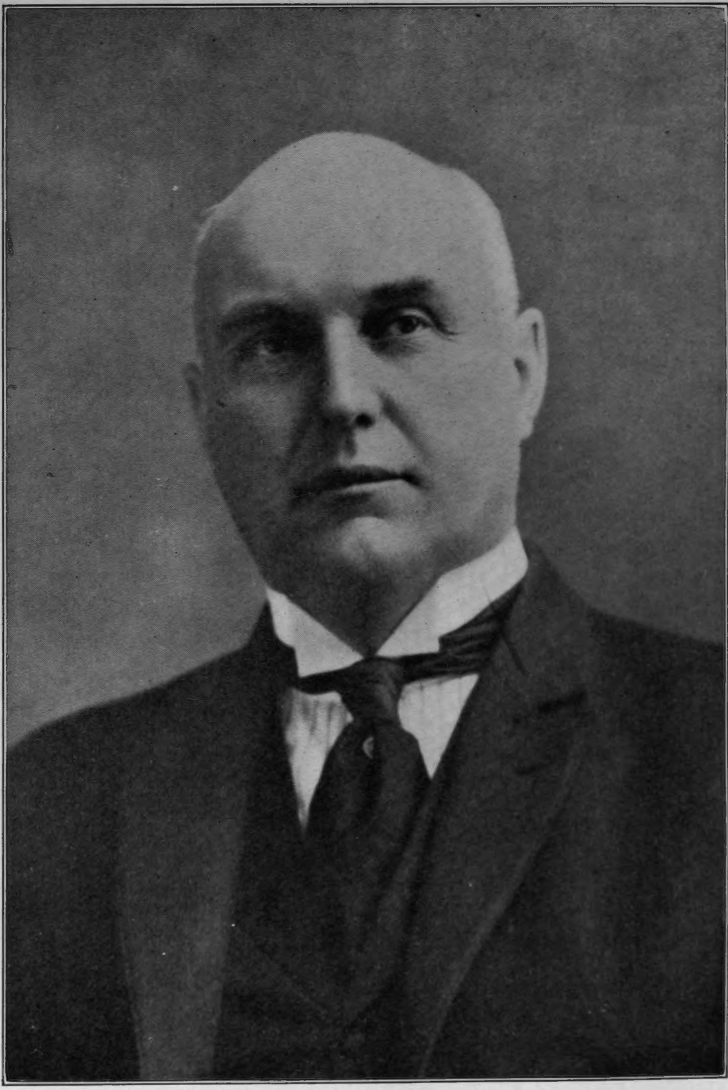
DOMINION OF CANADA
DEPARTMENT OF MINES

CANADA

GEOLOGY MINES *and* METALLURGICAL INDUSTRIES

SECOND (TRIENNIAL)
EMPIRE MINING AND METALLURGICAL CONGRESS, 1927

PLATE I



HONOURABLE CHARLES STEWART

PRESIDENT OF THE CONGRESS

AND

MINISTER OF MINES

DOMINION OF CANADA
DEPARTMENT OF MINES

CANADA

GEOLOGY MINES *and* METALLURGICAL INDUSTRIES

BY
WYATT MALCOLM
AND
A. H. A. ROBINSON

SECOND (TRIENNIAL)
EMPIRE MINING AND METALLURGICAL CONGRESS, 1927

PRINTED AT
GOVERNMENT PRINTING BUREAU
OTTAWA

CONTENTS

Illustrations

PREFACE

This handbook was prepared specially for the Second (Triennial) Empire Mining and Metallurgical Congress in order that those attending it from overseas might have available in concise and readily accessible form pertinent information concerning the mining and metallurgical industries of Canada and the natural resources upon which they are based.

In the first quarter of the present century the mining and metallurgical industries of Canada have steadily assumed world prominence from the points of view of production and of reserves, and their development has now reached a stage which makes a review of this kind of particular interest. It is hoped that this volume will prove worthy of the dual purpose for which it is intended —as a guide to the more important mining and metallurgical centres on the itinerary of the Congress, and as a handbook of general information concerning the development of these important industries in the Dominion.

CHARLES STEWART,

Minister of Mines; and President of the Second (Triennial) Empire Mining and Metallurgical Congress.

OTTAWA, CANADA,
June 1, 1927.

Canada: Geology, Mines, and Metallurgical Industries

CANADA

AREA AND EXTENT

The Dominion of Canada comprises the northern half of North America with the exception of Alaska, Greenland, Newfoundland, and the small islands of Saint-Pierre and Miquelon. It extends from the Atlantic to the Pacific —*Ab mari usque ad mare*—and from the 49th parallel of latitude and the Great Lakes to the north pole. The area is 3,797,123 square miles, approximately that of Europe.

GEOLOGY AND PHYSIOGRAPHY

Introduction

The outstanding feature of Canadian geology is the vast area underlain by formations of Precambrian age. These occupy nearly the whole of Canada east of a line joining lake Winnipeg and Great Bear lake, with the exception of the Maritime Provinces, the extreme southern parts of Ontario and Quebec, and a part of Ontario adjacent to the southern coast of Hudson bay. The Precambrian rocks include the oldest known geological formations and are the foundation of a part of the North American continent that has existed as a land mass at intervals throughout all that part of geological time that has been recorded in sedimentary formations exposed on the face of the earth.

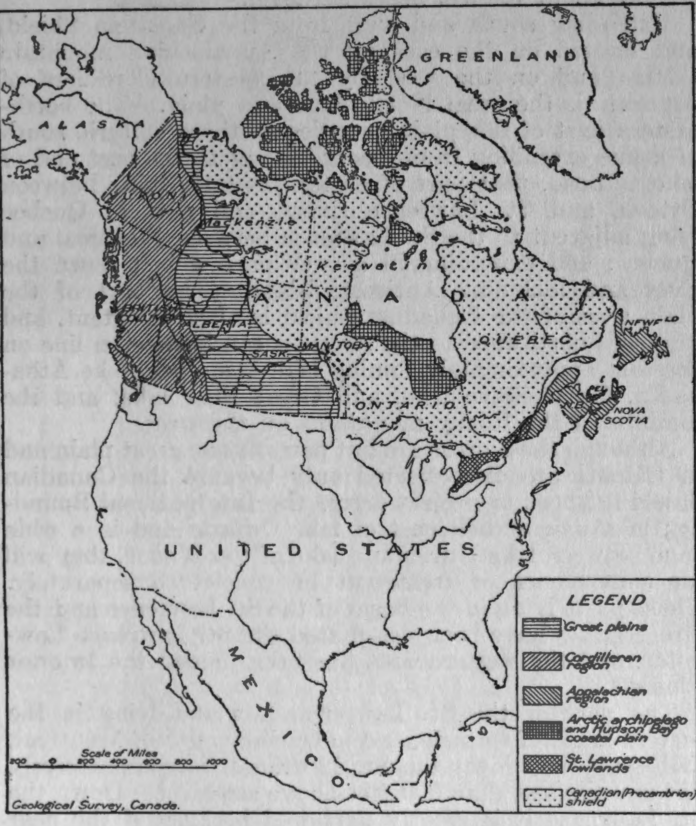
Another prominent feature is the wide extent of nearly flat-lying sedimentary formations of Palæozoic, Mesozoic, and Cenozoic age that almost wholly surround the Precambrian area. They form a mantle spread out on a sloping shelf of Precambrian rocks and at one time probably extended over a great part of the Precambrian area. In few places was there even fairly continuous sedimentation throughout the three great geological periods and the succession of strata is in most places broken and incomplete.

Approaching the Atlantic and Pacific coasts the flat-lying sedimentary series give way to great assemblages of folded sedimentary and volcanic rocks pierced by granitic bodies and forming the Appalachian system of mountains on the east and the great Cordillera on the west. In the folding, rocks of Precambrian age are again brought to the surface. In the extreme north an analogous mountain range stretches from Greenland westward into Ellesmere island.

Physiography

The physiography of Canada is the outward or surface expression of geological processes that have been in operation at the surface of the earth and at depth throughout geological time. It is the imprint made by the deposition of sediments, the folding of strata, the intrusion of igneous masses, the ejection of volcanic material, and the dissolving, eroding, and transporting of rock matter by agencies acting at the surface. The slow rising and sinking of broad continental areas, the forming of great mountain ranges, and their gradual levelling, are all involved. The present land form is only a momentary expression of a continent that is undergoing eternal change.

The great area in eastern Canada underlain by rocks of Precambrian age is known as the Canadian (or Precambrian) Shield, or the Laurentian plateau. It may be regarded as a subdued plateau or perhaps, more strictly speaking, a peneplanated surface that has been rejuvenated by Pleistocene glaciation and uplift. Its average elevation probably does not exceed 1,500 feet, and there are few areas except in the northeast that exceed 2,000 feet. In general, the surface slopes gently to the surrounding plain and there are long stretches of the boundary in which there is no marked difference of elevation between the Precambrian Shield and the adjacent Palæozoic plain; there are other long stretches in which there is an abrupt rise of several hundred feet above the plain or the sea. The greatest known elevations are in the eastern part of Baffin island and along the coast of northern Labrador. In Labrador there are four peaks in the Torngats said to have an elevation of 5,000 to 6,000 feet. The Torngats are carved from the edge of an elevated tableland which is highest towards the Atlantic and sinks towards the west. The coast is one of the most bold and rugged of the world with nearly vertical cliffs rising 1,000 to 2,000 feet in height. Though the Canadian Shield is an area of low relief and has a remarkably even sky-line, the surface is, generally, rugged, with successions of rocky hills, 100 to 200 feet high. Occasional exceptions occur in which there is a relief of several hundred feet, as in the hills on the north shore of lake Huron and the north shore of lake Superior. The area is dotted with lakes, large and small,



Map 1. Physiographic map of Canada.

of irregular outline, and with numerous islands. They are rock basins that spill their waters from one to another by short streams with rapids and falls. In an area of 250 square miles in western Ontario, that cannot be considered exceptional, aerial surveys have shown that there are seven hundred lakes. There are well-defined, deep trenches like that occupied by lake Timiskaming, related to faulting or other structural features. Saguenay river flows in a trench that descends to more than 800 feet below sea-level, and lake Superior, the largest body of fresh water on the face of the earth, fills a basin in the Canadian Shield that reaches about 400 feet below sea-level.

Extending south and west from the Canadian Shield, and limited on the east by the Appalachian mountain system and on the west by the western Cordillera of America, is the great North American plain. The north-eastern part of this plain occupies southern Ontario south of a line extending from Georgian bay to the east end of lake Ontario, that part of eastern Ontario lying between Ottawa and St. Lawrence rivers, and part of Quebec lying adjacent to the St. Lawrence between Montreal and Quebec, and extending in a very narrow belt down the river and including Anticosti island. The part of the plain west of the Canadian Shield is of wide extent, and stretches northward to the Arctic ocean between a line on the east approximately joining lake Winnipeg, lake Athabaska, Great Slave lake, and Great Bear lake, and the foothills of the Rocky mountains on the west.

Although these areas are but parts of one great plain and in Canada are disconnected only because the Canadian Shield happens to project across the International Boundary in a narrow belt east of lake Ontario and in a wide zone between lake Huron and lake of the Woods, they will for convenience of treatment be considered separately. Those parts lying in the basin of the St. Lawrence and the Great Lakes have been designated the St. Lawrence Lowlands, and the western area has been named the Interior Plains.

The part of the St. Lawrence Lowland lying in the eastern angle of Ontario, and in Quebec south of Montreal, and extending down the St. Lawrence, is comparatively flat and lies less than 500 feet above sea-level. Down the St. Lawrence it is greatly narrowed because of the near approach of the Appalachian system to the Canadian Shield. The part lying adjacent to lakes Ontario, Erie, and Huron is of less even surface, has its greatest elevation of over 1,700 feet south of Georgian bay, and slopes rather gently to the Great Lakes. A striking topographical feature is the Niagara escarpment. This is an eastward-

Power plant at Point du Bois, Manitoba, near western margin of the Canadian Shield.

A view in northern Manitoba showing characteristic lake country of the Canadian Shield.

facing escarpment having a height of 250 to 300 feet and extending from Niagara peninsula northwest to Bruce peninsula.

