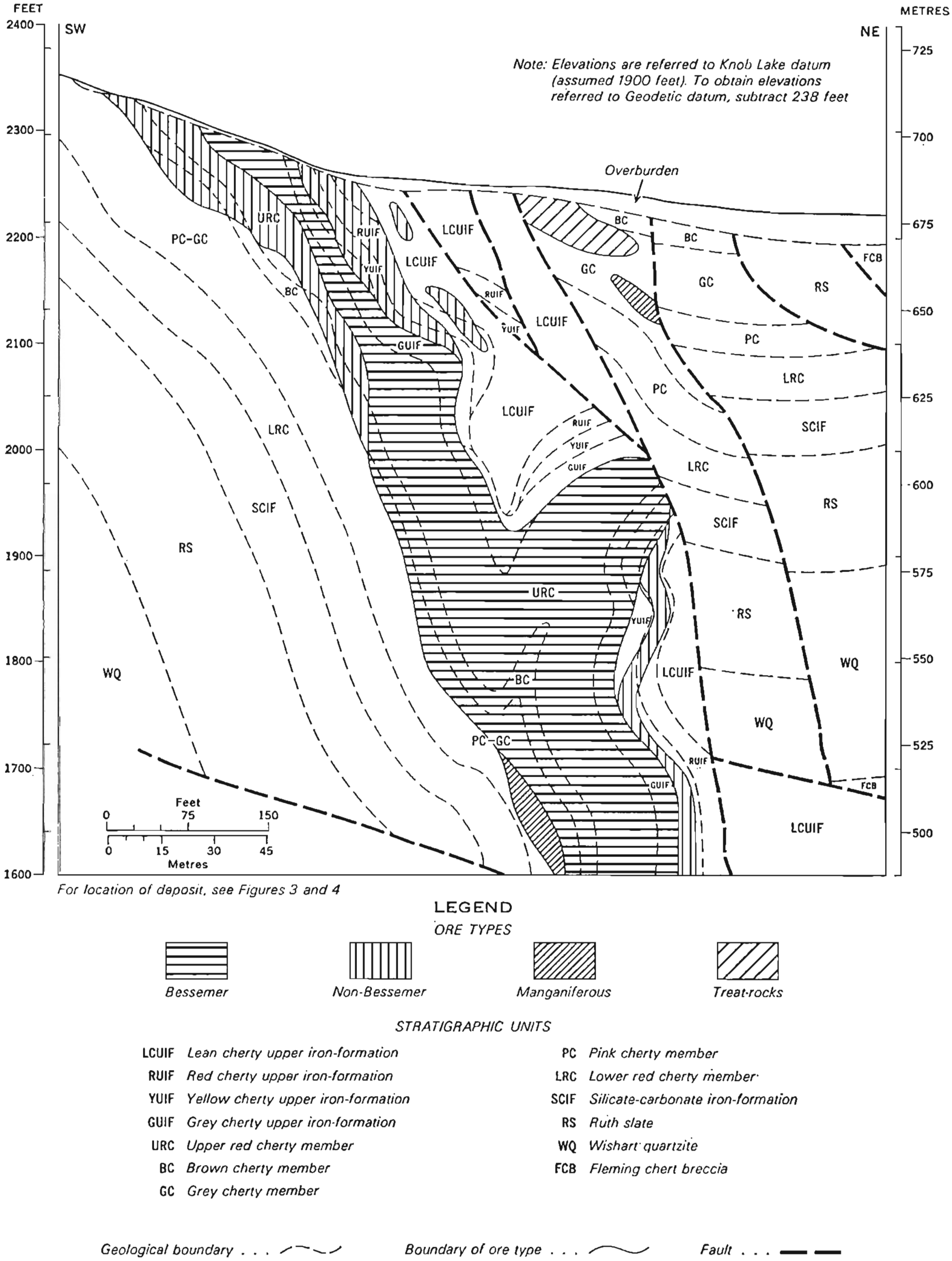
Gagnon A Mine

Ferriman 3 Deposit

The Ferriman 3 deposit is between 1½ and 2 miles northwest of French mine in the same band of iron-formation as the Burnt Creek 1 deposit. It is about 3,500 feet long and is in a major monoclinal structure deformed by a small south-plunging dragfold. It lies at about the middle of the deposit but projects to the surface at the north end. The iron-formation is bounded on the east by a series of steeply dipping thrust faults.

The hanging-wall of Ferriman 3 deposit contains a large block of ore which lies east of the hanging-wall fault. This mass of ore is covered by a thick thrust-faulted mass of quartzite.

In general the ore deposit is concordant with the stratigraphy and follows the shape of the drag-fold at depth. In detail however its borders are sinuous and cut across the bedding in the iron-formation. Ore is developed mainly in the stratigraphic interval between the grey cherty member and the yellow upper iron-formation member, and is predominantly of Bessemer grade in the lower part of the deposit. In the upper part the Bessemer ore is flanked by bands of non-Bessemer ore that contain a few pockets of manganiferous ore. At the north end of the deposit, where the dragfold appears on surface, ore is present in all parts of the iron-formation, from the silicate carbonate member to the red upper member. Northward the deposit plays out in a number of discordant tongues and islands of ore. The deposit has been tested to depths of more than 650 feet and the manner in which it bottoms is not known (Pls. V and VI A).



GSC

FIGURE 7. Typical cross-section of Ferriman 3 deposit, Gagnon A mine, showing distribution of ore (*from* Iron Ore Company of Canada).

Gagnon B Mine

Ferriman 5N Deposit

This deposit lay northeast of Ferriman 3, in a simple shallow symmetrical syncline that is part of a large drag-fold. It was about 1,500 feet long, 200 to 300 feet wide, and about 150 feet deep in the central part. Ore was developed in the upper part of the Ruth slate and in the silicate-carbonate member and was mainly of non-Bessemer grade with a few small pods of Bessemer ore. The deposit has been completely mined out and was found to bottom along a horizon marking the middle of the Ruth slate.

Gagnon C Mine

Ferriman 5S Deposit

This deposit lies in a large drag-fold in the same iron-formation homocline as Ferriman 5N and Burnt Creek 3 deposits. It is narrow and V-shaped in plan and about 4,500 feet long. The drag-fold plunges gently southeast and the west half of the V consists of ore in the trough of the synclinal part of the fold. The point and east half of the V are formed of ore over the anticlinal crest and in the east limb of the drag-fold. The two limbs are divided by an anticline of barren Ruth slate.

Figure 8 shows a typical cross-section near the middle of the orebody. The depth of ore apparently decreases both north and south from this section. The deposit is composed mainly of non-Bessemer ore, mainly derived from silicate-carbonate iron-formation, but some, with occasional small parts of manganiferous ore from the Ruth slate. Along the east limb of the fold much of the lower red cherty member is converted to Bessemer ore. Another zone along the east side, about 100 feet wide, consists of highly leached lower red to upper red members that forms potential 'wash ore' or 'treat rock' (Pl. VI B).

Ruth Lake Mine

Ruth Lake Deposits 3N and 3S

The Ruth Lake deposits 3N and 3S are in a synclinal structure which extends along strike for about a mile. The two orebodies are separated by a broad structural warp across the centre of the syncline in which Ruth slate is exposed at the surface.

The southeast orebody is about 3,000 feet long, 400 feet wide, and has an average depth of nearly 300 feet (Pl. VII A). The deposit lies in a broad canoe-shaped syncline in which the pitch of the axial line and hence the base of the deposit undulates over broad cross-flexures and warps. Most of the ore is derived from the middle part of the iron-formation, but it bottoms concordantly in Ruth slate and extends upward through the lower cherty metallic members. Non-Bessemer ore predominates but manganiferous ore is present in the slate around the rim of the orebody and pods of Bessemer ore are present in the central part. Shallow pockets of rubble ore were preserved at the north and south ends of the orebody. A small pocket of rubble ore was also present in a depression overlying leached quartzite on the southwest side of the deposit, which is of particular interest as it is the only known occurrence of rubble ore not overlying iron-formation and bedded ore.

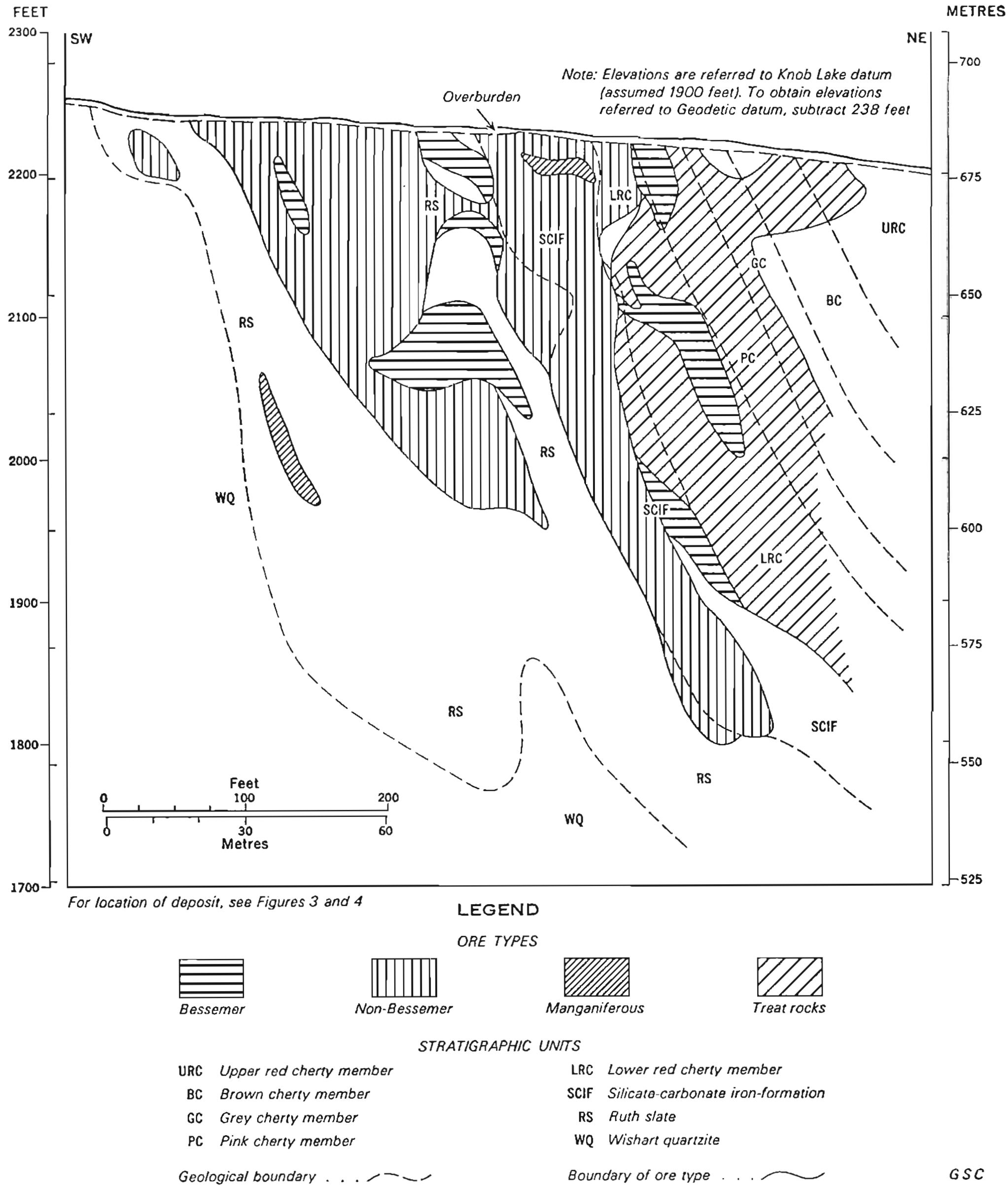


FIGURE 8. Typical cross-section of Ferriman 5S, Gagnon C mine, showing distribution of ore (from Iron Ore Company of Canada).

Northwest of the cross warp is a very deep body of ore, Ruth Lake 3N deposit (*see* Fig. 9). Like the southern deposit, the ore terminates in the middle part of the Ruth slate and is derived from lower red and silicate-carbonate members. A large deep pocket of rubble ore that lies in the middle of the deposit and contains Late

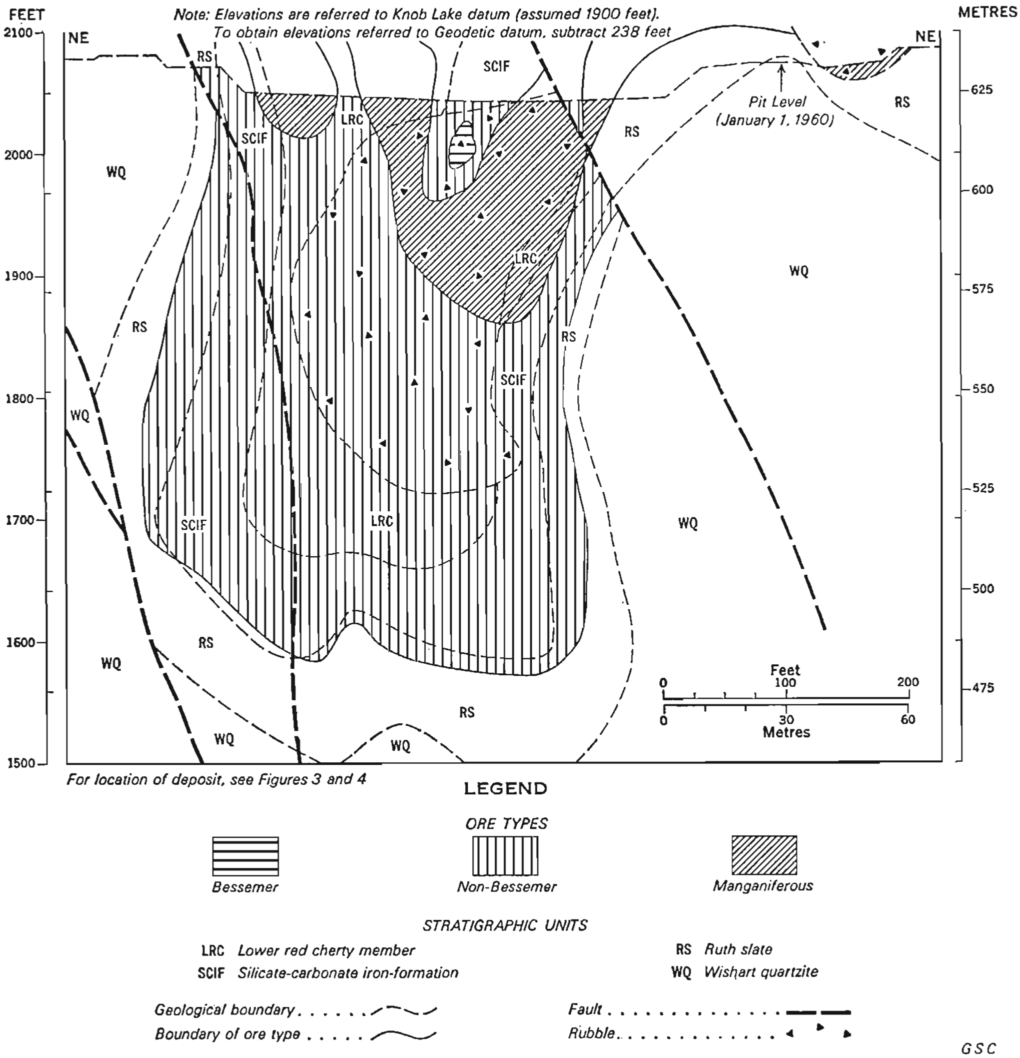


FIGURE 9. Typical cross-section of Ruth Lake 3N deposit, Burnt Creek mine, showing distribution of ore (from Iron Ore Company of Canada).

Cretaceous wood debris is particularly revealing. The structure in which the deposit lies is a closed syncline cut by a number of strike faults and several cross-faults. Folding and faulting appear to have taken place during a late stage of movement on the major thrust faults causing progressive rotation and plunge to the north of the ore mass between these faults. This resulted in burial of the rubble ore. The sack-like syncline is deeper to the northwest and the upper part narrower but the lower part is broad and maintains its bulbous shape for at least 1,200 feet along strike. Rubble ore extends to a depth of at least 800 feet in part of this structure and maintains its sack-like outline in cross-section. The base of the syncline gradually rises northward under the last 1,000 feet of the deposit and the ore becomes shallow. A large pocket of gravel rubble ore overlies the northwest end of this deposit (*see* Pl. VII A). Most of the ore in the latter part of the Ruth Lake deposit is non-Bessemer type, but manganiferous ore is present in the upper central parts of the main body, especially in the rubble pockets.

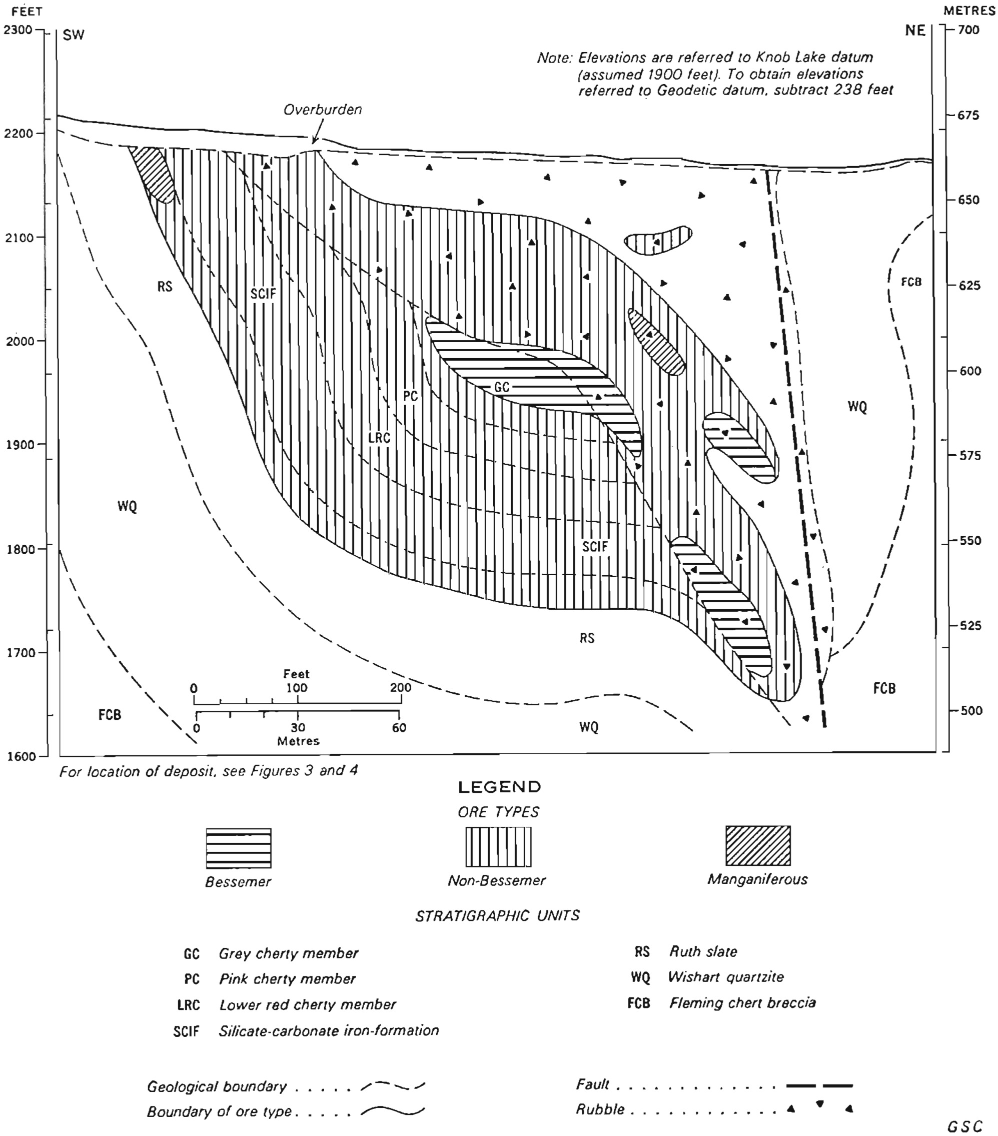


FIGURE 10. Typical cross-section of Burnt Creek 5 deposit, Burnt Creek mine, showing distribution of ore (from Iron Ore Company of Canada).

Ruth Lake Deposit 5

The Ruth Lake deposit 5 is in a syncline on the west side of the Ruth Lake mine and is separated from the Ruth Lake 3 syncline by a faulted anticline of quartzite. The iron deposit in this western syncline is about a mile long and the half of it southeast of the Labrador–Quebec border is named Ruth Lake 5 and the half northwest in Quebec is named Burnt Creek 5 (Pl. I).

The Ruth Lake 5 part of the syncline is broad and plunges northwest, and the upper part of the east limb is cut by an east-dipping thrust fault. It narrows in the central part and becomes shallow where the syncline is warped by a cross-fold (*see* Fig. 3). At the south end the basin structure becomes shallow as the Ruth slate extends up-plunge to the surface. To the north in the broad part of the syncline the ore is about 200 feet deep. Most of the ore is of non-Bessemer grade and is derived from the upper Ruth slate, silicate, and carbonate, and the lower red cherty members. Zones of Bessemer ore are present in the central upper parts of the deposit. Small bodies of non-Bessemer ore are present in fault slices on the east side of the deposit.

The deposits in the Ruth Lake and Burnt Creek mines contained 8.1 million tons of Bessemer ore, 32.5 million tons of non-Bessemer, and 13.9 million tons of manganiferous ore, according to figures quoted by Choubersky (1957).

Burnt Creek Mine

Burnt Creek 5 Deposit

This is the Quebec part of the orebody discussed in the previous section and is about 3,000 feet long and 400 to 500 feet wide. Ore is present in a syncline that plunges southeast at the north end. The east limb is cut off by a steeply dipping thrust fault. The northern third of the deposit is separated from the rest by a cross-fault and contains considerable rubble ore (*see* Fig. 10). The principal structure south of this cross-fault is like that illustrated, except that the rubble wedge thins out southward along the east boundary strike fault. The ore is mainly of non-Bessemer grade with some pockets of Bessemer grade in the central-upper part of the deposit, and a few lenses of manganiferous material. The ore bottoms concordantly in the upper part of the Ruth slate and is present in all members up to the brown cherty member. A narrow band of rubble ore is present along much of the east-bounding fault which may have been formed during late stage movement on this structure.

Gill Mine

Ruth Lake 1 Deposit

The Ruth Lake 1 deposit, almost a mile long, lies southeast of the Ruth mine in the same band of iron-formation as the Ruth Lake 5 deposit. Ore is present as a narrow concordant band in a homoclinal structure. It terminates at the north end in the trough of a south-plunging drag-fold on this homocline. The main deposit is joined at the south end by another small band of ore developed in a small syncline that has been thrust west against the main homocline. Most of the ore is in the upper red and grey iron-formation members and consists predominantly of long narrow concordant lenses of Bessemer ore interfingered with lenses of non-Bessemer ore. Pods of manganiferous ore are present near the north end of the deposit and some non-Bessemer ore is developed to the northeast around the anticlinal crest of the drag-fold. Manganiferous ore is developed in the slate and non-Bessemer ore in the silicate-carbonate member of the small syncline at the south end. Minor dislocation of ore and strata has taken place on cross-faults located at average intervals of 500 feet. The ore was exposed on the side of a steep dip-slope and was drilled to depths greater than 600 feet below surface exposure (Pl. VII B). Narrow bands of leached iron-formation are present along the east side of the deposit.

Wishart Mine

Wishart 1 Deposit

The Wishart 1 deposit, 3 miles southwest of Ruth Lake mine, is present in a broad symmetrical syncline that plunges gently to the southeast. The deposit has an overall length of nearly 2,500 feet, is hook-shaped in plan, and has a maximum width in the central part of 800 feet. Ore extends 800 feet farther southeast in the east limb of the syncline than in the west limb, and this extension is about 250 feet wide. Ore is derived from all members of the iron-formation up to the top of the grey upper member and reaches a maximum depth of 300 feet; the average depth is about 200 feet. There is an abrupt change in this area from the Ruth slate to the silicate-carbonate member and, as a result, the ore bottoms on the top of the slate or in the lower part of the silicate-carbonate member. The syncline is relatively undeformed and is cut by a few strike faults, which, however, produced very little displacement. Lenses and irregular zones of ore are interrupted by tongues of 'treat rock', highly leached iron-formation, and the deposit grades out at depth in a zone of 'treat rock'.

Most of the ore is of Bessemer grade and is mainly in irregular zones in the central part of the deposit (*see* Fig. 11). Non-Bessemer ore is present in irregular masses in the lower part of the deposit, and some of it is derived from the silicate-carbonate member. Manganiferous ore is not present. The deposit is surrounded by a broad irregular zone of highly leached iron-formation averaging about 150 feet in thickness. Other zones of leached iron-formation are distributed irregularly throughout the deposit. The very high proportion of high grade, blue type Bessemer ore is particularly distinctive in the Wishart 1 deposit. Much of this ore contains between 60 and 65 per cent iron, with 2 to 3 per cent silica, and from 0.03 to 0.18 per cent manganese. Phosphorus content is about 0.03 per cent (Pl. VIII A).

Ferriman Mine

Ferriman 1 Deposit

Ferriman 1 deposit lies about 1½ miles northwest of French mine (*see* Fig. 3). The main deposit is in two principal parts (*see* Fig. 12): a west limb 2,000 feet long and 200 feet wide, and an east limb 6,000 feet long and 200 feet wide. The Ferriman South deposit is a continuation of the east limb and is an additional 3,500 feet long and 150 feet wide.

Ore in the west limb, homocline structure, is present mainly in the silicate-carbonate and lower red cherty members but continues upwards in the succession into the

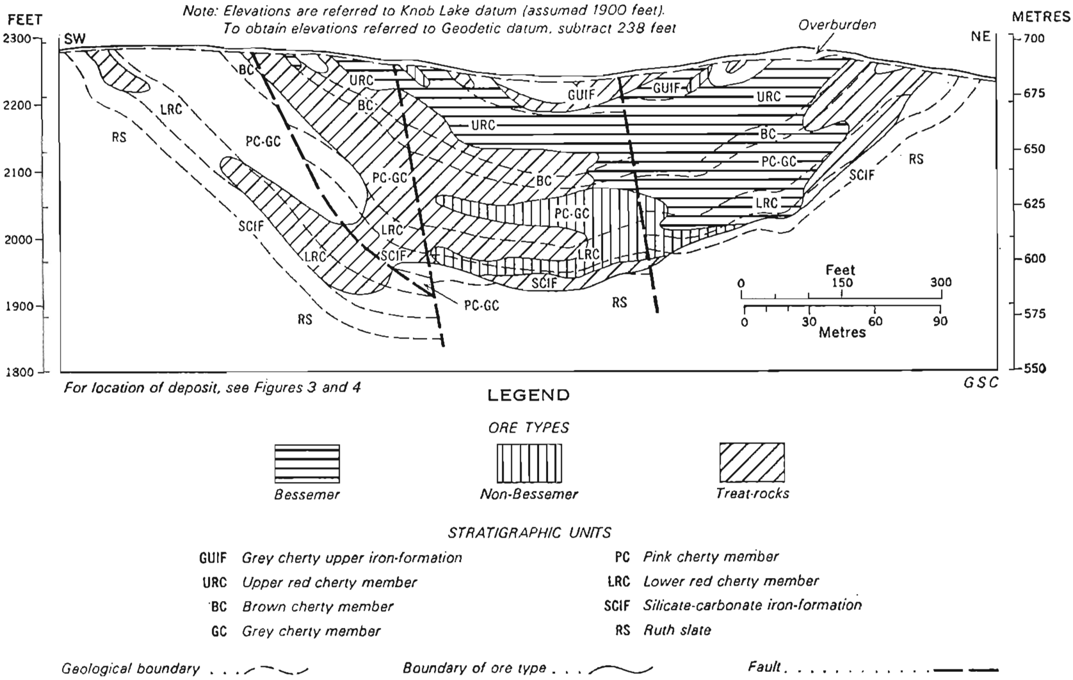


FIGURE 11. Typical cross-section of Wishart I deposit, Wishart mine, showing distribution of ore (from Iron Ore Company of Canada).

central part of the deposit where it is present in all members from the lower red cherty member up to the red upper iron-formation. Part of the ore deposit is more than 500 feet deep and is mainly of non-Bessemer grade except for Bessemer grade in the lower and upper red members. Between the two principal parts are a number of irregular discordant ore masses of non-Bessemer and Bessemer grade with a few small pods of manganiferous ore interspersed with irregular inclusions of both highly altered and relatively unaltered iron-formation. Yellow type ore is present in the upper silicate–carbonate-rich part of this member as well as in the lower main part.

In the centre part of this deposit very large masses of leached iron-formation are present to the east and also along the west side of the east limb. In the east limb of the deposit most ore is derived from strata between the grey cherty member and the grey upper iron-formation member and is of Bessemer grade except for irregular masses in the central part of non-Bessemer ore and pods of manganiferous ore distributed for 1,000 feet along strike.

The Ferriman South part of the deposit lies southeast of the eastern part of the main deposit, in the same homoclinal structure. The ore is present in the silicate–carbonate iron-formation and lower part of the lower red cherty iron-formation. Long narrow lenses of Bessemer and non-Bessemer ore interfinger along strike, and a band of highly leached iron-formation, 100 to 150 feet wide, lies next the east side of the ore in the pink and grey cherty members of the iron-formation.

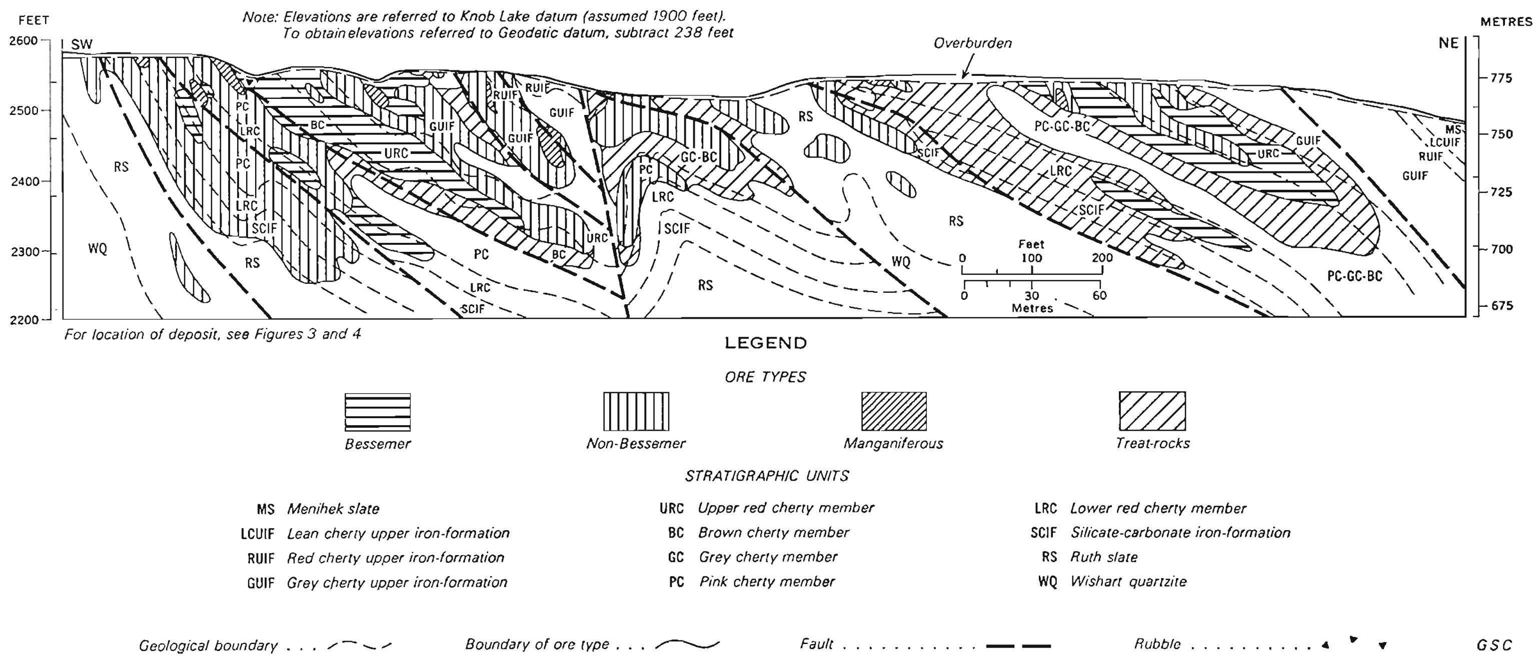


FIGURE 12. Typical cross-section of Ferriman I deposit, Ferriman mine, showing distribution of ore (from Iron Ore Company of Canada).

Goodwood Deposit

The Goodwood deposit is 30 miles northwest of Knob Lake on a broad southwest-facing slope east of Boundary Lake. It is the largest single orebody explored. The ore is in a broad flat syncline that plunges southeast and is developed concordantly in the lower members of the iron-formation. The deposit is heart-shaped in plan, about 3,000 feet long and about 2,000 feet wide in the broadest part to the southeast. The general pattern of ore distribution in this structure is illustrated in Figure 13. This is a cross-section of the deepest part of the deposit near the southeast end and shows the mode of occurrence of the various ore types and their relation to leached and relatively fresh bands of iron-formation. Much of the ore is of the yellow and red types but the bulk of it is of Bessemer grade.

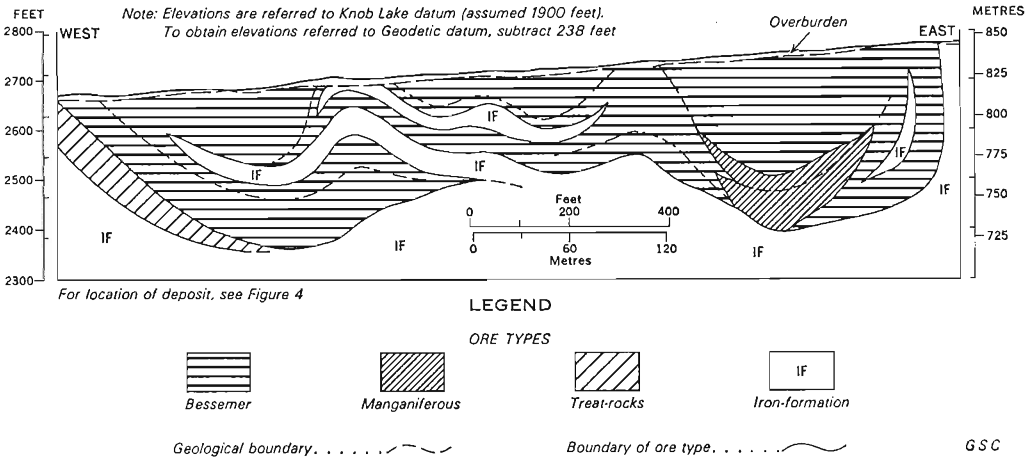


FIGURE 13. Typical cross-section of Goodwood deposit showing distribution of ore (from Iron Ore Company of Canada).

Origin of Deposits in the Knob Lake Range

The soft, "direct-shipping" type of hematite-goethite residual ore is derived from iron-formation as a result of two principal processes: leaching of silica, and secondary enrichment by goethite. Later stage modifications have been imposed on ores developed by these processes, and include structural deformation, destruction of primary textural and sedimentation features, and the emplacement of manganese oxides. The consistent occurrence of ore within iron-formation and the relationship of the various types of ore to lithological facies of protore are well established from observation and experience in the mining operations. Leaching and removal of silica in advance of secondary iron enrichment apparently was a separate stage in the development of most ore. Evidence for this is the large mass of highly porous friable ore that grades in one direction in a bed to lean ore and partly leached friable iron-formation and in the other direction to denser ore. In the dense ore goethite fills interstices, forms a matrix around hematite, chert and iron-oxide granules, and is present in veins and discordant masses. It is possible that leaching and secondary enrichment may have taken place in different parts of an orebody at the same time, but this was not a replacement process in the sense that there was intermolecular substitution of iron oxide for silica. Small veins, fracture fillings, and minor replacement of silica by goethite are found on a minor scale in iron-formation and other rocks near some orebodies, but these appear to be separate phenomena or border effects that are not necessarily a part of the main ore-forming processes. Selective alteration of carbonates and iron-silicate minerals to goethite and oxidation of magnetite to martite are generally the first changes detected in the conversion of iron-formation to ore, which shows that leaching took place in a strongly oxidizing environment. An increase in porosity resulting from the removal of silica followed by secondary goethite enrichment are the principal factors recognized in the transformation of iron-formation to the grade and structural quality of ore.

Investigations of the nature of the media that caused leaching and enrichment in this type of iron deposit have resulted in considerable divergence of opinion. Arguments have centred around the question as to whether descending groundwaters, hydrothermal solutions, or meteoric waters mixed with ascending emanations from deep seated sources were responsible for forming ore. Probably the greatest difficulty has arisen by assuming that all hematite-goethite residual ores were formed by the same process. On the contrary, it is possible that deposits in different areas may have been formed by different processes. Many features in the deposits could be caused by any one of these processes, and few criteria are distinctive of a specific type of leaching media. Several different lines of evidence lead to the conclusion that deposits of the Knob Lake range have been formed on or near a surface of considerable topographical relief by the action of descending groundwater in a humid tropical climate. Features of these deposits and the inferred environmental conditions at the time of their formation correspond to those of deposits being formed today in many warm temperate or tropical climates.

The Knob Lake deposits occur on the upper slopes of high hills and in the topographically high parts of the region. Although no deposits are present on the actual crests of the high ridges, it is interesting to note that deep orebodies such as Ferriman 3 and Ruth Lake 1 (neither of which has been drilled to the bottom) are mainly in homoclinal structures that form dip-slopes or project to surface along the flanks of very steep ridges. These steeply dipping, permeable beds were apparently exposed to weathering on or near the crests of hills prior to glaciation and would be obvious channels down which surface waters would penetrate to depth, leaching silica during their passage. In the final stages, bedrock topography has been sculptured by glacial erosion, but Henderson (1959) concluded that overall bedrock erosion may not have removed more than a few feet of the solid harder rocks after erosion of the mantle and top layer of shattered rock, and that much more rock was removed where scour was concentrated in deep valleys in relatively weak and faulted rocks. Glacial plucking has been more effective than abrasion in removing rock, and it is possible that the porous ore deposits were saturated with water and frozen solid so that plucking action over them was at a minimum. Contacts between ore and glacial till are sharp, and bedded ores show little or no evidence of disturbance at these contacts, suggesting that the ore was indeed frozen solid. Other factors, such as late thrust faults, have contributed to the preservation of some of these deposits. Erosion between Late Cretaceous and Pleistocene time no doubt modified the topography of the high ground to some extent, but it is unlikely that many deposits were much affected by it. A review of the literature shows that deposits of this type forming today in tropical regions occur as resistant cappings and penetrate along the flanks of hills and ridges that rise sharply above the surrounding terrain. Under these conditions many leached and enriched deposits of ore extend down the dip of iron-formation beds for several hundred metres. It can reasonably be deduced that very similar circumstances once existed in the Knob Lake range. Hard ore that may have capped the crests of hills was probably removed by glacial erosion, but where erosion was not extensive the ore that formed in deeper structural zones and at lower elevations was preserved on the flanks of the hills.

All the deposits extend down the dip or plunge of structures that are cut by the present erosion surface. It is deduced that these structures were open or connected to the land surface at the time of ore formation and that ore developed downward from the surface. The ore masses were certainly exposed on surface in Late Cretaceous time, as evidenced by the widespread occurrences of pockets of talus and gravel rubble ore containing fossil leaves, wood, and insects. The bulk of the ore was formed prior to the formation of these rubble pockets, but considerable secondary enrichment took place after deposition of the rubble as colloform textured goethite is the principal matrix around angular rubble ore fragments. Goethite enrichment evidently took place at every stage of ore formation, as most angular ore fragments embedded in impervious "rubble" clays have secondary goethite in their pores and interstices. As there was widespread simultaneous exposure of a great many deposits in Cretaceous time accompanied by abundant secondary enrichment, it is inferred that the relative position of the deposits and the land surface was much the same at that late stage of their history as in the early stages of leaching and enrichment.

Ore deposits of this type forming at the surface today in tropical climates are mantled by a thick indurated crust of rich ore. This crust, composed of primary oxides cemented by hematite or goethite, may range in thickness from a few inches to over a hundred feet, and changes abruptly downward to soft friable porous ore. In the Knob Lake range most of this type of material may have been removed by glacial erosion. In the area he examined, Harrison (1952) noted that exposed ore had hard cappings up to a few feet thick but that ore below glacial debris was soft. He inferred that these cappings resulted from recent weathering, but one the writer examined on a small occurrence north of Ferriman mine showed glacial striae and had evidently formed much earlier. Cappings of hard ore probably covered most deposits, but because of their brittle nature and vertical joints they were readily plucked off by glacial action. The porous friable ores are very like the 'powder ores' found below surface cappings in tropical deposits; they may have more secondary poethite.

Ore deposits in this range terminate at depth in leached iron-formation that gasses into fresh unaltered iron-formation, and bottom on barren formations in the troughs of folds or pinch out along major faults (*see* Table VI, *in pocket*). Except for a few deposits, such as Ruth Lake 3N, which is downdropped by late stage faults, or those in homoclines on steep dip-slopes such as Ruth Lake 1 and Ferriman 3, all deposits bottom at depths of 300 to 400 feet. In addition to those of economic interest shown on Figure 4, many small widely distributed occurrences, shown by drilling to be very shallow, illustrate the ubiquity of leaching and enrichment on or near a land surface that closely matched the present topography.

The marked tendency in many deposits for the grade of ore to decrease in depth, and the presence of broad zones of leached friable iron-formation below the ore in deposits that bottom discordantly in homoclines, are indicative of the action of downward penetrating solutions. Higher grades in the upper parts of deposits are accounted for by more extensive removal of silica followed by secondary goethite enrichment—processes most easily explained by the action of descending groundwater. Discordant deposits and leached zones are broadest near the surface and narrow downward, suggesting a funneling effect from the surface as groundwater penetrated downward. The deposits extend down-plunge or down-dip in permeable structures created by fractures associated with folds or faults. If solutions had worked their way up-plunge, ore would have developed to greater depths, its position strongly influenced by impermeable capping rocks, and the close parallel between the bottom of deposits and land surface would be much less marked.

Although some deposits are more than 500 feet deep, this does not mean that they were not formed by downward-penetrating groundwater. Rocks in tropical humid climates are leached, oxidized, and weathered to depths exceeding several hundred metres in areas of rugged relief—to well below the water-table and even below the floors of the deepest valleys. Where bedded rocks dip steeply and permeable zones are interspersed with impermeable zones conditions may be ideal for artesian circulation of groundwater. Oxygen-rich water from the surface may circulate as far below the valley floor as the intake area is above it, if structural conditions in the aquifers are suitable. Highly fractured brittle iron-formation lying between relatively impermeable slate beds in the steeply dipping folded and faulted beds of the Knob Lake succession is an ideal structure for artesian water circulation. It is interesting, however, to note that practically all the ore tested lies above the level of Astray Lake at the south end of the range of hills and, except for a few local situations, this ore could have developed without the aid of artesian water circulation.

The oxidation of iron minerals is uniform and complete throughout these deposits, even in the deepest ores. Fragments in rubble ore exposed to a strongly oxidizing environment in the humid tropical Cretaceous climate are no different from the banded oxidized ore in situ, and it is evident that a strong oxidizing environment prevailed at all stages of ore formation.

A limited amount of work on leached Menihek slate and Cretaceous clays, associated with the Knob Lake ore by Brady and Buchanan (1960), shows that kaolinite and minor gibbsite are the main clay minerals. According to studies by Bailey and Tyler (1960), these minerals are among the clay constituents that should be developed due to oxidation and leaching by cold groundwaters, although kaolinite may also be formed by hydrothermal solutions. They point out that the absence of a typical hydrothermal suite of clay minerals in the Mesabi ores does not prove that they were formed solely by groundwater, but the fact that the clays in the ores of northern Michigan differed from those in the Mesabi ores and may well have formed in a higher temperature, hydrothermal environment suggests that the Mesabi ores were formed by groundwater. The clay minerals at Knob Lake so far as is known resemble those in the Mesabi ores and may therefore also have been formed by descending groundwater.

The ability of groundwater in tropical regions to leach silica, alkalis, calcium, and magnesium and leave residual iron and aluminum is well recognized and details of the chemistry of these processes need not be discussed here. Lateritic deposits are forming in many parts of the world today, and deeper residual deposits of iron ore are being derived from iron-formation protore in Venezuela (Ruckmick, 1961), in India (Krishnan, 1952), and in Africa (Strauss, 1952). These ores associated with leached friable iron-formation are very similar in mineralogy, physical characteristics, and in the distribution of hard and soft ore types with respect to surface, to the deposits in the Knob Lake range, and a similar mode of genesis seems to be acceptable.

The solubility of silica increases directly with increasing temperature and with an increase in pH above 8-9, but ferric iron is relatively insoluble and is particularly stable under conditions of high pH and Eh. Weathering in most tropical areas thus removes silica and leaves residual iron. The situation may be a bit different however if humic acids are present, as they generally are where vegetation is abundant. Alexandrov (1955) studied the relative solubility of silica and iron in the presence of humic acids and showed that the ratio of iron to silica in the solutions increases below temperatures of 20°C and decreases above 20°C. Higher temperatures cause the decomposition of these acids, and with rising pH, bacteria become active in causing their further decomposition. Organic constituents from these decomposed acids are very effective in leaching silica from soils but ferric iron compounds are little affected. Iron residues therefore accumulate more readily with increasing temperature. This effect of temperature on the stability of humic acids is particularly important in determining whether podzolization, retention of silica, and leaching of iron takes place, or whether lateritization, leaching of silica, and retention of iron is the main process in soil formation. The general influence and importance of temperature fluctuations on the action of humic acids in the leaching and transportation of silica or iron are readily appreciated. Ferric oxides and ferric hydroxides are relatively soluble in humic acids and in many organic compounds, and with saturation of ferric hydroxide in these acids or with increasing pH hydroxides coagulate and precipitate. These acids would appear to offer very satisfactory media for solution and deposition of the secondary goethite in many of the ore deposits. In the Knob Lake area, interpretation of climatic conditions from fossil plants (Dorf, 1959) suggests a warm humid environment with abundant vegetation in Late Cretaceous time. These conditions in the Late Mesozoic would be very suitable for both inorganic and organic chemical activity, and a similar environment may have existed throughout Mesozoic time.

Iron may be transported and precipitated in these deposits by organic acids in the manner indicated in the foregoing, or by inorganic processes. Much ferrous iron is present in the protore in carbonates and silicates, and in magnetite. This could readily be transported in acid solutions in the ferrous state or as very finely divided

TABLE XI — *Analyses of Water Samples from the Knob Lake-Schefferville Area and Certain Other Freshwater Bodies (In Parts Per Million)*

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Ca	8.9	0.6	1.5	2.1	4.4	7.5	14.5	14.3	12.7	6.8	37.2	13.9
Mg	5.4	0.2	1.0	1.2	3.1	5.0	9.1	8.8	7.7	2.7	8.1	3.6
Na	0.9	0.2	0.1	0.3	0.2	0.4	0.3	0.2	0.6	2.7	8.0	1.6
K	0.9	0.2	0.2	0.2	0.3	3.0	0.3	0.2	0.3		1.4	0.9
Fe (total)	0.03	0.03	0.03	0.05	0.02	0.11	0.04	0.04	0.07	0.22	—	—
Fe (dissolved)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	0.05
Mn (total)	0.0	0.3	0.01	tr.	0.0	0.0	0.0	0.0	0.0	—	—	—
Mn (dissolved)	0.0	0.2	0.01	tr.	0.0	0.0	0.0	0.0	0.0	—	—	—
CO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0
HCO_3	46.3	1.2	9.4	12.2	26.2	49.5	97.4	85.5	77.0	24.3	111.0	56.7
SO_4	11.2	1.3	1.3	1.7	3.7	4.0	2.9	3.1	2.9	9.36	—	4.8
Cl	0.5	0.5	0.4	0.4	0.3	0.8	0.4	0.2	0.3	0.0	19.9	0.6
F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—
PO_4	—	0.0	—	—	0.03	—	0.0	0.02	0.03	—	—	—
NO_3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.7	—	—
SiO_2	3.5	1.1	3.5	4.1	4.8	3.7	3.6	3.5	3.1	4.4	2.8	3.3
Sum of constituents	54.1	4.9	12.6	16.0	29.8	48.8	74.1	72.4	65.6	—	134	57.7
Saturation index at test temperature	−1.5	−4.9	−3.4	−3.0	−2.1	−1.5	−0.5	−0.6	−0.8	−2.0	+0.3	−0.9
CO_2 (calculated)	3	0.7	1.8	2	2	3	1.8	2	2.5	—	—	—
pH	7.4	6.4	6.9	7.0	7.3	7.4	7.9	7.8	7.7	7.2	8.2	7.7
Alkalinity as $CaCO_3$ (Phenolphthalein)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—
Alkalinity as $CaCO_3$ (total)	38.0	1.0	7.7	10.0	21.5	40.6	71.7	70.1	63.2	—	—	—
Hardness as $CaCO_3$ (total)	44.7	2.2	7.8	10.5	24.0	39.0	73.7	72.1	63.5	27.9	126	50.4
Hardness as $CaCO_3$ (non-carbonate)	6.7	1.2	0.1	0.5	1.5	0.0	2.0	2.0	0.3	7.9	33.0	4.4

Note: Cu, Zn, Ni, Co, were analyzed for but not detected.

Samples 1 to 9 from Knob Lake-Schefferville area.

1. SQUAW LAKE: Sample taken at southeast end.
2. GILL MINE: Mine water taken on east side of orebody. Mine not worked for two years—water clear when sampled.
3. Sample taken from a pond fed by a small stream at south end of Ruth Lake extension deposit.
4. Sample taken from a stream crossing Ruth Lake extension deposit.
5. Sample taken from a stream flowing into Bean Lake from Ruth Lake extension area.
6. BEAN LAKE: Sample taken from northwest end.
7. REDMOND OREBODY: Sample taken from a stream 1,500 feet upstream from ore deposit.
8. REDMOND OREBODY: Sample taken from a stream at north end of the deposit.
9. Sample taken 1,500 feet downstream from sample 8.
10. OTTAWA RIVER: Sample taken at west dam, at Timiskaming, Quebec (average of 12 monthly samples).
11. ST. LAWRENCE RIVER: Sample from municipal purification plant intake, Gananoque, Ontario (average of 12 monthly samples).
12. LAKE SUPERIOR: Sample taken from municipal purification plant intake, Port Arthur, Ontario (average of 12 monthly samples).

1 to 9: Collected by G. A. Gross, Geol. Surv. Can.; analyzed by J. F. J. Thomas, Mines Branch, Can., 1961.
10: Water Survey Report No. 2, Mines Branch, Can., 1952, p. 36.
11, 12: Water Survey Report No. 3, Mines Branch, Can., 1954, pp. 18 and 38.

ferric hydroxide and would precipitate as ferric oxide where higher oxidation or pH conditions were encountered. Direct evidence for extensive transportation of iron is presented by the hard canga deposits (ore talus cemented on surface by secondary iron oxides), lateritic crustal cappings, and in secondary oxides in fractures and openings in the banded ores. Park (1959) noted that much of the secondary surface oxides is hematite rather than goethite or hydrous oxides. He suggested that rather than being a product of dehydration of limonite, hematite results from the combined actions of putrefactive and nitrifying bacteria, which could produce ferric nitrate and ammonia. The reaction between these would yield hydrous ferric oxide, which spontaneously loses water and becomes hematite. This process may also explain why much of the iron oxides in the red ore in slates at Knob Lake is hematite whereas secondary oxides in adjacent ore beds are goethite. The slate rocks unlike the iron-formation have a high primary carbon content which probably contributed to the formation of these constituents during decomposition and leaching and the final development of hematite.

It is assumed that these ores formed over a very considerable period of time and that leaching of silica by groundwater was a slow process. Ore was developed at a time when the Knob Lake range was uplifted and exposed to weathering in a warm, and possibly arid, climate. It has already been shown that the Mesozoic, particularly the Cretaceous, was the most likely time for these conditions to have occurred. At the rate of leaching now taking place in tropical regions this would give ample time for the ore to have formed. Studies by Ruckmick (1961) suggest that the large Cerro Bolivar deposit in Venezuela may have been developing for approximately 26 million years or since Oligocene time if the present climatic conditions prevailed. Analyses of springs emerging from the lower flanks of the orebodies show that the waters have a pH of 6.1 and contain an average of 7 ppm SiO_2 and 0.05 ppm Fe. The rate of removal of silica is thus approximately 80 times greater than that of Fe_2O_3. A few analyses of surface water in the Knob Lake area are given in Table XI. Some of these samples were from small streams that passed over ore deposits or have their source in ore zones. Comparison of these analyses with analyses from two major rivers and one lake shows that their content of silica and iron is not noticeably different from that of other waters in this part of the continent. They indicate that no more silica is being removed in solution from this area, which is underlain by cherty iron-formation, than from other parts of the Precambrian Shield and that no appreciable amount of silica is being leached from these deposits in the present cold climate. On the other hand, the silica content of the water from the Venezuelan deposit is approximately twice that of the water in the northern cold climate. The figures quoted for silica refer to dissolved silica and not to colloidal silica or silica in fine particles, which is many times greater than the amount of dissolved silica in most rivers.

Investigations of the chemistry of silica in water show that its solubility increases appreciably with increasing temperature, with an increase in pH above 8, with the presence of appreciable amounts of sodium and potassium in the water, and that it is particularly high where the silica being dissolved is present in a finely divided state as in colloids, amorphous forms, or as chert. Analyses of deep well waters from various places in the southern United States and other areas with a warm humid climate are quoted by Hem (1959). In these the silica content ranges from 29 to 103 ppm. The effects of some of the factors discussed above in dissolving silica are illustrated by the high silica content in these analyses.

Leaching of silica is more dependent on circulation of water through permeable zones and on fluctuations of the water-table (both of which remove silica-charged water) than on chemical conditions suitable to provide a maximum rate of solution of silica. Best conditions for leaching of silica exist in climates where the rainfall is abundant over a period of a few months followed by dry hot periods for the remainder of the year. During the dry hot period the groundwater becomes alkaline and warmer, the water-table may be lowered and much silica is taken into solution. During the wet season this silica-charged water is flushed from the permeable zones in the rocks and the pH falls. With the return of the dry season and alkaline conditions considerable silica is again taken into solution. Under such conditions the chemistry of organic constituents also favours solution of silica, iron being relatively stable. Leaching of silica in this general environment is not however confined to the zones where the water-table fluctuates but may be extensive along deep permeable zones in the drainage system.

Because the silica in the cherty iron-formation is very fine grained it is much more susceptible to leaching than the coarser quartz grains in the quartzites and other associated rocks. Quartzites adjacent to orebodies may be decomposed and become friable, due to leaching of intergranular cement, and chert breccia rocks are decomposed to a flour-like mass. The fine-grained slaty rocks adjacent to orebodies that normally contain 11 to 17 per cent alumina are altered by leaching to soft porous punky kaolinite clay masses showing ghost or relict banding. Much silica is removed and the remainder combines with alumina to form kaolinite and other clay minerals. A large amount of the clay-size material is fine powdery silica derived from the minute clastic quartz grains. The highly leached beds appear to contain appreciably more alumina as kaolinite and clay than the few available analyses indicate.

Comparison of the Knob Lake deposits with similar deposits forming today in warmer humid or tropical climates in other parts of the world leaves little doubt that these deposits were formed by leaching and secondary enrichment performed by descending groundwater. The topographic relief during the Mesozoic, as deduced from the available palaeogeographic evidence, suggests that conditions were then ideal for the formation of the Knob Lake deposits.

Historical Summary of the Development of the Knob Lake Deposits

The following is the sequence of events by which the iron deposits of the Knob Lake range probably developed:

1. Folding and faulting during the Labrador orogeny between 1,400 and 1,900 million years ago produced permeable structures.
2. Erosion of the orogenic belt, followed by submergence and possibly deposition of Palaeozoic marine sediments.
3. Uplift and sufficient erosion to expose the Knob Lake range and most of the strata of the Labrador geosyncline during the Permian and Mesozoic. It is

deduced that the Knob Lake range formed a prominent highland with rugged topography during the warm and relatively arid climate of the Mesozoic.

4. Very extensive deep chemical weathering of the highland belt took place in a tropical climate during the Mesozoic. Surface and descending groundwaters penetrating highly permeable structures produced extensive zones of oxidation, resulting in the leaching of silica and carbonates, hydration and martitization of iron oxides, enrichment by secondary goethite, and redistribution of considerable iron oxide in residual zones near the surface.
5. Development of abundant vegetation in a warm humid to tropical climate during Late Cretaceous time. Recurrence of reverse movement on early easterly dipping thrust faults during Late Cretaceous time, development of cross-faults, downfaulting of some fault blocks, and brecciation of ore along fault zones.
6. Accumulation in the downfaulted depressions of rubble ore derived by erosion and sloughing from the gradually rising fault scarps.
7. Considerable secondary enrichment and distribution of goethite in the rubble and upper parts of the ore deposits.
8. Further distribution of manganese oxides in porous and permeable zones.
9. Glacial erosion during the Pleistocene, the next event identified, presumably removed most of the weathered rock, plucked off most of the hard surface cappings on orebodies, and scoured the ridges to expose fresh unaltered rock. The ore deposits represent deeply leached and altered zones that were protected by topographical or structural features.

Ore Reserves and Potential in the Knob Lake Range

Direct Shipping Type Ore

At the beginning of mining operations in this area the proven ore reserves for 44 deposits were 417,707,000 long tons, according to Gustafson and Moss (1953). Reserves in 25 deposits in the Province of Quebec were about 281 million tons and in 19 deposits in Labrador, Newfoundland, 136.6 million tons. Average grade based on dry analyses of 364,341,000 tons of Bessemer and non-Bessemer ore and of 53,366,000 tons of manganiferous ore are given in Table IX.

This was generally regarded as a conservative estimate of the amount of ore in the various deposits and considerably more ore was proven in some deposits when they were opened for mining. Nearly 75 million tons of ore has been mined from this range and, although no estimates of reserves have been published by the company in recent years, there is reason to believe that the total proven reserves have not been greatly depleted. More detailed investigations by drilling and pitting have shown extensions to some orebodies and much of the development work has been centred around the existing mines.

There are good indications that as much additional ore may be discovered in this range as was proven at the beginning of mining. Considerably more ore of similar grade to that being mined will probably be found in the extensions of known ore structures or near the known deposits. Most of the orebodies found were exposed in outcrops, or were indicated on surface by frost-heaved fragments in the glacial till or by the colour of the soil. The iron-formation and geological structures have been mapped on a scale of 1 inch to 1,000 feet and many smaller areas have been mapped in even greater detail. Considerable iron-formation that is covered with overburden has not yet been systematically tested by drilling or pitting although exploration of low ground has been much less rewarding to date than exploration of the high ground. Even though optimum conditions for formation of ore are believed to have existed in the rugged topography of the highland ridges, it is possible that blocks of ground now underlying the lower slopes may have been downfaulted from this position during the Late Cretaceous and that pockets of ore may be preserved in these blocks. Any new discoveries will probably be similar in grade and quality to that already explored, as these characteristics in the known deposits are fairly uniform throughout the range.

Semi-Taconites as Potential Ore

Partly leached and enriched iron-formation or lean ore that is suitable for concentration by simple washing and gravity concentration is referred to as semi-taconite on the Lake Superior ranges. So far such material has not been used in the Knob Lake area, but it has been stockpiled where mining has necessitated its removal, and research is in progress to develop methods for economical concentration. Judging from the amount of friable oxidized material exposed in existing mines the amount of semi-taconite suitable for concentration may be estimated to be about one-tenth of the amount of high grade direct-shipping ore.

The semi-taconites vary greatly in composition, texture, and amenability to different concentration processes and their physical characteristics depend on the type of protore iron-formation from which they are derived. As indicated in earlier descriptions, the oxide facies with a high primary iron content usually decompose to a friable granular sandy mass with good segregation of discrete hematite or goethite granules and nodules mixed with floury textured silica. Very good grade concentrates with splendid recovery of iron can usually be obtained from this material by gravity or flotation after preparation by simple grinding and sizing.

The semi-taconite derived from silicate-carbonate facies is much more difficult to concentrate because of the very fine, sub-microscopic intergrowths of goethite and silica and the fact that much iron and silica are chemically combined in the iron-silicate minerals. An appreciable amount of fine clay is usually intermixed with this material. Even under the best conditions much iron is lost in slimes and the concentrates have too high a silica content.

Reduction roasting of semi-taconite to convert the iron to magnetite or maghemite, followed by grinding and magnetic separation or flotation to separate chert from iron oxide particles may provide an economical method for treating this material. Indeed the semi-taconite from oxide facies usually responds well to either of these processes but material from silicate-carbonate or slaty facies is more difficult to concentrate. Much of the iron in the latter forms fine intergrowths of silica and iron oxide and is difficult to liberate even after roasting. The iron silicates may be converted during roasting to higher rank silicates, commonly fayalite with minute magnetite inclusions, and this material follows with the magnetic concentrates and carries much silica with it.

Despite these difficulties encouraging results have been obtained by reduction roasting and flotation studies on lean ores from this area and it is expected that at least the higher grade semi-taconite and lean ore will be amenable to concentration. Owing to the variation in quality of the semi-taconites and the technological problems to be mastered before they can be concentrated economically, it is very difficult to indicate the actual ore potential of the semi-taconite.

Taconite as Potential Ore

No estimates have been made of the amount of iron-formation in this range that may be amenable to concentration. A wide variety of facies and types are present but only in certain selected zones can it be considered suitable for concentration. Because of the intense structural deformation in these zones, the iron-formation is broken up into a large number of structural blocks that would have to be mined separately. Despite these limitations there is a very large amount of potential taconite ore. Evaluation of this potential ore requires much more detailed study of stratigraphy and sedimentation. The iron-oxide facies that have distinct hematite- and magnetite-rich layers well segregated from chert layers are of particular interest. Other facies with coarse discrete hematite or magnetite granules or oölites and possibly some magnetite-rich silicate-carbonate facies may also be easy to beneficiate. Iron-formation with goethite replacing chert in the iron-rich bands is found in some areas. It may be possible to concentrate the iron from this material by coarse grinding and using spiral or gravity methods, as it breaks on bedding or lamination surfaces and the iron-rich layers separate readily from the chert.

Another type of material in the southern part of the range consists of greywacke, and coarse clastic and tuffaceous material that was deposited with cherty magnetite iron-formation. Some magnetite in discrete grains, together with cherty magnetite nodules and brecciated iron-formation, is mixed with the clastic material. It is possible that a clean magnetite concentrate could be obtained more easily from this material than from the cherty iron-formation.

Ore Deposits in Other Parts of Central Division

The Sawyer Lake Deposit

(65°59′ long., 54°27′ lat.)

This deposit is about a mile northwest of the west bay on Sawyer Lake and about 42 miles southeast of Knob Lake (Pl. VIII B). It is a small occurrence that differs from those on the Knob Lake range in that it consists of very hard dense blue hematite.

The deposit occurs in iron-formation in the south corner of the Petitsikapau syncline (Fig. 14). The southern limb of this structure strikes northeast and is deformed in a series of tight folds that plunge northwest. The succession of sedimentary rocks near the eastern border of the geosyncline in this area is similar to that in the

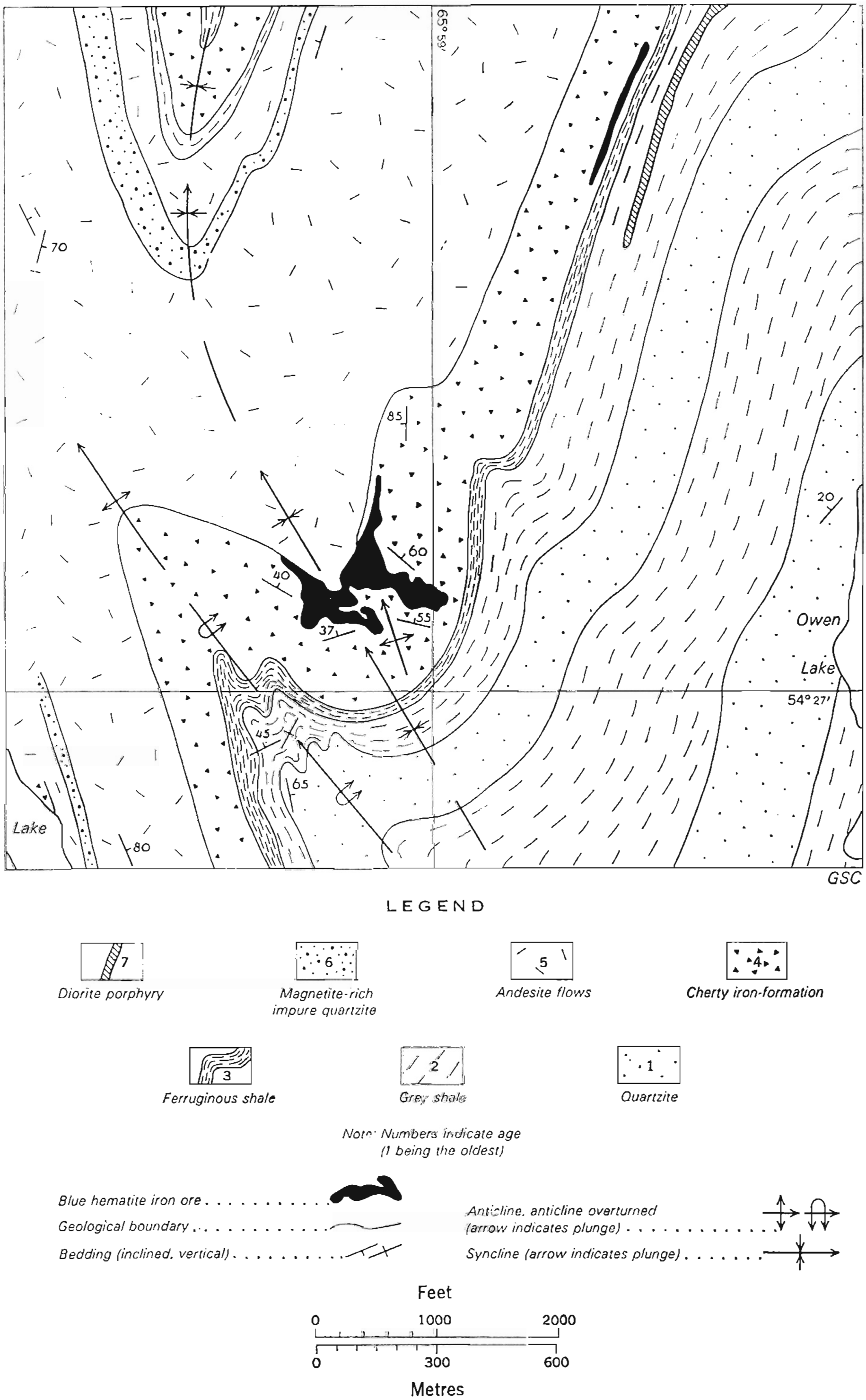


FIGURE 14. Geological setting of the Sawyer Lake deposit (after Labrador Mining and Exploration Company Limited).

Knob Lake area except that the iron-formation is thinner and a number of andesite flows and volcanic breccias and tuffs are interlayered with the sediments. The iron-formation north of Sawyer Lake is divided into two members by a bed of andesite pillow lava several hundred feet thick. This volcanic member cuts through the sedimentary succession to the northeast and passes below the Ruth slate near Mina Lake and eventually splits into several beds within the slate and coarse clastic material in the lower part of the sedimentary succession. The lava bed serves as a time marker and indicates that sand was being deposited in the eastern area at the time that the slate and iron-formation were being deposited farther west. If sand, mud, and silica-iron precipitates were deposited in this order from near shore to deep water, as they most likely were, then an eastern source is indicated for the sand and mud. In this area the lava flows thin eastward and were apparently contributed from a volcanic source to the west, centred near to what is now the east shore of Dyke Lake.

The lower part of the iron-formation and the slate and quartzite stratigraphically below it are lithologically similar to the lower red iron member of the Sokoman Formation, and the Ruth and the Wishart Formations of the Knob Lake succession. The hematite deposit in the upper part of the lower iron member near Sawyer Lake is present in the trough of a major north-plunging syncline. Deformed beds in the trough of this fold dip from 45°E to vertical and form a small north-plunging anticline. The surface outline of the deposit is irregular and is generally discordant with the highly contorted banding in the fold. Cross-sections outlining the ore mass, however, show that it has an inverted U-shape or saddle reef-like structure suggesting that hematite enrichment followed bedding over the crest of the small anticline. Some of the hematite jasper iron-formation is brecciated and ore is developed where hard blue hematite cements this breccia or replaces silica in the banded iron-formation. Another narrow band of ore is present on the east limb of the main syncline near the top of the lower iron-formation member. Ore is developed up to the top of this member but does not extend across the contact into the overlying amygdaloidal andesite flow rocks. No hematite veins were found in the andesite close to the contact although the actual contact was not seen.

The jasper iron-formation is not highly metamorphosed and contains more than 40 per cent iron in the form of dark grey-blue hematite distributed in fine granular textured layers interbanded with deep red jasper. Breccia ore and iron-formation are conspicuous in trenches along the east side of the deposit. The secondary hematite is steely blue and dense and replaces many fragments of banded iron-formation. Breccia zones near the margins of some ore shoots have vugs and open spaces lined with quartz crystals coated or intergrown with euhedral specular hematite grains. Silica has been removed from the porous iron-formation near breccia zones and the primary hematite granules are only partly cemented by later hematite.

The Sawyer Lake deposit differs from deposits in the Knob Lake range in many ways. The ore is very hard dense blue hematite with practically no goethite present, silica is replaced in many places with very little porosity or friability developed in the iron-formation, and effects of oxidation are not conspicuous in either the iron-formation or adjacent rocks. The ore is distributed along breccia zones and over the crest of a local anticline where permeability and dilatant effects are greatest. Because there is so little evidence of alteration and oxidation in the enclosing rocks, the hematite deposition and enrichment are not attributed to descending groundwater even though blue hematite and specular hematite may be deposited in this way. Hydrothermal emanations from a volcanic source in the area may have passed through this permeable zone which was capped by the relatively impermeable andesite lava, but if so a considerable amount of replacement by hematite along fractures in the lower part of the lava bed would be expected, but none is found. It is doubtful if any iron was introduced from outside the iron member. No doubt considerable connate water from the lower shales and sediments escaped during the period of folding through permeable zones such as the one in this structure. Such waters could be effective in redistributing the iron and removing silica along permeable channels, especially if their temperature was raised near sills or thick flows.

Nearly 2 million tons of ore carrying 66 per cent iron and about 3 per cent silica has been indicated in this deposit. Furthermore, material marginal to the orebody and much of the iron-formation may require only coarse grinding to enable concentration of the iron in gravity spirals or by flotation. Much of the iron-formation on the eastern side of the geosynclinal belt is covered, and the possibility of finding other deposits of this type must not be overlooked.

This deposit is significant when it comes to appraising the ore potential for the region. It is an unusual type and in a geological environment different from that of other deposits of hematite-goethite ore. If the Sawyer Lake hematite was concentrated in this structure by volcanic emanations or by warm connate water escaping during compaction of the sediments, then this deposit represents important concentration of iron in Precambrian time. Such early formed deposits would occur in very different circumstances to those in the main ore zone, where groundwater leaching formed ore during Mesozoic time. Such concentration of iron can be expected where iron-formations and lava flows are closely associated and the distribution of enriched zones will have no relation to the present or an earlier erosion surface. The depth to which enrichment may extend would be controlled more by structural factors than by pressure and chemical gradients related to a surface profile. Most of the iron enrichment would be expected to occur close to its source in the iron-formation but would not necessarily be confined to these beds. Iron enrichment would be expected where permeable zones were created by structural deformation; impermeable beds in the succession might form barriers that would channel the circulation of fluids and iron concentration would be expected where they cap or truncate permeable zones. Where dense hematite or magnetite replaces silica and other rock constituents, the enriched zones have higher density and may be easily detected by gravity surveys. If the iron-formation was replaced by magnetite, ore zones within it would be expected to give high intensity but erratic magnetic readings, and magnetic anomalies over ore zones could be easily overlooked in the general irregular high magnetic field of the iron-formation.

Astray Lake Occurrence

(66°17′ long., 54°25′ lat.)

A small amount of blue hematite is present in a band of jasper iron-formation about half a mile east of the southeast shore of Astray Lake and directly east of the south outlet of Marble Lake. The occurrence is on the west slope of a steep sided ridge and the thin band of iron-formation is overlain by andesite lava flows. The beds dip east and much of the ore is hard blue hematite replacing thin banded jasper-hematite iron-formation. Considerable leached friable iron-formation and red hematite stain are present in this zone. Brecciated ore and iron-formation suggest that hematite enrichment follows along a fault zone. The ore is more similar to that in the Sawyer Lake deposit than the hematite-goethite deposits in the Knob Lake range. Both hard blue hematite deposits are near the Dyke Lake centre of volcanism and appear to be a distinctive genetic type.

Cambrien Lake Area
(68°47′ long., 56°32′ lat.)

Small occurrences of ore grade material and considerable leached and enriched iron-formation are present near Hematite Lake in the Cambrien Lake syncline but no deposits of commercial size have been discovered. Oxidized and leached iron-formation is present mainly in the area south of Hematite Lake and in the area 2 to 4 miles west of the lake.

The Cambrien Lake syncline is outlined on Figure 1 by the distribution of the iron-formation. The stratigraphic succession in this area is very similar to that in the Knob Lake area, but the detailed stratigraphy in the iron-formation is not well known. Quartzite with conglomerate and slaty facies rests unconformably on the granite-gneiss along the west limb of this syncline and is succeeded upward by black graphitic slate, iron-formation, and upper black slate. To the south and east grey argillite and slate with thin lenses of dolomite are present below the quartzite and iron-formation. A thicker dolomite member, with chert breccia cemented by carbonate in its lower part, is present in the central and eastern part of the area. Farther south these rocks are unconformable over a thick succession of grey and red argillite, pink limestone, calcareous sandstone, arkose, and conglomerate that fill deep east-west depressions along the west side of the geosyncline belt. The iron-formation and upper black slate is overlain unconformably in the northeast by red quartzites, siltstones, and argillite, the upper part of the succession being intermixed with volcanic rocks. The iron-formation is more than 500 feet thick and is composed of a lower magnetite silicate-carbonate facies, succeeded by thin banded hematite-jasper, wavy banded to mottly cherty carbonate, and an upper thin-banded to slaty, lean cherty carbonate facies. Roscoe (1957) noted that the various types are gradational into one another and that granular oölitic and breccia textures and structures are common.