The Interior Plains region is in general a rolling country with broad undulations, and has a slope eastward and northward of a few feet a mile, descending from an elevation of 3,000 to 5,000 feet near the mountains on the west to less than 1,000 feet at its eastern border. The elevation of the Canadian Pacific railway at Calgary is 3,439 feet and at Winnipeg 772 feet. The rolling character of the area is relieved by several flat-topped hills, erosion remnants, rising hundreds of feet above the surrounding country, by flat areas that formed the beds of lakes of considerable extent, and by deeply incised river valleys. A striking feature is the broken escarpment of western Manitoba and eastern Saskatchewan, marking the rise of 400 to 1,000 feet from the Manitoba lowland to the upland on the west.

A lowland of considerable extent stretches for some distance into Ontario and Manitoba from the south shore of Hudson bay. The Arctic archipelago consists of large islands, many of which rise prominently from the sea as sloping tablelands, and others of which are comparatively low.

The Appalachian and Acadian regions occupy almost all that part of Canada lying east of the St. Lawrence, with the exception of the lowland west of a line joining Quebec city and lake Champlain. The Appalachian region is a continuation northward, into the province of Quebec, of three chains of the Appalachian system of mountains. The most westerly of these ranges stretches northeast into Gaspe peninsula where it forms flat-topped hills over 3,000 feet high. Botanist dome on Tabletop mountain has an elevation of 4,200 feet. The Acadian region, which includes New Brunswick, Nova Scotia, and Prince Edward island, is an alternation of uplands and lowlands. The northwest part of New Brunswick is an upland with hills and ridges rising to 2,500 feet or higher. Adjacent to the bay of Fundy is a series of ridges rising in places to an elevation of 1,200 feet or more. Between these two New Brunswick uplands is a lowland forming the whole eastern coast of the province and converging towards the southwest. This lowland extends east so as to include Prince Edward island, the western fringe of Cape Breton island, and the mainland of Nova Scotia north of Cobequid mountains. Cobequid mountains have an elevation of

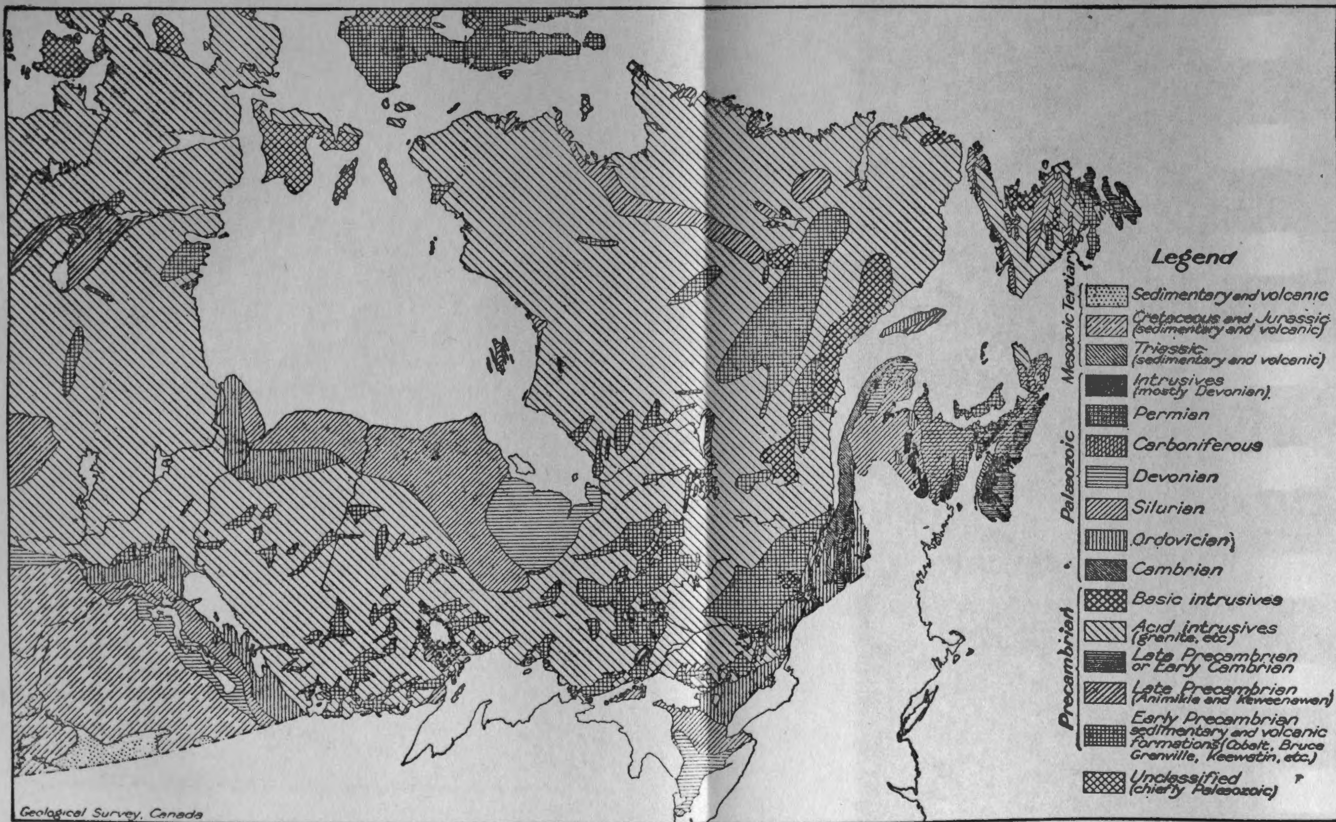
800 to 1,000 feet. South of them lies a long, narrow lowland stretching from Chedabucto bay to Minas basin and along the Cornwallis-Annapolis valley between North and South mountains. South of this is a highland sloping to the Atlantic coast and having an elevation at its highest part of about 700 feet. The northern part of Cape Breton island is a tableland 1,200 feet high and has for its highest point Ingonish mountain, 1,392 feet, the highest point in Nova Scotia.

The Cordilleran region, the mountainous area bordering the Pacific, extends northward from the United States through Canada into Alaska and embraces nearly all of British Columbia and Yukon and the western edge of Alberta and the North West Territories. The eastern part of the Cordillera is occupied by the Rocky mountains. They consist of overlapping chains with peaks rising to heights of 10,000 to 12,000 feet. They extend northwest and die away towards Liard river. North of this river the mountains with a similar trend lie 100 miles farther east and are known as Mackenzie mountains. The western part of the Cordillera is occupied by the Coast range and the mountains of Vancouver and Queen Charlotte islands. The Coast range rises to heights of 7,000 to 9,000 feet. Between the Rocky mountains and the Coast range lies a vast plateau system having elevations of 3,000 to 4,000 feet, and cut by deep river valleys. The plateau region merges into rugged mountain ranges as it approaches the Rocky mountains; it also breaks into mountains in northern British Columbia, but becomes subdued to a plateau again in Yukon. A striking feature of the Cordillera is the wide, deep trench that lies immediately to the west of the Rocky mountains, extends northwesterly from the International Boundary into Yukon, and is occupied by the headwaters of Kootenay, Columbia, and Fraser rivers and tributaries of Peace and Liard rivers.

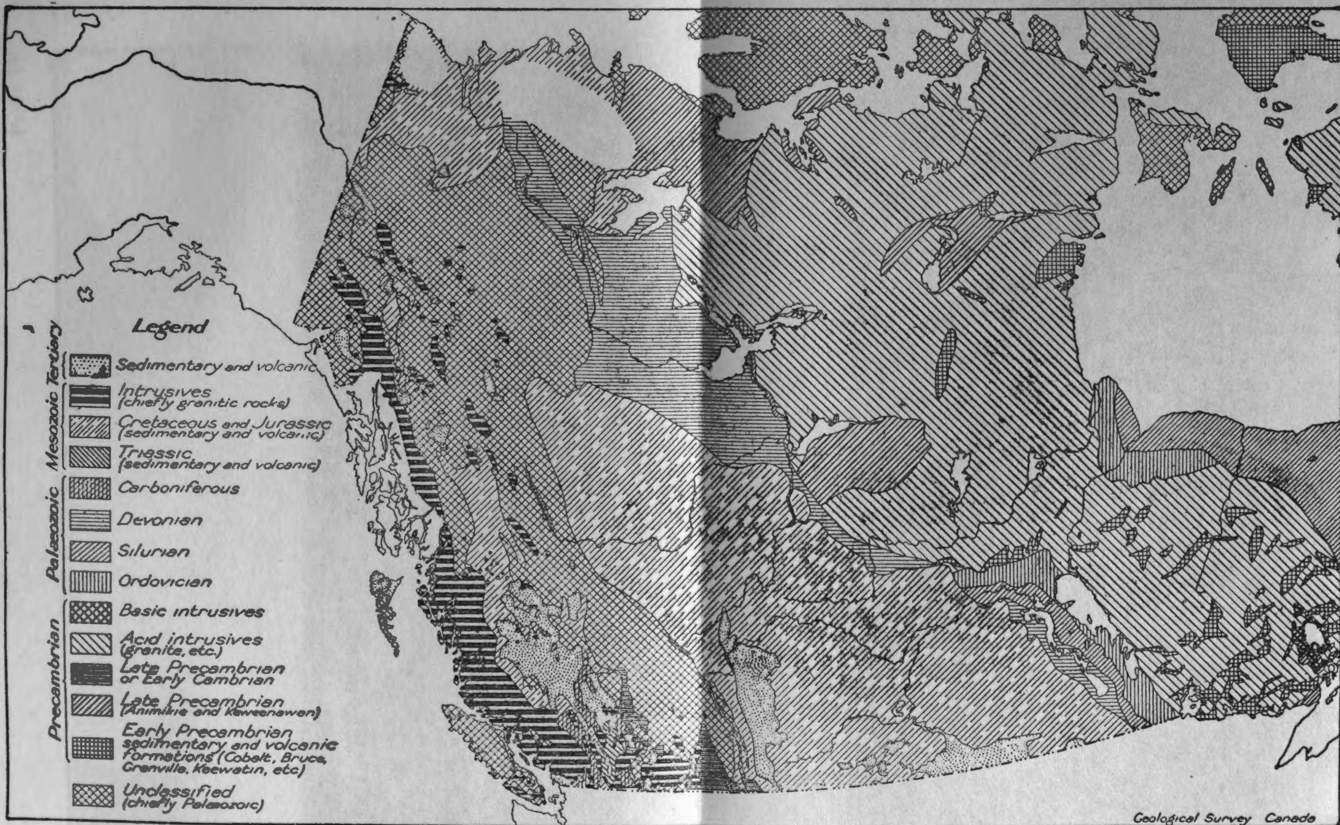
Geology

CANADIAN SHIELD

The Canadian Shield is underlain by rocks of Precambrian age. These consist of series of sedimentary and volcanic formations and igneous intrusives of great variety. They were subjected to mountain-building processes, folded, crushed, and metamorphosed. Although the mountains were reduced nearly to their present level before the

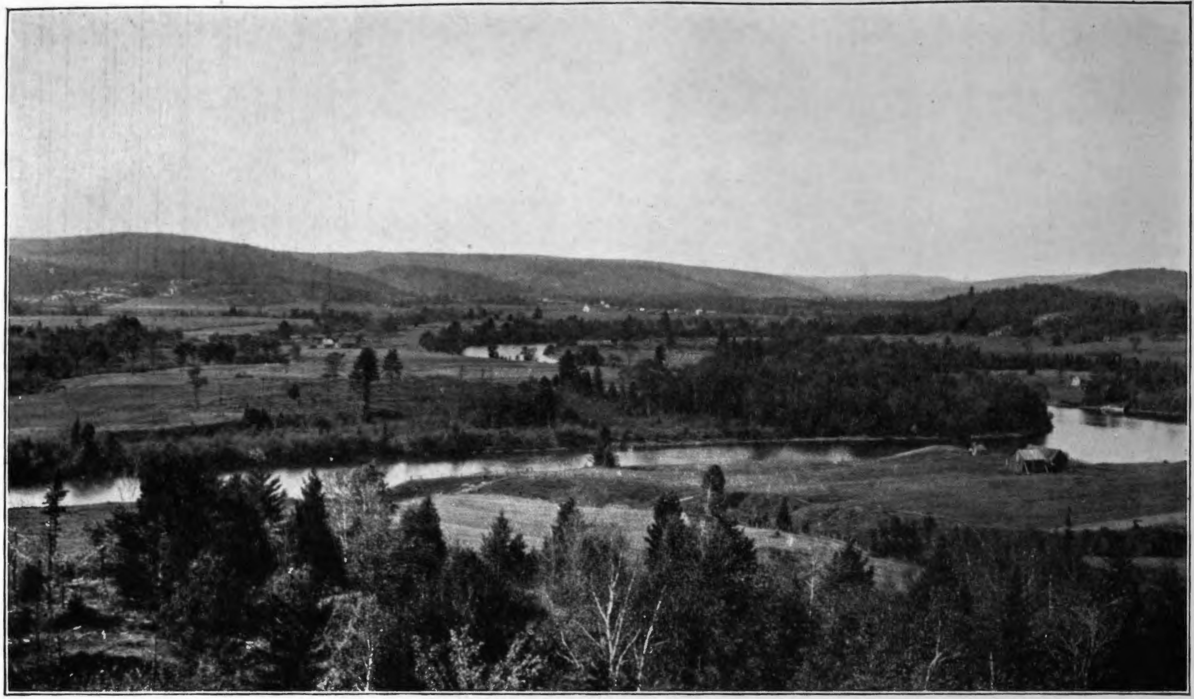


Map 2. Geology of eastern Canada.