Beds on the western limb of the syncline dip gently east and are not highly deformed. The southern part and east limb is tightly folded and thrust faulted, and most of the beds dip vertical or are overturned to the west.

More than 800 feet of local relief is present in the area and the high ridges to the northeast were probably more extensively scoured by glacial action than the southern part of the structure where oxidized and leached zones are found. Factors controlling leaching and enrichment in this area are similar to those in the Knob Lake range and, as the iron-formations are alike, any derived ore will probably also be similar to that in the southern range.

The Cambrien Lake syncline was included in the concession area granted under a special exploration licence to Fort Chimo Mines Company Limited, and surface prospecting in 1947 and 1948 included examination of rock exposures and digging a few test pits. Leached iron-formation and material of ore grade were found in some pits but no deposits of commercial interest were reported. There has been some sporadic investigation for iron ore since that time but no systematic testing of the iron-formation where covered with glacial till has been reported.

Otelnuck Lake Area

The iron range west of Otelnuck Lake was covered by a concession held by Norancon Exploration (Quebec) Limited and was extensively prospected on surface, but no discoveries of direct shipping ore have been reported.

Koksoak River Area

Much of this area was explored geologically and prospected by Fenimore Iron Mines Limited between 1948 and 1952, work in 1952 was directed by J. A. Retty and supervised by P. E. Auger. A number of zones of enrichment in iron-formation about 12 miles southeast of the east arm of Lac Bérard were drilled or explored on surface but ore of direct shipping quality was not reported.

The Gossan Hill–Old Red Hill prospects are about 2 and 4 miles south of the Larch River in the iron-formation exposed along the west edge of the geosyncline belt. The iron-formation is composed of an upper facies consisting of interbanded chert and siderite-rich layers overlying a lower magnetite–hematite–jasper facies. The siderite facies is exposed in these two hills and a bulk sample from Gossan Hill is reported in the 1952 annual report of the company to contain:

	%
Fe	27.5
SiO_2	26.2
Al_2O_3	0.33
CaO	1.57
MgO	5.70
P_2O_5	0.025
MnO	3.64
S	0.04
LOI	22.1
CO_2	24.7

Analyses of a separate siderite-rich band as reported indicate:

Fe	41.0
MnO	4.10
Ins	1.16
LOI	28.77

The carbonate iron-formation is exposed on Gossan Hill for a strike length of nearly a mile across a horizontal width of 3,200 feet, and the hill rises 167 feet above the surrounding terrain. Neither stratigraphic thickness of the carbonate facies nor structure of the deposit is indicated. Much of the siderite is in bands or lenticular beds several inches thick.

Because of the thicker banding and good segregation of carbonate and chert layers it may be possible to make a satisfactory siderite concentrate by gravity methods. These prospects represent yet another type of iron-formation in the Labrador–Quebec belt that is of economic interest as a beneficiating ore.

Murdoch Lake Area

(66°46′ long., 55°37′ lat.)

Iron-formation is exposed about 1,000 feet east of the northeast end of Murdoch Lake and has been traced south from there for about 3 miles. It is part of the Murdoch Formation (Baragar, 1958) which is composed of folded greywackes, basic lavas, and tuffs and is intruded by gabbro sills. The iron-formation is exposed around a small lake and altered gabbro forms a high ridge about 1,000 feet to the east. Fine-grained mica chlorite schist is exposed in the area between the iron-formation and this ridge.

The bulk of the iron-formation consists of thin-banded, dark grey to bluish black hematite–magnetite–quartz facies that is estimated to have an iron content of 35 per cent. Some carbonate is present in 5 mm-grain clusters which cause a pitted surface on weathering. Carbonate is more abundant near the top of the oxide member in beds that range from a fraction of an inch to 6 inches in thickness and grade upward to an iron-silicate carbonate facies. The lower contact of the oxide facies was not seen. The hematite is silver-grey, and magnetite is most abundant near the top of the member where 1 mm octahedra form distinct porphyroblasts. The oxide facies is characteristically thin banded with a granular to sugary texture and is highly crenulated near faults or in the crests of folds.

A transition zone composed of thin-banded grunerite–carbonate–magnetite and quartz is about 10 feet thick and is overlain by a carbonate and quartz member that is at least 50 feet thick. Alternate beds of quartz and ferruginous dolomite and ankerite vary from ⅛ inch to 3 inches thick and are highly crenulated and deformed.

The iron-formation, exposed over a horizontal width of 550 feet, dips 45°E, and strikes northwest parallel with the regional trend. There are at least three small anticlines in the exposure area which are overturned to the southwest and separated by strike faults spaced at intervals of 100 feet. The folds plunge steeply and the direction of plunge may be reversed within a few hundred feet along strike. Because of the intense deformation the true stratigraphic thickness of the iron-formation could not be determined.

The oxide iron-formation facies is judged to be sufficiently coarse grained for the iron oxides to be liberated by grinding to 150 mesh. Metamorphism has been more intense in this area near the eastern border of the geosyncline belt and the iron-formation is much coarser grained than in other parts of the central division of the belt. The Murdoch Formation is separated from other rocks to the west by a major fault but Baragar (1960) indicated that the Murdoch iron-formation is younger than the Sokoman iron-formation.

Ore Potential in the Central Division

The above brief description of various iron occurrences gives some idea of the types of deposits that may be found in this large division of the iron belt. The comments on potential taconite deposits in the Knob Lake range apply to many other zones of iron-formation in this division that are not mentioned. Because of the wide distribution of taconite in the region, development of this type of potential ore will probably depend mainly on its proximity to established transportation routes and on a vastly greater demand for ore in the future. Because of the amenability of cherty iron-formation to leaching and enrichment most of the areas underlain by iron-formation in this central division are considered to be favourable for the occurrence of residual hematite-goethite iron ore of the type described in the Knob Lake range.

Chapter IV

GEOLOGY AND ORE DEPOSITS OF THE NORTHERN DIVISION OF THE LABRADOR GEOSYNCLINE

The part of the Labrador geosyncline north of Lac Bérard[1] is designated the northern division. It differs from the central division by a marked increase in the rank of metamorphism and a consequent difference in its type of iron deposits. The iron deposits of this division consist of selected zones of iron-formation or metataconite that is relatively easy to concentrate because of its coarse granular texture and good segregation of iron oxides and gangue. The amenability of the iron-formation to concentration, the large size of exposed potential ore zones requiring a minimum of waste removal in mining, and the proximity of these ranges to tide water in the Atlantic market area are important factors that have stimulated exploration and economic appraisal of the deposits.

The distribution of the iron-formation and regional geology is shown on Figure 1, and the general geological setting of this division has been described in the previous section dealing with the Labrador geosyncline. More detailed description of the regional geology and the iron deposits is given in Gross, 1962. Iron ranges have been investigated in three principal areas near Leaf Lake, Ford Lake, and Payne Bay.

The Leaf Lake Iron Range

Exploration by Consolidated Fenimore Iron Mines Limited between 1951 and 1957 demonstrated the continuity of the iron-formation for a distance of 55 miles between Dragon Lake south of Lac Bérard and a point 8 miles south of Ford Lake. Most of the detailed exploration was carried out in three prominent outcrop areas between Leaf Lake and Finger Lake. Topographic relief in the area does not exceed a few hundred feet, and the iron-formation is exposed in a prominent range of hills along the western margin of the geosyncline belt.

Older Precambrian granite, gneiss, and metasedimentary rocks are overlain unconformably by quartzite, iron-formation, black slate, arkose, dolomite, biotite sericite schist and volcanic rocks of the Kaniapiskau Supergroup and are intruded by gabbro sills. These rocks on the west side of the geosyncline are only slightly deformed, strike north to northwest, and dip 10° to 30°E. About a mile east of the exposed contact they are tightly folded with some folds overturned to the west and disrupted by numerous thrust faults that strike northwest and dip steeply east. Another promi-

[1]Formerly Finger Lake

TABLE XII | *Stratigraphic Succession in Four Areas South of Leaf Lake*

Finger Lake[1] area (Bérard, 1958)	Gerido Lake area (Bergeron, 1954: Sauvé, 1955)	Thévenet Lake area (Gélinas, 1958)	Freneuse Lake area (Sauvé, 1957)
Gabbro sills	Gabbro sills	Pegmatite dykes	Pegmatite dykes
		Amphibolite, blotchy amphibolite with pegmatite	Mica schist with numerous thin amphibolite sills
Lavas, volcanic rocks	Lavas, volcanic rocks	Ultramafic rock	Amphibolite, ultramafic rocks, in part metamorphosed blotchy gabbro
Argillite, lava, phyllite, sandstone	Shale, siltstone, sandstone, dolomitic shale	Pillowed amphibolite	
Dolomite (Abner)	Iron-formation	Biotite-muscovite schist, amphibolite with pegmatite	
Sandstone, greywacke, arkose, conglomerate	Shale, siltstone, arenaceous rocks		
Slate and argillate		Grunerite schist	Iron-formation
Iron-formation		Conglomerate or breccia	
Quartzite, slate, green schists		Calc-silicate rocks, with amphibolite	
Unconformity		Biotite-muscovite-garnet schist, amphibolite and garnet amphibolite with pegmatite	Mica schist; minor quartzite, garnet schist, in part staurolite schist, part sillimanite schist
Gneiss, granite, schist		Dolomite marble, amphibolite, fine-grained quartzite, biotite-diopside schist	Actinolite marble, actinolite-diopside marble, calc-silicate rocks, actinolite-diopside gneiss, actinolite breccia
		Grey and pink gneiss, amphibolite with pegmatite, augen gneiss	Microcline gneiss, mainly fine-grained gneiss

Lithological units are listed from older to younger in ascending order and are not correlated between areas.

[1]Now Lac Bérard

nent set of faults along the west margin of the geosyncline strike west-northwest and pass through the gneiss and low dipping sedimentary rocks. These have left-hand displacement of as much as a mile and are spaced at intervals of ¾ mile to 2 miles.

Stratigraphy

The table of formations for the north of Finger Lake[1] area (Table XIII) summarizes the stratigraphy for the area and is based on a section near Sunny Creek about a mile west of the Chioack River. The gneiss and granite are overlain by dark green to grey quartzite that contains arkosic beds in places and is interbedded with magnetite-rich slaty beds in the upper part. The quartzite is overlain by a dark green to black magnetite–chlorite–biotite–quartz schist 10 to 20 feet thick. The upper half of it contains from 20 to 25 per cent fine-grained magnetite and about 5 per cent carbonate. Magnetite in some beds is distributed in ellipsoidal structures that are relics of granules or oölites that were present in the primary texture. This schist unit is equivalent to the Ruth Formation in the Knob Lake range.

[1]Finger Lake now Lac Bérard

TABLE XIII | *Table of Formations*[1], *North of Finger Lake Area*

	Local Formation Names	Lithology	Approximate Thickness[2] (feet)
LATE PRECAMBRIAN	Mannic schist	Quartz biotite and sericite schist	—
	Abner dolomite	Buff weathering, white to grey dolomite with secondary quartz along bedding planes	—
	Chioack Formation	Black to grey schistose shale, minor arkose	
	Fenimore iron-formation	Spotted silica, granular silica chert with much interbedded carbonaceous material and secondary cummingtonite Interbedded carbonate and chert, white to green chert and medium- to coarse-grained siderite, some brecciated material towards top Metallic magnetite and silica at top, oölitic and specular hematite at centre, granular quartz with disseminated magnetite at bottom	50-100 80-100
	Allison quartzite	Shale, dark green shale Quartzite, white, brown or black; rounded grains with some interbedded shale	10-20 30-50
	Archaean Complex	Unconformity Mainly gneissic granite	

[1]From Fenimore Iron Mines Limited.

[2]Thickness of formations determined by the writer; shale rocks listed are actually fine-grained schists.

The iron-formation is made up of two principal members, a lower magnetite–hematite–quartz facies and an upper siderite–dolomite–quartz facies with a low iron content. The lower member is thin banded, bluish grey to black, and consists predominantly of magnetite and quartz with some hematite. Bedding varies in thickness from a fraction of an inch to about a foot, and the top 20 feet of the member is thin banded to slaty. A dark grey speckled jasper band about a foot thick near the base of this member consists of specular hematite and magnetite in a fine granular quartz matrix. About 20 per cent of the quartz forms pink to red jasper granules 1 mm in size, which are cherty and much finer grained than the surrounding mosaic of quartz. Above this horizon the bulk of the oxide facies consist of interbanded magnetite-rich layers with some hematite, and layers in which hematite predominates. Jasper specks are more conspicuous towards the base of the member and the occasional band contains disseminated clusters of carbonate grains. The iron oxide minerals form well-defined granular or elliptical grain clusters that are derived from an oölitic or granular texture. Discrete grains of anhedral magnetite and hematite are present in this iron-formation as well as intimate intergrowths of the two minerals. The intergrowths are made up of narrow bars or bands of specular hematite that penetrate larger magnetic grains, and fine hematite grains are clustered around the borders of some magnetite grains. Platy specular hematite is developed along later shear planes that cut across magnetite grains. The upper slaty part is composed of magnetite in granular quartz with a small amount of grunerite and actinolite. The average thickness of the lower member near Sunny Creek is about 85 feet and contains approximately 30 per cent iron and 1 or 2 per cent manganese.

The upper carbonate-quartz member is 50 to 100 feet thick. The lithology is highly variable and intraformational breccia zones are present in the lower 40 feet. Most granular quartz bands are buff to grey on fresh surfaces but weather light buff to deep rusty brown, depending on the amount and kind of disseminated carbonate. Interbanded carbonate layers are cream to buff-grey and weather rusty brown or dark chocolate brown. Intraformational breccias in the lower part range in thickness from a few inches where bands of quartz half an inch thick are broken, up to several feet where fragments are much larger. Angular breccia fragments up to 6 inches thick are rectangular or elongated and distributed in random orientation in a brown weathering carbonate and quartz matrix. They consist of laminated sugary quartz, carbonate chips, and grey oxide facies of iron-formation which are most abundant near the base. A small amount of pyrite is present in the breccia matrix. Lean carbonate-quartz layers containing cummingtonite are interbanded with massive brown weathering dolomite layers above the breccia zones and spotted carbonate and quartz interbedded with dolomite and minor grunerite form the upper part of this member. A massive bed 5 to 6 feet thick, composed mainly of siderite, is present in the middle part of the upper member. Relic granules are discernible in many of the carbonate layers despite extensive recrystallization.

The upper iron-formation is transitional over a few feet to black schist composed of sericite, chlorite, quartz, and carbon with some cummingtonite-rich beds and some arkosic material. The black 'Chioack schist' is overlain by 'Abner dolomite' and this is succeeded by quartz biotite schists known locally as 'Mannic schist'. Intermediate to basic lavas are interbedded with Mannic schist and the upper part of the succession is intruded by gabbro dykes and sills.

Iron Deposits

The iron-formation of the Leaf Lake iron range extends along the west margin of the belt of geosynclinal rocks from Dragon Lake in the south, across Leaf Lake to Pig Lake in the north. Seven ore zones have been investigated along this 100-mile range and the three zones of greatest economic interest have been explored in considerable detail. Of the three zones, named the Western North Finger Lake, the Middle, and the South Leaf, the Western North Finger Lake zone is the largest and is situated along the west side of the Chioack River about 5 miles southwest of Leaf Bay. The iron-formation is well exposed along the east side of a north-trending range of hills. The deposit forms a monoclinal structure of metataconite that is about 3 miles long and dips 10° to 20°E. The metataconite zone is 80 to 100 feet thick and is composed mainly of thin-banded magnetite and hematite in granular quartz. Diamond drill holes in this zone have indicated more than 74,030,000 tons of potential ore carrying 29.4 per cent iron which can be mined with a very favourable stripping ratio of waste rock and overburden to ore. The average manganese content in this metataconite is between 1 and 1.5 per cent, but is higher in the siderite-rich zones above the metataconite. The phosphorus, titanium, and sulphur content is insignificant.

The Middle zone, 2.3 miles south of Leaf Lake, is more than 2,000 feet long and is part of a monoclinal structure that dips 20°E. The metataconite is comparable in thickness and grade to that of the Western North Finger Lake zone.

The South Leaf zone is immediately south of Leaf River and about a mile west of longitude 70°west. The metataconite zone is thinner in this deposit than in the two deposits immediately to the south but the grade of material is comparable.

The other four zones, as described by Waddington (1960), include the Dragon Lake–Irony Lake, West Finger Lake, Eastern North Finger Lake, and the Leaf Lake–Pig Lake zones. The Dragon Lake–Irony Lake zone is 9 miles long and has potential ore reserves of 16,240,250 tons at Dragon Lake and 87,768,780 tons at Irony Lake. It consists of spotted silica carbonate, thin-bedded jasper iron-formation, brown carbonate, and thick-bedded jasper formation. The West Finger Lake zone is exposed for a length of 12,000 feet and a width of 300 to 1,100 feet and consists of magnetite–hematite iron-formation beds up to 65 feet thick which contain 26,358,550 tons of potential ore. The Leaf Lake–Pig Lake zone, which extends north from Leaf Lake for a distance of 13 miles, consists of magnetite and hematite iron-formation similar to that found on the south shore of Leaf Lake. The grade of the ore is somewhat higher than elsewhere but the individual bands are narrower.

According to Waddington (1960), ore reserves in the Leaf Lake iron range are estimated to be 45,967,320 tons of carbonate ore containing 20.9 per cent iron, 2.06 per cent manganese, and 35.23 per cent insolubles, and 220,637,600 tons of magnetite–hematite iron-formation containing 31.12 per cent iron, 1.62 per cent manganese, and 43.73 per cent insolubles for a total of 266,604,920 tons of potential ore.

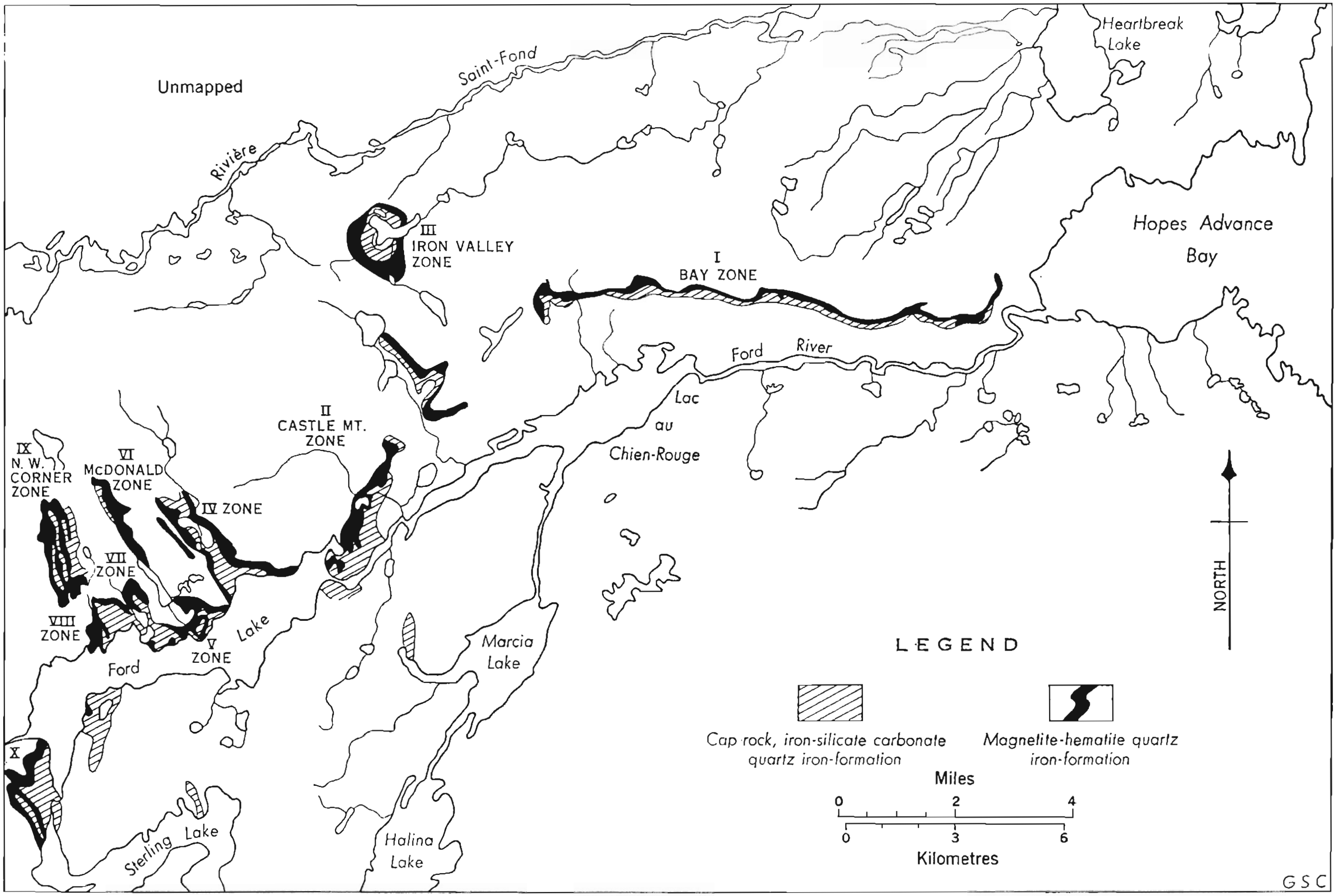


FIGURE 15. Potential ore zones on the Ford Lake iron range (*from* the Ungava Iron Ores Company).

The Ford Lake Iron Range

The Ford Lake iron range extends west from Hopes Advance Bay for 20 miles and was explored in detail between 1951 and 1958 by Atlantic Iron Ores Limited (Fig. 15). Eight major zones of potential ore were mapped in detail and drilled, and extensive metallurgical tests and engineering studies were completed in preparation for ore production. Well over half a billion tons of potential ore carrying 35.7 per cent iron was proven by this work and another 225 million tons of possible ore was indicated.

The iron-formation in this range is exposed along the northwest margin of the geosyncline belt and the general geological setting is similar to that at Leaf Lake. The regional structure consists of a broad synclinal fold that plunges gently south. At the west end of Ford Lake the strike of the geosyncline rocks changes from northwest to east and continues east as far as Hopes Advance Bay where it again swings north. The iron-formation for the first 8 miles west of Hopes Advance Bay is exposed almost continuously for 20 miles and dips gently south. From there as far as the east end of Ford Lake the general strike is southwest but the strata are more highly deformed. Northwest of Ford Lake around the axis of the regional syncline the iron-formation forms a number of broad open synclines which plunge gently south and are cut by thrust faults.

Stratigraphy

The distribution of the iron-formation and the ten zones of potential ore are shown on Figure 15. A table of formations based on observation in the Castle Mountain zone is included here and although there is considerable variation in the detailed stratigraphy of the iron-formation, this table shows a general stratigraphic succession for the range.

The Ford Lake Formation, composed of quartzite and garnet–biotite–chlorite schist, overlies the granite and gneiss complex unconformably. The quartzite at the base is fine grained, massive to poorly banded, and grades upward into thinly banded dark grey to green garnet–biotite–chlorite schist. The composition of the schist varies considerably and zones 10 to 15 feet thick in the upper part contain up to 20 per cent of finely disseminated magnetite.

The iron-formation is made up of three principal units which are carbonate–iron silicate–magnetite–quartz facies at the base, a hematite–magnetite–quartz facies or metataconite in the middle part, and a banded or spotted iron silicate–carbonate–quartz facies or cap rock forming the upper unit. There is a transition from schist to the lower iron unit and the base of this unit is recognized by the presence of dark amber coloured grunerite-rich bands, rusty brown carbonate lenses, or magnetite–grunerite–quartz bands in dark grey schist. Lithology in the lower unit is not uniform and carbonates, iron silicates, or magnetite may predominate locally in this thin-banded facies. Carbonate-rich lenses consist of bands, 1 inch to 4 inches thick, of grey-buff quartzite rock bearing disseminated carbonate and grunerite, alternating with bands composed of rusty brown weathering carbonate with coarse-grained grunerite and disseminated magnetite. Laminations in some beds are formed by the streaky distribution of grunerite and magnetite whereas some carbonate beds or lenses are stubby and irregular and contain boudins of quartz. Where carbonate is less abundant this unit is composed of thinly laminated to slaty grey quartz layers alternating with grunerite- and magnetite-rich layers containing some garnet and biotite; green amphibole is present in places. Carbonates investigated by X-ray techniques consist of dolomite, but no siderite was identified. Magnetite in dolomite is believed to have been derived from siderite during regional metamorphism.

The middle unit of the iron-formation is potential iron ore and consists of an oxide facies 160 to 200 feet thick. This unit is greatly thickened in many zones by structural deformation and by a rapid increase in thickness down-dip attributed to primary sedimentation. Four main lithological facies are recognized depending on the relative proportions of magnetite and specular hematite present in a granular quartz matrix. They are mapped magnetite, magnetite-hematite, hematite-magnetite, and hematite metallic iron-formation. These facies are lenticular in shape, vary in thickness, and are in no consistent order in the succession, but regardless of the facies present the average iron content is close to 35 per cent throughout. Banding in this dark grey to bluish grey unit ranges in thickness from one inch to one foot with thin laminations present in many bands. The texture and mineral composition is fairly uniform within individual bands but the proportion of magnetite to hematite varies from band to band. Relics of a primary granular to oölitic texture are still discernible in a fairly uniform mosaic of quartz. Anhedral magnetite grains are blocky but specular hematite grains are platy and where abundant the beds may be schistose. Magnetite and hematite have mutual grain boundaries and hematite plates cut across relic textures or penetrate magnetite grains, suggesting that much of it recrystallized during the late stages of metamorphism. Magnetite is predominant in the upper part of this unit and the oxide facies is transitional to an upper zone composed of thin-banded grunerite-magnetite facies with lesser amounts of anthophyllite, actinolite, and carbonate.

The upper unit of the iron-formation, called 'cap rock', is a banded to spotted quartzitic rock rich in carbonate and iron silicates. The transition from the silicate-carbonate-magnetite-quartz facies is abrupt and carbonate in this banded quartz rock is distributed either in wavy stubby lenses or in elliptical nodules ¼ inch to 3 inches long which are scattered through the quartzitic bands. The carbonate consists of dolomite and ankerite and in some places constitutes 50 per cent of the rock.

The schists and slate overlying the iron-formation are similar to that in the Leaf Lake area but probably somewhat coarser grained.

Iron Deposits

Metataconite deposits in this range consist of mixtures of specular hematite and magnetite in granular quartz and contain 35 per cent iron or more. Metallurgical tests indicate that concentrates carrying 68 to 71 per cent iron with 96 to 98 per cent recoverable iron can be made by magnetic roasting of the ore at ¾-inch size followed by grinding and wet magnetic separation and that iron can be concentrated satisfactorily by flotation. The potential ore zones shown on Figure 15 are described briefly below in order from east to west.

The Bay Zone (I) extends west from Hopes Advance Bay for 8 miles and the metataconite is exposed along a series of long narrow ridges that rise from 50 to 100 feet above the surrounding country. The metataconite is of average grade, consisting of banded mixtures of magnetite and hematite in granular quartz with some inter-bands of carbonate and iron-silicate-rich material. This iron-formation, in the lower part of the section, lies close to the unconformity with granite-gneiss and thickens and thins along strike, forming a series of lenticular metataconite zones that dip from 15° to 45°S. The amount of carbonate-quartz cap rock overlying the metataconite varies from place to place along strike but a substantial tonnage of potential ore has been outlined that will require the removal of a comparatively small amount of waste rock when mined.

TABLE XIV | *Table of Formations, Castle Mountain Zone*

	Local Formation Names (from Atlantic Iron Ores Limited)	Lithology	Approximate Thickness (feet)
LATE PRECAMBRIAN	Leaf Bay Group	Volcanic and sedimentary rocks. Diorite and gabbro sills, and amphibolite rocks	—
	Red Dog Formation	Micaceous schists and slates with minor carbonate and quartzose beds	—
	Iron-formation and cap rock	Iron-silicate, carbonate, quartz iron-formation Grunerite magnetite quartz iron-formation Hematite and magnetite quartz iron-formation Carbonate, iron-silicate, magnetite quartz, iron-formation	50-100 35-50 150-200 40-50
	Ford Lake Formation	Quartzite and garnet-biotite-chlorite schist	Up to 100
		Unconformity	
	Archaean Complex	Granite and granite-gneiss	

The Castle Mountain zone (II) extends north to northeast for more than 12,000 feet from the east end of Ford Lake and forms a low ridge that rises 50 to 75 feet above the level of Ford Lake. The stratigraphic section for this zone has already been described. The metataconite is of uniform grade throughout the deposit and is composed of bedded mixtures of magnetite and hematite in quartz. This deposit forms a monoclinal structure that strikes N25°E and dips 10° to 35°SE. Minor undulation of the iron-formation beds is caused by cross-folding and some repetition of the iron beds takes place along low easterly dipping faults that strike south. Primary sedimentary facies of iron-formation thicken appreciably from west to east in this deposit and the metataconite zone is more than 300 feet thick in the eastern part of the potential ore zone.

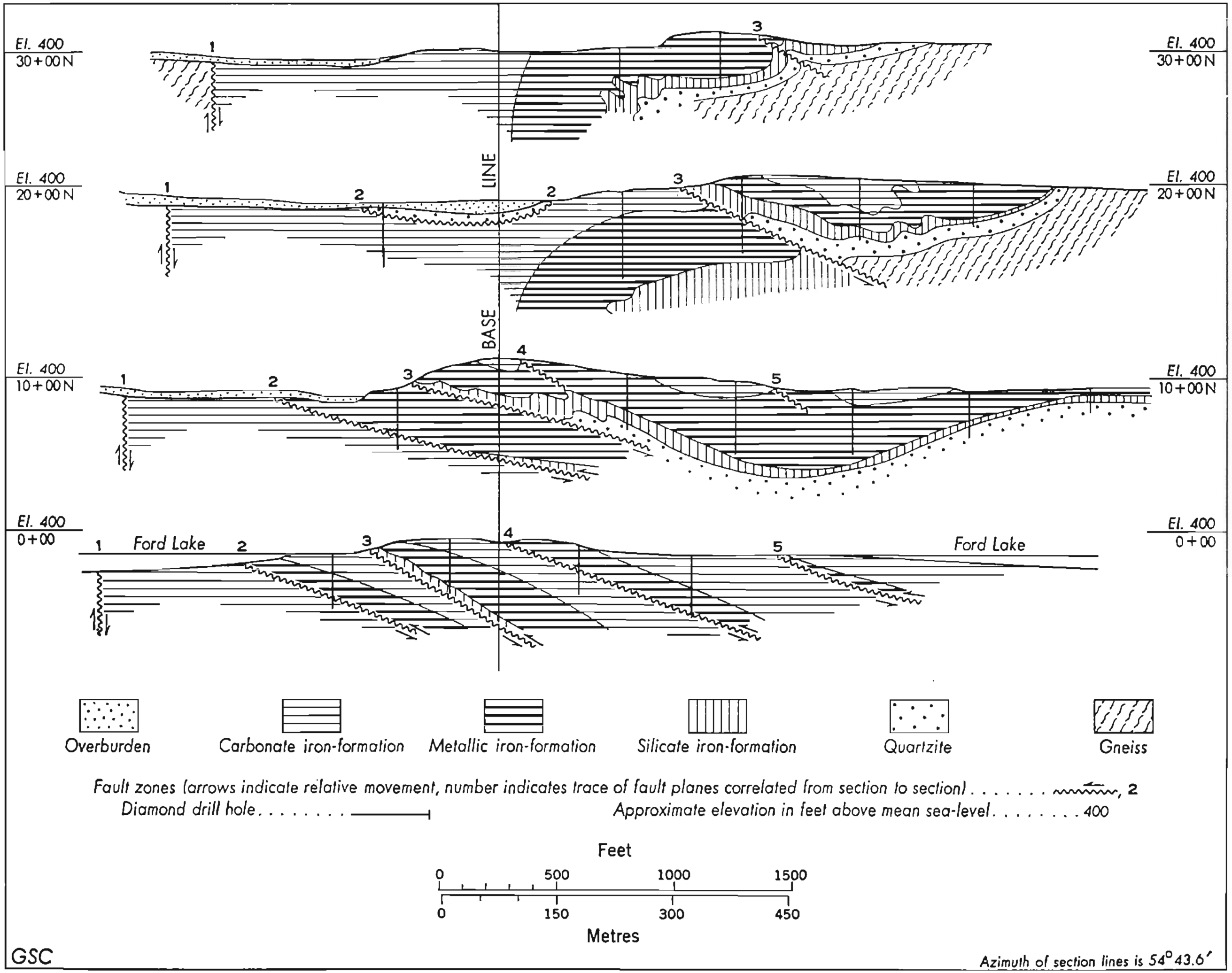


FIGURE 16. Cross-sections illustrating the geology of Number V zone in the Ford Lake iron range. Sections are spaced 1,000 feet apart from north to south (*from* the Ungava Iron Ores Company).

The Iron Valley zone (III) is about 5 miles north of the east end of Ford Lake. It forms a circular basin structure more than a mile wide around Hicks Lake, the border or rim of the basin rising more than 300 feet above the level of the lake. Around the north and east borders dips are nearly vertical or beds may even be overturned to the west. On the west side of the basin metataconite is well exposed and nearly flat lying. In the central and northeastern parts of the area, iron-formation is downfolded along a northwest-trending syncline and is covered with cap rock and schist.

Number IV zone is in a northwest-trending synclinal structure at least 8,000 feet long and 2,000 feet wide, which plunges southeast at its south end under Ford Lake. Its central area is covered with cap rock.

Number V zone extends north for nearly a mile from the centre of the north shore of Ford Lake. The metataconite beds are several hundred feet thick and form a very complex structure (Fig. 16). At the south end, the metataconite and cap rock form an imbricate structure on faults that dip east and strike northwest. Towards the north the iron beds form a flat basin or saucer-shaped syncline which is thrust west over the crest of an anticline overturned to the west. At the north end, the syncline plunges out and the crest of the anticline appears to plunge northwest. Figure 16 illustrates how very complex the local structures may be in this region and the necessity of obtaining a thorough knowledge of the stratigraphy and subsurface geology when proving ore and planning open-pit mine operations.

The McDonald zone (VI) extends for 2½ miles northwest from Number V zone along the west side of a northwest-trending granite ridge and dips 30°W. Drag-folds and fracture cleavage show that the upper beds on this slope have been thrust west relative to lower beds. It seems likely that the granite ridge formed a buttress and that only upper beds were transported by the stress directed from the east. West of this deposit the iron-formation is covered with cap rock and is bounded by a northwest-striking fault.

Zones VII and VIII, immediately west of Number V zone, underlie an area along the north shore of Ford Lake about 1½ miles wide and a mile long. They consist of two broad synclines that plunge southeast and are separated by a northwest-striking fault.

The Northwest Corner zone (IX) lies about a mile north of the west end of Ford Lake, and is about 2 miles long and more than half a mile wide. It consists of a number of east-dipping metataconite beds that have not been explored in detail.

Number X zone, at the extreme southwest end of Ford Lake, is more than 1½ miles long and a mile wide, and consists of a southeast-plunging syncline.

The Payne Bay Area

Area South of Payne Bay

The iron-formation south from Payne Bay for a distance of 30 miles was explored by Oceanic Iron Ore of Canada Limited between 1954 and 1957. A number of zones, described below, were selected for detailed mapping and extensive drilling, and metallurgical tests were completed on bulk samples. Basic engineering studies were carried out in anticipation of the time when market conditions warrant the development of these deposits.

Iron-formation in the western part of this area is folded into a series of three prominent anticlines and three synclines which plunge gently to the southeast. The general configuration of these folds appears to have been controlled by the hummocky topography on the original depositional surface and the synclines, although deformed by later structural movements, occupy the valleys in this old surface. The east limbs of the anticlines consist of low easterly dipping flat sheets and the crested segments of the folds are tightly folded, thrust faulted, and overturned to the southwest. Imbricate structures are common in the crests and west flanks of most anticlines. Extensive exploration was carried out in the Bay zone immediately south of Payne Bay (Payne Bay iron range) and in the Morgan Range situated on the west border of the geosyncline about 12 miles south of Payne Bay (Morgan Lake iron range).

Payne Bay Iron Range

The stratigraphy in the Payne Bay iron range is outlined in the accompanying table of formations (Table XV) and the structure and distribution of the iron-formation is illustrated in Figure 17. The early Precambrian rocks are overlain unconformably by 20 to 30 feet of grey to green, thin-banded biotite-chlorite-garnet schist. The schist is transitional to dark grey vitreous quartzite which is separated from the main iron-formation by a zone 20 feet thick of specular hematite-quartz schist, biotite-chlorite-garnet schist, quartzite, and grunerite-hypersthene-quartz schist in the upper parts.

The lower iron-formation is composed of iron-silicate–carbonate–magnetite–quartz and magnetite–hematite–quartz facies and the upper iron-formation or cap rock consists of grunerite–carbonate–quartz facies. The thin-banded to slaty silicate-carbonate facies at the base of the lower unit is composed of alternating bands rich in grunerite and hypersthene, magnetite, and quartz with carbonate, mainly dolomite and calcite, associated in specks, spots, and thin lenses. Variable amounts of hedenbergite, diopside, actinolite, and hornblende are associated with the other iron silicates. The proportion of silicates to magnetite is estimated to be about 3 to 1 and much of the magnetite is present in irregular to ragged grain clusters that measure 0.3 to 0.4 mm.

This lower facies grades upward to grey-blue magnetite–hematite–quartz facies or metataconite. Bands in this part of the section are usually less than half an inch thick with the occasional bed up to 10 inches, and the lower 20 to 30 feet is rich in magnetite associated with small amounts of grunerite. The upper parts of the facies contain appreciably more hematite intimately mixed with the magnetite. Less than 5 per cent dolomite is distributed in narrow lenses and specks along some layers and bluish green amphibole is disseminated on some bedding planes. Quartz in this facies is grey to glassy, has a sugary to granular texture, and forms a fairly uniform, fine-grained mosaic. The iron oxides are distributed in streaky bands and form irregular ragged grain clusters about 0.3 mm in size in which magnetite and hematite are intimately mixed. Specular hematite is more abundant along cleavage and bedding planes and some plates cut across granular intergrowths of magnetite. Relics of an

TABLE XV | *Table of Formations, Payne Bay South Area*

	Local Formations	Lithology	Approximate Thickness (feet)
LATE PRECAMBRIAN	Mica schist	Black and dark grey, fine-grained mica schist	—
	Iron-formation and cap rock	Grunerite-carbonate-quartz cap rock	—100
		Interbanded specular hematite, magnetite, and grunerite-quartz iron-formation	50
		Magnetite–specular hematite–quartz iron-formation, thin-banded	80
		Grunerite-magnetite-quartz iron-formation, thin-banded, highly schistose	80
		Biotite-chlorite-garnet schist interbanded with quartzite, thin-banded, with some magnetite and iron silicates	20
		Specular hematite–quartz iron-formation, glassy quartz and well developed platy specular hematite	2-3
	Quartzite	Quartzite, arkosic in places	30-40
	Lower schist	Biotite-chlorite-garnet schist	20-30
		Unconformity	
EARLY PRECAMBRIAN	Archaean Complex	Biotite feldspar gneiss, amphibolite, and gabbro	—

earlier granular to oölitic texture are still discernible in places, where shearing has not been intense. This unit is fairly uniform in composition with an estimated iron content of 30 to 35 per cent. This predominantly oxide facies is transitional upward through a distance of 30 to 50 feet to the upper cap rock. The transition zone is marked by a gradual increase in grunerite, hypersthene, and other silicates and the prevalence of thin banding. The overall magnetite content in this zone is estimated to be 20 per cent.

The cap rock weathers rusty brown, varies greatly in composition, and consists mainly of quartz, iron silicates, and ferruginous carbonate. Bands range from less than an inch to a foot in thickness, and sugary to granular textured quartz layers alternate with buff weathering dolomite that contains variable amounts of amber to khaki coloured iron silicate assemblages. Because of faulting and deformation the true

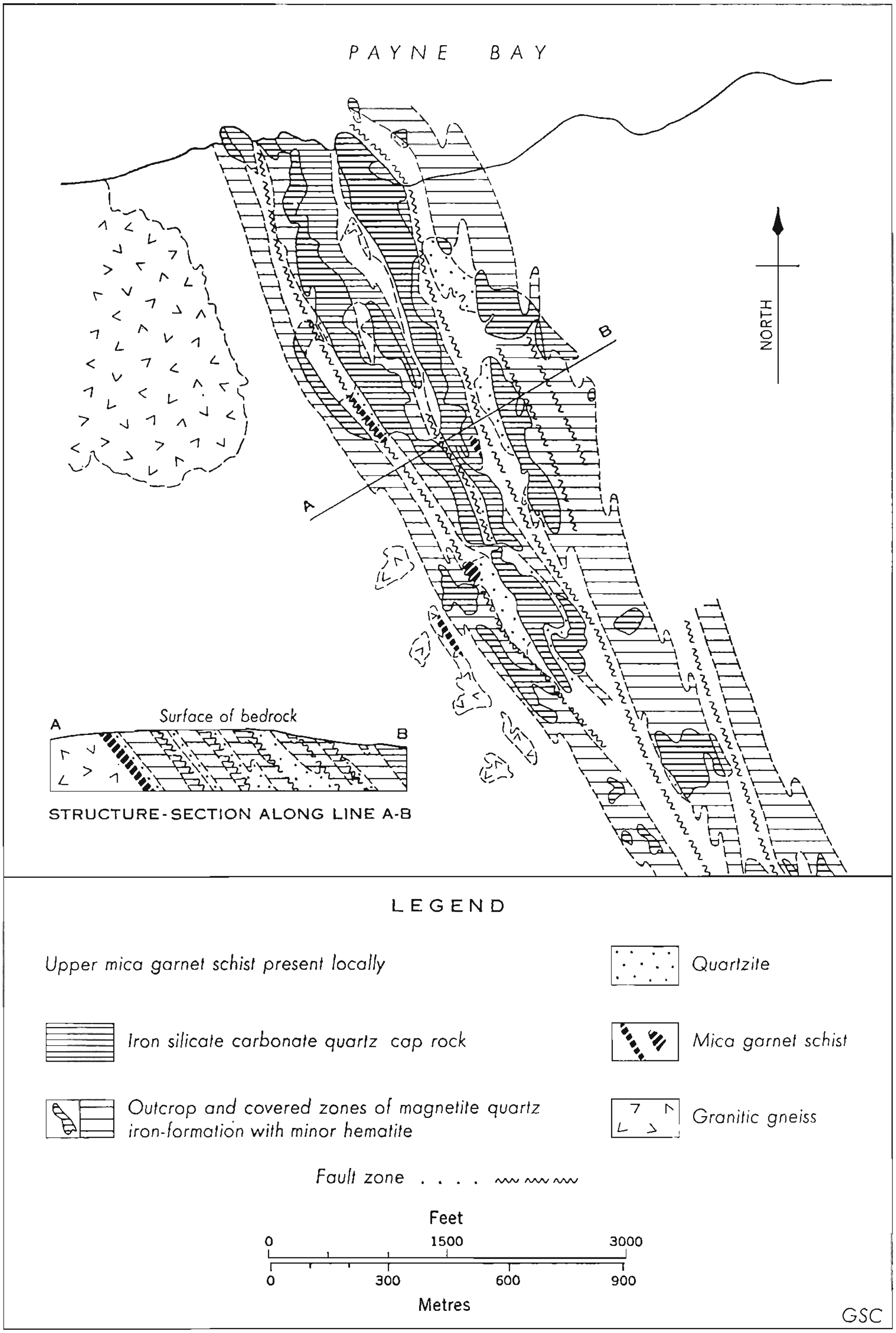


FIGURE 17. Geological plan and section of the shore outcrop area in the Payne Bay ore zone (*from the Oceanic Iron Ore of Canada Limited*).

thickness of the upper iron-formation could not be established, but it is judged to be less than 100 feet. The iron-formation is overlain by black micaceous schist and metavolcanic rocks and basic sills are present in the upper part of the section.

The imbricate structure caused by thrust faulting immediately south of Payne Bay is illustrated in Figure 17. The structure about 2 miles south of Payne Bay, near the Black area, is illustrated in a cross-section in Figure 18. Detailed structures are exposed there on a prominent hill and the iron-formation is repeated four times on thrust faults that strike north and dip 20°E or less. Some segments of the succession appear to be folded in two directions with the first order of folds having doubly plunging axial lines that trend north to northwest. Most of these folds have gently dipping east limbs but the west limbs dip steeply west or are commonly overturned to the west. Some of the west limbs of anticlines have been eliminated by steeply dipping thrust faults. Cross-folds that plunge to the southeast are imposed on the first order of folds. The complex structure of iron-formation belts in this region is indicated in Figures 17 and 18.

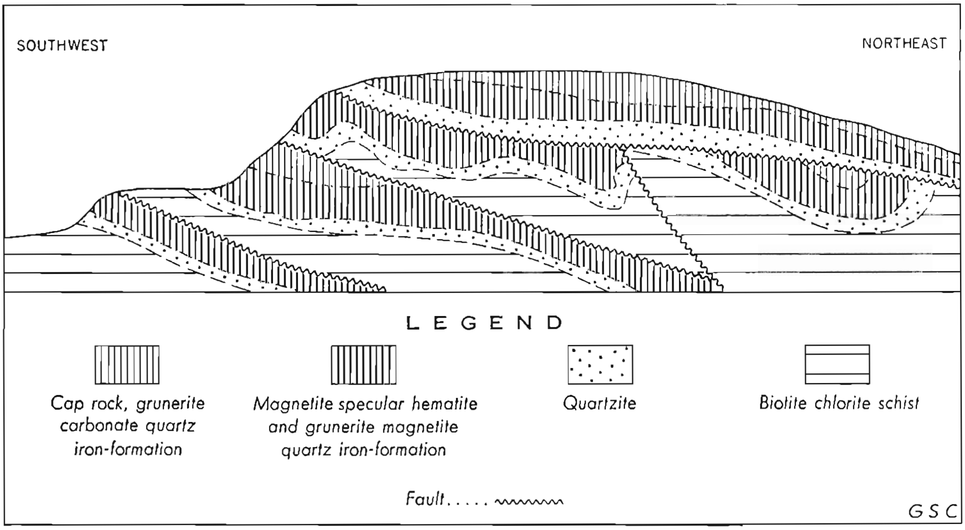


FIGURE 18. Diagrammatic section, approximately 3,000 feet long, of the geological structure in the Black area south of Payne Bay (*from a field sketch*).

The Payne Bay iron range, including the Shore outcrop and the Black area described above, extends southeast from Payne Bay for several miles. More than 71,300,000 tons of potential ore carrying 23.85 per cent recoverable iron from which a concentrate carrying 66.32 per cent iron can be made has been indicated by diamond drilling completed by Oceanic Iron Ore of Canada Limited.

Morgan Lake Iron Range

The Morgan Lake syncline is about 15 miles south of Payne Bay and about 15 miles west of the west coast of Ungava Bay. It forms a prominent northwesterly trending range of hills composed of younger trough rocks surrounded by granite-gneiss. The iron-formation is well exposed around the perimeter of this syncline, which is about 8 miles long and 3 miles wide. The syncline plunges southeast, the iron-formation on the west limb dipping gently east towards the centre of the basin and on the east limb dipping steeply west. International Iron Ores Limited holds claims covering most of the east limb and northwest part of the syncline and Oceanic Iron Ore of Canada Limited holds the southwest part of the west limb.

The main ore zone in the southwest part of the Morgan Lake range, explored by Oceanic Iron Ore of Canada Limited, is oval in plan and metataconite is well exposed over a plateau area 15,000 feet long and 1,700 feet wide. The higher grade metataconite is about 100 feet deep on an average and is underlain by about 30 feet of leaner material. The metataconite, consisting of thin-banded mixtures of magnetite, iron silicates, and quartz, is nearly flat lying in the western part of this plateau. Towards the northeast much of it is well exposed or covered with thin layers of siliceous cap rock. Granitic rocks are exposed in the central part of this plateau and iron-formation in the eastern part, beyond the area of indicated ore, is largely covered with overburden. Company engineers report that 350 million tons of potential ore, carrying 24.56 per cent iron that can be beneficiated to a concentrate running 63.3 per cent iron, has been indicated by diamond drilling in a 3-mile-long section, and that 181 million tons of potential ore, carrying 16.88 per cent iron that can be concentrated to 65.4 per cent iron, is indicated below the higher grade metataconite.

Metataconite in the northwest and east limbs of the Morgan syncline, explored by International Iron Ores Limited, is composed of thin-banded mixtures of magnetite, iron silicate and quartz with very little hematite. The iron-formation is well exposed along a strike length of 12 miles, and on the basis of surface sampling and geological mapping the company reports 25 million tons of metataconite carrying 32.4 per cent iron and 0.7 per cent manganese which can be easily concentrated. There are other indications of further ore potential in this range.

Area North of Payne Bay

International Iron Ores Limited has an exploration permit from the Province of Quebec for 443 square miles of land distributed around the north border of the geosyncline. Exploration of this ground was started in 1953, and intensive investigations were carried out in four selected areas.

Iron-formation is exposed intermittently around the perimeter of the geosyncline belt for a distance of 123 miles. On the basis of work to date, company engineers estimate that more than 800 million tons of metataconite averaging 36 per cent iron is mineable from well-exposed iron-formation along 58 miles of strike length. Considerable more metataconite is present in the region below shallow overburden or thin layers of cap rock.

Five areas particularly favourable for development because of their substantial reserves of potential ore and location are:

(1) The Kyak zone on the east limb of the syncline extending northwest from Payne Bay for 6 miles.

(2) The Igloo Lake zone on the east limb of the geosyncline directly east of Roberts Lake.
(3) The Hump zone on the east limb of the geosyncline 6 miles northeast of Roberts Lake.
(4) The Yvon Lake zone 4 miles northwest of Roberts Lake on the west limb of the geosyncline.
(5) The Synclinal zone near the west and southwest shore of Roberts Lake.

Kyak Bay Zone

The metataconite in this zone consists of banded mixtures of magnetite, hematite, and quartz underlain by a thin band of iron silicate and overlain by spotted carbonate-quartz cap rock. Most of the metataconite beds dip vertically or steeply west in this zone and the iron-formation is thickened and repeated numerous times by complex doubly plunging isoclinal folds and thrust faults. Some of the beds, which dip gently west, are overturned and are apparently parts of recumbent folds.

Zones around Roberts Lake

The four zones around Roberts Lake have not been examined as thoroughly as the Kyak zone. The metataconite is thin banded and consists predominantly of magnetite with hematite in granular quartz. Where examined by the writer in the Yvon Lake area it is 80 to 100 feet thick and is underlain by quartzite and grunerite-rich schist and overlain by carbonate-quartz cap rock.

Summary, Northern Division of the Geosyncline

Iron deposits in the northern division of the Labrador geosyncline consist of selected zones of metamorphosed magnetite–hematite–quartz iron-formation that can be concentrated to give high grade iron ore. Major features of the stratigraphic successions in each area are similar but the extent to which different facies of iron-formation are developed varies considerably. The rank of metamorphism increases progressively from the southern part of this division to the central part and from there decreases northward. Iron-formations from areas of high rank metamorphism are generally coarser grained and the iron-oxide minerals from these areas are concentrated more easily than those in less metamorphosed iron-formation.

The distribution of iron-formation as revealed by outcrops is shown on the Figure 1, but outside the occurrences shown other bands of iron-formation may be present but concealed by overburden or by thin sheets of barren rock thrust over the iron-formation on low dipping faults.

All potential ore proven to date is well exposed and only a very small amount of overburden or waste rock will need to be removed when this ore is mined. Very large tonnages of potential ore are indicated in zones adjacent to the proven orebodies where the ratio of waste rock to ore increases to two to one or greater. Many known iron-formation bands have not been fully explored and may contain large amounts of ore.

Chapter V

GEOLOGY AND ORE DEPOSITS OF THE SOUTHERN DIVISION OF THE LABRADOR GEOSYNCLINE

The southern division of the Labrador geosyncline lies within the Grenville Province where all rocks are highly metamorphosed and deformed. It extends southwest for 200 miles from the east shore of Shabogamo Lake to near Pletipi Lake and varies in width from 10 to 60 miles. Only rocks such as the iron-formation, metadolomite, and quartzites can be recognized as the metamorphosed equivalents of Kaniapiskau rocks mapped in other parts of the geosyncline. The boundaries of the Labrador geosyncline in this region are therefore inferred from the distribution of structurally isolated occurrences of iron-formation and other distinctive kinds of rocks.

Very little was known about the geology of this region prior to 1950, but recognition of the special value of the coarse-grained metamorphosed iron-formations as a source for high quality iron-ore concentrates soon led to extensive and rapid exploration and mine development. Very large deposits of iron-formation amenable to concentration by simple inexpensive processing are distributed throughout this division and work to date has indicated more than 10 billion tons of potential crude ore recoverable from open pit mines.

The first ore was produced in 1961 by the Quebec Cartier Mining Company, a subsidiary of United States Steel Corporation. It came from the Lac Jeannine deposit near Barbel Lake where facilities were established for an annual production of 8 million tons of ore concentrate. Very large deposits west of Wabush Lake have been developed by the Iron Ore Company of Canada where milling and plant facilities are established for the production of 6 million tons of high grade ore pellets per year. Wabush Iron Company holds a billion-ton deposit south of Wabush Lake; it started production in 1965, and expects to produce about 5 million tons of pellets a year. A number of other deposits in this region, with ore reserves measured in hundreds of millions of tons, have been investigated with development and production planned when market conditions are appropriate. The southern division of the Labrador geosyncline has now become one of the major sources of iron ore in the Atlantic market area and contains the greatest reserves of potential ore known on the North American continent.

General Geology

The general distribution of the iron-formation and related rocks is shown on Figures 1 and 19 (*in pocket*). Much of the area to the south and west has not been mapped in detail, and the regional extent of the metamorphosed geosynclinal rocks is not completely defined. Nearly all the area has however been covered by airborne magnetometer surveys flown for private companies, and the principal iron ranges known are indicated on Figure 19. The conspicuous difference in structural trend and pattern between the central and southern divisions of the geosyncline can be clearly seen on Figure 1. The change in structural pattern is accounted for by more intense deformation in the Grenville Province resulting from at least two major periods of folding in the southern division in contrast to only one in the central division. Structural deformation throughout the southern belt was accompanied by flowage and recrystallization of the metasedimentary rocks during high rank regional metamorphism. The iron-formation is broken up into isolated structural segments and correlation of metasedimentary rock groups is most difficult. It appears, however, that iron-formation occurs in one restricted zone in the stratigraphic succession and that this zone may be used as a marker bed for interpreting the regional structure.

The boundary zone between the central and southern divisions trends northeast and cataclastic zones in the gneisses south of Sawbill Lake indicate major northeast-striking faults. Stocks of granite of considerable size, which appear to intrude and assimilate geosynclinal rocks and basement gneisses, are reported along this boundary by company geologists. Most of the critical boundary zone is drift covered and the separation of the iron-formation beds shown on the map may be more apparent than real. There is a marked difference in rank of metamorphism between rocks on opposite sides of this boundary. To the northwest metamorphism has not risen beyond the greenschist facies and the slates, argillites, and iron-formation are relatively fresh and undeformed. To the south, however, metamorphism has reached epidote–amphibolite rank or higher, and the equivalent metasediments are phyllites, schists, gneisses, and granular textured iron-formation. Metamorphism increases in rank southward and it becomes increasingly difficult to correlate schist and gneiss units.

There is no question that the belt of Kaniapiskau rocks continues into the metamorphosed Grenville terrain. Airborne magnetometer surveys show a high anomalous magnetic pattern throughout the area suggesting that the iron-formation is continuous except possibly for local structural breaks. The same stratigraphic succession is recognized on both sides of the boundary zone and metasediments of the Kaniapiskau Supergroup continue southward without interruption as far as Long Lake. Beyond this area the metamorphic equivalents of Kaniapiskau rocks are only recognized in isolated structural segments by the presence of iron-formation, marble, and quartzite. Detailed mapping and magnetometer surveys show that the iron-formation is much more continuous than indicated by earlier work and that it is not necessary to postulate more than one major iron-formation unit in order to define the regional structures.

Stratigraphy

Correlation of stratigraphic groups and interpretation of structure are greatly hindered by the lack of criteria for determining the tops of beds. Most sedimentary and structural features normally used for this purpose have been obliterated by recrystallization during metamorphism and by structural deformation. Colour banding in some of the quartzite suggests crossbedding and stromatolite forms are suggested by colour and textural variations in meta-dolomite, but none of those found is well enough preserved to be used with confidence. The unconformity between younger rocks of the iron bearing succession and older gneiss has been recognized in a few places and the stratigraphic succession in the younger rock group can be determined at these points. The succession, however, is not the same from place to place and there are changes in facies within short distances. The information gained from exposed unconformities is therefore of limited use. Without the benefit of normal stratigraphic methods for determining the sedimentary succession and the distribution of separate facies, only general inferences can be made about the regional geology. Without confirmation of stratigraphic tops of beds most structural patterns can be interpreted in at least two ways and unique solutions to local structural problems can only be made after considerable detail is available from diamond drilling. Very often drilling to the economic depth for mine development still leaves information in the third dimension inadequate for confirming the nature of the whole structure. Nevertheless, confirmation of structure by detailed work in many local areas has provided sufficient information to enable some evaluation of regional stratigraphic and structural features.

A few general premises are accepted in the following discussion of regional stratigraphy which appear from the limited information available to be valid. There is believed to be only one major iron-formation assemblage throughout the region and this can serve as a horizon marker. The variations in iron-formation facies and prominent lateral changes in the lithology of this unit are presumed to reflect variations in primary sedimentary facies and the nature of the environment in which they formed. The order in which metasedimentary rock types occur in the succession is not consistent throughout the region but reflects variations in the sedimentary environment. Prominent dolomite and quartzite beds may be present either above or below the iron-formation, as they are in some areas farther north in the geosyncline. The iron-formation member thickens and thins laterally and may be absent locally.

Considerable regional information has been summarized in Figure 19 to show the general distribution of prominent facies of iron-formation and associated metasediments. The main stratigraphic succession, including dolomite–quartzite–iron-formation in ascending order, has been traced southward through the Wabush Lake area as far as Lac Carheil. The dolomite pinches out westward below the iron-formation but forms a prominent continuous unit along the eastern side of the geosynclinal belt. The prominent quartzite formation below the iron-formation in the northern part of the geosyncline is traced southwest as far as Kissing Lake, Bloom Lake, and Green Water Lake, where it pinches out as shown in Figure 19 and on detailed maps of the Quebec Department of Mines (Clarke, 1960). Farther east where the quartzite thins out the thickness of the underlying dolomite formation increases. In the Mount Wright area, detailed work has shown that a thick quartzite formation lies stratigraphically above the iron-formation and this change in the order of succession of beds corresponds with a distinct change in facies in the iron-formation. The iron-formation throughout the Wabush Lake area is composed of a silicate-carbonate facies at the base overlain by iron-oxide facies and this unit thins eastward and gives way to dolomite. To the northwest the iron-formation thins but transgressively overlaps the lower quartzite with some silicate-carbonate facies present where the quartzite pinches out. A thin silicate-carbonate member associated with magnetite quartz facies is present on both the northeast and northwest sides of Boulder Lake, but near the south end of this lake specular hematite and quartz facies rest on mica schist and granitoid gneisses in two small synclinal outliers. Interpretation of detailed structure in the Bloom Lake area to the southeast of Boulder Lake shows two successions of iron-formation separated by feldspar–mica–hornblende gneiss, quartzite and amphibolite. These iron-formations consist of magnetite–specular hematite–quartz facies in the west part of this structure but change along strike to the east to magnetite–silicate facies. Quartzite in this area lies below the upper succession and pinches out near the western side of the syncline. South of Bloom Lake in the Mount Wright area the iron-formation west of Moiré Lake is predominantly specular hematite–quartz facies overlain by quartzite, but east of this lake there is a transition to silicate-carbonate facies and ferruginous dolomite. It is important to note that in the Mount Wright–Bloom Lake area marked changes in the stratigraphic succession coincide with changes of facies in the iron-formation, and that this area may have been a shallow water zone in the sedimentary basin or a delta where oxide facies of iron-formation was precipitated and later covered with sandstone. Deposition of sandstone over oxide facies of iron-formation may have been typical in other deltas around the margin of the sedimentary basin.

A great amount of iron-formation is preserved in the structural complex between Lac Carheil and Lac Georget. Most geologists who have worked in this area have considered the stratigraphic succession in ascending order to be dolomite–quartzite and iron-formation overlain and underlain by metasedimentary gneisses and schists. Rock members in this succession thicken and thin considerably and there are conspicuous variations in the thickness of different iron-formation facies. In the Fire Lake area no appreciable thickness of quartzite is present and the iron-formation grades upward from magnetite to specular hematite–quartz facies, which is overlain by a thin dolomite member. The thick oxide facies of iron-formation may have been deposited in a local shallow water zone and later covered during transgressive overlap of dolomite from the east. The band of magnetite–specular hematite iron-formation between Esker and Tuttle Lakes in the northern part of this area is considered to be a near-shore facies like that in the adjacent Mount Wright area to the north. Iron-formation extending east from Lac Cassé to Plaine Lake is reported to be very thin and probably absent in some places, and it may mark the limit of deposition in deeper water in this part of the basin or geosyncline.

A few general stratigraphic relationships are apparent in the Round Lake–Mount Reed–Lac Jeannine area. Specular hematite–quartz–iron-formation exposed at Lac Jeannine in the south is overlain by mica schist and a thin dolomite unit. Some iron-silicate magnetite facies is present in this succession northwest of there, near Barbel

Lake. Detailed work at Mount Reed shows the succession there to be impure quartzite grading upward to silicate–magnetite facies, magnetite–specular hematite–quartz, silicate–magnetite facies again, impure quartzite, and dolomite at the top. It appears that near-shore oxide facies of iron-formation grades northward from Lac Jeannine to deeper water magnetite and silicate facies, and thickening of the overlying dolomite in this direction would also suggest deepening of the basin in the Mount Reed area to the north. The relationship between strata at Mount Reed and in the area east of Lac Georget is not clear, but the iron-formation and associated rocks in the two areas were probably deposited on opposite sides of the main geosynclinal basin.

The iron-formation extending southwest from Racine-de-Bouleau River and across the Seignelay River is mainly magnetite and specular hematite–quartz facies with local lenticular development of silicate–carbonate facies. A great amount of muscovite–biotite schist is associated with the iron-formation, and there is considerable local variation in the stratigraphic succession. A thin but fairly persistent band of quartzite lies below a few hundred feet of mica schist at the base of the iron-formation. Thin lenses of dolomite are present above the iron-formation or in places interbedded with it. The predominance of specular hematite–quartz facies suggests that much of this iron-formation was deposited in shallow water and that the northern margin of the basin lay in this area. Silicate–carbonate iron-formation northeast of Dart Lake appears to lie unconformably over granitoid gneisses and may have been deposited in a local deeper water embayment along the margin of the geosyncline.

The distribution of iron-formation facies in the western part of the geosyncline belt around Matonipi Lake is still not well defined. A relatively thin band of specular hematite and magnetite–quartz iron-formation can be traced intermittently in the area between Lac Larocque and the Mouchalagane River and south to Parr Lake. It continues south along the Mouchalagane River where it changes to a magnetite–iron-silicate facies and is associated with dolomite. Another band of specular hematite–magnetite facies iron-formation is exposed between Matonipi and Matonipis Lakes and on some of the islands in Matonipis Lake. This band may possibly be followed to the Hummingbird Lake area south of Lac Larocque. At Hummingbird Lake the western exposures of iron-formations are hematite-rich oxide facies, but there is a transition eastward in this area to magnetite and magnetite–iron-silicate facies which are underlain intermittently by lenses of impure quartzite.

The iron-formation west of Matonipi Lake is relatively thin and is composed of a band of magnetite and specular hematite–quartz facies that is gradational to upper and lower silicate carbonate units. The succession of rocks unconformably overlying the granite–gneisses, in ascending order, is micaceous quartzite, iron-formation, quartzite, dolomite, quartzite, and biotite–garnet gneiss and schist. The iron-formation is even thinner southwest of Matonipi Lake and iron-silicate minerals are more abundant, and the limestone unit thickens towards the southwest suggesting deposition in deeper water. These metasedimentary rocks near Matonipi Lake are preserved in a narrow syncline and their relationship to other iron-formations to the east is not well established.

The granitoid gneisses distributed throughout this southern division of the geosyncline are mainly metasediments but may have been derived from several rock groups. Some of the rocks closely associated with the iron-formation are metamorphosed clastic sediments equivalent to the Kaniapiskau Supergroup, but other gneisses and schists may be part of the metamorphic complex on which these younger rocks were deposited. Good criteria have not been established for distinguishing between the two types, and as both were metamorphosed during the Grenville orogeny and are presumably very similar in composition, they present a difficult regional problem. Duffell and Roach (1959) attempted to define two main groups associated with the iron-formation and recognized a third group northwest of Boulder Lake and Lac Gensart composed of granitic and dioritic hypersthene–biotite gneiss. Of the first two groups, biotite- and hornblende-feldspar gneisses, migmatites, and various biotite–muscovite schists, and muscovite–kyanite schists, were believed to underlie the iron-formation, and a group of hornblende–garnet gneisses, migmatite, graphitic gneisses, and schists to overlie it. Rocks of these two groups are practically indistinguishable in the field, as the writer has found in doing detailed mapping, and there is little reason to believe that graphitic gneiss should only be found above the iron-formation. Slate formations both below and above the iron-formation at Knob Lake contain carbon, and the graphitic metamorphic equivalents of this slate are likely to be present in both positions in the southern division. Kyanite and garnet schists are present above the iron-formation at Mount Wright, but it is doubtful if this material is confined to any one part of the gneissic group.

The regional extent of geosyncline rocks cannot be defined in detail until much more is known about the gneisses and suitable criteria are discovered for distinguishing between the various groups. Some of the marginal areas of the southern geosynclinal basin are inferred from the distribution of specular hematite–quartz facies of iron-formation but regional information is incomplete. Much of the exploration in this region has been guided by airborne magnetometer surveys, and there may still be undetected non-magnetic hematitic bands of iron-formation along the margins of this belt. Iron-formation in many drift-covered areas may be discovered when a better appreciation is gained of the regional structure. Available information indicates that the stratigraphic succession in the eastern and central parts of the southern division, as far west as Lac Georget, is similar to that near Wabush Lake. In the southwestern part, dolomite where present is apparently in the upper part of the succession and overlies the iron-formation, and the quartzite units appear to be thin and discontinuous. Areas where the iron-formation is almost exclusively specular hematite and quartz lie near the margins of the known geosynclinal belt, and the stratigraphic successions, like the one at Mount Wright, differ from that in the central and eastern parts. Thick strata of specular hematite and magnetite iron-formation are present throughout the central part, but these are usually associated with silicate-carbonate facies.

Gabbro and Derived Amphibolite

A major suite of gabbroic intrusions and amphibolites derived from them have been mapped in the northeast part of the southern division of the geosyncline. The largest masses are present in the area east of Wabush Lake and south of McKay Lake, but smaller masses occur as far southwest as Little Manicouagan Lake. Most of the smaller masses are sills or sheet-like emplaced between competent metasedimentary beds, in fault zones, or in dilatant zones around the crests of folds. They appear to have been emplaced near the end of the Grenville orogeny as their position is controlled by major structural features, and in some areas, as near Wabush Lake, they have contact metamorphic aureoles imposed on highly metamorphosed metasediments. Border zones around larger masses and most smaller masses are altered to foliated garnet–biotite–feldspar–hornblende amphibolite in which foliation is parallel with that in the adjacent metasedimentary rocks.

East of Wabush Lake large intrusions are composed of anorthositic gabbro according to Fahrig (1960), and in the Pegma Lake area to the south a differentiated sill with peridotite at the base is mentioned by Gleeson (1956). Gabbros in the cores of amphibolite masses in the Mount Wright area examined by the writer (1955) are dark purple to brown, medium to coarse grained, and have a subophitic texture. They are composed of 60 per cent plagioclase (An_{40}-An_{60}), 5 per cent augite, 15 per cent amphibole, and 3 to 5 per cent of olivine, biotite, magnetite, garnet, and chlorite with a variety of accessory minerals including zircon, monazite, apatite, and scapolite. Transition zones from gabbro to amphibolite show a breakdown of mafic minerals with coronas of amphibole, garnet, and magnetite followed by alteration of feldspars to less calcic varieties and in places scapolite. The transitional material is altered further to foliated magnetite–garnet–biotite–plagioclase amphibolite. Chemical studies show that this is an isochemical transformation of gabbro to amphibolite.

Intrusions of these rocks are present in all fault and shear zones and as phacoliths in folded metasediments. In the marginal parts of the orogenic belt to the northwest they are most abundant in structures within the more highly competent quartzite and iron-formation rocks where fault zones probably extended to greater depths than in the less competent gneisses.

These gabbro intrusions were emplaced in structures formed during the Grenville orogeny and are younger than the group of basic rocks intruded along the northeast side of the Labrador geosyncline. They may be related genetically to the anorthositic rocks to the south, in the Grenville belt but there is insufficient information to demonstrate this relationship. The relationship, if any, between these gabbroic rocks and the intrusions in the Otish Mountains area is not known.

Regional Structure

The structure throughout the southern division is extremely complex, as shown by a limited amount of regional mapping and by the detailed investigations on a large number of iron deposits. Only a summary description of regional structure can be given here with an outline of the major stages in its evolution as now understood. Some appreciation of the complexity and details of local structures can be gained from the descriptions of deposits given below. Larger structural features are outlined in Figure 19 together with a few regional trends, but very detailed maps are needed to show the complex structure in most iron deposits.

At least two stages of deformation are recognized. The first stage produced linear belts that trend northwest, like the well-defined structural trends in the central part of the Labrador geosyncline; the second stage formed linear belts that trend east to northeast, parallel with the major structural trends developed in the Grenville Province. Folds now present (illustrated in Figure 19) reflect both stages of deformation in form and orientation. For example, in the Wabush Lake area folds trend N20°E and in the central part of the area, around Lamêlée Lake and Midway Lake, N35°W. Isoclinal and recumbent folds overturned to the west or southwest are common, and it is inferred that this deformation produced thrust faults striking northwest and dipping east. Structures developed during the earlier stage of deformation are believed to have been similar to those now seen in the central part of the Labrador geosyncline, and it is highly probable that the structures produced by this early stage of deformation in the south and those in the central and northern regions were produced by the same orogeny.

The second stage of structural deformation took place during the Grenville orogeny between 800 and 1,200 million years ago, as indicated by isotope age determinations. Its effects are not so intense north of Wabush Lake near the margin of the Grenville belt as they are throughout the region to the south. Near the margin of the Grenville belt cross-folds trending east or northeast appear to be superimposed on the earlier northwest-trending structures. Around Mount Wright and farther south the trend of the overall structure is east to northeast and the prevailing dip of foliation is 55°N. Tightly folded and faulted structures developed during the earlier stage of deformation were further deformed by folding and faulting during the Grenville orogeny. Oblique sections through the resulting complex fold structures are exposed at the present erosion surface. Many of the minor folds appear to plunge steeply to the northwest, but the axes of these folded folds are not straight for any appreciable distance. In places different parts of a major fold are exposed in the oblique surface section and no consistent pattern in plunge or attitude can be observed.

Complex fold structures all through the region southwest of Mount Wright, particularly in the area between Harvey Lake and Midway Lake, formed under similar circumstances. The general structural trend changes from north-northwest at Lamêlée Lake to northwest at Mount Reed.

Regional structures developed during the Grenville orogeny play out against the stable craton area of the ancient Superior Province (*see* Fig. 19, cross-section). Folds and faults along the northwest margin of the Grenville Province trend west, and the general pattern of folds overturned to the south or southeast formed in conjunction with north-dipping reverse faults indicates overriding of the northerly blocks towards the southeast. The relative amount of movement between adjacent fault blocks is suggested by the position of iron-formation in local structures. In the Boulder Lake area to the north the iron-formation is preserved in a number of shallow isolated synclinal basins. South of there, at Bloom Lake, iron-formation is present in a relatively simple syncline which extends to a much greater depth than that in the Boulder Lake basin. Still farther south at Mount Wright, the erosion surface cuts the upper part of steeply plunging folds. The cross-section, Figure 19, shows how the folded iron-formation unit has been moved upward in successive fault blocks to the north. Southeast from the margin of the Grenville belt the dips of westerly striking faults are progressively less steep and the greatest amount of movement appears to have taken place between the Bloom Lake fault block and the Mount Wright block. The iron-formation marker bed is not exposed south of Mount Wright for a distance of 10 miles in an area that appears to form a broad syncline. It is again exposed from there south as far as Plaine Lake in a number of complexly folded structures that extend from Harvey Lake in the west of Midway Lake in the east.

The iron-formation and associated metasedimentary rocks, which were derived from an assemblage of continental shelf-type sediments, do not appear to extend south beyond a line trending northeast from the Hart-Jaune River linear to Plaine Lake and northeast to Ossokmanuan Lake. Granite–gneisses, charnockites, and anorthosites are part of the rock assemblage south of this line. These typical deep seated Grenville rocks may have been thrust northwest along a system of faults that coincide with this line. The large suite of gabbro intrusions in the area between Wabush Lake and Ossokmanuan Lake probably were intruded along faults in this linear zone. A small differentiated gabbro sill with a peridotite layer at its base also occurs in this zone near Pegma Lake, about 6 miles west of Lac Felix, and is another indication of a major structural break in this part of the Grenville belt.