MAP 3. Geology of western Canada.

Interior Plateau of British Columbia looking across North Thompson River valley.



Lièvre River valley, Quebec. A valley floored with Pleistocene clay, within the southern margin of the Canadian Shield.

earliest Palæozoic sediments were deposited, the Precambrian area has throughout nearly all recorded geological time maintained itself as a continent, a land mass offering a stout barrier to the buffeting of the waves and a stubborn resistance to the eroding action of the elements.

The period of time represented by the Precambrian sedimentary deposits is probably much greater than that which has since elapsed.

Geologists do not agree on the main subdivisions of the Precambrian formations. They are, however, unanimous on one great unconformity which represents a long period of erosion and which divides the stratified rocks into two groups, an earlier group consisting of a great mass of volcanics with associated sedimentary rocks and a later group consisting more fully of sediments. The earlier group is greatly folded and altered; the later group has in general been less disturbed and altered. In the earlier group the most important series of rocks is that known as the Keewatin. The Keewatin consists essentially of lava flows accompanied in many places by tuffs and basic intrusives. It includes iron formation which in many places is made up of thin layers of chert-like quartz alternating with quartzose layers holding magnetite or hematite, or both. Sedimentary rocks consisting of conglomeratic, sandy and slaty strata are in many cases associated with the volcanics and are in places of considerable thickness and extent. They may underlie the volcanics like the Couchiching of Rainy Lake area, they may be interbedded with the volcanics like the Dore formation of Michipicoten, or they may overlie the volcanics like the Timiskaming formation of northeastern Ontario and western Quebec. Between the volcanics and overlying sediments of northeastern Ontario and western Quebec there is an unconformity that is regarded by some geologists as of major importance. The early Precambrian formations occupy numerous areas of various sizes up to several hundred square miles in western Quebec, northern Ontario, eastern and central Manitoba, and to a less degree in Saskatchewan and the North West Territories.

The later Precambrian formations consist in a large measure of sedimentary rocks—conglomerates, quartzites, and slates. In an area lying immediately north of lake Huron and stretching northeast to beyond lake Timiskaming lies a succession of sediments known as the Huronian. These consist of: (a) the Bruce series made up of conglomerates, quartzites, and impure dolomitic limestone with an aggregate thickness of 2,700 to 12,000 feet; and (b) the Cobalt series made up of boulder conglomerate and other materials probably of glacial origin, overlain by quartzite and calcareous quartzite, with an aggregate thickness of 12,000 feet. An erosion interval of considerable time intervened between these two series. These strata are undulating with gentle dips, except on the north shore of lake Huron and eastward where they stand at high angles and represent the core of an ancient mountain range that probably flanked the southern edge of the continent.

In the vicinity of Port Arthur there is a series of nearly horizontal strata consisting of conglomerate, iron formation, and slate. This is the Animikie series. It belongs, probably, to the Huronian system and may be equivalent in age with the Whitewater series north of Sudbury, consisting of conglomerate, volcanic tuff, slate, and sandstone. East of Port Arthur the Animikie is overlain by the Keweenawan series of several hundred feet of red conglomerate, sandstone, shale, calcareous beds, tuffs, and lavas.

Strata, presumably of late Precambrian age, are known to occur on lake Athabaska, Great Slave lake, east of Great Bear lake, on Belcher islands, on the east of Hudson bay, and at other points in Ungava peninsula. In the southern part of Ungava peninsula sediments are found that bear a resemblance to the Grenville-Hastings group of southern Quebec and southeastern Ontario.

The Grenville-Hastings group consists of closely folded, highly altered sediments intruded by, and in places interleaved with, granite. They are in general rusty-weathering, banded gneisses, quartzose gneisses grading into quartzites, crystalline limestones, amphibolites, pyroxene-rich rocks, and volcanic schists. Pegmatite dykes are common and anorthosite occupies large areas. The Grenville-Hastings group forms a belt in the southern part of the Canadian Shield extending east from Georgian bay. The formations have not as yet been indubitably correlated with the Keewatin and Huronian rocks to the north.

The Precambrian sediments have suffered intrusion at various times by granites. These have been unroofed at different stages in the history of the Precambrian, and pebbles of granite as early as those of Keewatin age are found in the conglomerates. So complete has been the unroofing of the granites that they are exposed over

St. Lawrence lowlands, with St. Hilaire mountain.

the greater part of the Canadian Shield. Basic intrusives were common in later Precambrian times. Sills and dykes of diabase cut the late Precambrian sediments around lake Nipigon, west of lake Timiskaming, and at many other points. A thick laccolith is found in Sudbury district.

The Canadian Shield was intensely glaciated during Pleistocene time, with the exception of the more elevated parts of the northern Labrador coast, and in general only a scant amount of soil was left, sufficient partly to conceal the rocks, and maintain a forest growth. In some areas, as in part of northern Ontario and Quebec adjacent to the Canadian National railway, stratified fine sediments were deposited in lakes formed in front of the retreating glacier.

The Precambrian formations are prolific of mineral deposits of great number, variety, and extent. They occur generally at or near the contact of the intrusives and the intruded rocks. Among them are the gold deposits of Porcupine and Kirkland lake associated with intrusions of porphyry; the silver deposits of Cobalt, South Lorrain, and Gowganda associated with diabase sills; the enormous nickel-copper deposits of Sudbury associated with norite of a thick laccolithic intrusion; the auriferous copper sulphides of western Quebec; the copper-zinc sulphides of Flinflon; and the iron ores and iron pyrites of many localities of Ontario; and in the Grenville-Hastings area are found deposits of galena, mica, graphite, feldspar, magnesite, fluorite, kaolin, molybdenite, talc, and apatite.

ST. LAWRENCE LOWLAND

The St. Lawrence Lowland is divided into two parts by an arm of the Laurentian plateau that extends southward into New York state and crosses the St. Lawrence between Kingston and Brockville. It is underlain by nearly horizontal Palæozoic sediments dipping gently away from the Canadian Shield and deposited on the sloping surface of Precambrian rocks that had, prior to the deposition of the Palæozoic strata, been reduced to a physiographic condition similar to that existing on the Canadian Shield today.

The sediments are almost wholly of marine origin, consist mainly of limestone, magnesian limestone, and shale, and range in age from late Cambrian to late Devonian.

In the Ottawa-Montreal division the latest strata are Ordovician and these, together with the Potsdam sandstone (Cambrian), have a thickness of about 6,000 feet. In the Great Lakes region of southern Ontario the Ordovician formations are succeeded upward by those of Silurian age and these in turn by strata of Devonian age. The Ordovician formations form a zone extending from Kingston to the Niagara escarpment and stretching northwest to Georgian bay and into Manitoulin island. The Silurian formations are exposed in the Niagara escarpment and westward in a belt 25 to 50 miles wide stretching northwest from Niagara peninsula into Manitoulin island. West of this, nearly the whole of the area between lake Erie and lake Huron is underlain by Devonian limestones and shales. Each in turn is exposed over an area farther to the southwest than the older and underlying formation, so that in travelling westward from Kingston to Sarnia one passes over the bevelled edges of successively younger strata. Borings made in the township of Dawn show a thickness of nearly 3,900 feet of sedimentary rocks.

It is evident that the seas in which some of these sedimentary rocks were formed extended northward over the Precambrian rocks through Hudson bay into the Arctic ocean. The presence of outliers on lake St. John, lake Nipissing, and lake Timiskaming in the south, on lake Nicholson west of Hudson bay, of broad areas of Ordovician, Silurian, and Devonian formations south of Hudson bay, and of Cambrian, Ordovician, Silurian, and Devonian formations on the islands of the northern part of Hudson bay and of the Arctic seas is clearly indicative of wide submergence. On the Arctic islands, formations of Carboniferous (with coal seams) and Triassic age are widespread, and there are patches of Tertiary sediments with lignite. There is also evidence of the occurrence of rocks of Mesozoic age in Moose River basin.

The St. Lawrence Lowland was covered by the glaciers of Pleistocene time and the bedrock is to a great extent concealed by thick deposits of glacial till. In places, stratified deposits are found that formed in lakes at the edge of the retreating ice-sheet. Marine deposits were laid down in an arm of the sea that extended up St. Lawrence and Ottawa valleys above Ottawa.

The only intrusives worthy of mention are the igneous rocks of alkali types that form the Monteregian hills of southern Quebec—mount Royal and seven others to the

Valley of St. Mary river, Nova Scotia, showing upland underlain by the Gold-bearing series.

east. They are circular or oval hills that rise 600 to 1,200 feet above the plain and appear to be stock-like bodies or conduits that may have led to volcanic vents or larger masses of intrusives.

The mineral deposits are such as are usually found in the less altered sedimentary rocks. Petroleum has been produced in southern Ontario for over 60 years; natural gas has been produced for nearly 40 years in the counties bordering on lake Erie; salt has for a great many years been obtained from thick beds lying at a depth of about 1,000 feet in the counties bordering on lake Huron and lake St. Clair; gypsum is produced in the valley of Grand river; limestone and dolomite, utilized in chemical and metallurgical industries, are widespread; materials for construction, for brick, tile, and cement manufacture, are abundant.

The St. Lawrence Lowland is the most densely populated part of Canada; agriculture and manufacturing are the important industries.

APPALACHIAN AND ACADIAN REGIONS

The Appalachian and Acadian regions are composed of geological formations ranging from Precambrian through Palæozoic to Mesozoic. The Palæozoic sediments pass from dominantly marine formations upward into dominantly continental formations. A complete succession is not found and there are several hiatuses in sedimentation.

Sediments probably of Precambrian age occur in southeastern Quebec, southern New Brunswick, northern Cape Breton island, and on the Atlantic coast of the mainland of Nova Scotia. The thick series of slates and quartzites known as the Gold-bearing series forms a belt occupying a very considerable part of the mainland of Nova Scotia, faces the Atlantic coast, and is probably of late Precambrian age.

During the Palæozoic period numerous disturbances took place in sedimentation; there were periods of uplift, of folding, and of erosion, and it is difficult to arrive at conclusions as to how extensive the various formations have been. Cambrian formations are found in southeastern Quebec; Ordovician formations are of extensive development in the Appalachian region from Vermont to Gaspe; and Silurian and Devonian are well developed in Gaspe and the northwestern part of New Brunswick.

Patches of Cambrian, Ordovician, Silurian, and Devonian rocks are found in other parts of the Appalachian and Acadian regions.