One set of faults in the Mouchalagane and Manicouagan Lakes area cut early Palaeozoic rocks and post-date the Grenville structures. Other faults post-dating Grenville metamorphism have been recognized in the Mount Wright and Wabush Lake areas. At Mount Wright these younger faults dip steeply north, strike west to northwest, and cut obliquely across iron-formation beds and earlier structures. Fine-grained gouge from one of these fault zones is composed of kaolinite and rusty mylonite, and the clay contained considerable anatase. These late faults probably formed by movement and adjustment along earlier formed faults and zones of weakness and very little late displacement may have taken place along them.

Metamorphism

All rocks in the southern division are much more highly metamorphosed than those in other parts of the Labrador geosyncline. Because of the coarsening of grains and other textural and mineralogical changes brought about by metamorphism, much of the iron-formation can be considered as potential ore even though there has been no natural enrichment of iron or depletion of silica from these beds. Mineral assemblages in metamorphosed iron-formation beds reflect the nature of the primary sedimentary facies from which they are derived. Thus beds of high metamorphic rank rich in iron silicates and carbonate correspond to primary silicate–carbonate facies, and iron oxide–quartz beds to primary chert–oxide facies.

Mineral assemblages in geosyncline rocks in the northwest part of the belt are typical of the epidote–amphibolite to amphibolite metamorphic facies and farther south, nearer to the centre of the orogenic belt, are typical of somewhat higher metamorphic rank. Metamorphism is regional in scale and any effects that can be attributed to specific intrusions are minor and very local in extent. Aside from the general increase in rank of metamorphism from north to south, there may be minor local differences in metamorphic rank. Most mineral assemblages studied in this area indicate that equilibrium was attained under the most intense metamorphic conditions and little evidence remains of the metamorphic history of the rocks. Equilibrium relations in mineral assemblages in the iron-formation in the Bloom Lake area have been examined in detail by Mueller (1960) and in the Mount Reed and Hobdad Lake area by Kranck (1961); further detail regarding chemical reactions is given in their work. Although metamorphism may have involved very complex chemical reactions, there appears to have been a minimum of diffusion of elements between beds, and the bulk composition of beds has not changed appreciably except for the loss of volatiles such as H_2O and CO_2.

A conspicuous metamorphic feature of economic significance in this region is the marked increase in grain size with increase in metamorphic rank. Rocks composed of many chemical components have complex metamorphic mineral assemblages but metamorphism in rocks composed of only a few elements is reflected mainly by changes in grain size. During metamorphism of the iron-formations the Si, Fe, and Mg were segregated in a few coarse-grained minerals. Several factors contribute to the development of metamorphic textures: the amount of vapour or volatile constituents present which promote ionic diffusion between grains, the length of time a set of conditions that promoted development of uniform granularity existed, the presence of compressional or shear stress, and elevated temperatures. Conditions were favourable throughout this southern region for a combination of those factors that produce relatively coarse grained rocks, and their mineral constituents can be separated mechanically without difficulty.

Final stages of recrystallization took place after most of the folding and faulting, and not only are the primary sedimentary features removed or obscured but many structural features, such as cleavage, shears, or fault zones, are unrecognizable.

The Wabush Lake Area

The geology and iron deposits in the area extending south from Sawbill Lake to the northwest end of Kissing Lake and west of Shabogamo Lake and Wabush Lake are described in this section. The rocks in this area are mainly Kaniapiskau sediments that have been traced continuously from the central division of the geosyncline. The general geology is shown on Figures 1 and 19 and the geology of the main ore producing area west and south of Wabush Lake is shown on Figure 20 (*in pocket*).

Stratigraphy

The stratigraphic sequence as determined by company geologists is given in Table XVI. Maximum rock exposures are found in the highland area west of Wabush Lake where stratigraphy and structure have been studied in detail. To the north the iron-formation and associated rocks have been explored with both magnetic and gravity type geophysical surveys and by considerable diamond drilling. Except for a narrow break east of Sawbill Lake, the iron-formation and related rocks have been traced from Schefferville to Wabush Lake and the metamorphosed Wabush iron-formation is the stratigraphic equivalent of the Sokoman Formation to the north. The similarity in the rock successions near Wabush Lake and at Knob Lake is shown in the comparative table of formations listed in Table IA.

The Kaniapiskau rocks lie unconformably over a complex group of granitoid gneisses and schists along the central-western border of the geosyncline, but gneisses

TABLE XVI *General Table of Formations for the Wabush Lake Area (from Macdonald, 1960)*

<table>
<tr><td>CENOZOIC</td><td colspan="4">Glacial deposits, lake and stream deposits</td></tr>
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of the basal complex south of Sawbill Lake are difficult to distinguish from metamorphosed argillaceous and feldspathic rocks of the Kaniapiskau Supergroup. Both groups of rocks in the south have been recrystallized and isotope ages range from 1,200 to 1,000 million years.

The Katsao Formation is composed of quartz–muscovite–biotite schist with variable amounts of garnet, kyanite, amphibole, and feldspar. It underlies quartzite or dolomite in this area, being interlayered with them in transitional zones. The schist is regarded as the metamorphosed equivalent of the Attikamagen slates farther north.

The Duley Formation, composed of meta-dolomite, is present in the area south and east of Wabush Lake and is stratigraphically above the Katsao schist and below the quartzite. It appears to thicken towards the southeast and evidently the sedimentary basin in which it was deposited sloped in that direction towards deeper water. The dolomite is massive to thick banded, medium to coarse grained, and contains quartz lenses, siliceous beds, and light coloured tremolite and diopside. Fibrous to radiating clusters of tremolite needles up to a foot long are a conspicuous feature in this rock.

The Carol (Wapussakatoo) Formation quartzite forms the white ridges and pinnacles in the highland west of Wabush Lake known as the Wapussakatoo Mountains. It underlies the iron-formation and appears to have a maximum thickness of about 500 feet in the central part of the area. Muscovite and almandine garnet schist are present in the lower part of this formation and carbonate lenses and considerable goethite or manganese oxides occur in the upper part where it grades into iron-formation. The main part of the formation is massive to thick banded and is composed of coarse-textured glassy quartz in tight interlocking crystalline intergrowths. Small amounts of muscovite, garnet, or feldspathic material are distributed in poorly defined lenses and faint colour banding is present in some places. It is equivalent to the Wishart Formation in the Knob Lake section.

The Wabush iron-formation overlies the quartzite and is succeeded in the section by biotite schists that contain graphite.

This upper schist, the Nault Formation, is lithologically similar to the lower Katsao schists and gneisses, but is distinguished by its graphitic content and stratigraphic position. Local zones in this formation are calcareous or pyritic, and some kyanite and amphibolite rocks occur together with garnetiferous schist and gneiss. Biotite and hornblende granitoid gneisses are the predominant metasedimentary rocks farther east.

Company records mention a schistose grit, made up of a fine-grained matrix of biotite and plagioclase containing elliptical fragments of quartz and feldspar one quarter to one half inch in size and flattened parallel with the schistosity. It is called the 'Julienne Formation' and may be younger than the Nault schists.

The Wabush Iron-Formation

The Wabush Formation is divided into two main stratigraphic units. The lower unit is composed of thin banded quartz, grunerite, hypersthene, actinolite, and other ferromagnesian silicate minerals, and ferruginous carbonate. The upper unit is composed of thin-banded quartz, specular hematite, and magnetite. It is the thicker of the two and is of major economic interest. The lower unit grades upward into the upper, but lateral gradations between them also occur in the transition zones. The distribution of the two units is indicated in Figure 20, and oxide facies particularly suitable for beneficiation are indicated. The undifferentiated iron-formation shown on this figure is composed mainly of silicate-carbonate facies but may contain considerable magnetite-rich material and infolded beds of the oxide facies.

The lower silicate–carbonate–magnetite unit is widely distributed through the area and estimates of its stratigraphic thickness range from 50 to 350 feet. It is generally thinner along the northwest side of the folded belt and thickens to the southeast, where it probably reaches its maximum thickness west of Little Wabush Lake before it grades into muscovite-quartz schists and meta-dolomite to the south. There are two major lithological facies in this unit. The one is composed of banded carbonate and quartz with minor amounts of grunerite and iron-silicate minerals and the other of thin-banded quartz, grunerite, hypersthene, actinolite, diopside and other silicates, magnetite, and minor carbonate. These two facies may be interbanded but in general the carbonate facies is most abundant in the lower part of the unit. The iron-silicate–magnetite–quartz facies apparently overlaps the carbonate facies to the west and is the principal type in the belt northwest of White Lake.

Mineralogy and texture vary considerably from place to place in the iron-silicate facies. Some zones consist almost entirely of amber coloured grunerite and hypersthene interbanded with quartz but in many others this assemblage contains up to 25 per cent magnetite and variable amounts of ferruginous dolomite, ankerite, and in places siderite. Other zones rich in magnetite contain darker grunerite and hypersthene associated with variable amounts of actinolite, diopside, a number of ferromagnesian silicates, garnet, iron-rich chlorites, and some calcium iron silicates or carbonate. Specific assemblages of silicate minerals are distributed in individual layers and lenses separated by quartz-rich layers and represent metamorphosed primary sedimentary beds of different composition and texture. A large proportion of the silicate minerals are elongated parallel with the banding and contribute to the schistosity of the rock, however some are oriented with long axes perpendicular to the banding. In other layers random or decussate mineral orientation is prominent and sheaf-like or radiating clusters of amphibole needles that penetrate the adjacent quartz beds are common. These mineral intergrowths range in size from microscopic to coarse clusters where minerals may be 5 to 10 mm long and occasionally even longer. Crystal growth apparently continued after structural stresses subsided and permitted random orientation of many late stage minerals.

Much of the magnetite in the lower unit is present as discrete porphyroblastic grains within the felted silicate mass. The grains are normally less than a millimetre in size but occasionally, especially in carbonate-rich beds, they are 10 mm or coarser. Much magnetite is present as very fine inclusions in the silicate minerals, and the two minerals cannot be separated easily by magnetic methods. The silicate facies grades upward into the magnetite-quartz oxide facies of the upper unit, and this primary transition together with folding and intense crenulation makes it difficult to define the limits of these facies.

The carbonate-rich facies in the lower part of the lower unit is made up of interbanded quartz and carbonate-rich layers. The thickness of quartz layers ranges from less than an inch to several feet in the transition to quartzite at the base of the unit. Most of the carbonate is present in bands less than an inch thick but some is disseminated in the quartz layers. The carbonate layers are generally composed of granular mixtures of ferruginous dolomite, ankerite, and siderite and very little is known about the stratigraphic distribution of these minerals or the relative proportions of the different types. Grunerite, ferromagnesian silicates, and calcium–iron silicates are present in some layers and become increasingly abundant in the upper part of the facies. The iron content of the fresh carbonate–quartz facies probably does not exceed 20 per cent.

Many exposed zones are highly decomposed and contain up to 30 to 40 per cent goethite in friable coarse granular quartz. Most of the goethite has colloform texture and ranges from fine disseminations to pea-sized nodules. Some is in massive layers, veins, or stringer intergrowths and frequently mixed with black manganese oxide. These appear to be deeply weathered zones derived from carbonate-rich beds or from silicate–carbonate–magnetite facies.

The upper unit of the Wabush Formation is composed of magnetite and specular hematite–quartz facies, and is the principal iron ore producer in the region. This unit is between 400 and 500 feet thick in the central part of the region but is thinner towards the north and northwest and appears also to thin towards the southeast where the Kaniapiskau succession is represented mainly by meta-dolomite and Nault schist. The true stratigraphic thickness cannot be accurately determined because of folding and intense deformation, and the boundaries of specific facies within the unit are difficult to define. In general the lower part of this unit is rich in magnetite and the specular hematite content increases upwards, with predominantly specular hematite beds occurring in the central and upper parts. Near the top, magnetite is once more plentiful and iron-silicate minerals become abundant. Individual beds have a fairly consistent ratio of magnetite to hematite, but there may be a marked difference in the ratio of these minerals between beds. Test work on the ore deposits indicates that the middle and lower part of this unit has an iron content of 37 to 38 per cent which is very uniform regardless of the mineral composition of individual beds. A lean facies in the upper part of the unit, which may be up to 100 feet thick south of Carol Lake, is estimated to contain 15 to 20 per cent iron, but on the whole the unit contains 35 per cent or more iron.

The upper unit of the iron-formation is a dark bluish grey rock with bands ranging in thickness from less than an inch to several feet. Much of it is made up of massive beds 4 to 10 inches thick with occasional schistose beds or zones (Pl. IX). The mineral composition throughout much of the unit is remarkably simple with clusters of magnetite and hematite grains dispersed in a granular mosaic of quartz. Grunerite and ferromagnesian silicates are present in minor amounts in magnetite–quartz beds in the lower part of the unit, and Kline (1960) and Chakraborty (1963) reported that anthophyllite, manganese-rich grunerite, and minor amounts of phlogopite and spessartite are present in specular hematite-rich beds, especially in the upper part of the unit. Carbonates, mostly dolomite and ankerite, are disseminated in small grain clusters or thin lenses in some beds but rarely comprise more than 3 per cent of the rock. Grains of magnetite and hematite range from 0.03 to 1.0 mm in size, most being 0.2 mm or larger. Most of the iron oxide has formed uniform discrete grains during recrystallization, but these are commonly distributed in clusters around 2 mm oval-shaped forms which are relics of primary granules and oölites. Segregation of quartz and iron oxides was nearly complete during recrystallization and iron oxide inclusions in quartz grains are smaller than 0.01 mm. Quartz forms a fairly uniform mosaic of 0.1 mm grains, but with some variation in grain size. The uniformity of texture in this member is an impressive feature, but the occasional band or small area containing jasper specks is found. These are cherty granules of red jasper quartz not so coarsely crystalline as the matrix quartz and iron oxides, and indicate that crystal growth was not uniform in the folded iron-formation. The amount of iron-formation with jasper granules increases north of the Wabush Lake area.

The manganese content of fresh iron-formation appears to be less than one per cent and is distributed in manganese-rich cummingtonite, anthophyllites, garnets, and carbonates (Chakraborty, 1963, 1966). Black manganese oxides are present in the friable weathered material where they coat iron-oxide grains and form secondary stringers or mixtures with goethite. The manganese content increases to 2 or 3 pe-cent in some weathered material.

The friable nature of the iron oxide–quartz iron-formation facies is attributed mainly to leaching of silica and carbonate by surface water. The coarse granular texture contributes to friability but leaching of silica around grain boundaries has weakened the bonding between interlocking grains leaving friable crumbly beds. Leaching has penetrated several feet on exposed areas and more than a hundred feet in structurally favourable zones. It may be much deeper in some low ground. Martitization and development of secondary goethite is associated with leached friable material and in general the alteration of the iron-formation is similar to that at Knob Lake, where it led to the development of hematite–goethite direct shipping ore. Coarse-grained quartz is leached much more slowly than chert so that most of the metamorphosed iron-formation is not altered beyond the friable stage (Pl. IX A).

Intrusive Rocks

A number of gabbro stocks and sills are shown on Figure 20 (*in pocket*). They are part of a large suite of basic intrusions distributed along the northwest margin of the Grenville belt. Most of the gabbro is medium to coarse grained with subophitic texture, dark greenish grey to purple-grey, and is composed of labradorite, pyroxene, and olivine. The borders of many intrusive masses are altered to schistose or gneissic garnet-biotite amphibolite, and foliation is generally parallel with the banding in adjacent metasediments. Gabbro is found only in small central parts of some of the large amphibolite masses. Contact metamorphic effects are found in metasediments bordering some of these masses where very coarse grained pyroxene, amphibole, and garnet assemblages are developed. South of Lorraine Lake small gabbro–amphibolite masses are intruded intermittently along a well-defined fault zone in the iron-formation. In other places these rocks are present as folded sills or discordant stocks.

Granite intrusions in the Sawbill Lake area were described earlier.

Structural Geology

Major structural features illustrated in Figure 20 are isoclinal folds overturned to the northwest that are separated by thrust faults which dip 45 degrees or more steeply to the east. The prominent trend in the area is N20° to 30°E and parallels the strike of axial planes of major folds and of thrust faults. Erosion has been deep enough to expose long narrow bands of quartzite and schist along the crests of the anticlines that separate broad synclinal basins of tightly folded iron-formation. These predominant structural features were developed during an early stage of deformation which may have been caused by the same orogeny that caused isoclinal folding and thrust faulting in the central part of the geosyncline to the north. A second stage of deformation imposed on these earlier structural features caused cross-folding that trends from west to N20°W. The plunge of axial lines of northeast-trending folds undulates; as a result some anticlines are broadened to form dome-like structures and many synclines are broadened locally to form wide basins.

The net movement on many thrust faults did not cause more than 100 feet of dip-slip displacement, and strike-slip movement was relatively minor. Major fault movement preceded recrystallization, and early developed fault zones, shears, and fracture cleavage were cemented and even masked by metamorphism. One of these fault zones was examined south of Lorraine Lake where distorted, folded beds of iron-formation are truncated by narrow parallel bands that apparently represent recrystallized shears (Pl. XI A). Movement may have taken place on many of these faults during later periods of deformation. Minor fault zones southwest of Little Wabush Lake are marked by soft clay and mylonitized quartzitic material. Fracturing and shearing along many north-striking faults have increased the permeability of the rocks, and water penetrating from the surface has leached the beds, making them friable, and has introduced goethite and manganese oxides.

A number of east- and northeast-striking faults in the area northwest of Shabogamo Lake are related to the Grenville orogeny and parallel the biotite isograd. Large blocks of gneiss are brought into juxtaposition with metamorphosed Kaniapiskau rocks along cataclastic zones in this area, and Fahrig (1960) suggested that normal faults may be present that resulted from relaxation of stresses at the close of the Grenville deformation. These fault blocks may be part of a succession of fault blocks similar to that already described in the Mount Wright area, where reverse dip-slip rather than normal movement has taken place on steeply dipping faults. Minor cross-faults occur on the noses of plunging anticlines and are common in many parts of the area. A northwest-striking fault is believed to pass under Luce Lake and to continue northwest to the south end of Stevens Lake, northeast of Carol Lake.

Metamorphism

Mineral assemblages indicate that the rank of metamorphism reached the epidote-amphibolite and amphibolite facies. The rocks are also medium to coarse grained. There is a gradual increase in grain size southward from Sawbill Lake to the area west and south of Wabush Lake where rock textures are fairly uniform. Metamorphism in the area was principally an isochemical process, which caused a decided increase in the grain size of minerals, the development of mosaic or interlocking textures, a decrease in porosity, and the development of minerals that were stable under higher temperature conditions. Recrystallization of chert in the iron-formation has produced coarser quartz grains with the expulsion of much of the finely disseminated iron oxide from jasper granules and the development of larger discrete grains of iron oxide. There is no evidence of reaction between quartz and iron oxide to form silicate minerals in the oxide facies of iron-formation. Individual bands have a uniform ratio of quartz to iron oxides and of magnetite to hematite and reflect the uniform composition of primary beds. Each bed apparently responded during metamorphism as a separate chemical system and very little migration of ions between beds took place. Narrow stringers or veins of massive iron oxide pass across beds and probably follow earlier fractures or shears and indicate mobilization of a small amount of iron within the beds. Likewise coarse textured quartz veins are present that are practically free of iron oxide. Vugs and geodes up to a foot in diameter containing terminated quartz crystals mixed with large crystals of platy specular hematite are common and are regarded as minor late stage metamorphic phenomena. Textures in many sections suggest that considerable specular hematite recrystallized later than the magnetite. Relics of primary granules are discernible in much of the iron-formation where shearing has not been intense.

There may be a relationship between the size of primary granules and oölites and the grain size of the quartz in metamorphic textures. A number of beds were observed in the Wabush area, especially east of Wabush Mountain, that contain relic granules 3 to 5 mm in size, fine grained and cherty. If textures in these beds after diagenesis were relatively coarse, it is possible that in them metamorphic reactions were slower than in the finer cherts and that quartz was generally less reactive. The phenomenon is thought to be analogous to that in graded beds in greywacke where the finer grained parts recrystallize first and eventually become coarser grained than the original coarser parts. The beds with larger granules are assumed to have been coarser grained prior to the major period of metamorphism. Greater permeability in this material would permit enlargement of quartz grains in diagenesis and the eventual sealing of pores. Quartz grain enlargement is not well developed in other iron-formations until advanced stages of metamorphism. In many fresh, relatively unmetamorphosed cherty iron-formations the size of quartz grains in the matrix relative to that in granules and oölites is generally greater in beds where granules are larger.

Metamorphic reactions in the iron-silicate–carbonate facies were much more complex and are not well defined. Some magnetite in predominantly carbonate facies is thought to have been derived from siderite and some of the silicates may have formed from reactions of carbonate and silica. Most of the silicates however are uniformly distributed in individual beds and most likely were derived by recrystallization of primary silicates. Detailed studies on the composition of these minerals support this view (Chakraborty, 1966). Much of the iron-silicate-rich iron-formation is schistose with the silicate minerals generally oriented with their longest axes parallel with the rock banding, but many form radiating and sheaf-like grain clusters or decussate textures. Evidently recrystallization continued for some time after the stress in the rock relaxed. A period of thermal metamorphism after tectonic stresses ceased is also indicated by lack of strain in most quartz crystals and, as Gastil and Knowles (1960) pointed out, carbonates lack certain twin lamellae that are attributed to stress.

Contact metamorphic aureoles around some gabbro–amphibolite masses have been observed, but these are narrow zones with only local metamorphic effects. Small pegmatitic veins and stringers are present in some feldspathic metasediments.

Weathering of Iron-formations

Oxidation and leaching caused by preglacial weathering is widespread in this region and extends to depths of several hundred feet. The main effects, as already noted, are the development of friable zones, martitization of some magnetite, distribution of goethite and manganese oxides in permeable zones, and development of residual goethite-rich zones in carbonate facies of iron-formation. Rounded friable boulders of iron-formation in glacial till overlying friable decomposed iron-formation were examined in trenches south of Little Wabush Lake (Pl. XI B). These boulders are highly decomposed and must have been frozen solid during transportation in order to have been preserved.

Most of the exposed iron-formation is leached and friable at the surface, but oxidized and decomposed material extends deeper on the flanks of hills and drilling in low ground shows that it may be several hundred feet deep. Decomposed weathered material is believed to have been scoured and removed from the hills by glacial action, but much is preserved in the low ground or where it was protected by resistant quartzite ridges. In nature and distribution the leached friable iron-formation is particularly interesting because of its effect on ore treatment and beneficiation. This material is ground and pulverized much more readily than fresh iron-formation, but the distribution of secondary goethite and manganese oxides is of particular concern in beneficiating and in controlling the grade of the iron-ore concentrate.

Iron Ore Deposits of the Wabush Lake Area, Labrador

Iron-oxide facies of iron-formation and some magnetite-rich zones in the magnetite–silicate–carbonate facies are considered to be potential ore, as the grade and quality of this material is suitable for beneficiation. So far only zones of iron-oxide facies have been investigated in detail and developed, and reports indicate that well over 3 billion tons of iron-formation, containing 35 to 38 per cent iron in the form of magnetite and hematite with coarse crystalline quartz, is present within the limits of open pit mining. The total amount of potential ore has not been determined but can be inferred in a general way from the stratigraphic distribution of the oxide facies of iron-formation.

Major zones of potential magnetite–hematite–quartz ore are indicated on Figure 20, but the detailed distribution of oxide facies is not shown and considerably more material of this type is undoubtedly present in the undifferentiated iron-formation to the north and the southwest.

Deposits West of Wabush Lake

The deposits west of Wabush Lake are within the concession of land granted to the Labrador Mining and Exploration Company Limited in 1936 by the government of Newfoundland. The Iron Ore Company of Canada, formed in 1949, has the right to sub-lease two thirds of the iron ore in selected areas of this region from Labrador Mining and Exploration Company Limited. Extensive exploration was started in 1949 by these companies. The Iron Ore Company of Canada began a construction and development program in 1958, and produced ore concentrate in 1962 and pellets in 1963.

Exploration and development in this area have included detailed geological mapping, magnetic and gravity geophysical surveys, a very extensive diamond drilling program, and the construction and operation of a 250-ton-per-day pilot plant. This plant was operated for 2 years to determine beneficiation characteristics of the ore. The cost of a 28-mile railway to join this area with mile 224 on the Quebec North Shore and Labrador Railway connecting Sept-Iles and Schefferville has been shared by the Wabush Iron Company and Iron Ore Company of Canada. These two companies together with the British Newfoundland Corporation Limited have shared the expense of developing a 120,000 horsepower hydro-electric power plant at Twin Falls on Unknown River, 110 miles east of Wabush Lake. Further developments required for production include establishment of open pit mine workings, construction of 6 miles of automated railway between the mine and the mill site, erection of a crushing and gravity concentration plant, a pelletizing plant and a town, Labrador City, to accommodate about 5,000 people. Full capacity production will involve the handling of about 15 million tons of crude ore averaging 37 to 38 per cent iron for an annual production of 7 million tons of concentrate or pellets carrying 66 per cent iron.

Smallwood Mine, Wabush 5 Deposit

Mining in the region west of Wabush Lake was initiated at the Smallwood mine, which lies between Luce Lake and Pointer Lake (Fig. 20). It forms a prominent hill that rises 300 to 500 feet above the level of Luce Lake, is more than 10,000 feet long and is from 500 to 2,500 feet wide (Pl. X A). More than 38,000 feet of diamond drilling was completed and two adits, one near the north end and one near the south, were driven across parts of the structure to provide bulk samples for beneficiation tests. It is estimated that 350 million tons of crude ore mineable by open pits was proven by this work.

The deposit consists of a large synclinal fold in which beds of specular hematite–magnetite iron-formation are tightly folded and crenulated and overturned to the northwest. The upper iron oxide–quartz ore beds are underlain by carbonate iron-silicate iron-formation which borders the deposit and is presumably interfolded with the ore beds at depth in the basal part of the syncline. The main deposit appears to be free of silicate–carbonate zones, and apparently interfolding of beds of the two iron facies does not occur within several hundred feet of the surface in the central part of the syncline. The deposit is cut by at least one major fault that strikes southwest and extends from the south end of Lorraine Lake along a valley on the northeast side of the deposit and passes through the southeast part of the ore zone. Another fault in the northeast end of the deposit, which may be a subsidiary to this main fault, strikes north, has right-handed displacement, and complete recrystallization in this zone indicates that it has been dormant since the main period of metamorphism in the region (Pl. XI A). A number of small plugs of gabbro and amphibolite are emplaced along this structure. The southern part of the Wabush 5 syncline is dislocated either by a major fault zone that extends northwest from Luce Lake to Heath Lake or by a cross-fold.

North of the main Wabush 5 orebody, recent detailed work has located another zone of iron-formation that forms an overturned syncline. This zone is crescent-shaped in plan and plunges southwest under the north end of the Wabush 5 syncline, and is apparently part of a cross-fold imposed on the main structure. The axial line of the main syncline follows a Z-shape in this northern area and the northern zone of iron-formation, as it appears in a longitudinal section, is present in the lower right part of the Z-shape. The main syncline has been folded and thrust northeast so that it overlaps the northern iron-formation zone by nearly 2,000 feet. This local folding and overturning of part of the Wabush 5 syncline is believed to be related to the second stage of folding in the area which produced many cross-folds and warps. Iron-formation in the northern structure of Wabush 5 has considerably enlarged the ore reserves.

The ore in this deposit is remarkably uniform in grade and contains 37 to 38 per cent iron, 35 to 40 per cent silica, 3 to 4 per cent CaO, less than 1 per cent MgO, and from 0.26 to 0.30 per cent manganese. The manganese content in the silicate–carbonate facies is higher, but this material will be avoided or eliminated in mining. The manganese content in magnetite-rich ore ranges from 0.35 to 0.70 per cent and in predominantly specular hematite ore from 0.1 to 0.3 per cent, with a gradual increase as the magnetite content increases. The phosphorus content is very low; other deleterious constituents are not present in significant amounts. The total specific gravity of the crude ore is reported to be 3.7. The ratio of magnetite to hematite varies, but the total magnetite content is about 18 per cent and the amount in the concentrate varies from 25 to 50 per cent. Judging from the stratigraphic distribution of magnetite-rich beds in this synclinal structure, the magnetite content will vary from about 5 per cent in the central part to about 25 per cent in the peripheral and deeper parts of the syncline. About 15.5 million tons of iron-formation is treated to produce 7 million tons of iron ore concentrate carrying 66 per cent iron. The ore is concentrated in two stages in Humphrey Spirals with considerable recovery of +14 mesh size material and the bulk recovered at mesh sizes larger than 200. Pelletizing requires grinding of the concentrate to −200 mesh with about 80 per cent of it being −325 mesh. More than 70 per cent of the total iron content is recovered by this two stage gravity concentration process. The silica content in the concentrate ore is less than 4 per cent and the manganese content is less than 0.1 per cent with a reduction in amount of all other constituents in the crude. Typical composition of the ore concentrates is:

	%
Fe	66
O	28
SiO_2	4.0
P	0.01
Mn	0.1
Al_2O_3	0.3
CaO	0.4
MgO	0.4
S	trace

Crude ore rich in magnetite must be ground finer than ore rich in specular hematite in order to obtain suitable iron recovery, because the magnetite is generally finer grained, tightly interlocked with the quartz, and iron-formation containing it is harder and more difficult to grind. A considerable difference in grinding rates is experienced between friable material from near surface and that in deeper parts of the deposit where no appreciable amount of silica has been leached.

Carol East Deposit[1]

This deposit is one of the largest in the area and extends from Heath Lake northeast to Lorraine Lake (Pl. X B). The ore zone is more than 15,000 feet long and from 1,200 to 2,000 feet wide. The magnetite–hematite–quartz ore is similar in most respects to that described in the Wabush 5 deposit and lies within a long narrow synclinal structure. The deposit is bounded along most of the east side by a fault that strikes northeast and dips steeply east. The synclinal structure is disrupted by a

[1]Now Humphrey mine

number of other northeast-striking faults and is highly deformed at the south end in the Heath Lake–Luce Lake, northwest-striking fault zone. The tightly folded and crenulated oxide facies is bordered by silicate–carbonate facies except on the east side where this member is cut off by a fault. The lower iron-formation unit on the west flank is probably not more than 50 feet thick. This lower unit was initially much thinner in this western part of the area than in the central part, and its thickness has been decreased even more on the western limb of the syncline by deformation during folding.

The bulk of this deposit is composed of tightly folded, medium-grained, massive to schistose, blue-grey magnetite–specular hematite–quartz iron-formation. The iron content ranges from 36 to 38 per cent and the total carbonate content is estimated to be less than 5 per cent. In general the magnetite content increases in carbonate-rich zones where it may be as high as 35 per cent but on the whole appears to range from 10 to 20 per cent.

Local variations in the iron-oxide–quartz ore are noticeable in some of the surface pits blasted to obtain bulk samples for metallurgical tests. Alternate thin pink and grey bands of siliceous, fine-grained iron-formation interbanded with magnetite-rich bands are exposed in a pit on the east side of the deposit. The iron-rich layers are much coarser grained than the pink and grey quartz and much more of this iron-formation is hard and non-friable. The coarser magnetite-rich layers contain conspicuous tabular porphyroblasts of specular hematite that vary in size from one eighth to one half inch. Iron-formation exposed in a test pit in the central part of the deposit and west of the first pit consists of tightly folded bands from 3 to 6 inches thick with variable proportions of magnetite and hematite. Up to 20 per cent of this facies is composed of thin carbonate-rich lenses interlayered or distributed in spots in the oxide facies. These weather out leaving deep grooves or pits. At least 60 per cent of the iron-oxide facies in this pit is medium-grained, hard resistant iron-formation. A third pit to the west exposes friable thin-banded iron-oxide and carbonate-rich material interlayered with thicker, more massive, hard iron-oxide beds. Black manganese oxides are prevalent in joints and along bedding planes. The carbonate-rich beds are most friable, and this partly decomposed material extends to a depth of 10 to 15 feet. Iron-formation along the west side of the deposit, exposed in a number of test pits, is highly decomposed and is sandy and friable except for the occasional resistant bed. A great deal of secondary goethite disseminated in this leached zone gives the iron-formation a dark chocolate colour. Some goethite is present in botryoidal and colloform masses. Manganese oxides are mixed with the goethite, and are also present in joints or openings.

A very extensive diamond drilling program has confirmed the general synclinal configuration of this deposit, which may contain more than 850 million tons of crude ore within the limits of open pit mining.

Wabush Signal Deposit

The high ground between Carol East deposit and Stevens Lake is capped by a broad zone of potential ore (Pl. X B). This was one of the first deposits to be systematically sampled on surface in the early stages of exploration in 1950. The iron-formation lies within a broad curved syncline that is about 6,000 feet long and 800 to 1,500 feet wide. This is a distorted canoe-shaped fold that plunges north at the south end and the beds in general dip 45 degrees east. Practically all the iron-formation is magnetite–specular hematite–quartz facies. Iron-silicate–magnetite iron-formation is exposed around the south and west side of the deposit where it is drag-folded and not more than 50 feet thick. The depth of iron-oxide facies iron-formation is not known, but judging from the rather shallow plunge of folds at the south end it may be relatively shallow.

Carol West Deposits

This very large ore zone east of Carol Lake extends southwest from Heath Lake for about 5 miles. The potential ore is present within two long parallel synclines. The iron-oxide iron-formation in the east syncline is known to be at least 1,000 feet wide and that in the west to be several hundred feet wide. This zone has not been tested in detail and the potential orebodies may be much larger. Judging from field examination, the ore within the areas indicated is comparable in texture and grade to that in the Carol East deposit. Larger zones of leaner upper iron-formation have not been included in the estimates of potential ore, and if the grade limits were lowered from 37 to 30 per cent iron vastly more material could be included as potential ore. With a reserve of more than a billion tons of good grade iron-formation indicated in the area, probably only the richest material will ever be considered.

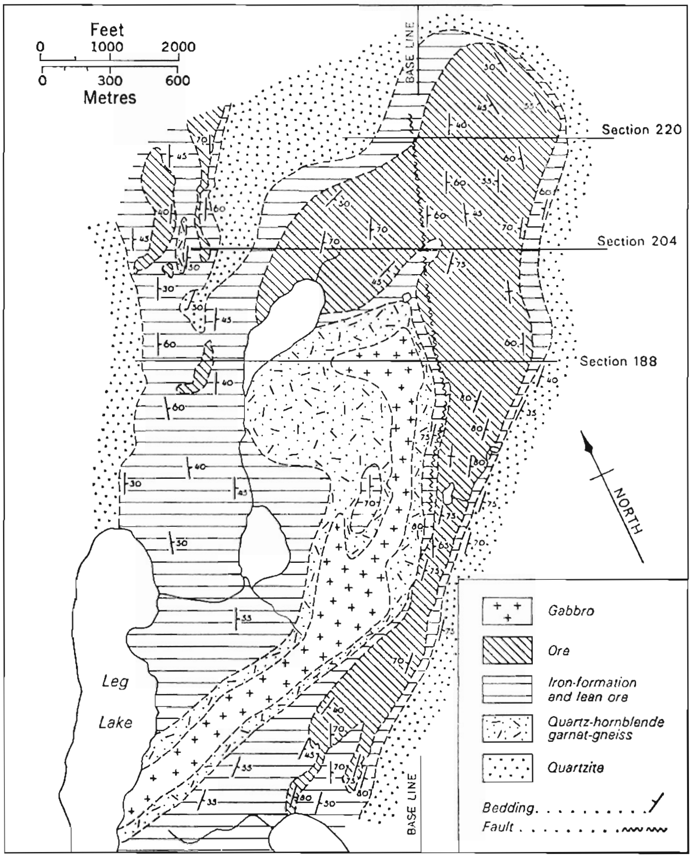
Labrador Ridge (Wabush 3) Deposit

This deposit lies northeast of Leg Lake; its general structure is illustrated in Figure 21 together with profiles from magnetometer and gravity surveys. The orebody is contained in a large, complex, overturned synclinal fold with an axial strike of about N25°E and a plunge to the southwest of 15 degrees. The beds have been closely folded and faulted. The orebody has a maximum length of about 5,800 feet and a maximum width of about 3,900 feet; holes have been drilled to more than 800 feet without reaching the bottom.

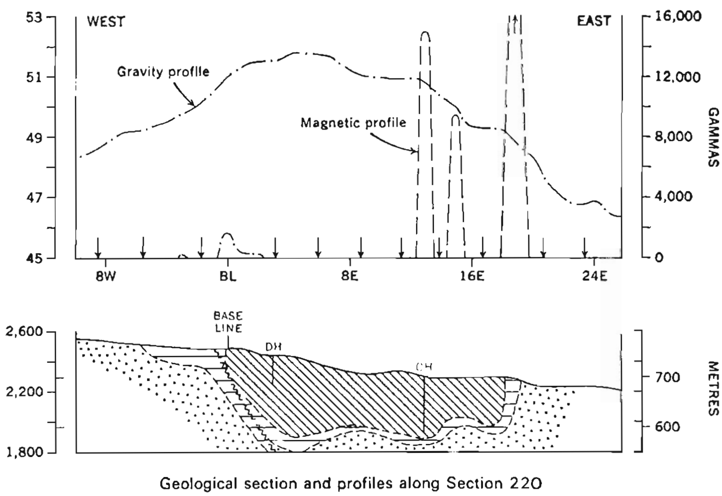
To the south, the ore plunges beneath a gabbro mass lying along the axis of the syncline. One long narrow tongue of the ore, believed to represent the outcropping of the east limb of the syncline, extends south along the flank of the gabbro. Amphibolite gneiss extends, in a sill-like mass, from the gabbro northward along the axis of the syncline, and fingers out to the north. The west limb of the syncline also extends southward, but is not defined by drilling or surface exposure.