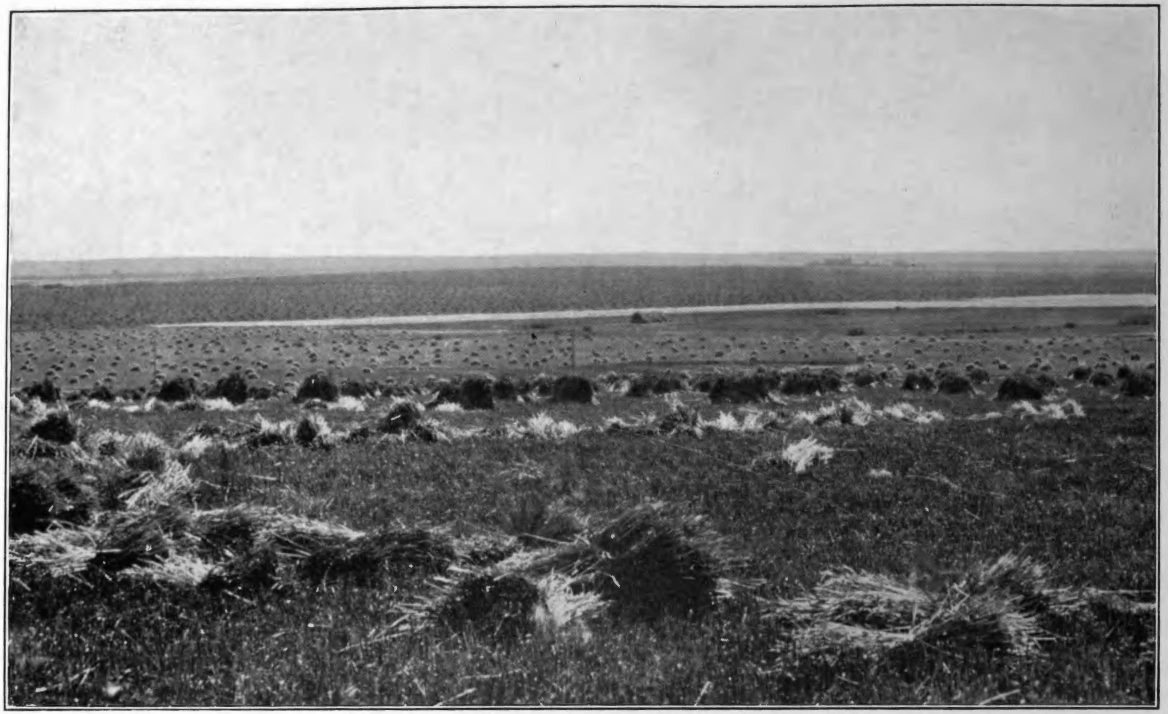
The system of sediments most widely distributed in the Maritime Provinces is the Carboniferous. The formations are mainly of continental deposition, although during Mississippian time a part of the area was submerged and received marine sediments. Towards the close of the Devonian period there was a period of intense mountain building and igneous activity. Granite batholiths of large size were formed in Nova Scotia and New Brunswick, and of smaller size in Gaspe and southeastern Quebec. The upheaval was succeeded by intense erosion, for some, at least, of the granite batholiths were exposed in early Carboniferous time.

The Carboniferous system occupies the triangular lowland forming much of the southeastern half of New Brunswick, the part of Nova Scotia north of Cobequid mountains, part of the lowland to the south of these mountains, southwestern and northeastern Cape Breton island, and Prince Edward island. On Prince Edward island the Carboniferous may pass upward into the Permian. In the Carboniferous system are found the coal measures of Sydney and Glace bay; of Inverness, Pictou, and Cumberland counties, Nova Scotia; and of the Minto coal-field, New Brunswick. The extensive gypsum deposits and the salt beds of Nova Scotia and New Brunswick are found in a formation of Mississippian age, and the bituminous shales of New Brunswick and Nova Scotia are also of early Carboniferous age. The Carboniferous system has in places been subjected to folding and faulting, but considerable areas have suffered little disturbance since these sediments were laid down.

Sandstones and lava flows of Triassic age are exposed on the bay of Fundy, particularly on the south coast. North mountain is composed of basic lava flows capping Triassic sandstone. During the Pleistocene period the whole of the Appalachian and Acadian regions, with the exception of the higher parts of Gaspe, was subjected to glaciation.

The most important economic minerals of the Appalachian and Acadian regions are coal, asbestos, and gypsum. Asbestos occurs in altered peridotite in southeastern Quebec. The most productive deposits of the world lie there. Chromite also occurs in the peridotite.

Farm scene, Prince Edward Island.



Wheatfields of Saskatchewan.

Auriferous quartz veins, mainly of the interbedded type, are found on domes and pitching anticlines of the Gold-bearing series of Nova Scotia. Zinc-lead deposits occur in the Devonian shales and limestones of Gaspe peninsula; zinc-lead-copper sulphides in the southern part of Cape Breton island in a series of lava flows; and copper deposits in southern Quebec.

INTERIOR PLAINS

The Interior Plains are underlain by a series of nearly horizontal sedimentary rocks of Palæozoic, Mesozoic, and Tertiary age. The Palæozoic rocks, consisting mainly of limestone, dolomite, and shale of Ordovician, Silurian, and Devonian age, form a belt extending north through Manitoba and northwest through Saskatchewan and northeastern Alberta down the basin of Mackenzie river. East of the Mackenzie, rocks of Cambrian age are exposed in an area of limited extent. The Palæozoic formations rest upon the gently-sloping shelf of the Canadian Shield and pass westward, with a dip of a few feet, a mile beneath the shales and sandstones of Cretaceous age. The Cretaceous formations occupy nearly the whole of the plain from western Manitoba to the Rocky mountains and extend northward nearly to Mackenzie river. There are also large parts of Mackenzie basin, particularly of the lower half, in which the Devonian limestones are overlain by Cretaceous sediments. The Cretaceous sediments vary from shales, in the east, predominantly of marine origin, to sandstones, in the west, predominantly of continental origin. Between the two are alternations of shales of marine origin with sandstones of brackish water or fresh-water origin.

The Cretaceous beds are overlain in places by sediments of Tertiary age. The most extensive Tertiary formations are found in the hills of southern Saskatchewan, and in a belt running north through central Alberta, where they lie in a broad syncline. Glacial till is widespread, and clays were deposited in large lakes formed on the retreat of the ice-sheet. A large part of southern Manitoba formed the bed of glacial Lake Agassiz.

The Interior Plains region is the great wheat-producing area of Canada. The mining of coal is one of the important industries; bituminous coal and lignite are produced in large quantities in Alberta, and lignite in smaller quantities in Saskatchewan. The Cretaceous sediments are the reservoirs of great quantities of natural gas, and these and underlying formations are the source of the oil of the Turner Valley and Wainwright oil-fields. Oil has also been struck in the Devonian rocks north of Norman on Mackenzie river. Gypsum is obtained from the Palæozoic rocks of Manitoba.

WESTERN CORDILLERA

In the western Cordillera a fairly complete succession of sediments of Precambrian, Palæozoic, Mesozoic, and Tertiary age, with a few breaks, is met.

The mountains to the west of the Rocky Mountain trench in southern British Columbia are composed of a series of late Precambrian quartzites, slates, and magnesian limestones of great thickness. The area underlain by these widens near the International Boundary and extends east beyond the Rocky Mountain trench and west beyond Kootenay Lake valley. On Kootenay lake there is a series of mica schists, quartzites, and crystalline limestones penetrated by pegmatites and other plutonic rocks of Mesozoic age. This is the Shuswap series. It may belong to the early Precambrian or be an altered phase of the late Precambrian. On the west shore of the lake the series grades upward into less altered rocks. These are overlain by sediments of Carboniferous age which extend northward to the main line of the Canadian Pacific railway. The Shuswap series extends from east of Revelstoke to Shuswap lake and northward to the headwaters of Fraser river. In places they are much altered and associated with intrusive rocks. Gneissic and schistose rocks, probably of the same age, are found on Finlay and Omineca rivers. Quartzites, mica schists, and crystalline limestone with interbands and broad areas of schists of various kinds and intrusive granite gneiss are found over a wide stretch of the Yukon plateau. Slates, quartzites, and conglomerates, also probably of Precambrian age, occur on the northern part of the Alaska-Yukon boundary, in the Ogilvie range, and in Kluane district.

The Rocky mountains consist of a series of great fault blocks in which an enormous thickness of Palæozoic and Mesozoic sediments is exposed. Many thrusts of great extent have resulted in an over-riding of the Mesozoic sediments by the Palæozoic, and the erosion of the softer strata of the former has produced longitudinal valleys between the harder Palæozoic blocks. The Palæozoic formations consist mainly of limestones with less amounts of sandstone and shale. A succession with few breaks from the Cambrian through the Ordovician, Silurian, Devonian, and Carboniferous is found, and extends probably, with certain deviations, throughout the length of the Rocky mountains and Mackenzie mountains. Between the Cambrian and Precambrian beds there is apparently little angular unconformity, but the variation horizontally in the Precambrian strata on which the Cambrian formations rest and a similar variation in the ages of the overlying Cambrian strata furnish evidence of a long period of erosion.

The Mesozoic strata consist of soft shales and sandstones, some of which are coal bearing. Strata of Triassic, Jurassic, and Cretaceous age are represented.

On the Interior Plateau of British Columbia, limestones, quartzites, and argillites of Carboniferous age, known as the Cache Creek group, are of wide distribution. These are succeeded upwards by argillites and limestones and a great mass of volcanic intrusives and effusives of Triassic age, and these are succeeded by sediments and volcanics of Jurassic age. The Triassic and Jurassic formations are widely distributed, are found on the islands to the west, and some at least extend into Yukon.

Formations of Cretaceous age are found on Vancouver and Queen Charlotte islands and in a belt extending up the Fraser and along the eastern edge of the Coast range into Skeena valley. They are mainly formations of continental origin and carry coal seams, but also include sediments of marine origin and volcanics.

Very early Tertiary time was characterized by widespread orogenic disturbances in the Cordillera. The Rocky mountains were formed, and there was much folding and faulting in places in the interior, followed by intense erosion. Tertiary sediments, partly of continental deposition with seams of lignite and partly of marine deposition, occur at many points throughout the interior of the Cordillera and on Vancouver island. Lava flows capping some of these sediments cover broad stretches of the Interior Plateau.

In Pleistocene time nearly the whole of the Cordillera with the exception of a large area in Yukon was subjected to glaciation, and glaciation still persists in the mountainous regions. Volcanics of Recent age are found in areas of limited extent.

An episode in the geological history of the west, of great economic importance, was the intrusion of the granitic rocks of the Coast Range batholith and of acid rocks at different points in the interior, particularly in the southern part of British Columbia, in Mesozoic time. Many of the more important mineral deposits of British Columbia, such as the copper deposits of Hidden creek, Britannia creek, and Allenby mountain, the gold-silver deposits of Salmon River district, and the silver-lead deposits of the Slocan, had their origin in solutions given off by the magmas of these acid intrusives.

The lead-zinc deposit of the Sullivan mine lies in sedimentary rocks of Precambrian age. The Cretaceous and Tertiary formations carry seams of coal and lignite of great importance. There are economic deposits of other minerals in great variety throughout the Cordillera, and British Columbia is one of the leading mineral-producing provinces of Canada. The gold of the once famous Klondike region was found in placers of an unglaciated area, and the gold of Cariboo district occurs mainly in Tertiary placers that were unaffected or little affected by glaciation.

MINERAL INDUSTRY

Each of the great geological regions described is rich in mineral wealth, but differs from the others both as regards variety and amount.

In the Appalachian and Acadian regions are the asbestos deposits of southeastern Quebec, which for a long period have furnished the world with the greater part of its supply of this commodity, and the important coal fields of Nova Scotia. Within the St. Lawrence region are the salt beds and petroleum fields of Ontario. The Canadian Shield contains the Sudbury nickel-copper mines, which are the world's chief source of nickel, the spectacular gold mines of Porcupine and Kirkland lake, and the rich silver deposits of Cobalt district. The Interior Plains over hundreds of square miles are underlain by coal. In the Cordilleran region are extensive coal-fields, important placer gold-fields, large deposits of copper-gold ores and of silver-lead-zinc ores. In the Arctic archipelago extensive deposits of coal are known to exist.