The ore consists of a medium- to coarse-grained aggregate of granular quartz, specularite, and magnetite. It has been calculated to contain 550 million tons of easily beneficiated ore having an average grade of 37.7 per cent iron and with a rock stripping ratio of only 0.03 cubic yard per ton. The magnetite content is variable but appears to increase slightly with depth and where the ore is in contact with gabbro. The orebody averages about 21 per cent magnetite and 32 per cent specularite. Minor amounts of accessory minerals are present, such as amphibolite, grunerite, dolomite, ankerite, and siderite.

Much of the ore consists of iron-rich bands alternating with quartz-rich bands.

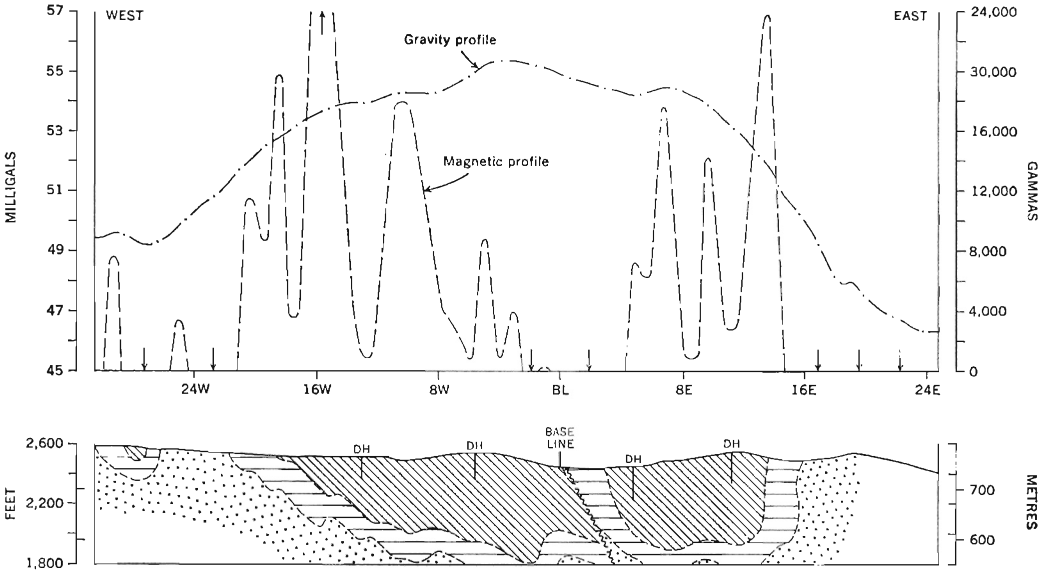


Geological plan, Wabush 3 deposit

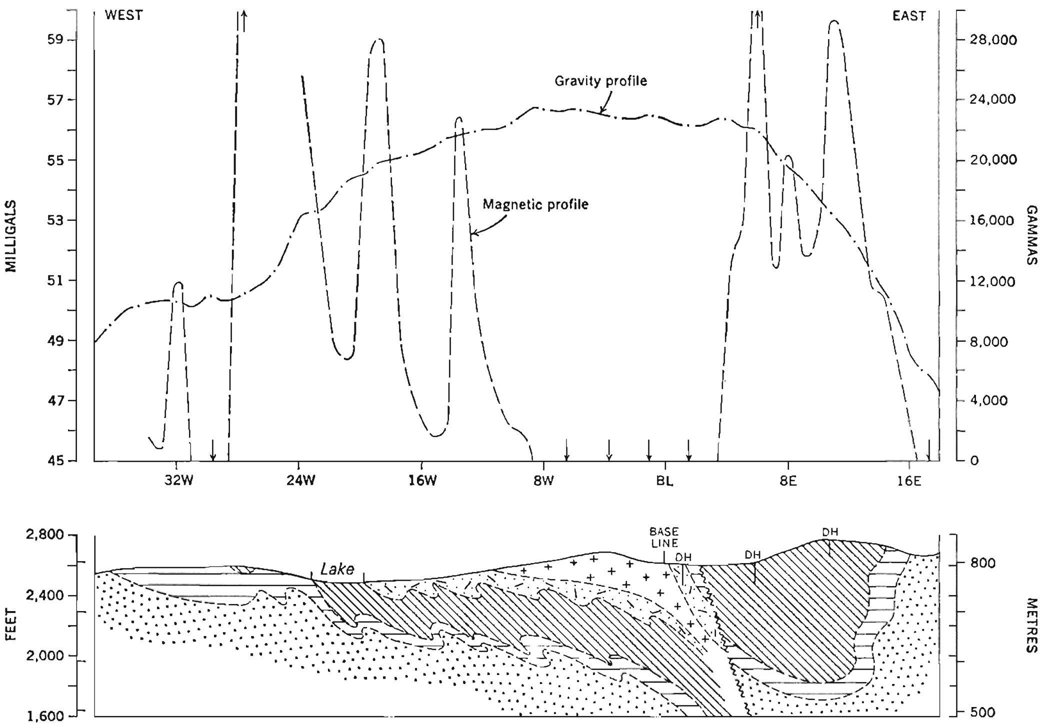


Geological section and profiles along Section 220

FIGURE 21. Geological plan and cross-sections, Wabush No. 3 deposit (*after* Macdonald, 1960).



Geological section and profiles along Section 204



Geological section and profiles along Section 188

Horizontal scale of sections and profiles twice that of Geological plan

GSC

The texture of the ore varies from massive to schistose, depending on the degree of orientation of the platy specularite and acicular silicates. The granularity also varies, in a general way, depending on the amount of magnetite, as the ore with a higher magnetite content is finer grained.

Because of marked variations in magnetometer readings over different parts of the body despite a fairly uniform iron content, it has not been possible to outline the deposit by magnetic surveys alone. Furthermore, drift cover is too extensive to permit all ore structures to be determined by surface mapping. A combination of gravimetric surveys, magnetometer surveys, and field geology has proved to be the best method of delimiting extensions of ore-bearing structures and interpreting detailed geology. The profiles over the Wabush 3 deposit from the report of Macdonald (1960) (*see* Fig. 21) are typical.

The profile of magnetometer readings is very irregular, indicating extreme variations in magnetic intensities. In general, high intensities are recorded near the borders of synclines where the magnetite–silicate facies or other magnetite-rich beds are present, but magnetic readings are erratic even over fairly uniform grade material. Where the proportion of hematite in the iron-formation is high, magnetic intensities do not bear any relationship to the total iron content of the ore and may be very deceptive with regard to the distribution of ore zones. The gravity profiles, in contrast, show a pronounced uniform rise over zones of denser iron-formation and by utilizing data on the gravity of specific rock types calculations regarding the possible depth of specific iron-formation structures may be made. It is interesting to note that quantitative interpretation of the gravity data in section 188 indicates that the gabbro amphibolite mass must be a sill underlain by denser iron-formation rather than an intrusive plug. Most of the drill-holes have not been deeper than 200 feet and depth projections from gravity data have not yet been confirmed. In one instance where the depth of iron-formation was interpreted from gravity data to be 600 feet, two drill-holes bottomed in iron-formation at a depth of 500 feet.

Other Deposits West of Wabush Lake

A number of other potential ore zones are indicated on Figure 20 on which limited exploration work has been done. In one zone to the southwest near Kissing Lake 375,000 tons of ore per vertical foot is indicated that carries 31 per cent iron. Another ore zone, reported by Labrador Mining and Exploration Company, near Grace Lake in the southwest part of their concession, is reported to be 10,000 feet long and 2,000 feet wide.

Deposits South and East of Wabush Lake

Wabush Iron Company Deposit

A very large area between Little Wabush Lake and Long Lake is underlain by oxide facies of iron-formation, and an ore zone more than 20,000 feet long and averaging about 5,000 feet in width has been explored in considerable detail. Because of the relatively low relief of this area with very little bedrock exposure, geological appraisal has been difficult and costly. The entire extent of the iron-formation has consequently not been defined and reserves of potential ore may greatly exceed what has already been proven.

The deposit area was leased in 1954 by Canadian Javelin Limited from the Newfoundland and Labrador Corporation Limited, which held a large part of the Labrador region under lease from the Province of Newfoundland. By the summer of 1957 preliminary exploration by the Javelin company (mainly diamond drilling with the widely spaced holes, a few test pits, and some laboratory investigations) was completed and considerable grading done on the railway spur line running west from the Quebec North Shore and Labrador Railway towards the property. A long term lease on 5.5 square miles covering the deposit area was arranged late in 1956 and in 1957 with the Javelin interests by Wabush Iron Company Limited for the purpose of further investigating and developing the deposit for production of iron ore concentrates. This operating company is managed by Pickands Mather & Co., and is owned by a number of steel companies based in Canada, United States, and Europe. Very extensive detailed investigations of the deposit have been completed, a large pilot plant was operated for about 2 years to study beneficiating characteristics of the ore, and production commenced in 1965. Initial plans indicate that 5 to 6 million tons of 65 per cent iron concentrate will be produced per year from iron-formation containing 37 to 38 per cent iron. Various estimates of ore reserves in this deposit suggest an excess of one billion tons of crude ore.

It has been particularly difficult to gain an accurate knowledge of the geological structure because of the lack of rock exposures and the fact that much of the iron-formation is leached and friable to depths of several hundred feet so that only a small percentage of core was recovered in diamond drilling. Much of the later test drilling was done with large rotary machines which produced sandy pulverized samples suitable for testing the grade and mineral composition of the material but providing little information on the structure or textural characteristics of the ore. This drilling method has proven to be less costly and information from it more reliable than from diamond drilling. More than 65,000 feet has been drilled in holes spaced at intervals of 1,000 feet with an average depth of about 300 feet. Hole spacing is as close as 250 feet in the initial pit area.

The general stratigraphic succession appears to be similar to that described for the area west of Wabush Lake, but thicknesses of individual units are not well defined because of intricate folding and lack of core samples. The oxide facies consists of medium-grained (0.4 mm) mixtures of specular hematite and magnetite in granular quartz. These grade into the iron-silicate–carbonate–quartz members in the lower part of the iron-formation. The writer interprets the general structure as a broad synclinorium that trends northeast on which a series of anticlinal and synclinal cross-folds have been imposed. Others have interpreted the structure as a monocline. There is abundant evidence that complex folds exist. According to the writer's interpretation the axes of these cross-folds trend southeast and, although they probably undulate in plunge, the net plunge is mainly southeast. The general strike of the highly folded beds is to the southwest and dips range from 30 to 60 degrees. Cross-folds appear to be more closely spaced towards the east with intervals of about 1,000 feet between major anticline axes, but in the west may be spaced up to a mile apart. There may be some overturning of beds in minor folds to the northwest in the south part of the deposit due to folding during the first stage of deformation, but the scanty amount of structural information does not suggest overturning related to the cross-folds. Much of the iron-formation is highly crenulated and there appears to be considerable repetition of the iron-oxide units in the deposit. Work to date (1961) indicates that the greatest depth of iron-oxide facies material is near the east side where the folds are closely spaced. This material has been tested to depths of 500 feet in this area but it may be only half as deep in the western part of the folded basin.

There are indications that a major fault passes through the deposit that strikes N10° to 15°W and crosses the east end of Knoll Lake. The southwest part of the deposit appears to have been displaced southeast relative to the northeast part. Quartzite is seen in contact with oxide facies of iron-formation in trenches along the northeast side of the deposit. The quartzite is brecciated and some soft manganese oxide cements the breccia. This fault zone strikes west to southwest and appears to dip steeply. Other narrow fault zones are marked by breccia cemented with soft white or pink clay. These strike in the same direction, but dip variously from steeply south to gently south or nearly flat. Slickensided and sheared clay or altered mica indicate that movement has taken place after regional metamorphism. Some of these narrow zones may be subsidiary faults associated with a major fault that passes along the north side of the deposit along which there has been sufficient displacement to bring quartzite into contact with the upper part of the iron-formation.

Iron-formation in the Wabush deposit is much more friable and leached on the whole than other deposits in this region and the decomposed material consistently extends to greater depths. The friability has resulted from very extensive leaching of silica around grain boundaries leaving a minimum of intergranular cohesion and bonding, and this characteristic will facilitate grinding and liberating of iron oxide minerals from quartz grains when milling this ore. Silica leaching has been accompanied by very considerable oxidation in the ore, and carbonates are altered to goethite and magnetite converted to martite in large parts of the deposit. A more disconcerting feature associated with leaching and oxidation has been widespread distribution of secondary manganese oxides in joints, veins, and permeable zones. The distribution of manganese tends to be erratic and almost unpredictable because of the decomposed nature of much of the ore in this area of low relief.

The crude ore material averages about 38 per cent iron and 1.8 per cent manganese with no appreciable amount of sulphur, but up to 2.5 per cent manganese is present in many parts. An average of 20 per cent magnetite is present with specular hematite in the crude ore. About 75 per cent of the iron can be recovered in gravity spirals from +150 mesh material and a large amount of iron can be recovered from considerably coarser fractions. Concentrates can be produced from +150 mesh material in the gravity spirals that carry 65 per cent iron or better with 1.5 per cent manganese, and it is expected from results of current research work that a higher iron recovery and a reduction in manganese will be achieved by the time full-scale production is started.

The Julian Deposit

A deposit stated to consist mainly of magnetite–specular hematite–quartz iron-formation underlies the large peninsula on the northeast shore of Wabush Lake and has been explored by Julian Iron Corporation, a subsidiary of Canadian Javelin Limited. After considerable drilling in this area the company has indicated that at least 350 million tons of potential ore carrying 36.5 per cent iron is present.

This company has further indicated that a commercial-sized deposit of similar material may be present at Wabush Mountain near the southeast shore of Wabush Lake.

The Mount Wright Area

The Mount Wright iron range, 20 miles southwest of Labrador City, is exposed on a high plateau about 10 miles long and 2 miles wide that rises 500 to 1,000 feet above the level of Hesse Lake and Mogridge Lake. The sharp knob or pinnacle at the west end of this plateau, called Mount Wright, is close to latitude 52°45.5′N and longitude 67°21′W with an approximate elevation of 3,000 feet (Pl. XII A). The iron-formations in this structure constitute one of the major reserves of potential iron ore in the region with more than a billion tons of specular hematite and quartz, with a grade of 30 to 35 per cent iron, within the limits of open pit mining.

The early history of exploration is not well known, but more than 700 square miles in this region was covered in reconnaissance mapping by the United Dominion Mining Company Ltd. in 1948, and 4,400 feet of diamond drilling was completed around Mount Wright under the direction of W. E. Hesse. Airborne magnetometer surveys of the region sponsored by the Oliver Iron Mining Division of United States Steel Corporation were carried out during the winter of 1951 and 1952 and ground of potential interest was staked. During 1953 and 1954 under the direction of the writer the plateau area was mapped in detail; dip-needle surveys were carried out; sampling and 12,000 feet of diamond drilling were completed. No further major investigation has been carried out in the area except for drilling on one band of iron-formation southeast of Mogridge Lake by Mount Wright Iron Mines Company Limited and regional mapping by the Geological Survey of Canada and the Quebec Department of Mines.

Major features in this area are shown on Figure 22 (*in pocket*). It is evident from this map that evaluation of the iron deposits requires detailed knowledge of the stratigraphy and structure of the iron-formation and associated rocks and the following is based mainly on the writer's work prior to 1955.

Stratigraphy

The principal stratigraphic units are shown in the table of formations, Table XVII. The quartz–biotite–feldspar gneisses and schists above and below the quartzite iron-formation part of the metasedimentary succession are similar and are considered as parts of one group. They are well-banded, medium-grained rocks with an estimated average composition of 40 per cent quartz, 35 per cent feldspar with equal proportions of microcline and oligoclase (An_{25}), 20 per cent biotite or other mafic minerals, 5 per cent or less of almandine, and lesser amounts of muscovite, scapolite, zoisite, titanite, apatite, and zircon. Bedding plane foliation and augen structures are well developed, and much of this group is highly crenulated, with many ptygmatic folds, and numerous small pegmatitic veins.

TABLE XVII | *Table of Formations—Mount Wright Area*

Era	Approximate Thickness (feet)	Formations and Lithology
RECENT		Glacial deposits, unconsolidated surface material
PRECAMBRIAN		*Amphibolite*—hornblende–biotite–feldspar–garnet gneiss
		Gabbro
		Quartz–feldspar–biotite gneiss
	300-400	*Orthoquartzite*—muscovite quartzite. Muscovite–quartz schist and impure quartzite with facies bearing potash-feldspar, garnet, kyanite, and specular hematite
	250	*Iron-formation*—specular hematite–magnetite–quartz
		Metataconite type—iron-formations; border zones bear muscovite
	100	*Iron-formation*—grunerite–hypersthene–magnetite–carbonate–quartz iron-formation, transitional along strike to metataconite type iron-formation
	30±	*Quartz–hematite–muscovite rock*—of variable thickness, transitional to quartz–feldspar–biotite gneiss
		Quartz–feldspar–biotite gneiss

Iron-formations

Two types of iron-formation are present in the area. A specular hematite–magnetite–quartz facies west of Moiré Lake is the principal facies (Pl. XII B). Of less importance is an iron-silicate–magnetite–carbonate–quartz facies present south and east of this lake. One type grades into the other along strike southwest of Moiré Lake, in the eastern end of the plateau.

The specular hematite-magnetite-quartz facies is thin banded and medium grained, and grades through a transition zone 2 to 5 feet wide into the overlying quartzite formation (Pl. XII C). The lower boundary of the unit was not seen in outcrops but granular quartz–muscovite–feldspar schist on one side of the iron-formation apparently represents a transition zone to the gneisses stratigraphically below it.

It has been difficult to determine the average thickness of this unit due to intense deformation by folding and faulting, and the intrusion of gabbro and amphibolite, but drill-holes indicate that it is approximately 250 feet in the area south and west of Mogridge Lake.

Because of the coarse granular nature of this iron-formation and its amenability to concentration, it is referred to as metataconite. It consists of interbanded quartz and specular hematite with quartz-rich bands varying from an average of a quarter of an inch up to several inches and bearing finely disseminated grey hematite particles 0.1 to 0.01 mm or less in size. The actual grain size of the quartz is about 0.2 mm but it usually appears coarser megascopically and forms a uniform mosaic texture. Bands of specular hematite comparatively free of quartz are present. These are lens-shaped to irregular, one eighth inch or less thick, and are composed of granular grey hematite grains 1.5 to 0.5 mm in size. Some of the grey hematite is platy in habit, and locally this type may predominate over the granular type especially in shear zones or in the transitional zones between metataconite and quartzite or schist. Fracture fillings and replacement veinlets of grey hematite are also common in this position, suggesting considerable migration of iron oxide into the border facies.

The iron content in this facies varies from 30 to 40 per cent, but in most of the formation is between 30 and 35 per cent. More than 90 per cent of the iron occurs as specular hematite with quartz. Magnetite is present in minor amounts as very fine inclusions in the specular hematite grains and it is rarely detectible megascopically. Octahedral crystals up to a quarter of an inch in size are found occasionally, and magnetite is erratically distributed in iron-formation adjacent to some amphibolite masses. Other minor constituents in the oxide facies are muscovite (especially near the borders of the formation); occasional grains of tourmaline, rare crystals of pyrite, and very fine carbonate particles are present in some quartz grains.

Quartz-rich bands and hematite laminae are conspicuously parallel. Cutting across these, having presumably crystallized later, are numerous stringers, veins, and fracture fillings of coarser grained hematite. Fractures, cleavage planes, and crests of minor folds have provided structural control for the emplacement of this iron oxide. The hematite ranges from 1 to 3 mm in grain size, and the masses vary from an inch to a few feet in width. Vuggy openings range in size from a fraction of an inch to more than a foot and are commonly lined with striated hematite and terminated quartz crystals several inches long. Glassy, coarse-grained quartz forms small veins which are surrounded by aureoles of grey hematite several inches wide.

Much of the iron-formation is highly crenulated and deformed by folding. Because of its thin-banded nature, it appears to have yielded during deformation by folding much more readily than adjacent massive quartzite beds. There has been considerable small-scale faulting in the iron-formation and the limbs of many minor folds are displaced for tens of feet and truncated against adjacent parallel beds. Little or no brecciation has been observed in these small-scale imbricated zones.

The iron-formation has been derived from a primary oxide facies, but most of the primary features have been destroyed during recrystallization. Relics of a granular texture are discernible in some beds. Metamorphism of this facies is believed to have been mainly a recrystallization process with nearly complete segregation of quartz and iron oxide in coarse grains. A minor amount of iron oxide has been mobilized and probably migrated a few feet, as suggested by the hematite veins noted above.

Much of the iron-formation in the Mount Wright range is friable and highly decomposed as a result of intergranular leaching of quartz. This material is particularly abundant in drill-cores from many fault zones and a friable leached zone is well exposed on the west side of Mount Wright peak. Much of this silica leaching and alteration has taken place prior to glaciation and is similar to that in the Wabush Lake area. Circulating groundwater is considered to be the main agent that removed silica, deposited some goethite and hematite, and altered muscovite and feldspar to kaolinite.

Analyses of iron-formation southwest of Mogridge Lake made by Mount Wright Iron Mines Company Limited (Koulomzine, 1961) indicate a soluble iron content of about 30 per cent, 54.71 per cent insolubles, 0.0039 per cent phosphorus, 0.27 per cent aluminum, 0.0024 per cent sulphur, 0.06 per cent manganese, and traces of MgO, CaO, and TiO_2.

Iron-silicate–magnetite–carbonate iron-formation is present in one narrow lens in the most southerly band of oxide facies south of the west arm of Mogridge Lake and in the area south and east of Moiré Lake. The first indication of a facies change along strike in this area is seen in an exposure area about half a mile west of the south end of Moiré Lake. Green actinolite and diopside are present in the grey hematite–quartz facies and farther east grunerite, hypersthene, and magnetite form a well-foliated schist interbanded with magnetite–hematite-rich layers. Eastward along this band the iron-formation changes to predominantly medium-grained grunerite–hypersthene–magnetite–quartz layers interbedded with ferruginous dolomite and the whole formation is 100 to 150 feet thick. This facies in general lacks uniformity in the thickness of beds and in the relative proportions of different constituents.

The iron-silicate-rich bands are coarse grained with lath-shaped grains of silicate varying in length from 2 to 10 mm or even larger. Magnetite grains in these silicates are usually less than 1 mm. Much of the silicate is present in randomly oriented, felted grain masses that transect crudely defined banding. Dolomite bands and lenses weather dark brown and consist of coarse-grained (3 to 4 mm), buff dolomite with about 10 per cent disseminated grunerite and hypersthene. Minor quantities of diopside and actinolite are present with these iron-rich silicates. This facies is highly deformed having yielded by flowage, folding, and shearing.

Because of its heterogeneous nature, there appears to be little possibility of finding material of suitable mineral and textural quality in zones large enough to be of potential ore value.

Orthoquartzite

This light grey to milky white, coarsely crystalline rock forms prominent resistant ridges in the plateau area. Most of the rock is composed of ½-mm grains of white glassy quartz that are tightly interlocked in a granoblastic texture. Five to ten per cent of muscovite is present with the quartz, and occasionally some biotite and garnet or kyanite in border facies where muscovite is more abundant. Faint colour banding is seen in some outcrops, some of which suggests crossbedding, but no other primary textures were recognized.

The quartzite is a highly competent rock deformed by fracturing, shearing, and faulting, but because of its massive character folding is not well defined. There is some question as to whether this is a metamorphosed clastic rock or a thick chert unit, but the heavy mineral fractions recovered from it (which included hematite, magnetite, tourmaline, garnet, zircon, titanite, rutile, anatase, epidote, zoisite, kyanite, fluorite, and apatite) contain zircon and some rutile grains that are rounded and have sedimentary characteristics indicating a clastic origin. In a few local areas lenticular masses and layers of interbanded quartz and specular hematite are present in the quartzite. The iron content in them does not exceed 15 per cent and these beds are believed to lie near the transition zone between iron-formation and quartzite or they may be crests of small folds of iron-formation infolded in the quartzite.

Stratigraphic Sequence

Without the benefit of primary features to indicate the tops of beds, it is very difficult to determine the stratigraphic sequence in this highly deformed structure. The gneissic rocks are all much alike, and the main problem is to determine whether quartzite is stratigraphically above or below the iron-formation. There is apparently only one major quartzite formation, as quartzite is found only on one side of the iron-formation. It can be seen from Figure 22 that quartzite overlies iron-formation in a small synclinal structure south of the west arm of Mogridge Lake. About a mile west of this structure quartzite again overlying iron-formation can be traced around the crest of a large anticline that plunges 30 degrees west. Similarly quartzite is present in the central part of a syncline south of Hesse Lake and forms a thin layer overlying iron-formation that dips 10°N in the area south of Irene Lake. If the sequence suggested by these structures is accepted, other stratigraphic and structural relationships are easily fitted into the regional structural pattern. If, on the other hand, the quartzite lies stratigraphically below the iron-formation, one has to postulate complete overturning of the succession to a nearly horizontal position over much of the area prior to the deformation that produced the folds indicated on the map. Most of the minor folds and detailed relationships cannot be fitted into such a postulated structure. It seems reasonable therefore to accept the sequence with quartzite overlying the iron-formation as correct. Objections to this sequence have been based mainly on the fact that quartzite underlies iron-formation throughout much of the geosyncline and must therefore be in the same position here. Regional mapping however shows that the lower quartzite pinches out in the area north of Mount Wright and that iron-formation transgressively overlaps lower members in the succession. Directly associated with this pinch-out is a change to the southwest in the iron-formation to a shallow water, oxide facies which may, as seems to be so in this area, be overlain by a different quartzite formation. Indeed, if this area represents a near-shore environment at the margin of the geosyncline thick clastic sedimentary deposits may well be expected to overlie the iron-formation. Moreover marked differences in the stratigraphic sequence in the southern and northern parts of the geosyncline show that conditions of sedimentation were far from uniform throughout the belt. The succession quartzite over iron-formation is assumed to be correct and is used in the structural interpretations given in the next section.

Structural Geology

Subsurface and geophysical information has demonstrated that in detail structures are more complex than would appear on the surface. Thin bands of amphibolite were found that were not visible and many thin fault slices are present within what appear to be single lithological units.

In general, the Mount Wright structure is a broad arcuate belt composed of tight recumbent folds that appear to have been overturned to the southwest and then rotated north during later deformation so that the major rock bands now dip 40° to

60°N. Reverse dip-slip movement on a complex set of north-dipping and westerly striking faults has resulted in imbricate structures superimposed on the early folded and faulted structural pattern. Some of these faults are parallel with the axial planes of early folds but others dip more steeply north. The general structural configuration is shown on Figure 22 with a few illustrative cross-sections. The structure south of Irene Lake consists of a recumbent anticline overturned to the south, which plunges eastward and is cut by later faults. The trend of the structure east of Moiré Lake swings sharply north and then curves northwest, and the lower part of a recumbent anticline north of this lake, shown on Figure 19, forms a trough-like structure and because the beds are overturned iron-formation now overlies quartzite. The quartzite capping the hill west of Moiré Lake is apparently overturned and represents a southerly extension of this recumbent fold. The thin quartzite band southeast of Lake Louisette may be the western extremity of the quartzite formation that underlies iron-formation in the eastern part of the region.

Folds

At least two orders of folding are recognized. The first consists of a series of very tight recumbent folds with axial planes dipping from 80°N to nearly horizontal. The plunge of these folds, as shown by minor secondary folds, is generally low, possibly up to 45 degrees, but reversals of plunge within a few hundred feet are common. The prominent westerly to southwesterly strike of the rocks is due mainly to this order of folding.

A second order of folding imposed on the isoclinal folding is present but is not so well developed or so conspicuous as the isoclinal folding. The plunge of the second order of folds is west to northwest and apparently does not exceed 45 degrees. To illustrate, the iron-formation half a mile southwest of Elgor Lake forms an isoclinal fold that has been folded into a syncline of the second order. Three quarters of a mile northeast of this lake an anticlinal structure of the first order, although disrupted by faulting, has been folded into a syncline of the second order.

Secondary folds in the area may be related to first or second order of folding or to certain ages of faulting and their use is thus limited until they are correlated to appropriate major structures. Changes in plunge as indicated by these secondary folds may be reversed within short intervals which are often less than the distance between outcrops, and much of the iron-formation is highly crenulated and directions of relative movement on some exposures are not clearly defined.

Faults

Four sets of faults are recognized. The first set includes strike faults with approximately the same attitude as the folded beds. These thrust faults are directly related to the isoclinal folding and strike east to northeast. Their presence is inferred from the structural configuration of the sedimentary beds, but the actual locations of the fault zones are difficult to recognize due to later recrystallization during advanced stages of metamorphism. These faults are believed to have developed during the early stage of deformation and to have formed at the same time that the deformation took place in the central part of the geosyncline.

A second set of faults, which is believed to be closely related to but later than the first set, strikes north to slightly east of north. These faults are steeply dipping cross-structures along which the east side appears to have moved south in relation to the west side. Some of these may have formed at about the same time as the cross-folds and may be related to early stages of deformation in the Grenville orogeny when much of this early structure was gently folded.

The faults of a third set appear to form the most continuous breaks in the area. They are sinuous, steep, north-dipping zones that strike west to northwest and meet the first set of faults at 20 to 30 degrees. In places they appear to follow the fault zones of the first set for hundreds of feet before diverging and pursuing an independent course. The relative movement on this set of faults, as shown by the outcrop patterns and the offset of the iron-formation, is north side west and up. The fault zones are marked by strong shearing and the period of faulting may coincide with or overlap the period of gabbro intrusion. Much of the highly sheared amphibolite intersected in drill-holes is found to coincide with the projection of fault zones from the surface. Some of these faults have been the site of movement since the Grenville metamorphism, as gouge and kaolinite are present.

The youngest and fourth set of faults, striking N45°W, is indicated by the offsetting of amphibolite and iron-formation bands in the cross valley extending south from the western extremity of Peter Lake. These are apparently part of the same set that produced the well-defined lineation shown on Figure 19.

Iron Deposits

Mount Wright Deposits

Practically all the highland belt is held by Quebec Cartier Mining Company, which has investigated the area sufficiently to appraise the potential worth of the deposits. Because of the relatively uniform composition of the oxide facies material, the simple mineralogy, low manganese content, and relatively coarse grain size, it is probable that this material will be concentrated in gravity spirals and most of it will not require grinding finer than 20 mesh. Conservative estimates indicate that there is more than a billion tons of mineable material carrying 30 per cent or more iron. Because of the complex structure, this material is distributed in a large number of separate structural blocks.

Southeast Mogridge Deposit

A section of the northern band of iron-formation, 4,000 feet long and 250 to 500 feet wide immediately south of the southeast arm of Mogridge Lake, has been investigated by geophysical surveys, diamond drilling, and metallurgical testing by Mount Wright Iron Mines Company Limited. They estimate that 147 million tons of open pit ore lies within their ground with the same composition as the Mount Wright deposit. Various concentration methods have been investigated and it is found that crude ore assaying 30.61 per cent iron can be treated, after grinding to 20-35 mesh size, to give concentrates assaying 65 to 68 per cent iron with 95 per cent recovery of the iron. The ratio of crude to concentrate is 2.24.

Quartz Lake Deposits

A number of zones of iron-formation suitable for concentration are present in the folded structure northwest of the north end of Moiré Lake. The southern part of this structure is held by Bellechasse Mining Corporation who have optioned the ground to W. S. Moore Company and the northern part is held by Ferrous Iron Mines Limited, a subsidiary of Consolidated Fenimore Iron Mines Limited. Iron-formation facies present include quartz–magnetite–specular hematite, quartz–specular hematite, quartz–magnetite–iron silicates, and quartz–iron silicates. There is considerable interfingering of these facies and they are intruded by a number of amphibolite masses. The structure is complicated by intense folding.

Approximately 6,000 feet of drilling on this structure has indicated ten ore zones with about 30 per cent soluble iron in the iron oxide facies and this material can be concentrated by gravity methods to give a good grade concentrate after grinding to -35 mesh. Magnetite-rich facies need to be ground to -100 mesh to give a satisfactory concentrate. The iron-formation is reported to be 250 feet thick, but parts rich in iron-silicate minerals are concentrated with difficulty and the iron recovery is low, due to much of it being chemically combined with silica as grunerite, hypersthene, actinolite, and diopside, which cannot be extracted. According to reports, there may be at least 200 million tons of potential ore within the limits of open pit mining in this structure.

Bloom Lake Deposits

The Bloom Lake deposits are about 15 miles southwest of Labrador City and about 5 miles north of the Mount Wright range. The western 4 miles of this range contains very large reserves of specular hematite–magnetite iron-formation in a synclinal structure that is regarded as a southwest extension of the Wabush Lake ranges. Claims were first staked before 1952 to cover a small showing of cobalt minerals, and the ground was held by Quebec Cobalt and Exploration Limited who did initial exploration of the iron ore. In 1956 the iron deposits were optioned to Jones & Laughlin Steel Corporation who enlarged the property and through a subsidiary, Normanville Mining Company, leased the claim in 1958. At this time Boulder Lake Mines, Inc., a subsidiary of Cleveland–Cliffs Iron Company, acquired a 50 per cent interest in those deposits from Normanville Mining Company. A very intensive investigation including detailed geological and geophysical mapping, nearly 20,000 feet of diamond drilling, and bulk sampling was carried out prior to 1959.

Geology

The distribution of the iron-formation and structure of the area are illustrated in Figure 23 (*in pocket*). The iron-formation and quartzite are conformable within a metasedimentary series of biotite–muscovite–quartz–feldspar–hornblende–garnet–epidote schists and gneisses in a broad synclinal structure. This succession, following the first stage of folding and faulting, was intruded by gabbroic sills which were later metamorphosed and transformed into amphibolite gneiss with foliation parallel with that in adjacent metasediments. Two separate iron-formation units are present; these join northwest of Bloom Lake, but are separated by several hundred feet of gneiss and schist in the southern part of the structure.

Quartzite, present below the upper member throughout the eastern part of the area, pinches out near the western end. Folded segments and inclusions of iron-formation in the central part of the syncline that are surrounded by amphibolite, are in most cases thought to be part of an overlying sheet that was thrust over the main syncline during the first period of deformation. The large amphibolite mass in the central part of the area was apparently emplaced along the zone of weakness created by this early thrust fault.

Iron-formation in the western 3 to 4 miles of the structure is predominantly of the magnetite–specular hematite–quartz facies that forms the major zones of potential ore. A fairly abrupt change in facies takes place along strike east of a line passing northwest across Bloom Lake, east of which the grunerite–Ca-pyroxene–actinolite-magnetite–carbonate facies predominates. The oxide facies to the west is uniformly banded with variable proportions of magnetite and hematite in a medium-grained quartz matrix. Accessory amounts of actinolite, talc, and carbonate are present in this facies. The lower unit is less than 100 feet thick in some places and is considerably thinner than the upper unit. The iron content ranges from 32 to 34 per cent in this facies.

In places the silicate–carbonate facies to the east contains more than 50 per cent cummingtonite, which in part is magnesium rich, and the manganese content ranges from 0.1 to more than 2.0 per cent. Mueller (1960) has studied the complex assemblage of minerals in this rock and has discussed chemical reactions during metamorphism in considerable detail. He has shown that a close approach to chemical equilibrium in the amphibolite metamorphic facies is indicated by the orderly distribution of Mg, Fe, and Mn among coexisting actinolite, Ca-pyroxene, and cummingtonite, and the restriction in the number and type of minerals in association with each other. Furthermore, a comparison between the composition of the silicates and the presence or absence of hematite shows that the Mg to Mg plus Fe ratio is increased but is much less variable when hematite is present.

The iron-formation forms a long doubly plunging syncline which is canoe-shaped but buckled across the centre to produce two distinct oval-shaped basins. Although this structure appears to be relatively simple in form it seems to have been developed during two stages of deformation. Folding along northwest-trending axes and overthrusting of the upper iron-formation during the first stage of deformation appear to have been followed by gabbro intrusion, folding along east-west axes, faulting, and metamorphism during the Grenville orogeny.

Iron Ore Deposits

Available reports indicate that potential ore reserves in excess of 500 million tons of crude ore are present. High recovery of iron has been obtained on material ground to 60-100 mesh by both gravity spirals and high tension magnetic separation methods. Either of these methods is expected to provide concentrates running better than 65 per cent iron from iron-formation with an average composition of about 30 per cent iron.

Boulder Lake Iron Deposits

A number of smaller occurrences of iron-formation near Boulder Lake held jointly by Normanville Mining Company and Boulder Lake Mines Incorporated were investigated and drilled in 1960. Boulder Lake is about 6 miles northwest of Bloom Lake and about 10 miles north of Mount Wright.

Specular hematite–quartz iron-formation forms a small syncline exposed on Sudbury Hill, 1½ miles east of the south end of Boulder Lake. Iron-formation capping this hill is exposed over an area 1,150 feet long, 600 feet wide, and over a vertical range of 150 feet. The iron-formation dips or plunges towards the centre of this hill, with dips varying from 45 degrees in the north to 60 degrees in the south. The beds are tightly folded and crenulated and may continue to considerable depth. The iron-formation directly overlies biotite–muscovite–quartz schist that contains porphyroblasts of salmon coloured feldspar up to 2 inches in size which is exposed on the lower slope of the hill.

The specular hematite–quartz unit is thin banded, medium to coarse grained, free of any appreciable amount of silicate minerals, and is generally friable. The average iron content is estimated to be between 25 and 32 per cent.

Another iron deposit in a similar geological and topographic setting is exposed three quarters of a mile west of the south end of Boulder Lake, on Roach Hill. The iron-formation is similar to that on Sudbury Hill and is exposed for a distance of 1,500 feet along an east-west line and over a width of 1,000 feet at the east end. The beds form a syncline, and strike west and dip at 45 degrees or more into the hill. The average iron content is estimated to be about 25 per cent. It is interesting to note that dip-needle readings over both these hills are low negative to low positive and that these deposits are not likely to be detected by airborne magnetometer surveys.

A band of iron-formation 8,000 feet long and 150 to 500 feet wide is exposed in the low ground north of Roach Hill. The beds dip 65°S, strike west, and form a tight syncline that plunges 60°SE. The southern part of this fold is cut by a west-striking, steeply dipping fault zone that is marked by a topographic depression. Deeply weathered and decomposed iron-formation and gouge-like material were recovered from the drill-holes. The iron-formation is bordered on both sides by muscovite-quartz schist, and iron silicate–carbonate–magnetite iron-formation has been traced around the western and northern sides of the fold. This facies is tightly folded and contorted and grades south and east to magnetite–quartz facies. Some specular hematite–magnetite facies is present in the central part of the structure. A narrow mass of amphibolite trending northwest cuts through the structure. The iron-formation is somewhat finer grained than that on Roach Hill. The fault zone is believed to be one of the set of faults that form the composite-wedge structure in this area and late stage fault movements are indicated by the gouge. Highly permeable ground along this zone is suspected because of artesian water flowing from some drill-holes.

Iron-formation on claims held by Quebec Cobalt and Exploration Limited is exposed about a mile northeast of the north end of Boulder Lake in the area known as Labrador Hill[1]. Thinly banded iron-silicate facies, grading southeast to magnetite–iron-silicate facies, strikes north and dips steeply east and is exposed around the north end of this hill, where it is tightly folded and deformed. Very good grade, thin-banded magnetite–quartz iron-formation with only minor amounts of grunerite was seen about 1,000 feet southeast of this exposure on the east slope of the hill. This iron-

[1]Now Beaugay Hill

formation is believed to be part of a south-plunging synclinal structure underlain by mica schist. It is particularly interesting to note that both facies of this iron-formation near the margin of the Grenville orogenic belt is much finer grained than material of similar mineral composition near Bloom Lake and many more primary features are recognizable.

Peppler Lake Iron Deposit

(lat. 52°21′, long. 67°36′)

The general geology of this deposit is illustrated in Figure 24. The following description is by Phillips (1959):

> Quebec Cartier Mining Company has completed an assessment program on its property including drilling, detailed geological mapping, and dip needle surveying. The property of this company comprises most of the syncline. Jubilee Iron Corporation, Limited, holds a group of five claims covering the northern end of the Peppler Lake syncline.
>
> The iron-formation here occupies an open syncline 2 miles by 1 mile, bounded on the east by a fault over which a tight overturned syncline in Iron Formation rocks has been thrust. Southwards this easterly dipping thrust fault merges into the isoclinal overturned southern part of the main structure. The tight syncline east of the thrust may become monoclinal northeastwards and join up with the southern end of deposit (2) below (Jean Lake). Oxide iron-formation is developed at two horizons in the sequence. The lower horizon is generally less than 50 feet thick and thins out around the northern nose of the syncline. It contains magnetite only and averages about 20 per cent iron oxide. The upper horizon is exposed over large areas in the centre of the main syncline and is more than 200 feet thick in places. It is higher grade, with magnetite dominant except in the central part which is composed of specularite. General lack of overburden, shallow synclinal structure and friability make this deposit an excellent prospect.

Jean Lake Deposit

(lat. 52°24′, long. 67°33′)

"Poorly exposed Iron Formation extends southwards from Jean Lake and probably joins the eastern part of the Peppler structure. The bands dip steeply to the west and are strongly deformed on a small scale. Exposures suggest that the oxide iron-formation member is thin, but data from magnetic surveys indicate a widening in the northern part." (Phillips, 1959). This zone is held by Quebec Cartier Mining Company.

North Lamêlée Hill Deposit

(lat. 52°28′, long. 67°31′)

"This structure is interpreted as an overturned isoclinal syncline with a northward dipping axial plane, which has been refolded about a north-south synclinal axis. The lower beds of the sequence have been removed by erosion, but one oxide member containing as much as 30 per cent magnetite and specularite remains. At least one layer, that forming the north-facing slopes of the lunate-shaped hill, is of economic value.

"North of this structure the full Iron Formation sequence is exposed in a band offset by several cross-faults. Two oxide horizons occur. Both increase in thickness eastwards at the expense of the silicate-carbonate facies, and this increase is accompanied by a change from magnetite to specularite. These exposures of Iron Formation are under claim by Quebec Cartier Mining Company." (Phillips, 1959). *See* Figure 25.

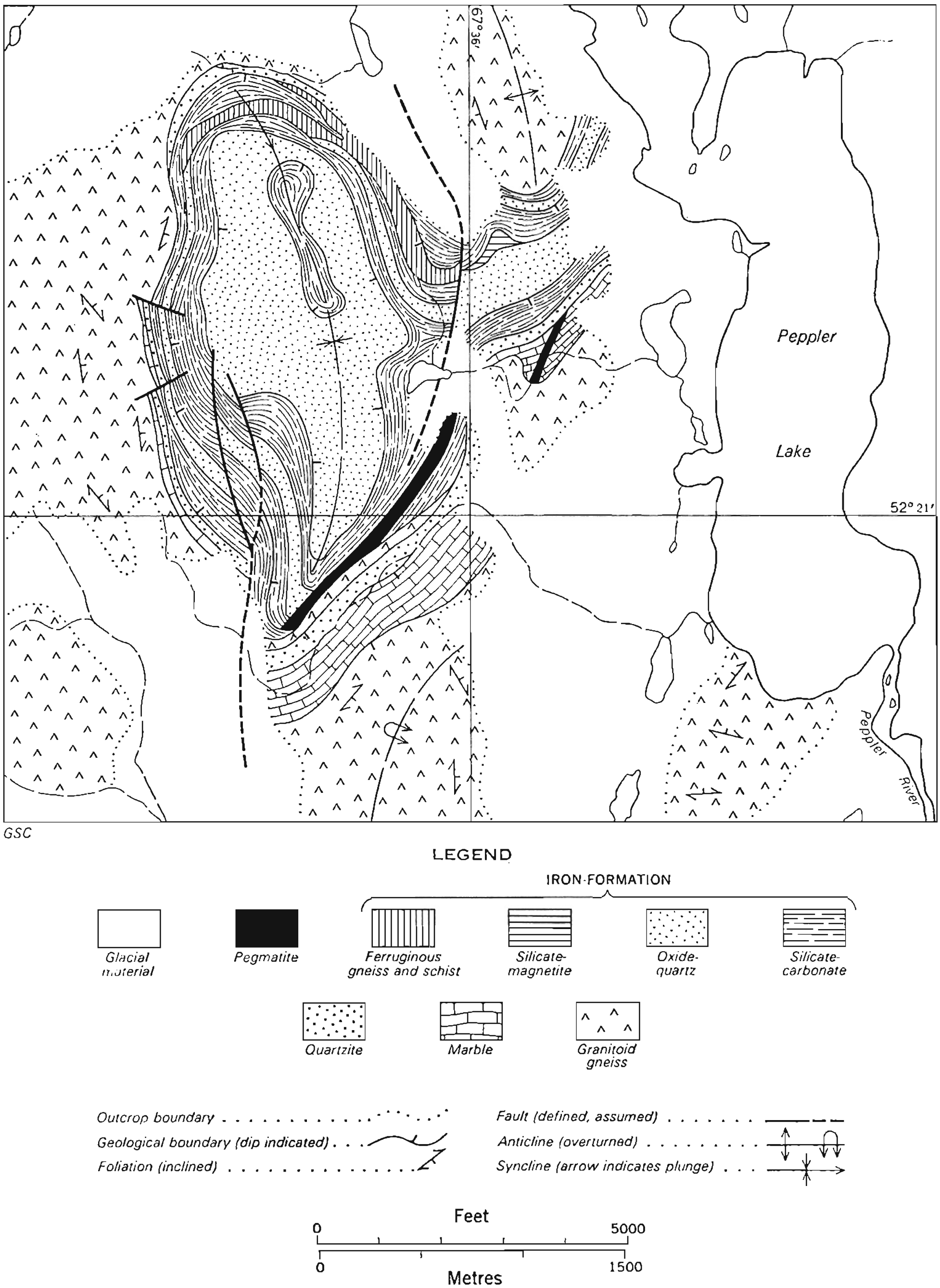


FIGURE 24. Geology of the Peppler Lake deposit (*from* Preliminary Report No. 401, Department of Mines, Quebec, 1959).

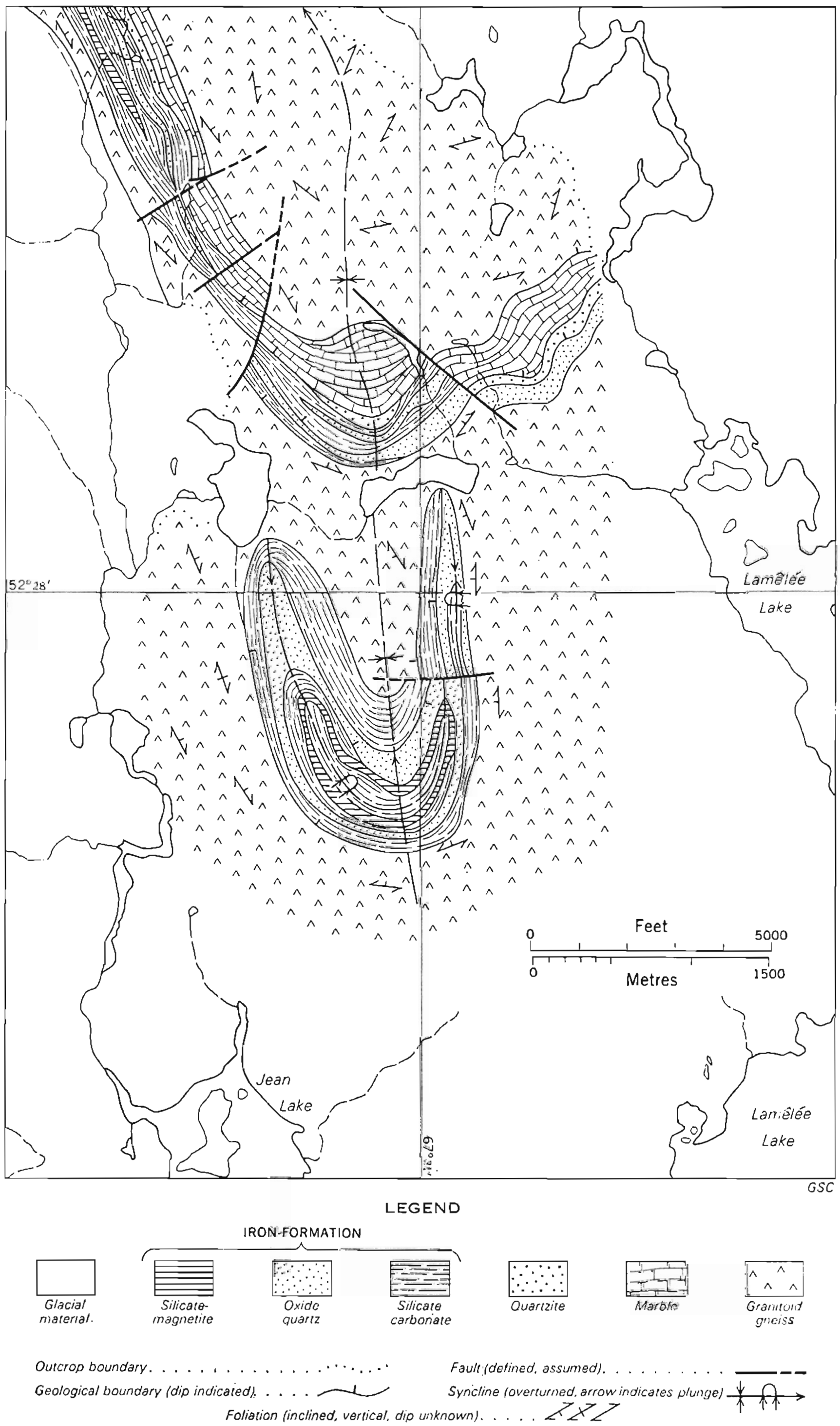


FIGURE 25. Geology of the Lamêlée Hill deposit (*from* Preliminary Report No. 401, Department of Mines, Quebec, 1959).

Lac Cassé–Plaine Lake Iron-Formation

A thin band of crystalline limestone with associated lenses of magnetite-rich iron-formation extends eastward across the area between these two lakes. The beds dip gently south and appear to mark the southern limb of the large complex Tuttle Lake–Pekons River anticlinorium. Iron-formation around Lac Cassé is composed mainly of a thin, folded specular hematite-rich facies.

Fire Lake Deposit

(lat. 52°21′, long. 67°22′)

This deposit, held by Quebec Cartier Mining Company, is about a mile northeast of Fire Lake and has been explored in considerable detail by geological and geophysical surveys and by diamond drilling.

The stratigraphic succession is made up of the following units which appear to be in the order given from bottom to top:

—Biotite–feldspar–quartz gneiss
—Thin-banded magnetite–quartz iron-formation
—Specular hematite–quartz iron-formation
—Lean specular hematite–quartz iron-formation
—Dolomite present locally in lenses up to 100 feet thick, possibly thickened in places by folding
—Biotite–feldspar gneiss.

The main part of the deposit forms a broad open syncline that plunges south to southwest and overlies a low easterly dipping fault zone. The structure west of this fault is interpreted as two small recumbent anticlines, with axial planes dipping east and striking north to northeast, separated by a second thrust fault. The dolomite unit is present along the east and south sides of the deposit and, if the above succession and structural interpretation is correct, it is overturned and forms the lower limb of the recumbent anticline. The major synclinal structure may be thrust westward to overlie much of this overturned limb.

The deposit of iron ore covers an area some one mile from east to west and up to half a mile north to south along the axis of the main syncline. The main ore zone is composed of relatively coarse-grained specular hematite–quartz iron-formation which closely resembles the ore in the Lac Jeannine deposit. A thin magnetite-rich unit is present below the specular hematite unit and some iron-silicate and carbonate facies are distributed at the base of the magnetite units. The configuration of the syncline indicates that specular hematite ore may be present to depths of several hundred feet over a large part of the structure.

The average grade of the hematite-rich facies is estimated to be 35 per cent iron. The upper layers are leaner but lenticular zones more than 10 feet thick containing 80 per cent coarse specular hematite have been intersected. As the grade of iron increases, particularly in beds containing more than 40 per cent, the grain size of the hematite increases appreciably and may form equigranular aggregates of 3 to 4 mm crystals. The coarse-grained material in this deposit is friable and crumbly. It is believed that the lack of granular cohesion may not be caused by silica leaching as at

Wabush Lake but by the fact that the blocky rhombohedral hematite crystals do not form a good interlocking texture and that quartz grains are not firmly attached to the planar crystal faces of the hematite. A very large proportion of the hematite in this deposit is present in 1 mm or larger grains.

The hematite- and magnetite-rich facies in this succession are fairly well segregated, with the magnetite-rich material at the base and only a thin transitional zone of mixed iron oxides. There does not appear to be appreciable interfolding of the magnetite unit with the hematite unit in the main syncline and the major ore zone appears mineralogically uniform.

It is expected that the hematite–quartz ore can be concentrated in gravity spirals without grinding finer than 20-35 mesh. With simple iron oxide–quartz mineral assemblages and only minor amounts of muscovite or carbonate in the ore there is no reason to suspect any quantity of deleterious constituents.

The Mount Reed Deposit

(lat. 52°01′, long. 68°05′)

The complexly folded iron-formation at Mount Reed is one of the principal zones of potential ore in the southern part of the geosyncline. The deposit was first examined in 1952 and since that time has been mapped in detail and diamond drilled, and bulk samples from four pit areas were tested in a pilot plant at the deposit site. The main highland ridge (Pl. XIV A) is about 12 miles north of Lac Jeannine mine and about 150 miles north of Port Cartier on the Gulf of St. Lawrence. The ore structure is more than 3 miles long, 1,000 to 2,000 feet wide, and several hundred feet deep. The iron-formation is composed of a thick magnetite and hematite–quartz unit that lies between thin iron silicate–magnetite–carbonate units.

The stratigraphic succession at Mount Reed, according to the writer's interpretation based on limited field work, is as follows, starting with the lowest unit:

—A lower group of biotite–feldspar–quartz gneisses of metasedimentary origin that is transitional to

—a lower quartzite unit, 20 to 30 feet thick, that is thin banded (1 inch to 4 inches), pinkish grey and interbedded in places with 1- to 2-inch bands of buff weathering rusty dolomite. Dolomite is more abundant in the upper part, where some iron silicate is also present, and weathers rusty brown. It is transitional upward over a few feet to

—thin-banded grunerite–hypersthene–magnetite–quartz iron-formation with interbanded silicate and magnetite-rich layers. The iron silicates are amber to khaki with a greenish cast, and the banding is lensy to irregular. This unit is 20 to 30 feet thick where examined and magnetite–quartz layers are interbanded in an upper gradational zone a few feet thick.

—A magnetite–specular hematite–quartz facies forms the thickest unit in the iron-formation, more than 200 feet thick. The lower 20 to 30 feet of this unit is composed almost exclusively of medium-grained magnetite and quartz with a little hematite and some green silicates–actinolite, pyroxene, or cummingtonite. The main part of the unit is composed of relatively thin banded oxide facies with variable proportions of magnetite and specular hematite in individual bands, magnetite being more abundant than hematite in the overall section. The unit can be separated into subunits, 20 to 40 feet thick, that have a consistent magnetite and total iron content. A band, about 10 feet thick, rich in rhodonite is present in the central part of the unit. It has been examined in several outcrop areas and appears to be a good marker bed for structural and stratigraphic studies. The average iron content in this unit is estimated to be 30 to 32 per cent with considerable material containing 35 per cent.

—The oxide facies grades upwards to a garnet–iron silicate–magnetite unit approximately 25 feet thick, very similar in most respects to the lower iron-silicate-rich unit.

—Fairly massive coarse-grained quartzite overlies the iron-formation. In places it is thin bedded and occasionally has colour banding suggestive of cross-bedding. This upper quartzite is 20 to 30 feet thick and is transitional upwards to a dolomite unit.

—The dolomite is medium to coarse grained, and forms fairly uniform beds a few inches to more than 10 feet thick. It is cream to buff on fresh surfaces and weathers dark buff to brown. A small amount of white tremolite and diopside is present in rosettes and clusters of crystals up to 4 inches long. Numerous thin, coarse-grained quartz bands are interbedded in the dolomite and the unit may in places be more than 100 feet thick.

—The dolomite is overlain by biotite–feldspar–quartz gneiss. A feldspar–quartz–dolomite gneiss with disseminated magnetite, more than 10 feet thick in places, may represent a sub-facies associated with the iron-silicate units.

The iron-formation in the Mount Reed structure forms a broad U-shaped fold that is open to the northwest. The beds on both sides of this structure dip 25 to 30 degrees N or NE and strike northwest in the north flank and west in the south flank. Quartzite and dolomite are present around the border of this structure. Both arms are more than a mile long and the distance along the axial line from one end of the U to the other is nearly 20,000 feet. Iron-formation is exposed over horizontal widths of 800 to 2,000 feet on cross-sections perpendicular to the axial line of the fold that makes the U-pattern.

The structure is interpreted as a folded recumbent fold with the apex of the first order fold at the west and the axial planes in the north and south segments are parallel with the beds. The lower overturned limb of the north fold continues around the inside of the U to become the upper limb of the south fold. The plunge of this double fold structure is to the northwest with possibly a steeper plunge in the southern fold than in the northern fold. The structure is believed to be cut on the east side by major steep-dipping faults that strike northwest and extend under the two lakes in this area. Dolomite exposed east of these lakes is thought to be the upper part of a normal sequence that has been thrust west along this fault. The western end of the south fold may be cut by another fault zone that strikes northwest.

The structure appears to have been developed during two major stages of deformation. A series of recumbent folds overturned to the southwest and separated by thrust faults was formed during the first stage of deformation. The axial planes of these folds were horizontal to easterly dipping and axial lines trended northwest. During a later stage of deformation, probably during part of the Grenville orogeny, these folds were further deformed on east-west axes causing tilting of the earlier structures to the north and some cross-folding of existing recumbent folds. The Mount Reed folds appear to have been tilted about 20 degrees as shown by the present plunge to the northwest. The major northwest-striking faults developed after this stage of deformation and may follow some of the earlier fault zones where thrusting took place during initial stages of deformation.

The north segment of the fold structure is eroded more deeply than the south segment, and much of the northeast or upper limb of this north fold, exposed on the northeast side of the hill, has been eroded. Lower gneiss, quartzite and the lower silicate–carbonate–magnetite unit is exposed near the top of the hill in a narrow zone along the axial plane of the recumbent north anticline. A section of iron-formation that is completely overturned is exposed on the southwest side of Mount Reed and it overlies upper quartzite and dolomite in the central part of the U (Pl. XIV A). The southern fold is exposed at a lower elevation than Mount Reed where there is less relief and where more of the iron-formation in both limbs of the fold may be preserved within the limits of open pit mining. Brecciated iron-formation near the east end or base of the U is cemented with creamy coloured feldspar and some carbonate, and graphite is present on numerous late slip planes. This breccia may have been formed during several stages of movement on the northwest-striking faults or from intense deformation near the axial plane of the recumbent fold.

A fault zone extends northwest for some distance from the northeast side of the structure and is recognized about 2 miles from Mount Reed where a section of iron-formation is exposed at a waterfall on a south flowing creek. The beds dip 60°NE at this waterfall and strike southeast and a complete stratigraphic section from lower quartzite through iron-formation to upper dolomite is exposed. Southwest of the waterfall the iron-formation can be traced around several broad folds that plunge 30 degrees northwest. The iron-formation overlies biotite–feldspar–quartz gneiss and is overlain by dolomite, exposed on its north side. This southerly band of iron-formation and the band at the waterfall are offset several hundred feet by a fault on the west side of the creek valley, the east side having moved northwest relative to the west.

Material exposed at the base of the lower quartzite at the waterfall section may represent a basal conglomerate marking an unconformity between the quartzite and gneissic rocks below. This material is composed of rounded cobbles of coarsely crystalline quartz in a matrix of biotite-garnet schist and appears to be metamorphosed conglomerate. The iron-formation evidently rests directly on gneiss or is separated from it by very thin beds of conglomerate immediately to the west. If this is an unconformity between younger sediments and earlier gneisses, it is possible that the thin-banded younger sediments were later thrust over the competent basal gneiss complex and recumbent folds such as those at Mount Reed were common structures in the area.

The stratigraphy and structure at Mount Reed indicate that the deposit there contains a very large tonnage of potential ore. Typical of most magnetite-rich iron-formations in this region, the Mount Reed oxide facies is not as coarse grained as specular hematite–quartz beds but the Mount Reed ore is sufficiently coarse grained to permit recovery of a high percentage of iron without grinding finer than 150 mesh. The iron-silicate-rich facies is undesirable and mining will have to be conducted so that much of this material can be eliminated or avoided in the pits. Where oxide and iron-silicate facies are interbanded or intermixed due to drag-folding a much more elaborate and complex milling process may be required to produce high quality concentrates. Because of the complex structure and stratigraphy very detailed geological work may be required to guide mining and to provide a uniform mill feed. Very large tonnages of oxide facies, however, can be selected from this deposit in the initial stages of mining.

Lac Jeannine Mine

(lat. 51°51.5′, long. 68°06′)

Iron ore concentrate in the southern division of the Labrador geosyncline was first produced in 1961 at the Lac Jeannine mine, owned by the Quebec Cartier Mining Company a subsidiary of United States Steel Corporation. The size of this deposit and the exceptional quality of the ore were first realized during the preliminary drilling in 1954 and a development program to prepare the property for production was started early in 1956. The deposit is about 140 miles northwest of Port Cartier on the Gulf of St. Lawrence and 4 miles southeast of Barbel Lake (Pl. XIII A).

This is the largest single mining operation in the Quebec-Labrador area and preparation for production involved seven major projects: preparing the open pit mine for an annual production of 20 million tons of crude ore, the building of a concentrating plant with an annual capacity of 8 million tons of concentrate, construction of 191 miles of railway to connect the concentrator at Lac Jeannine to Port Cartier, the excavation of a 50-foot-deep harbour at low tide that required removal of 10 million tons of rock as well as the construction of ore handling and loading facilities, the completion of a hydro-electric plant on the Hart-Jaune River near Lac Jeannine with an initial capacity of 60,000 H.P., and the building of two towns, Gagnonville near Barbel Lake, and Port Cartier near Shelter Bay to accommodate a combined population of 8,000. Production and shipment of ore is carried on throughout the year.

The crude ore consists of coarse-grained specular hematite and quartz (Pl. XIII B) which has an average grade of 31 per cent iron and is easily concentrated in gravity spirals, a fact that had considerable bearing on the choice of this deposit for initial production in the area. The ore is mined from 40-foot benches in the pit and trucked to the concentrator where it is passed through 66x84-inch jaw crushers, and through 30x70-inch gyratory crushers before being fed to 18x5-foot cascade mills for wet autogenous grinding. Concentration of -10 mesh ore from the grinding circuits takes place in batteries of rougher and cleaner gravity spirals to produce a product that contains 66 per cent or more iron with 4 per cent silica; 85 to 88 per cent of the total iron in the crude ore is recovered. The mill is designed to treat up to 60,000 tons of ore per day and the concentration ratio of ore to concentrate is about 2.6 to 1.

The geology of this deposit is relatively simple compared with others in the area.

The stratigraphic succession, as examined on the northeast side of the deposit, is made up of the following rock units in order from east to west or from top to bottom:

—Medium- to coarse-grained biotite–feldspar gneiss uniformly banded with one-half-inch to 2-inch thick layers and has some *lit-par-lit* bands of salmon-pink feldspar.

—A band of white marble 10 to 20 feet thick, below the gneiss, thin banded, medium to coarse grained, and containing appreciable coarse-grained muscovite in places.

—The marble grades to a lean iron-formation or quartz rock that is dark grey, crudely banded, and composed of coarse glassy quartz in one-quarter-inch irregular grains, 10 to 15 per cent muscovite in streaky beds or lenses, and 10 to 20 per cent specular hematite. This unit is 100 to 200 feet thick and has thin bands of marble or muscovite in its upper part.

—A band of biotite muscovite schist separates the upper iron-formation from the lower. It is about 20 feet thick and contains the occasional band 2 to 3 inches thick that bears a high proportion of coarse granular magnetite.

—The main iron-formation below this unit is more than 200 feet thick and the iron content ranges from 30 to 45 per cent but is estimated to average between 30 and 35 per cent. It is composed of silvery grey to bluish grey hematite in 1 to 2 mm grains in friable grey granular quartz that is somewhat finer grained than the hematite. Much of the hematite is segregated in streaky or lenticular layers one-quarter of an inch thick and practically free of quartz. Well-defined thin banding is present in some parts of the unit but much of it is nearly massive with poorly defined lenses of hematite. Layers up to 8 inches thick that contain 60 per cent hematite by volume are present locally and are extremely friable. The hematite in these layers forms blocky equidimensional grains that range from 1 to 5 mm in size. It is found in general that as the hematite content increases in bands more than a quarter inch thick the size of the hematite grains increases to about 5 mm. Examination of thin sections from this unit shows a remarkably good segregation of quartz and iron-oxide with only a very small proportion of the iron in grains smaller than ½ mm. Dusty hematite inclusions in quartz with a mosaic texture suggest relics of an earlier granular texture. A small amount of fine-grained muscovite is present in some layers. Very little magnetite is present in this iron-formation although there is an appreciable increase in magnetite in some layers near the northwest end of the main orebody, where small amounts of pyroxene and grunerite are present.

—A thin band of quartzite is present between the iron-formation and the lower gneisses.

The Jeannine deposit forms an anticline that is overturned to the southwest and plunges 10 to 15 degrees to the southeast. Beds on the east limb dip 40°NE and the axial plane of the anticline strikes northwest and dips 60°NE. The main structure in the iron-formation is more than 10,000 feet long and varies from 300 feet wide at the northwest end to 1,500 feet wide at the southeast, where lower iron-formation is present over a width of 600 feet. It appears as though three quarters of the reserve of potential ore may lie in the southeast third of the deposit as outlined, and the ultimate depth from which ore may be mined at the south end of this gently plunging fold has not been determined. Stratigraphic units in and associated with the iron-formation are remarkably uniform and can be traced continuously around the configuration of the fold. The limbs of the anticline are divided at depth by the lower quartzite and gneiss present near the axis of the fold. The limestone unit overlying the iron-formation is thickened on the southwest side where it is overturned.

The main fold structure is cut near its northwest end by a north-striking and steeply dipping fault. The southeast part of the structure has moved up relative to the northwest along this fault which is thought to be one of a major set of late stage faults in the region. Very coarse feldspar and quartz has been emplaced in irregular masses over a width of 20 feet in the vicinity of the fault. Some of this pegmatitic material is fractured and shattered suggesting late stage movements along the fault zone. Aureoles of specular hematite up to 2 feet wide surround some of these pegmatite masses and consist of one-inch hematite blades in random orientation in a quartz matrix. Evidently iron and quartz were mobilized and migrated away from this zone to make room for the emplacement of feldspar and pegmatite.

The Jeannine deposit is farthest south and probably closer to the centre of the Grenville orogenic belt than any other major deposit in the region. It is present in an area where metamorphism is of higher rank than at most deposits to the north and the iron-formation is the coarsest grained of any investigated in the region. The ore is friable and coarser grained material has less granular cohesion than finer grained material. Friability or lack of granular cohesion is considered to result from the nature of the metamorphic texture rather than from intergranular solution and removal of silica, as indicated in the Wabush area. The hematite at Lac Jeannine, for the most part, has well-developed crystal faces that are planar or only slightly distorted and the rhombohedral grains are not tightly bonded or interlocked with the coarse granular quartz. The significance of this textural feature in milling the ore is apparent as the iron grains can be liberated without elaborate or lengthy grinding.

The ore concentrates are free of any significant amounts of deleterious constituents and a very uniform grade of ore is produced. Reports indicate that ore reserves within the limits of open pit mining are sufficient to maintain production at present capacity to about 1975. Considerably more potential ore is present if economic conditions should warrant a change of mining method or technological factors permit mining to greater depths.

The Seignelay River Iron Range

This iron-formation range extends northeast from the junction of Seignelay and Séchelles Rivers for more than 25 miles and contains major reserves of potential ore. Iron-formation was first located in this area in 1958 by C. C. Houston and Associates under direction of Pickands Mather & Co. following an airborne magnetometer survey flown in 1956, and was re-evaluated in 1957. The exploration was carried out in the interest of the Steel Company of Canada and Pickands Mather & Co. and the preliminary exploration was followed during the next few years by further investigations.

Although the overburden in most of this area is not more than 50 feet deep and usually much thinner, rock exposures are small and scattered. The iron-formation and associated metasedimentary rocks dip 15°SE throughout much of the area and the general northeast-strike is shown on Figure 19. Broad open folds are characteristic. These plunge gently to the south or southeast and local shallow basin and dome structures in the iron-formation show that the axes undulate. There is some evidence of low-dipping thrust faults. The range is particularly interesting because of a number of facies changes along strike in the iron-formation, and the stratigraphic succession is not the same in all exposed areas. Up to 300 feet of muscovite schist is present between the iron-formation and the underlying quartzite and there is considerable interlensing of muscovite schist with iron-formation. A lenticular dolomite unit overlies the iron-formation in some places and thin dolomite lenses are also present in the lower schist. Much of the iron-formation is composed of a coarse specular hematite–quartz facies or specular hematite and magnetite facies, but thin iron-silicate–magnetite facies are found locally mixed with oxide facies. The abundance of hematite iron-formation, numerous facies changes, and lack of uniformity in the stratigraphic succession suggest that these metasediments may have been deposited near the shore or margin of the sedimentary basin where conditions fluctuated.

Outcrops of iron-formation were examined along this range for a distance of 2 miles east of Seignelay River. The stratigraphic sequence in this area includes the following main units in ascending order:

—At the base biotite–feldspar–quartz gneiss is present below a thin quartzite unit associated with muscovite–feldspar–quartz schist and containing appreciable specular hematite in some parts.

—Biotite and muscovite schist and gneiss up to 200 feet thick overlie the quartzite. Lenses of crystalline limestone or dolomite are present in the upper part of this unit but not everywhere at that horizon.

—The main iron-formation succession is composed of several lithological units. A magnetite–quartz unit with minor amounts of grunerite, hypersthene, and other iron silicates is present in the eastern part of the area but changes westward along strike to a mixed magnetite- and hematite–quartz facies, and finally to a predominantly specular hematite unit. The specular hematite–quartz beds, predominant west of Seignelay River for at least a mile, appear to be the westward continuation of this lower unit. The iron-formation exposed on a ridge about three quarters of a mile east of the river dips 25°S to SW, and is composed of medium-grained magnetite–quartz facies at the base with a few wispy bands of iron silicates and small vugs lined with 1-inch specular hematite and quartz crystals. This relatively thin banded facies grades upwards to magnetite–quartz facies in fairly massive layers 2 feet thick, which in turn grade into thin-banded magnetite- and specular hematite–quartz facies. This unit is medium grained, with a good granular texture that is friable in places, and with an iron content of 30 to 35 per cent.

—A garnet–biotite–quartz schist is present within the iron-formation interbedded with magnetite–quartz-rich layers and may in places contain appreciable magnetite or iron silicates.

—The upper iron-formation unit is composed mainly of thin banded (½-inch to 8-inch) magnetite-quartz facies that is relatively coarse grained (average grain size about 1 mm) and the iron content ranges from 30 to 37 per cent. The grain size varies appreciably between beds and much of the magnetite is in 3 to 5 mm blocky grains. Grunerite, hypersthene, actinolite, and other silicates are present in the upper part of this unit. Iron-formation is present over a stratigraphic thickness of 200 feet and probably more in this area and the iron-rich beds form well over 100 feet of this part of the section.

—Garnet–biotite–quartz schist is interbedded with the upper iron unit and is present above it.

—A buff to brown weathering dolomite in the upper schist unit is medium grained and thin banded. Some parts are composed of 1-inch crystalline aggregates of carbonate, green amphibole, and pyroxene which appear to be a late stage metamorphic development.

The structure in this area is characterized by gently dipping beds that form a series of open folds plunging gently to the southeast. Crenulations and drag-folds in the iron-formation have sharp pointed crests and long straight limbs that dip gently to the southeast which suggest that major recumbent folds and low-dipping thrust faults may have been developed by the same stresses that produced these folds. It is not known whether the whole iron-formation succession has been repeated in recumbent folds or not but in places it may well be so. With the low dips and plunges noted, the iron-formation, although perhaps not present to great depth, may be accessible over a wide area and thus provide large tonnages of potential ore.

Two synclinal basin structures were examined in the area about 4 miles northwest of Lac la Bouille. The northern basin is oval-shaped, and is about 2,400 feet wide and 3,000 feet long. The iron-formation around the north and east side of the syncline dips 30°SW and towards the centre of the structure around the southern border. Dips within this area vary from 10 to 45°SW. Quartzite is exposed about 500 feet north of this structure, indicating that the biotite–quartz schist exposed between it and the iron-formation may be about 200 feet thick. The iron-formation is best exposed on a north-facing cliff that marks the north and northeast edge of the structure. A thin-banded and relatively coarse grained specular hematite–quartz facies is predominant. This is friable in part and contains from 30 to 35 per cent iron. Distinct banding is preserved but much of the hematite is segregated in thin lenses one eighth inch and 6 inches long that parallel the main banding. The blocky specular hematite grains are 0.5 to 1.0 mm in size and are clustered in patches and lenses in a coarse granular quartz matrix. The iron-formation near the base of the north cliff is much richer in coarse specular hematite and the iron content in 50 feet of the exposed section ranges from 45 to 55 per cent. This higher grade unit may be as much as 100 feet thick. The total stratigraphic thickness of the iron-formation is estimated to be about 200 feet but the amount of thickening and repetition by folding in the central part of the basin is not known.

The southern structure consists of a broad open syncline that plunges gently to the southwest. The iron-formation is exposed over an area 4,000 feet long and about 1,400 feet wide. Specular hematite–quartz iron-formation is exposed in a cliff around the north and east sides of the syncline where it dips 20 to 25°W and 15°E on the west side. In other areas the beds dip 15 to 20 degrees towards the centre of the basin. No dips steeper than 45 degrees were seen. The iron-formation is at least 100 feet thick and contains 32 to 35 per cent iron. A relatively coarse granular specular hematite facies is predominant but some magnetite is present in the southern part of the deposit.