Many other types of mineral wealth occur in the various regions, more particularly in the Appalachian and Acadian regions, the Canadian Shield, and the Cordilleran region. A list of the products of the mines and quarries of Canada would include the names of most of the materials of mineral origin in demand at the present time, but not of precious stones, nor of ores of aluminium and of tin, nor of various commodities mostly of relatively minor importance. The annual mineral production is now worth over $220,000,000, and the growth of the industry is indicated by the following table, which gives the value of the annual production at intervals since 1886, when statistics for the whole of Canada were first collected.

1886	$ 10,221,255
1890	16,763,353
1900	64,420,877
1910	106,823,623
1920	227,859,665
1925	226,583,333

The present population of Canada is about double that of 1886, but the value of the mineral production is twenty-two times as great as that of 1886. The per capita production has, therefore, increased elevenfold.

A consideration of the future possibilities of the industry leads to our dividing the minerals, for convenience, into two groups, those for which the market is to a great extent of a local nature and are consumed almost wholly in Canada, and those that are not dependent upon local consumption but enter into the markets of the world. The production of both classes has increased at about the same rate, but it seems improbable that this can continue indefinitely.

The first group includes fuels such as coal, lignite, and natural gas, and materials for construction such as building stone, limestone, clay products, and Portland cement. The per capita production and consumption of these hardly can continue to increase at any such rate as held during the last forty years, but there will probably be a continued growth.

The supplies in Canada of both fuels and structural materials are enormous, though not uniformly distributed, and are capable of satisfying any demand likely to arise during an indefinitely long time to come. Therefore, with an increasing per capita consumption and a growing population, it is evident that the value of the annual output of fuels and the so-called structural materials will continue to increase and may at no very distant date amount to over $200,000,000 and equal, if not exceed, the value of the whole mineral output of the present time.

The remaining classes of mineral products, the ores of gold, silver, copper, nickel, lead, zinc, iron, etc., asbestos, graphite, mica, and so on, although some or many of them may be largely or even solely consumed within Canada, are not dependent for a market on this country alone, and their prices and the demand for them are, on the whole, determined in the general markets of the world. Their production in some cases is wholly independent of Canadian consumption. The status of this phase of the mineral industry is largely conditioned by the demand for such materials throughout the world, and in the past this demand has been insistent. Therefore, it is reasonable to assume that a market will always be open to Canada's output of this second group of mineral products and that in this instance the limits of production are not set by the rate of Canadian consumption, but by the extent, character, and availability of the country's mineral resources.

The great increase in the production of the second group of minerals has resulted from the discovery of mineral deposits of value in districts largely or wholly unsettled, since the mineral deposits of this second class as a whole do not occur in the pre-eminently agricultural regions of Canada, but in the more rugged, less-developed regions of the Cordillera, the Canadian Shield, and the Appalachians.

Under the most favourable conditions the determination of the extent of the mineral resources of regions such as these must proceed slowly. In Canada it has proceeded very slowly and is still far from complete because the territory is so vast and, in comparison, the population and the transportation facilities are so meagre. More than one-half of the population is concentrated in the St. Lawrence region and one-fourth is distributed over the southern parts of Manitoba, Saskatchewan, and Alberta. Naturally it is within these regions that railway facilities have been mainly provided, whereas in the Canadian Shield and the Cordilleran region, from which so much mineral wealth is derived, the total population, if a few centres be excluded, is less than 200,000, and of necessity railway facilities are limited to a few trunk lines. Over many extensive districts wherein general geological conditions are known to favour the occurrence of valuable mineral deposits, few or no important discoveries have been made, not necessarily because valuable deposits do not occur there, but in all probability because, as mining is rarely profitable in districts remote from satisfactory transportation routes, the chances of obtaining an adequate reward have not been large enough to induce a sufficient number of prospectors to enter and search such districts. A few prospectors wander far afield, and possibly no part of Canada, not even excepting the Arctic archipelago, is beyond the reach of prospectors possessed of only a very moderate amount of capital, but, in a general way, active prospecting tends to be confined to the neighbourhood of established transportation routes. These lines of communication, in the main, are the railways and certain steamship routes such as exist on the Pacific coast or Yukon river. In the main, the fields within which prospecting is most likely to prove profitable are confined in the Cordilleran region to the vicinity of the Pacific coast and the railway lines, and in the Canadian Shield, to the neighbourhood of the railways. In the case of the Cordilleran region the area so defined is considerably less than one-half of the whole, and in the Canadian Shield it is not more than one-eighth of the total area. Statements such as these, however, do not adequately represent the general situation, for these estimates relate largely to areas in which it would be profitable to work deposits of high-grade ore or very large deposits of low-grade ore. Within the areas indicated are mineral deposits which lie idle because they are only a few miles from railway or steamship routes, and are not of sufficient value to warrant providing the necessary transportation facilities.

Unlike the case of the fuels and structural materials whose distribution and value are approximately known and whose rate of production is mainly dependent on the Canadian demand, the mineral products of the second class occur in such ways that as yet no reliable estimate can be made of the country's wealth in these substances. Numerous districts are known within which geological conditions are such as to induce the belief that deposits of value may occur therein. In many districts discoveries of importance have been made, but whose individual actual values still await determination. In various localities deposits of known value remain undeveloped because of temporary causes. Few if any of the known mineral-bearing districts have been so carefully prospected as to preclude the possibility of further important finds being made therein. Periodically important discoveries are made which, so far, have more than compensated for the exhaustion of previously known deposits. New methods of treating ores, and increasing demands for various mineral products, are causing the development of deposits at one time considered to be of little value. Finally, the growth of the mineral industry of itself is productive of further growth through providing over widening areas the facilities for treating ores and through inducing settlement and increasing transportation facilities and thus stimulating prospecting.

As yet, therefore, there are no indications that Canada has approached her maximum annual rate of production of the second of the two great classes of mineral products. Instead, it seems that the output will continue to increase for many years to come, although the rate of increase may not be as great in the future as it has been in the past.

The following table of production for 1925 shows the great variety of minerals now produced and their relative importance.

—		Quantity	Value
METALLIC			$
Antimony	Lb.	1,751	206
Arsenic (As_2O_3)	"	3,434,137	130,302
Bismuth	"	19,667	18,566
Cobalt	"	1,116,492	2,328,517
Copper	"	111,450,518	15,649,882
Gold	Fine oz.	1,735,735	35,880,826
Iron ore sold for export	Tons	3,978	11,934
Lead	Lb.	253,590,578	23,127,460
Molybdenite	"	22,350	11,176
Nickel	"	73,857,114	15,946,672
Palladium, rhodium, iridium, etc.	Fine oz.	8,288	648,969
Platinum	"	8,698	1,028,192
Silver	"	20,228,988	13,971,150
Zinc	Lb.	109,268,511	8,328,446
Total		....	117,082,298

		Quantity	Value
NON-METALLIC			$
Actinolite	Tons	40	500
Asbestos	"	290,389	8,988,360
Barytes	"	95	2,259
Bituminous sands	"	1,148	4,594
Coal	"	13,134,968	49,261,951
Feldspar	"	28,681	235,789
Fluorspar	"	3,886	19,234
Graphite	"	2,569	158,763
Grinding pebbles	"	105	945
Grindstones	"	2,562	124,165
Gypsum	"	740,323	2,389,891
Iron oxides	"	7,118	91,913
Magnesite	"	5,576	122,325
Mica	"	4,020	261,463
Mineral water	Gals.	190,134	28,413
Natro-alunite	Tons	20	1,000
Natural gas	M cu.ft.	16,902,897	6,833,005
Peat	Tons	1,370	8,394
Petroleum, crude	Bls.	332,001	1,250,705
Phosphate	Tons	16	189
Pyrites	"	15,605	58,899
Salt	"	233,746	1,410,697
Quartz	"	197,224	363,612
Sodium carbonate	"	1,120	8,140
Sodium sulphate	"	3,876	19,380
Talc and soapstone	"	14,474	205,835
Volcanic ash	"	160	1,380
Total		....	71,851,801
STRUCTURAL MATERIALS AND CLAY PRODUCTS			
Cement	Bls.	8,116,597	14,046,704
Clay products—			
Brick—			
Soft-mud process — Face	M	27,701	521,739
Soft-mud process — Common	"	51,214	753,970
Stiff-mud process (wire-cut) — Face	"	93,903	1,883,856
Stiff-mud process (wire-cut) — Common	"	116,105	1,635,257
Dry press — Face	"	37,201	800,504
Dry press — Common	"	22,053	270,135
Fancy or ornamental brick	"	524	26,320
Sewer brick	"	2,485	52,382
Firebrick	"	6,197	305,332
Fireclay	Tons	623	6,544
Fireclay blocks and shapes		....	36,567
Structural tile—			
Hollow blocks (including fire-proofing and load-bearing tile)	"	115,576	1,093,397
Roofing tile	No.	78,479	6,323
Floor tile (quarries)	Sq. ft.	140,927	28,338
Drain tile	M	14,552	401,503
Sewer-pipe (including copings, flue linings, etc.)	Tons	73,791	1,440,269
Pottery, glazed or unglazed		....	267,255
Lime	Bush.	10,256,542	3,387,652
Sand and gravel	Tons	11,018,647	3,220,410
Stone	"	5,706,119	7,464,777
Total		....	37,649,234
Grand total		....	226,583,333

MARITIME PROVINCES

Coal, the principal mineral product of Nova Scotia, is mined not only in the island of Cape Breton in the extreme east of that province, but also in smaller, though important, fields in Cumberland and Pictou counties on the mainland. Coal is also the chief mineral product of New Brunswick, where it is mined from thin seams at shallow depths, in some cases in open-cast workings, but the output and reserves are quite small as compared with those of Nova Scotia. In both provinces, gypsum, next to coal, is the most valuable mineral product; most of it is exported in the crude state to the United States.

In addition to coal and gypsum, Nova Scotia has an important and growing salt-mining industry, and gold and barytes are also mined; in New Brunswick there is a small output of petroleum and natural gas, and occasionally antimony. Both provinces produce important quantities of clay products, structural materials, and grindstones.

The third of the Maritime Provinces, Prince Edward Island, though well and favourably known for its agricultural, fishing, and fur-farming industries, records no mineral production.

COAL-FIELDS OF NOVA SCOTIA AND NEW BRUNSWICK

Coal mining in Nova Scotia and iron mining in Quebec are the oldest mining industries of Canada.

The first printed reference to the existence of coal in Nova Scotia appeared in 1672 in a "Description géographique et historique des costes de l'Amérique septentrionale, avec l'histoire naturelle du pais par Monsieur Denys, Gouverneur Lieutenant Général pour le Roy et propriétaire de toutes les terres et isles qui sont depuis le cap de Campseaux jusques au cap des Roziers."

In 1677 M. Duchesneau, the Intendant of New France, issued a proclamation, exacting a royalty of 20 sous per ton from all persons taking coal from Cape Breton. In 1711 Admiral Walker—who commanded an expedition to reduce Quebec—mentions in his journal that he procured a supply of coal from the cliffs, with no other appliances than crowbars.

The initial attempt at systematic mining was made in 1720, when it was found necessary to procure a supply of fuel for the men who came from France to lay the foundations of the fortress of Louisburg. The pit openings then made can be seen even at the present day at Port Morien, Table head, and other places. During the next hundred years very little work was done, the coal mined being used almost exclusively by the garrison at Halifax. In 1820, however, when Cape Breton island became part of the province of Nova Scotia, a considerable tonnage of coal was being mined. In 1827 all the mines were transferred to the company known as the 'General Mining Association' by the London firm of goldsmiths (Rundle, Bridge, and Rundle), who had secured the mines and minerals concession for the entire island province of Cape Breton, from the Duke of York. The new owners immediately organized, opened out, and systematically operated mines in Cape Breton, Pictou, and Cumberland counties.

In 1858 the General Mining Association surrendered its claims to the government of Nova Scotia.

From about the middle of the nineteenth century coal mining developed rapidly. The growth is indicated by the following table of output.

	Tons
1880	1,177,669
1890	2,181,033
1900	3,623,536
1910	6,431,142

The maximum was reached in 1913 when the output amounted to 7,980,073 tons. Since then there has been a falling off, and the normal annual production in recent years has been about 6,000,000 tons. Nova Scotia and Alberta now vie with each other for first place in amount of production.

The annual output of New Brunswick is not large. During recent years it has exceeded 200,000 tons and in 1922 reached 287,513 tons.

Nova Scotia and New Brunswick are the only provinces in which coal seams of Carboniferous age are known to occur. Sedimentary rocks of the Carboniferous system underlie a great part of the lowlands of these two provinces, pass in general in a northerly and northeasterly direction beneath the sea, and abut in a landward direction against hills several hundred feet high, composed of sedimentary and igneous rocks of greater age. As they outcrop on the island of Newfoundland it is not impossible that they underlie much of that part of the basin of the gulf of St. Lawrence that lies between New Brunswick and Nova Scotia on the west and south, and Newfoundland on the east.

The Carboniferous formations occupy a large, triangular area in New Brunswick lying east of a line stretching from Bathurst southwest beyond Fredericton nearly to the bay of Fundy, the mainland of Nova Scotia north of Cobequid mountains, and much of the lowland to the south, a part of southern Cape Breton island, the western edge of the island, and a considerable area in the vicinity of Sydney in the eastern part of Cape Breton. Only a small part of this area is underlain by formations carrying coal seams of economic importance; this statement applies especially to New Brunswick.

The main coal fields are: the Sydney field of Cape Breton county in the northeastern part of Cape Breton island; the fields of Inverness county on the western coast of Cape Breton island; the Pictou field in Pictou county on the mainland of Nova Scotia; the Springhill and Joggins fields of Cumberland county, Nova Scotia, and the Minto field in New Brunswick, 50 miles north of St. John.

The Carboniferous formations consist mainly of conglomerates, shales, and sandstones of continental deposition. The sediments of Mississippian age are in part of marine origin and carry numerous and extensive deposits of gypsum, and deposits of salt. The oil-shales of southeastern New Brunswick that it is hoped will eventually form the basis for an industry similar to that of Scotland, and the gas-bearing and oil-bearing sediments in the vicinity, are of early Carboniferous age. The coal-bearing Pennsylvanian sediments are not all of the same age and possibly not all of similar origin. Whereas conditions in one part of this eastern continental area were favourable to the accumulation of vegetable matter in quantities sufficient for the formation of coal seams, conditions in other parts were unfavourable. It is thought that the vegetation from which most of the coal seams were formed, such as those of the Sydney coal basin, accumulated at the point of growth in a slowly subsiding, broad river basin, but Bell states that there is evidence of the accumulation in lakes of much of the vegetable matter of the Pictou coal area. Thus, whereas the theory of the origin in situ accounts for much of the coal of the Maritime Provinces, the drift theory accounts for much of the Pictou coal.

The coal measures of the Sydney, Inverness, and Pictou fields are of Upper Westphalian age and those of the Joggins area are Middle Westphalian. In few places, if any, was sedimentation continuous throughout the Carboniferous period, and field studies have revealed evidence in many places of erosional unconformities. One of the most important and conspicuous breaks in sedimentation on the mainland area of Nova Scotia preceded the deposition of the Upper Westphalian series of strata. It is important because it accounts for the absence eastward of the formation that carries the workable seams of the Joggins and Springhill fields.

A second major break occurs within the Lower Westphalian series in the New Glasgow district and elsewhere south of the Cobequids, and a third break, of Upper Westphalian age but more local in significance, is shown where the Plymouth member of the Stellarton coal-bearing series (Upper Westphalian) rests with angular discordance upon Lower Westphalian strata. Unfaulted, non-discordant contacts between Mississippian and Pennsylvanian formations were observed in several localities. On the Merigomish shore, near Lismore, marine strata of Upper Windsor age (Upper Mississippian or Visean) that rest directly upon freshwater strata of Upper Horton age are overlain disconformably by Lismore Lower Westphalian strata. At Joggins and Sydney there is likewise a marked accordance of dips. Near Port Hood coal measures of Middle Westphalian age unconformably overlap Mississippian strata. At Joggins there is no direct evidence of erosional unconformity between Mississippian and Pennsylvanian rocks, although in southern New Brunswick, close by, Pennsylvanian coarsely clastic rocks of the same age overlap upon Mississippian beds. The coal-bearing strata of the Minto field, New Brunswick, have been correlated with the top of the Middle Coal Measures of England (Westphalian of Kidston) and are probably a little earlier than the main seams of the Sydney field. The Fern Ledges near St. John, which are correlated with the base of the Middle Coal Measures of England, suffered important folding and some alteration, whereas the sediments of the Minto basin lie almost horizontal. This fixes the date of one important structural disturbance in southwestern New Brunswick.

The Sydney coal field lies on the northeastern coast of Cape Breton island, extends from Mira bay west to a short distance beyond Great Bras d'Or channel, a distance of 35 miles, and occupies a land area of about 250 square miles. The formations dip seaward at low angles and are gently folded into four basins separated by anticlines: Cow Bay or Morien basin, Glace Bay basin, Lingan-Victoria basin, and Sydney Mines or Bras d'Or basin. One of the difficult problems of the field has been the correlating of the coal seams of the different basins. The aggregate thickness of coal in workable seams, outcropping on the shore, and for the most part exposed in the bays and cliffs, is from 40 to 50 feet; the seams vary from 3 to 9 feet in thickness. Following is a typical section of the productive measures of the Lingan-Victoria basin.

Local name of seam	—		Thickness of measures		Total depth
	Ft.	In.	Ft.	In.	Ft.
Carr seam	3	0	3	0	
Strata			170	0	
McNeill seam	3	5	3	5	176
Strata			341	0	
Barachois seam	6	0	6	0	523
Strata			55	0	
Dunphy seam	3	0	3	0	581
Strata			306	0	
Victoria seam	7	0	7	0	894
Strata			257	0	
Fairy House seam	3	5	3	5	1,154
Strata			66	0	
Northern Head seam	5	0	5	0	1,225
Strata			113	0	
Lingan seam	8	0	8	0	1,346
Strata			134	0	
Emery seam	2	8	2	8	1,483
Strata			1,000	0?	
Mullins seam	6	0	6	0	2,489

Mining operations have been directed to the thicker and more accessible seams, but as the land areas are becoming exhausted attention is being given to the extraction of the thinner seams and to workings in submarine areas. The seaward extension of the seams is not known, but it seems probable that the distance from the shore to which submarine mining can be carried is an economic problem and will be limited by prohibitive costs of extraction rather than by the exhaustion of the seams.

The Pictou coal field is 11 miles long and 2½ miles wide. It is divided into three parts known as the Westville, Albion, and Vale divisions, in order from west to east. The whole field has an extremely complicated structure;

seams found in the three divisions have certain resemblances, but correlation is difficult. It is a field with a great many seams and with seams of great thickness, one of the most interesting coal-fields known.

The following section of the Albion measures to the McGregor seam is condensed from a report by Edward Hartley, 1869. This is followed by a section below the McGregor seam as determined by the diamond-drill.

—	Coal Ft.	Coal In.	Measures Ft.	Measures In.
Three-and-a-half-foot seam	3	6	3	6
Measures			1,128	7
Main seam	34	7	34	7
Measures			148	1
Deep seam	22	11	22	11
Measures			106	8
Third seam	5	7	5	7
Measures			113	0
Purvis seam	2	8	2	8
Measures			130	0
Fleming seam	3	3	3	3
Measures			4	3
McGregor seam	11	7	11	7
Totals of Hartley's 1869 section	84	1	1,714	8
Section as disclosed by diamond-drill below the McGregor seam:				
Measures			45	0
Coal	21	9	21	9
Measures			14	4
Coal	3	6	3	6
Measures			127	8
Stellar seam (or oil-coal)	5	0	5	0
Measures			31	10
Coal	6	6	6	6
Measures			169	9
Coal and shale mixed (not good)	29	9	29	9
Measures			47	6
Coal and shale mixed	4	11	4	11
Measures			74	8
Coal (good seam)	20	4	20	4
Measures			190	4
Coal (coarse)	3	2	3	2
Measures			9	9
Coal (good)	9	8	9	8
Measures, hard grey shale			251	0
	188	9	2,781	1

There are two coal-fields in Cumberland county, the Joggins field and the Springhill field. The most important seam in the former field is the Joggins Main seam which is

6 feet thick. In the Springhill field the following section has been disclosed.

—	Coal		Measures	
	Ft.	In.	Ft.	In.
North seam	13	0	13	0
Measures	....		105	0
Coal	5	0	5	0
Measures	....		130	0
Coal	2	4	2	4
Measures	....		185	0
Main seam	11	0	11	0
Measures	....		80	0
Back seam	11	0	11	0
Measures	....		100	0
Coal	4	0	4	0
Measures	....		176	0
Coal	2	0	2	0

The seams are highly inclined and in some places approach the vertical.

The Minto coal basin lies in the interior of New Brunswick, 35 miles east of Fredericton. Continuous mining began in 1825, but it is only within recent years that operations have been carried on extensively. The coal seam is 18 to 24 inches thick. The measures, although warped into gentle undulations, are nearly horizontal, and faulting is rare. The seam lies at no great depth and in some places is near enough to the surface to permit of its recovery by stripping the overburden.

The following table of analyses reveals the character of the coals.

Chemical Analyses of Coal from Nova Scotia and New Brunswick

Description (Name of mine and kind of sample)	Proximate analysis as received: Moisture per cent	Ash per cent	Volatile matter per cent	Fixed carbon per cent	Sulphur per cent	B.T.U. per pound	Coking properties
Sydney Area							
Dominion Coal Co., Glace Bay—							
No. 22 colliery (Gowrie seam). Mine	3·4	5·3	35·5	55·8	2·0	13,430	Good
No. 4 colliery (Phalen seam). Tipple	1·4	9·0	34·3	55·3	4·5	....	Fair to good
No. 11 colliery (Emery seam). Tipple	2·3	10·4	33·8	53·5	2·4	....	Good
No. 12 colliery (Victoria seam). Mine	3·7	5·7	37·4	53·2	3·5	13,230	Fair to good
No. 16 colliery (Lingan seam). Mine	3·0	5·4	32·5	59·1	2·1	13,600	Good
Inverness Area							
Inverness Railway and Coal Co. (Inverness)							
No. 1 seam	4·3	8·8	39·1	47·8	5·5	....	Poor
Pictou Area							
Intercolonial Coal Mining Co., Westville—							
Scott seam. Tipple	2·3	22·1	25·5	50·1	1·2	11,080	Poor
Main seam. Tipple	1·8	14·4	26·0	57·8	0·8	12,660	Good
Acadia Coal Co., Stellarton—							
Allan shaft. Tipple	1·8	13·2	29·6	55·4	0·9	....	Fair
Albion bankhead. Tipple	2·4	11·9	29·5	56·2	0·8	12,590	Poor
Springhill Area							
Cumberland Railway and Coal Co.—							
(Springhill No. 2 mine). Tipple	2·4	10·7	29·5	57·4	1·6	13,020	Good
No. 6 mine. Tipple	4·1	12·7	31·0	52·2	2·1	....	Fair
Joggins-Chignecto Area							
Maritime Coal, Railway, and Power Co.—							
Old Joggins seam. Mine	4·0	13·1	35·4	47·5	6·4	11,250	Fair
Minudie Coal Co.—							
Queen seam. Tipple	2·6	18·7	34·1	44·6	6·5	10,940	Fair to good
Minto Area							
Minto Coal Co.—							
South holdings. Tipple	1·0	18·3	30·3	50·4	7·3	....	Fair to good
Harvey Welton, South Minto. Tipple, lump	1·1	15·3	30·9	52·7	5·6	....	Fair to good