Iron-formation was examined on this range in the area extending 2 miles east of the last described structure and near a creek that flows south into Lac la Bouille. Relatively coarse grained specular hematite–quartz facies with a few thin bands of magnetite-rich facies overlies lenses of crystalline limestone that are interbedded with quartz–biotite and muscovite schist. Thin magnetite iron silicate beds are present in the upper part of the iron-formation and are transitional to the overlying mica schist. The iron-formation is less than 100 feet thick in parts of this area but averages 30 to 35 per cent iron and is mostly lensy, banded, granular, hematite-rich facies. It dips 15°S in general, but is folded and dips range from 30 to 45 degrees east to west where beds strike southwest. Beds dipping 70°E appear to be parts of asymmetric folds that may be overturned to the southeast. The pattern of broad open folds with the occasional asymmetric or overturned folds in this area is favourable for the occurrence of iron-formation in a broad zone at the present surface of low relief.

Iron-formation is exposed along a creek about 6 miles north of the northwest end of Lac la Bouille and about 3 miles northeast of the last area described. Outcrops are found intermittently for a distance of 2 miles between the two main exposure areas. The general regional strike is northeast and the beds dip gently, about 15 to 20 degrees, southeast. Much of the unit is crenulated and folded in a series of minor recumbent flexures that have pointed crests and straight limbs. The axial planes of these flexures dip 15°SW and axial lines plunge southeast. They may be the result of thrusting from the southwest. The iron-formation is warped into a series of broad anticlines and synclines that plunge gently to the southeast.

The iron-formation is estimated to be about 200 feet thick stratigraphically but the actual thickness in this folded structure is not determined. It is underlain by mica-quartz schist with lenses of dolomite and overlain by mica schist and gneiss. It is mainly thin-banded specular hematite–quartz facies that is medium grained. Magnetite-rich beds are present in some parts. Lower parts of the unit may have lenses very rich in hematite but most of it contains about 25 per cent iron.

Matonipi Lake–Mouchalagane River Area

Highly metamorphosed iron-formation is exposed at a number of places in an area that lies about 170 miles northwest of Sept-Iles and 120 miles southwest of Mount Wright. The occurrence of "bedded iron ore" in this area was first reported by Low (1897) of the Geological Survey of Canada and investigations were conducted in the following years by H. L. F. Blake in 1920 for British interests, by R. Gilman in 1937, by A. E. Walker in 1938 for the M. A. Hanna Company, by John B.DeMille for New Quebec Exploration Ltd. in 1948, and by G. H. Babcock and W. S. Moore Company in 1949 and 1951 respectively. Claims in the area were optioned from the W. S. Moore Company by Oliver Iron Mining Division of United States Steel Corporation and investigated in 1952 and 1953. The writer completed systematic geological mapping of a number of claim groups as a part of this program. Since that time the iron-formations in the area have been examined by several other companies operating under option agreements with the W. S. Moore Company.

Iron-formation is exposed intermittently in the area west of Mouchalagane River for a distance of 30 miles. Much of it is relatively thin and deposits explored to date are of marginal economic interest. They consist of beds repeated by intense folding and faulting within zones large enough to be considered for future mining. There are marked differences in the predominant facies outcropping in various parts of the area, with lateral gradations to specular hematite–quartz members as well as local thickening and thinning of the iron-formation. Because of these variations in facies types, the regional distribution of the iron-formation is difficult to trace by magnetometer surveys. Considerable detailed geological information is required before the complex structure and quality of the iron-formation can be appraised with any degree of certainty.

A number of local areas are described briefly below to give some appreciation of the iron potential in this western end of the geosyncline belt.

Matonipi Lake Area

Iron-formation is exposed in a series of folds that form a synclinal belt about 2 miles wide and 10 miles long along the west side of Matonipi Lake. The Table XVIII

TABLE XVIII | *Table of Formations—Hugh Knob Area*

Era	Approximate Thickness (feet)	Formations and Lithology
RECENT		Glacial deposits, unconsolidated surface material
PRECAMBRIAN		*Granite* intrusions and pegmatite dykes
		Gneiss and schist
	20-30	Quartz–muscovite–garnet schist
	50±	Feldspar–biotite–hornblende–quartz gneiss
	20±	*Upper quartzite*
	150-200	Meta-dolomite: crystalline dolomite bearing considerable siliceous material
	10-15	*Middle quartzite*
		Iron-formation
	30-40	Iron-silicate–magnetite–quartz iron-formation; minor carbonate
	50-60	Magnetite–specular hematite–quartz iron-formation; metataconite type
	30-40	Iron-silicate–magnetite–quartz iron-formation; minor carbonate
	5-20	*Lower quartzite:* upper parts bear lenses of ferruginous carbonate. Lower parts are biotite rich
		Feldspar–biotite–hornblende–quartz gneiss

gives the stratigraphy at Hugh Knob[1] near the northwest corner of this belt, which is representative of the region.

Stratigraphy

Gneisses above and below the iron-formation sequence were not mapped separately and are very similar to those seen in other parts of the region. They are essentially thin-banded, medium-grained, feldspar–biotite–muscovite–hornblende–quartz rocks with well-developed foliation. Plagioclase (An_{20}) is usually more abundant than microcline, and muscovite and biotite are in equal proportions except where hornblende and biotite constitute mafic bands and muscovite is lacking. Considerable titanite is present with the biotite, and almandine garnet and epidote are present in various amounts. Zircon and apatite are fairly abundant accessory constituents.

Quartzite below the iron-formation is medium grained, fairly massive, and contains considerable biotite and garnet. The transition zone to the overlying ferruginous rocks consists of irregular lenses and thinly laminated patches of brown weathering ferruginous dolomite unevenly distributed in quartzite (Pl. XIV B). The lower quartzite varies in thickness and appears to be derived from unevenly distributed irregular clastic lenses. This unit is missing in some sections.

The iron-formation at Hugh Knob consists of two distinct lithological facies typical of the facies found in many parts of the region. The order of succession at Hugh Knob is typical of that present in many of the ferruginous deposits, but specific lithological units may range in thickness from a few feet to more than a hundred.

Iron-silicate–magnetite–carbonate–quartz facies. The lower part of this facies is marked by thin-banded quartzite and dolomite, the banding usually a fraction of an inch to an inch thick. The quartz bands, which make up about 60 per cent of the rock, are medium grained (1-2 mm) and consist of a mosaic of buff glassy grains. They form fairly continuous ribbons or laminae which stand out on the weathered surface. The intervening laminae of ferruginous dolomite are medium grained and weather rusty brown. Considerable hypersthene is disseminated in the ferruginous dolomite.

The dolomite–quartz beds grade into grunerite–hypersthene–magnetite–quartz beds with only a minor amount of dolomite. In this facies the quartz bands are thinner and less conspicuous, due to the development of coarser, rich silicates. The grunerite and hypersthene are intimately mixed in a felted mass of variable grain size with fibrous to sheaf-like clusters of silicate grains varying from several inches to a few millimetres in length. Good bedding plane foliation in the rock is caused by preferred orientation of most of the grunerite and hypersthene, and much of the hypersthene shows a pronounced lineation parallel with the fold axes. Some of the coarse silicate aggregates along certain bands have decussate texture and may represent a late stage of recrystallization. A few narrow stringers and veins of coarse-grained hypersthene oriented perpendicular to the vein walls cut across the banding and foliation.

The magnetite disseminated in this facies is mostly fine grained, much of it occurring as very fine specks in the silicate minerals but the occasional silicate band bears coarse (4-5 mm) anhedral magnetite clusters. Almandine garnet occurs very sparingly, but may form conspicuous 4-5 mm crystal aggregates. About 60 per cent of this zone is composed of a mosaic of quartz grains, approximately 1 mm in size.

[1]Now Peguin Knob

The upper part of this unit is transitional to the iron oxide–quartz unit. The transition is marked by a decrease in amount and grain size of the grunerite and hypersthene and an increase in the amount and grain size (0.1-0.5 mm) of the magnetite. The grunerite and hypersthene are more evenly disseminated and thin banding is emphasized by quartz-rich and magnetite–silicate-rich laminae. Some of the silicate-rich laminae in this part of the transition consist of medium-grained, blue-green hornblende and occasionally a little actinolite. Much of the green amphibole is unevenly distributed in crudely defined lenses.

Magnetite–specular hematite–quartz unit. This metataconite type iron-formation is of economic interest and is composed of interlaminated quartz and ferruginous quartz bands a fraction of an inch thick. On the whole, banding in the Matonipi Lake metataconite is somewhat thinner than in the Mount Wright metataconite, but where this unit thickens, as it does in the Jones Creek[1] and Hummingbird Lake[2] areas, the banding may increase in thickness, and massive beds up to 2 feet thick are common. The rock is dark blue-grey and forms a very tough resistant unit in the stratigraphic sequence.

The mineral composition is simple, including 25 to 30 per cent of magnetite and specular hematite, the remainder being largely quartz although a small amount of fine-grained hypersthene and grunerite is occasionally distributed in the ferruginous bands. The quartz forms a tightly interlocked mosaic of irregular grains ranging in size from 0.5 to 1 mm. The iron oxide is distributed in crudely defined bands, about 75 per cent of it occurring in grains 0.5 to 1 mm in size. The remainder of the oxide is finer grained. Some of the coarser magnetite grains are well-formed octahedrons, but the bulk of the oxide grains are irregular and lack crystal outline.

The specular hematite is erratically distributed with the magnetite and only a small amount of the iron is present as hematite. Generally, specular hematite is not found where iron silicate minerals are present and is consequently more common towards the central part of the metataconite facies. Specular hematite is impressive where it forms large platy crystals up to an inch long that line cavities and pockets in the rock. Coarse quartz crystals may also be present in these vuggy openings. The hematite does not appear to follow distinct bands, nor is it confined to any one horizon. Inadequate exposure has obstructed study of the distribution of the hematite in this unit, but it is interesting to note that polished surfaces reveal irregular cores of magnetite in some of the coarser (1 inch) hematite plates. The textural evidence is not conclusive but these clusters of fine magnetite grains developed in the hematite plates suggest that part of the specular hematite was altered to magnetite. At one outcrop in the Jones Creek area, hematite crystals over an inch long have a radial arrangement forming a distinct rosette which cuts across the banding of the rock (Pl. XV B). The finer grained hematite associated with magnetite appears to form discrete grains, so the relationship between the iron oxides is not clear. The coarse-grained porphyroblastic hematite with the evidence of its alteration to magnetite suggests that the paragenesis of the iron oxides may be very complex.

There is very little evidence of migration of the iron oxides during metamorphism.

[1]Now Rousy Creek
[2]Now Bartel Lake

There is an apparent increase of magnetite in individual bands along the crests of minor folding, but hardly any evidence of iron oxide migrating across the banding.

'Upper iron-silicate–magnetite–quartz unit'

The uppermost unit of the iron-formation is similar to the lowermost but the order of lithological facies is reversed. The metataconite grades upwards into a thin-banded iron-silicate-rich facies, which in turn grades over a few feet into the overlying 'middle quartzite'. A small amount of ferruginous dolomite is present in the transition zone adjacent to the middle quartzite.

One interesting zone about 1½ feet thick, near the base of the unit is distinctly lenticular, very like the wavy banded carbonate-silicate-chert iron-formation of the Negaunee Formation of the Marquette Range in Michigan. The lenses vary from 4 to 8 inches in length and at most 1 inch or 2 inches wide. The banding in the iron-formation adjacent to this lenticular banded zone is straight with little or no contortion and there is no evidence of shearing; in fact, decussate texture is present in some of the bands in all facies examined. The lenticular forms are developed by pinching and swelling of adjacent quartz bands, and the lens-like masses consist of thinner laminae that form concentric shells (Pl. XV A). Of the numerous small-scale textural features in less metamorphosed cherty iron-formation, very few, if originally present, have been preserved in this area. The lenticular banded layers in these rocks appear to be primary sedimentary features. The rocks resemble wavy banded cherty rocks and were probably developed from them. It may be argued that these lens-like masses are structural features produced by shearing, but the thin quartz bands in this whole section are not broken or offset and the most delicate bands in the centres of the lenses are distinct and undisturbed.

'Middle quartzite'

This thin but persistent band of quartzite lies above the iron-formation and is fairly massive with some crudely defined banding suggestive of original bedding. It is composed of a medium-grained recrystallized mass of quartz grains tightly interlocked in a mosaic texture. Most of this quartzite contains less than 10 per cent biotite or muscovite, but a few zones contain 15 to 20 per cent biotite and 10 to 15 per cent albite. Minor amounts of garnet are usually present.

Crossbedding or enlarged quartz grains have not been found, but well-rounded zircon grains in the heavy mineral fraction indicate a clastic, sedimentary origin.

The transition from quartzite to the overlying dolomite takes place over a few feet and is characterized by interbanded quartzite and dolomite lenses, usually a few inches thick. In some places the quartzite lenses are fractured and form boudinage structures in the dolomite.

Meta-dolomite

Most of the area for 2 miles west of the west shore of Matonipi Lake is underlain by medium- to coarse-grained siliceous dolomite. The bands vary in thickness from a few inches to a foot and are highly deformed. The dolomite is buff to brown on weathered surfaces and is exceedingly friable, with numerous resistant siliceous bands and nodules. Numerous thin quartz bands present in some areas are thought to be metamorphosed cherty layers. Very coarse tremolite and actinolite grain clusters are conspicuous on weathered surfaces and kyanite is associated with them in places. Talc schist is present in some shear zones that post-date the intense deformation in the dolomite.

'Upper quartzite'

A thin quartzite unit, similar lithologically to the middle quartzite, is present above the dolomite in some areas. It is overlain by coarse-grained almandine muscovite schists interbedded with gneiss.

Structural Geology

Two principal bands of iron-formation form the limbs of a broad synclinorium. The eastern band of iron-formation and associated metasediments dips 75°W and the band along the western side of the area dips 35 to 70°E. A number of long narrow bands of tightly folded and faulted iron-formation with meta-dolomite are exposed in the central part of this synclinal belt. The plunges of major folds in general do not exceed 30 degrees, and long sinuous bands of iron-formation exposed at the surface are faulted sheets or the narrow crestal parts of anticlines. The general pattern of folding, as shown by interbanded meta-dolomite, quartzite, and iron-formation along the north end of the Hugh Knob area, is typical of that found in much of the belt. The anticlines are narrow inverted V-shaped flexures separated by broad well-rounded U-shaped synclines. The iron-formation and associated quartzite apparently responded as very competent beds during folding but the overlying dolomite was much less competent and probably yielded more by flowage than by folding. Under compression the siliceous rocks were thrust upwards in narrow anticlinal flexures into the less competent dolomite.

Besides the thrust faults associated with the folds, there are northwest-striking cross-faults. Some of these have left-hand displacement and others right-hand.

Metamorphism

Mineral assemblages indicate that equilibrium was achieved in the epidote–amphibolite to amphibolite metamorphic facies. All lithological units are medium grained and most small-scale primary features have been destroyed during recrystallization. Metamorphism has been an isochemical process in most units except in some of the schists and gneisses where small veins of quartz and feldspar cut across the banding and may pass into the ferruginous or carbonate beds. This material is considered to have come from the gneisses and to have been mobilized during the main period of metamorphism.

Iron Deposits

The largest zones of iron-formation are at Hugh Knob in the northwest part of the belt and near Jones Creek at the south end. Most bands are too narrow to be of economic interest and very limited tonnage is indicated within the depth of open pit mining.

Matonipis Lake Area

Small exposures of magnetite–specular hematite–quartz iron-formation occur on the portage between Matonipi and Matonipis Lakes and on the islands at the northwest end of the latter.

Much of the iron-formation indicated by a magnetic anomaly lies under the lake, and only narrow widths are exposed.

Hummingbird Lake Area

(long. 69°33′, lat. 51°45′)

Iron-formation forms two prominent hills west of this lake, which lies 4 miles southeast of Lac Larocque. The main exposure called Barn Mountain[1], immediately west of the lake, is 4,000 feet long. It is from 500 feet wide near the north and south ends and about 1,500 feet wide in the central part. Surface dips of the beds, about 35 degrees around the border of the structure and from 15 to 75 degrees in the central part, indicate tight folding of the beds in a syncline. Thin bands of iron-formation associated with gneiss on the east side of the hill dip 25 to 45 degrees west. Some of these are infolded synclines of iron-formation, but one or two others may be separate iron-bearing units at the base of the main formation. Judging from the nature of the folding around the borders of this structure it is doubtful if mineable iron-formation is more than a few hundred feet deep.

The iron-formation is associated with banded gneisses and garnet–biotite–hornblende schist. Oxide facies consisting mainly of thin-banded magnetite and quartz is underlain by a khaki to dark green, thin-banded to schistose grunerite–hypersthene–magnetite–quartz unit that has carbonate-rich zones and is overlain by a thin unit composed of similar material. There is considerable interfolding of these units in the large drag-folds that form part of the major structure.

South Mountain[2] is about a mile west of Hummingbird Lake and like Barn Mountain has a very steep west slope formed by iron-formation, which underlies an area about a mile long by 500 to 1,500 feet wide. The dips of the beds range from 55 to 10°E with the lowest dips being in the central part of the area. The major structure is interpreted as a doubly plunging asymmetric syncline and the very irregular deeply indented margin and highly crenulated outcrops along the borders indicate intense drag-folding around the base of the structure.

The iron-formation in the western exposures is mainly specular hematite and quartz with minor magnetite, which overlies a succession of thin silicate–carbonate–magnetite beds. This silicate facies is found near the margins of the syncline and may be thicker towards the east. Magnetite is more abundant in the oxide facies to the east. The hematite-rich facies in South Mountain is typically coarser grained than the magnetite-rich facies in the area but both are medium to relatively coarse grained. Very good concentrate can be made from this iron-formation which grades from 32 to 35 per cent iron with splendid recovery ratios on material ground to −65 mesh.

[1]Now Mount Langy
[2]Now Mount Megré

Parr Lake Area

Parr Lake lies east of Hummingbird Lake and 2½ miles west of the Mouchalagane River. A band of specular hematite–quartz iron-formation associated with gneiss that dips steeply east extends north for about 1½ miles from the northeast end of the lake. Another band composed of specular hematite–quartz facies and magnetite–quartz facies is exposed on the higher ground about a mile south of the south end of Parr Lake. It has been traced for at least a mile south from this location.

Lac Bacouel Area

Specular hematite–quartz iron-formation forms two synclinal structures in an area a mile or two east of the south end of Lac Bacouel which lies immediately northeast of Lac Larocque.

Another band of iron-formation examined is about 4 miles northeast of Lac Bacouel and about 1½ miles west of Mouchalagane River. A narrow folded band of specular hematite–quartz iron-formation was traced northward along strike for a distance of 2 miles. The iron beds are associated with quartzite and the succession infolded in a series of gneissic rocks. In general, these beds dip 10 to 30°W with local steepening or reversal of dips. It is particularly interesting to find up to 6 feet of massive specular hematite and magnetite at the base of this succession in the northern exposures. This is believed to have been a primary, hematite-rich unit that may be correlated with hematite-rich beds near the base of the section in some parts of the Seignelay River range.

Magnetite-rich zones are present in some parts of the hematite-rich succession. A vein of fine-grained, massive magnetite, several feet thick and containing patches of milky white quartz, is exposed at one place on the east side of this iron-formation. It is one of the few veins of this type seen anywhere in the region.

Mouchalagane River Area

A thin band of magnetite-rich iron-formation associated with meta-dolomite and gneiss is exposed along this river east of Parr Lake. It has been traced intermittently south along the river for at least 6 miles.

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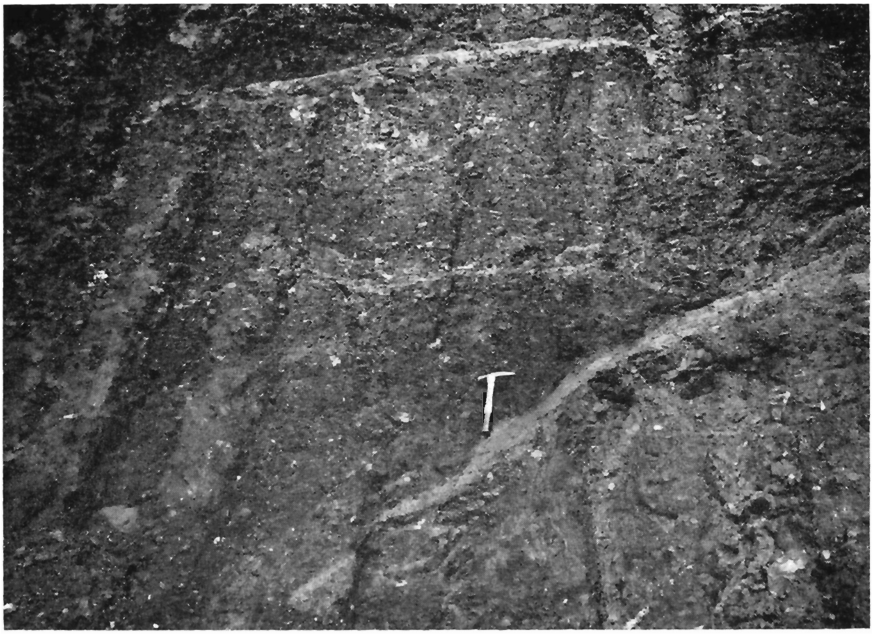
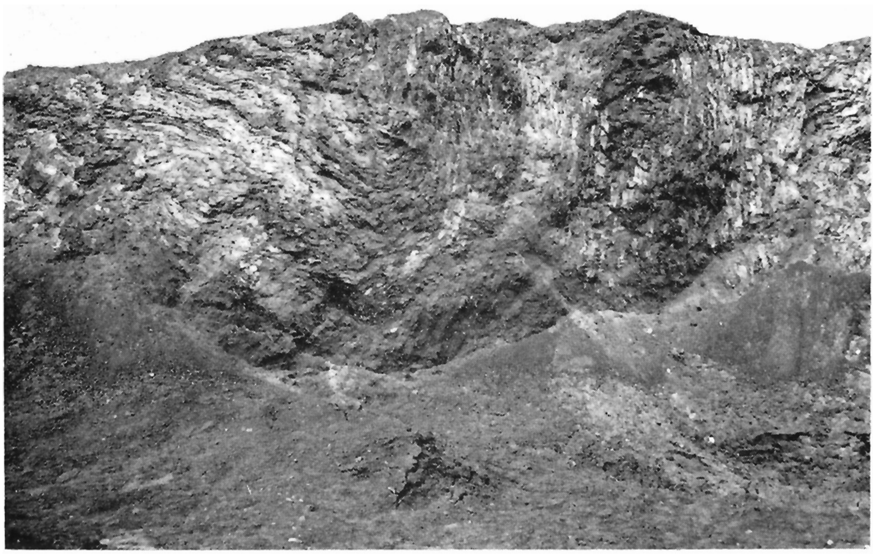
Plates III to XV



Gross, 9-7-60
130843

A. Typical pit face of rubble ore, Ruth Lake mine, Labrador, Newfoundland. Note accumulation of ore fragments and clay seam below hammer.

PLATE III



Gross, 2-7-62
130990

B. Folded and deformed beds preserved in highly leached and friable cherty iron-formation, Wishart mine, Labrador.

Gross, 8-5-60

A. The west end of French mine, Quebec, northwestward, 1960.

130830

PLATE IV

Gross, 9-10-60

B. Loading iron ore in French mine, Quebec, 1960.

130845

PLATE V. THREE STAGES IN THE DEVELOPMENT OF GAGNON A MINE, QUEBEC; VIEW NORTHWARD

A. The northwest face of the mine in 1957

Gross, 3-4-57 152336

B. Gagnon A mine in 1960

Gross, 7-11-60 130825

C. Gagnon A mine in 1962

Gross, 2-6-62
130989

Gross, 2-1-62
130984

A. Ore conveyor system and loading station, Gagnon A mine, Quebec, 1962.

PLATE VI

Gross, 7-10-60
130824

B. View northward into Gagnon C mine, Quebec, 1960.

Gross, 8-8-60
130832

A. The southeast part of Ruth Lake mine, Labrador; southward, 1960.

PLATE VII

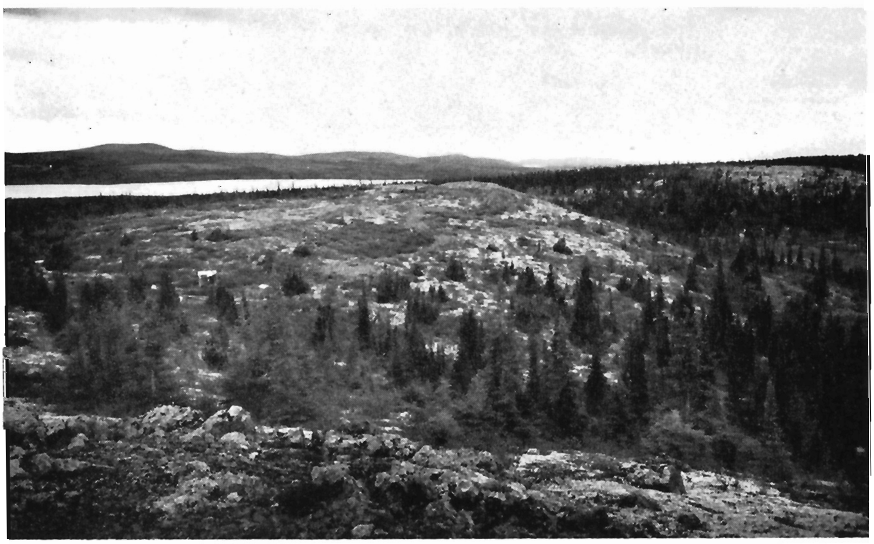
Gross, 112341-D

B. Gill mine, Labrador, 1957, southward. The iron ore deposit lies along the east side of a steep dip-slope.

Gross, 9-1-60
130837

A. Wishart mine, Labrador, during early stages of development, 1960; southeastward.

PLATE VIII



Gross, 7-8-60
130822

B. View southward over the Sawyer Lake iron deposit, 1960.

Gross, 3-6-57
152337

A. Differential erosion of leached and friable magnetite hematite quartz iron ore.

PLATE IX. IRON-FORMATION IN THE WABUSH LAKE AREA, LABRADOR

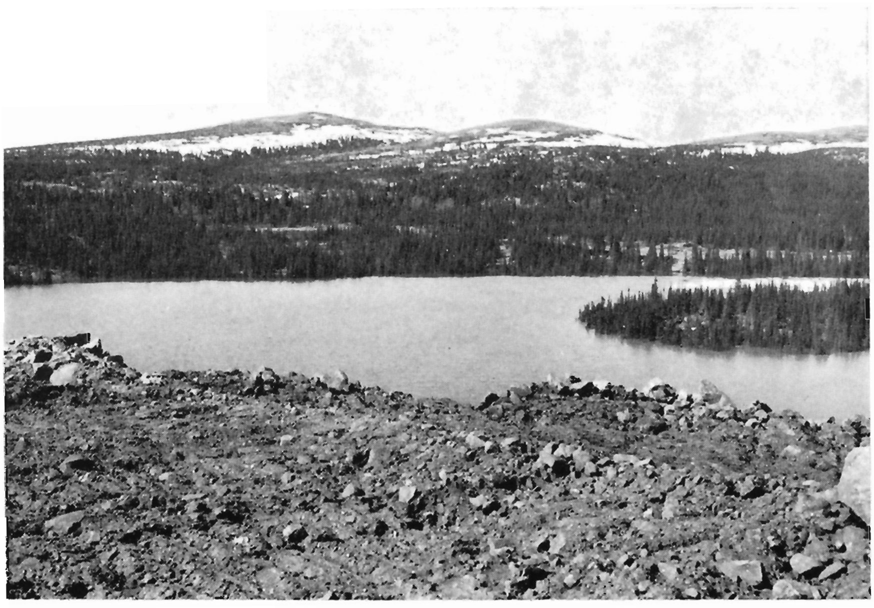
Gross, 1-7-62
130978

B. Typical folded and deformed magnetite–hematite–quartz iron-formation, Smallwood mine, Labrador

Gross, 112341 -T

A. The south end of Smallwood mine during early stages of mining, 1962; looking west.

PLATE X



Gross, 1-10-62
130981

B. View northwestward to Wabush Signal hill and Carol East iron ore deposit, Wabush Lake area, Labrador.

Gross, 112341 -J

A. Northward along a fault zone that cut folded and deformed beds of iron-formation prior to the major period of metamorphism. South of Lorraine Lake, Wabush Lake area.

PLATE XI

B. Glacial till overlying leached and friable iron-formation south of Little Wabush Lake, Labrador. Pocket beside hammer left by disintegrated boulder of iron-formation.

Gross, 7-4-60

130818

PLATE XII

A. Typical topography over the Mount Wright highland, northeastward; Mount Wright in the distance.

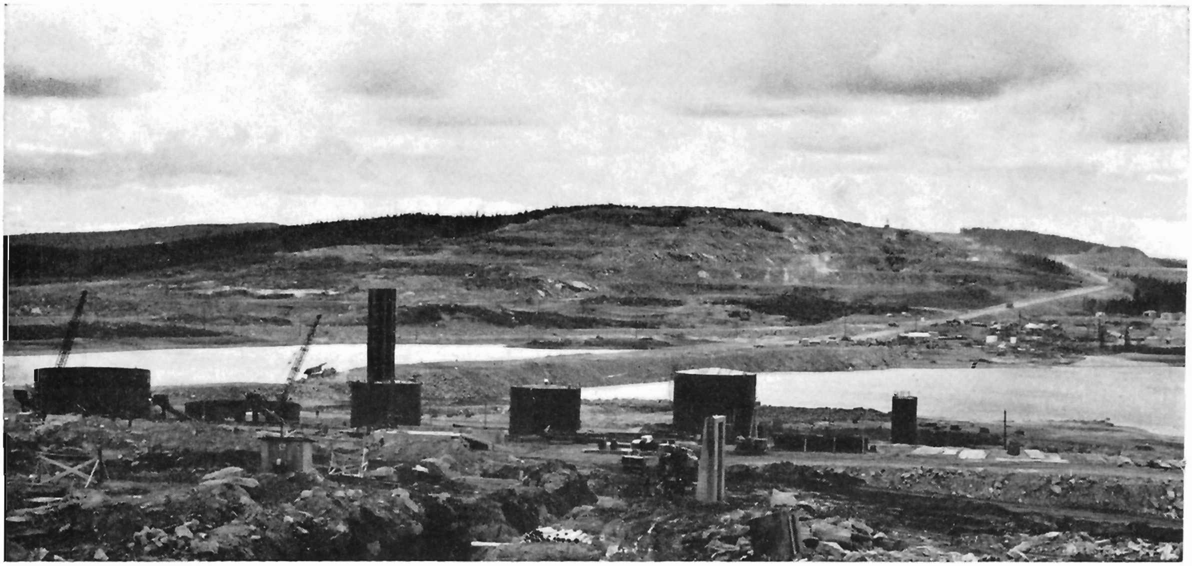
Gross, 112341 –M

B. Typical thin-banded hematite quartz iron-formation at Mount Wright.

Gross, 112341 – P

C. Transition from hematite–quartz iron-formation (dark grey) to orthoquartzite (light), Mount Wright area, Quebec.

Gross, 112341 –X



A. Lac Jeannine mine, Quebec, westward, 1960.

Gross, 4-7-60
130789

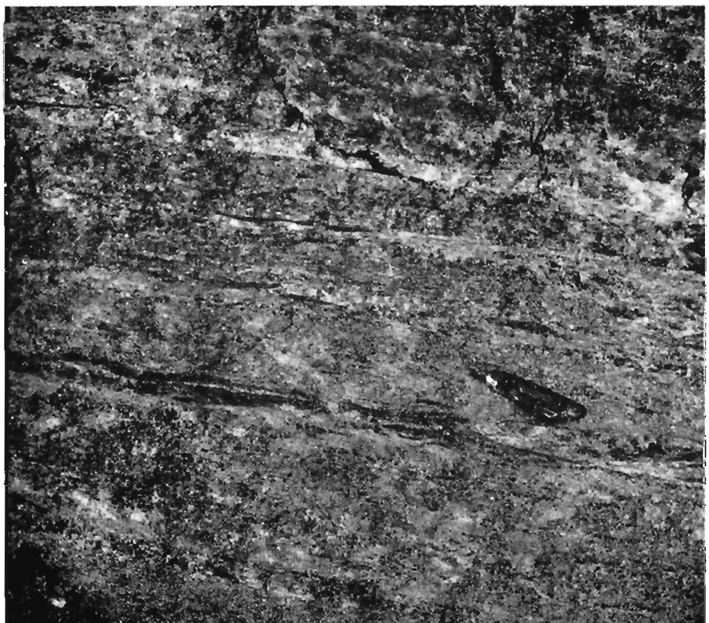


PLATE XIII

Gross, 130778

B. Coarse-grained hematite-quartz iron ore, Lac Jeannine mine.

Gross, 2-5-60
130768

A. Mount Reed, Quebec, northward to north-east part of the iron ore deposit (1960).

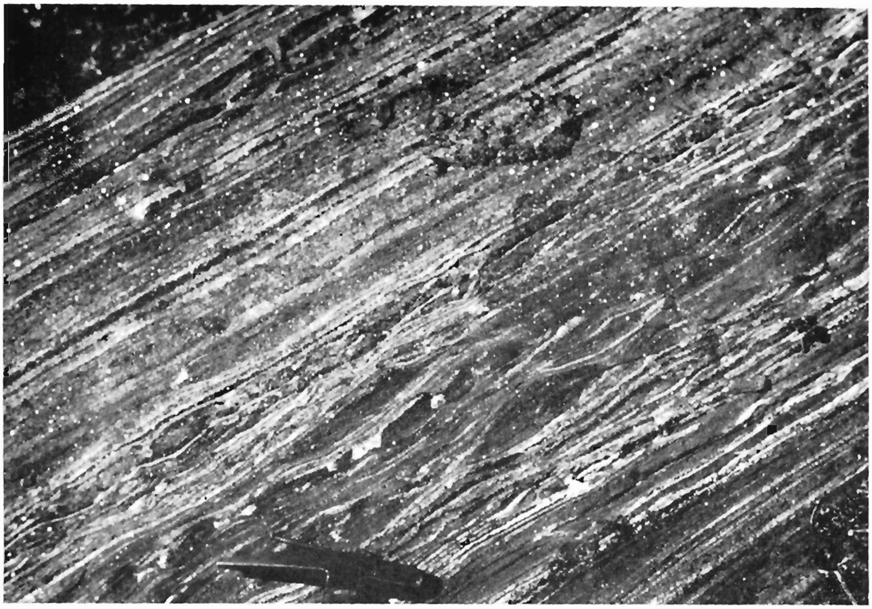
Gross, 3-7-60

130777

PLATE XIV

B. Transition from quartzite to carbonate facies to thin-banded iron-silicate facies of iron-formation, west of Matonipi Lake, Quebec.

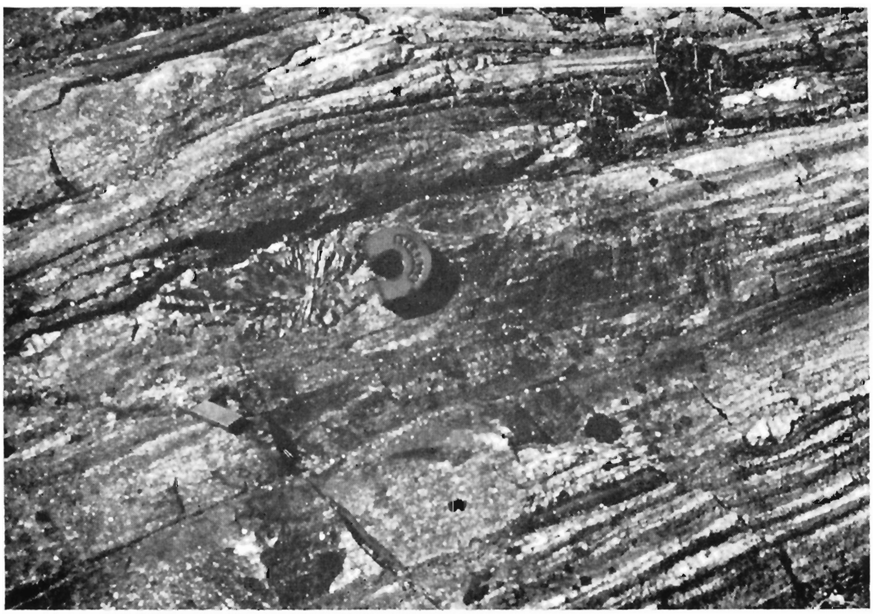
Gross, 112341 -N



Gross, 112341-I

A. Wavy banding in magnetite—quartz iron-formation, west of Matonipi Lake, Quebec.

PLATE XV



Gross, 112341-H

B. Rosette of hematite crystals in magnetite· quartz iron-formation near Matonipi Lake, Quebec.

INDEX

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Comprehensive studies of economic interest on a broad regional basis. Some recent titles are listed below (Queen's Printer Cat. No. in brackets):

1 Geology and economic minerals of Canada (4th ed.), *by* Officers of the Geological Survey, 1957, $4.00 (M43-1)

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