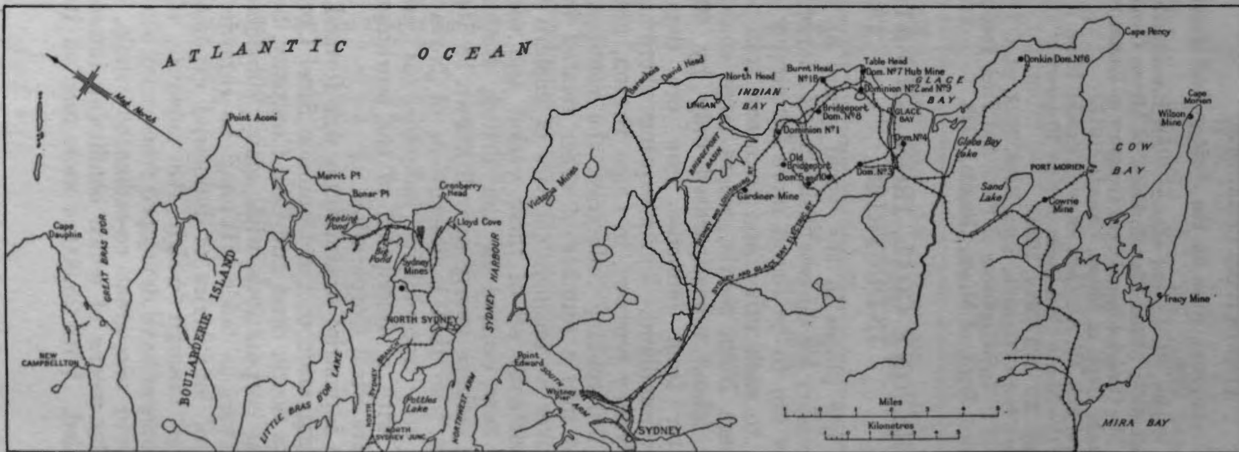
AUTHORITIES CONSULTED

Fletcher, H.: "Descriptive Note on the Sydney Coal Field"; Geol. Surv., Canada, 1900.
Porter, E. M., Durley, R. J., and others: "An Investigation of the Coals of Canada"; Mines Branch, Dept. of Mines, Canada, 1912.
Gray, F. W.: "The Coal-fields and Coal Industry of Eastern Canada"; Mines Branch, Dept. of Mines, Canada, 1917.
Hayes, A. O., and Bell, W. A.: Geol. Surv., Canada, Mem. 133 (1923).
Dyer, W. S.: "The Minto Coal Basin of New Brunswick"; C.I.M.M., Bull. 145, pp. 251–275 (May, 1924).
Bell, W. A.: Geol. Surv., Canada, Sum. Rept. 1924, pt. C (1926).
Nicholls, J. H. H.: "Investigations of Fuels and Fuel Testing, 1924"; Mines Branch, Dept. of Mines, Canada, 1926.

CAPE BRETON'S COAL, IRON, AND STEEL INDUSTRIES

There are few places in the world where all the raw materials necessary for the establishment of a large iron and steel industry are to be found more favourably situated with respect to each other and to ocean transportation than in eastern Nova Scotia, where large coal-fields in Cape Breton island are separated only by 400 miles of deep water from immense iron ore deposits at Wabana, Newfoundland. In consequence there has grown up around Sydney harbour, in Cape Breton, great coal-mining and iron-making industries, the ramifications of which extend into a number of other related industrial fields and cover a considerable part of eastern Canada. Control of virtually all of these varied and widespread activities is now centred in the British Empire Steel Corporation, perhaps nearly as well known by its shorter name "Besco," so that a description of Nova Scotia's coal-mining and iron-making industries is practically synonymous with a description of the workings of the British Empire Steel Corporation.

This great industrial organization was formed in 1921 by the amalgamation of the Dominion Steel Corporation and the Nova Scotia Steel and Coal Company, both large and powerful corporations with many subsidiaries and activities in various fields. It may be regarded as the culmination of long series of industrial expansions and consolidations through which the separate efforts of industrial pioneers have developed from small and modest beginnings into one great co-ordinated whole, and the instrument by means of which conflicting interests have been reconciled. With 25,000 or more men on its payroll

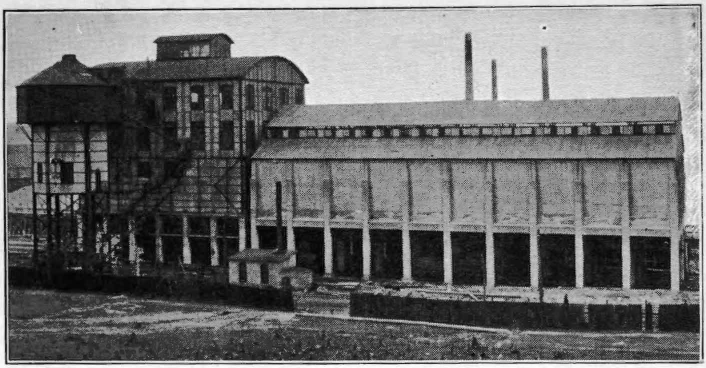


MAP 4. Sketch map of Sydney coal-field.

PLATE X

The Dominion Coal Company's No. 2 colliery at Glace Bay, N.S

PLATE XI



The Dominion Coal Company's coal washery at Sydney, N.S.

when operating to capacity, Besco is the largest industrial organization of its kind in Canada, owning and operating its own ore, coal, and limestone deposits, timber lands and sawmills, steamships and railroads; producing its own iron and steel, and manufacturing a wide variety of finished products—in short, supplying from its own resources every requirement for its own operations, it is the best example in Canada of that modern industrial development, the great self-contained, integrated industry.

Coal-fields

The Sydney coal-field, on which the iron and steel and allied works at Sydney and Sydney Mines depend, is the most valuable and extensive in the province. It is situated on the northeastern coast of Cape Breton island and dips seaward at a gentle slope; has a frontage along the coast-line of some 35 miles and a maximum width inland of some 9 miles, the land area of the field thus consisting of about 200 or 250 square miles. The extent of the sub-marine part of the field is still unknown. It has been proved for a distance of 3½ miles off shore and as the strata throughout are free from serious faults or disturbances, so that the coal seams are regular and continuous, there seems to be every possibility that the field extends far beyond the present limit of economical mining. About 130,000,000 tons of coal have already been extracted from the Sydney field, and it is estimated that the quantity of coal available within 5 miles of the shore-line and recoverable under present economic conditions approaches 2,500,000,000 tons, of which about 70 per cent is sub-marine. Figures much exceeding these are sometimes given, estimates differing according as different assumptions are made as to the distance the field can be economically worked both seaward and to depth, and the minimum thickness of coal seam that will ultimately be profitable to mine.

Up to the present most of the coal mined in the Sydney field has come from the three thickest of the upper seams, that is from the seams known in the Glace Bay basin as the Hub (4 feet 7 inches), Harbour (5 feet 10 inches), and Phelan (7 feet 6 inches), and by various local names in the other sections of the field; there are, however, at least nine known seams in the Glace Bay basin that have a thickness of 3 feet and over. The collieries are worked both by the room-and-pillar method and by long wall, the latter method being of comparatively recent introduction. The coal is cut mechanically, chiefly by machines of the radial type, though chain-cutters are now being used also to some extent. Nine of the fifteen British Empire Steel Corporation's collieries operating in the Sydney coal-field now draw their entire output from submarine workings lying 200 to 1,500 feet under the bed of the ocean.

A feature of the room-and-pillar collieries is the winning of the coal through long headways—2,000 to 4,000 feet in length—in preference to shorter headways to a greater number of levels, by which means not only is a saving in costs effected but a considerable advantage is gained by the utilization of the long grade to generate useful energy. This is now being done by means of compressed air hoists —believed to be the first installation of the kind on this continent—and by electrical hoists designed for the same purpose.

Throughout practically all the Cape Breton collieries much money has been expended in the construction of permanent air-courses and roadways. Especially elaborate and durable underground structures are those at No. 1-B colliery of the Dominion Coal Company, the newest colliery in the district, opened in 1924 for the working of large submarine areas. It is estimated that 140,000,000 tons of coal will eventually be won through No. 1-B shaft and that its life will probably be 125 years or more; great care has, therefore, been exercised to secure the most permanent type of construction, especially in the main underground haulage ways.

All the Cape Breton mines are gassy and safety lamps are in universal use, examiners and officials using the flame Koehler safety, miners the Edison 3-candlepower electric. To eliminate as far as possible the coal-dust hazard, stone-dusting has been introduced in the Glace Bay collieries. Limestone crushed so that 85 per cent will pass through a 200-mesh sieve is used for this purpose. Definite dust zones are established to isolate panels of the mines and the aim is to keep all dust on main roadways under 40 per cent in combustible matter.

The productive future of the Sydney coal seams is largely dependent on their undersea extensions, so that this field will for many years focus the attention of those interested in the fascinating subject of submarine mining.

Iron-ore Deposits

The iron-ore deposits on which Cape Breton's iron and steel industry depends for its supply of ore are not in Canada, but in the neighbouring sister Dominion, Newfoundland. Like the Cape Breton coal seams, they are beds interstratified with other bedded rocks; outcropping on land, but dipping seaward with their greatest extent underseas; so that they present for their exploitation, in a general way, the same problems in submarine mining as do the coal seams.

Disregarding 7 or 8 seams too thin to be worked profitably, the ore reserves of the Wabana iron-ore field, all owned by the British Empire Steel Corporation, are contained in 3 beds; the topmost, known as the Little Upper, averaging 6 feet in thickness; the Scotia, 60 feet below it, about 8 feet; and the Dominion, 350 feet below the Scotia, with an average workable thickness of about 16 feet. The 3 beds show an average aggregate thickness of 30 feet over the entire areas so far explored, and form one of the largest and most compact of the world's known iron-ore reserves; the extent of the Wabana reserve will probably be fixed by working conditions and costs rather than by running into barren ground. The ore averages about 9 cubic feet to the ton, or about 90,000,000 tons to the square mile, and after liberally discounting for all adverse factors it may fairly be assumed that the Wabana trough as a whole contains at least 4,000,000,000 tons of recoverable ore, and possibly a great deal more. Up to the present, probably not more than 20,000,000 tons have been mined, though the deposits were first opened up in 1895.

The ore itself is dense and fine grained, and is classed commercially as a non-Bessemer red hematite. It carries from 48 to 57 per cent of iron and 6 to 12 per cent of silica. The Scotia seam shows the highest grade of ore; that from the Dominion seam, from which most of the shipments have been made, will average 48 to 50 per cent iron, which can be increased to 50 or 52 per cent by passing it over picking belts and tables. Phosphorous is rather high, up to 0·70 or 0·85 per cent, but the sulphur content is low.

The land part of the deposits, which outcrop on Bell island in Conception bay, have been largely worked out, by quarrying. To exploit the submarine areas, slopes following the beds, which dip seaward at a prevailing angle of about 8 degrees, have been driven from the island outcrops for a distance of over 2 miles under the ocean. The lowest workings are about 1,800 feet vertically below the sea bottom.

The general working plan adopted for the extraction of the undersea ore is the room-and-pillar method so commonly used in coal mines. The mine is dry and little pumping is necessary. The workings are carried large enough to allow electrically driven dipper shovels to operate, which load the broken ore into cars. These are trammed to the slope, up which the ore is hoisted some 12,800 feet to the surface in 20-ton skips travelling at the rate of about 3,500 feet a minute. From the ore-pocket at the deckhead the ore is carried on a tramway 2 miles long, across the island to a shipping pier, where ships carrying 13,000 tons lie afloat at all tides and can be loaded at the rate of 2,000 tons an hour.

The rate of shipment to date has not exceeded 1,500,000 tons per annum, but the mine is developed to the stage at which it can furnish an annual output of 2,500,000 or 3,000,000 tons without difficulty.

In spite of the fact that they are submarine, Wabana iron ores can be mined and shipped at a low cost—so low in fact that Wabana ore is probably the cheapest iron ore available for delivery at eastern Atlantic or in German or English ports.

Most of the ore mined in the past has been taken by the Nova Scotia furnaces, the remainder being exported to Germany, the United States, England, and Holland.

Iron and Steel Works

The works of the Dominion Iron and Steel Company at Sydney and the works of the Nova Scotia Steel and Coal Company at Sydney Mines (constituent companies of the British Empire Steel Corporation) consist of the following principal items: 2 Baum coal-washers capable of treating 4,000 tons of coal daily; 150 non-recovery coke-ovens with appliances for the utilization of surplus gas; 200 improved Otto-Hoffman recovery coke-ovens; 180 Koppers recovery coke-ovens. Recovery plants in connexion with the coke-ovens are equipped for the production of tar, benzol, naphtha, sulphate of ammonia, etc., and the surplus gases are used in other parts of the works for heating purposes.

There are 8 standard blast-furnaces, 6 at Sydney and 2 at Sydney Mines, capable of producing 750,000 tons of basic and foundry iron annually.

At Sydney Mines there are 5, and at Sydney 10, basic open-hearth furnaces, 3 open-hearth mixers, and 2 basic Bessemer converters of 15 tons capacity each, for use in connexion with a duplex steel-making process. These, working together, are capable of a daily output of 1,600 tons of steel ingots.

At Sydney, the equipment available for converting the steel into saleable form consists of a 35-inch blooming mill with gas-fired soaking pits; a 28-inch rail mill capable of producing daily 800 tons of heavy rails, 60 to 100 pounds to the yard; a Morgan continuous wire-rod mill of 300 tons daily capacity; a Morgan semi-continuous bar-and-rod mill with a daily capacity of 400 tons bars and 150 tons rods; a 16-inch merchant-bar mill with a daily capacity of 200 tons; and a 10-inch plate mill, daily capacity of 450 tons sheared plate. There is also a Harmet fluid compression plant, producing compressed steel ingots up to 30 tons weight; and a complete plant for the manufacture of wire, wire fencing, nails, etc., and for galvanizing.

The works are served by boiler plants using waste gases from the blast-furnaces and by electric power-houses using exhaust steam from the mills and gas from the blast-furnaces; the whole generating upwards of 15,000 k.w. of energy.

There are also iron and brass foundries, and machine shops fully equipped to meet all the requirements for the maintenance and repair of the whole of the plant; and facilities for the manufacture of bricks.

Standard- and narrow-gauge railways equipped with adequate rolling stock connect all parts of the works, and the works with the collieries and shipping wharves. There are 48 miles of standard-gauge and 4·3 miles of narrow-gauge track; 21 standard-gauge and 7 narrow-gauge locomotives, and 750 cars of various kinds.

At the north end of the plant are the necessary piers for the discharge from ocean-going vessels of ore, stone, and other raw materials; equipped with unloading machinery capable of discharging 10,000 tons a day.

The following table gives the yearly capacity outputs of the various departments of the Sydney plant.

	Tons
Pig iron	580,000
Steel ingots	420,000
Blooms	375,000
Billets	150,000
Rails	240,000
Wire rods	90,000
Wire nails, fencing, etc.	60,000
Plates	150,000

During recent years steel products from Sydney have been exported to Australia, New Zealand, Japan, Europe, and South America.

The sulphate of ammonia made in the by-product plant is in good demand by sugar growers in the West Indies, as well as for a general purpose fertilizer in Canada. The tar produced at the coke-ovens is worked up into various distillate products by the Dominion Tar and Chemical Company whose works are situated near the coke-ovens. The residual pitch from the distillation process is shipped to Great Britain.

The phosphatic slags produced in the steel-making process form the base of a fertilizer made by the Cross Fertilizer Company, whose works are also near the steel plant.

A cooperage shop makes the barrels and other containers for the shipment of nails, and the reels for barbed wire; from lumber cut on the company's timber lands, in company mills, in New Brunswick.

The company's ore- and coal-carrying fleet includes 14 ocean-going steamers having a dead weight capacity of approximately 70,000 tons.

AUTHORITIES CONSULTED

Anon.: "The Largest Industry in the Dominion"; The Montreal *Gazette*, vol. CLII, No. 6, p. 37 (Jan. 6, 1923).

Jones, A. R. R.: "The British Empire Steel Company and What it Means to Canada"; Iron and Steel of Canada, Oct., 1924, pp.183 *et seq.*

Cameron, C. S.: "Iron and Steel Industry in Canada"; Proc. Empire Min. and Met. Cong., June, 1924, pt. IV, pp. 219 *et seq.* (1925).

Moffat, John: "Dominion No. I-B Colliery"; Iron and Steel of Canada, May, 1925, p. 96.

Hay, A. M.: "Colliery No. I-B of the Dominion Coal Co."; Eng. Journal, Jan., 1926, pp. 12 *et seq.*

Mifflen, S. C.: "Recent Progress in the Sydney Coalfield"; Can. Min. Jour., Mar. 26, 1926, pp. 342–344.

Kuhn, O. R.: "Wabana Ore from an Island of Ore"; Iron Age, May 6, 1926, pp. 1264–66.

British Empire Steel Corporation: Annual Reports.

QUEBEC

In addition to her wonderful asbestos mines in the Eastern Townships, and her new copper-gold fields in Rouyn district, Quebec has also the only producing zinc mine in eastern Canada: the Tetreault mine, at Notre-Dame-des-Anges in Portneuf district.

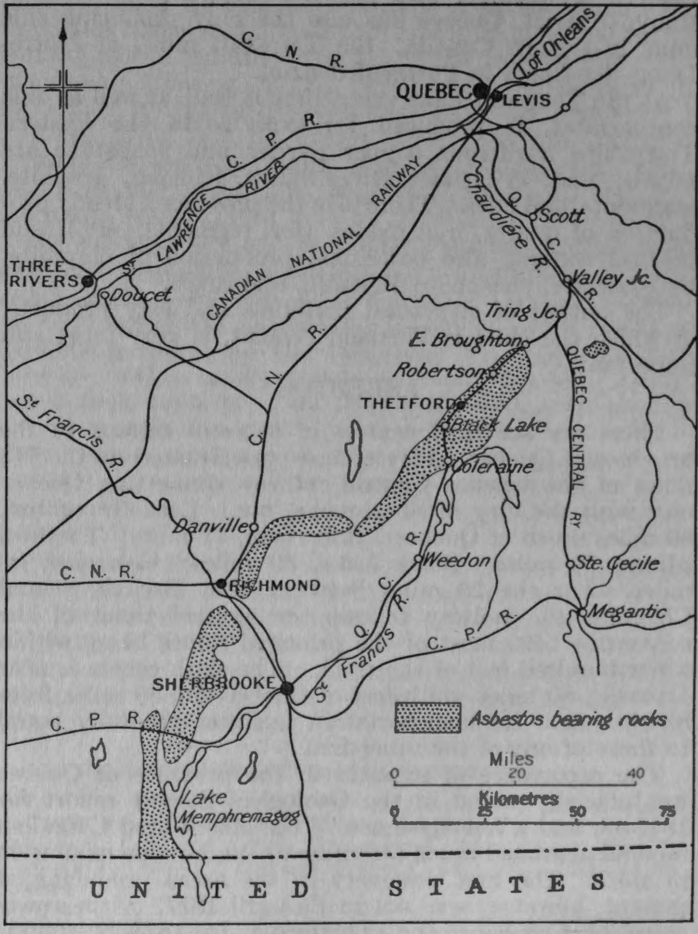
At the Tetreault mine argentiferous lead, as well as zinc concentrates, is produced for export. In the Eastern Townships auriferous copper pyrites and soapstone are mined; and, in Ottawa River valley, feldspar, graphite, magnesite, and mica. There is in the province a steady production of quartz, iron oxides (for pigments, etc.), and mineral waters; also occasional production of chromite, molybdenite, phosphate, ilmenite, and rutile.

The output of structural materials and clay products, of which the chief is Portland cement, is very large and important.

ASBESTOS

There are six chief centres of asbestos mining in the province of Quebec. Five of these are situated on the 143 miles of the Quebec Central railway connecting Quebec city with the city of Sherbrooke, viz.: East Broughton, 60 miles south of Quebec; Robertson, 71 miles; Thetford Mines, 76 miles; Black Lake, 80 miles; Coleraine, 86 miles. For the 26 miles between East Broughton and Coleraine the railway follows the general trend of the serpentine belt, most of the principal mines being within a few hundred feet of the track. The sixth centre is near Danville, 80 miles southwest of Quebec and 30 miles from Sherbrooke. Its transportation facilities are fully equal to those of any of the other five.

The occurrence of asbestos in the province of Quebec was officially noted in the Geological Survey report for 1847-48, and a fine specimen of the silky-fibred Canadian mineral attracted much attention at the London exhibition in 1862. The first discovery in the areas producing at present, however, was not made until 1877, in the townships of Coleraine and Thetford. In 1878-79 mining commenced, and three mines were opened up at Thetford Mines; it is rather remarkable that these three mines, 48 years after their discovery, are still considered the best and richest in the region. The first year's mining produced only 50 tons, for which it was difficult to find a market. During the next 22 years, however, the asbestos industry developed rapidly; the quality of the fibre was excellent, the width of the veins being ½ inch up to 2 inches, 3 inches, and in some places 4 inches or more. Shipments of the



Map 5. Sketch map of Quebec's asbestos-producing district.

better grades aroused great interest in the British market and, extensive tests having proved the exceptional spinning qualities of the Canadian material, it soon commanded high prices. In 1885, seven quarries reported operations and the aggregate output for the year was

2,440 tons, for which $80 per ton was obtained at the mines for the highest grade, with corresponding prices for the lower grades. Between 1885 and 1900 the price for first quality asbestos advanced as high as $300 per ton and the output of all grades in the latter year was 21,621 tons.

But this state of affairs did not continue; prices gradually dropped and it was found that the prevailing methods of extraction by hand were too expensive for profitable operation, especially with regard to the lower grades. Under these conditions only those quarries that were working rich ground, having a large proportion of long-fibre asbestos, could carry on at a profit; many quarries whose output consisted largely of the lower grades were forced to shut down. Compelled by circumstances, the operators then set their inventive faculties to work, with the result that mechanical methods of treatment for the lower grades of asbestos were devised, and gradually displaced the old hand-cobbing system. These newer methods have been developed and improved with such conspicuous success that today every asbestos mine in the district is equipped with a complete milling and fibreizing plant, and all the shorter fibre that in the earlier years of operation was left in the ground or thrown on the dump is now saved and utilized. New uses for this formerly waste material have been, and still are being, developed, and conditions in the industry have so changed that short-fibre asbestos, though not nearly as valuable ton for ton as the crude (long fibre), is now in most instances the main source of revenue.

There are 19 or 20 asbestos companies listed by the Quebec Bureau of Mines as operating in the province, but all of these do not operate quarries; some have been formed to work over old dumps for the recovery of short fibre. The total output in 1925 amounted to about 281,663 tons, divided according to grades and prices as follows:

—	Tons	Average value per ton
		$ cts.
Crude No. 1	806	384 12
Crude No. 2	2,701	206 22
Other crudes	205	145 98
Spinning stocks	13,509	106 43
Shingle stocks	48,259	36 05
Millboard and paper stocks	94,350	31 04
Fillers, floats, and other short fibres	73,774	12 84
Sand, gravel, and crushed rock	48,059	6 42

The progress that has been made in the industry in the 47 years since its inception in 1878 can be still further illustrated by the statement that Quebec now supplies over 80 per cent of the world's consumption of asbestos, and that with the exception of coal and cement, it is now, in point of value, the most important of Canada's non-metallic mineral products; the value at the mill of the asbestos products shipped in 1925 being about $8,995,850.

The most important recent event in the history of Quebec's asbestos industry was the merging in 1925 of a number of the chief operators into one large company. This organization, which came into effect January 1, 1926, is called the Asbestos Corporation, and is made up of the following constituents operating in the Thetford, Black Lake, and East Broughton fields: Asbestos Corporation of Canada, Ltd.; Consolidated Asbestos, Ltd.; Federal Asbestos, Ltd.; Thetford Vimy, Ltd.; Maple Leaf Asbestos Corporation; Asbestos Mines, Ltd.; and Black Lake Asbestos and Chrome Company. Its formation was brought about to provide a remedy for the demoralized condition into which the Quebec asbestos industry had fallen as the result of a sharp decline in prices in 1921, due mainly to severe competition from South African asbestos, but further aggravated by a price-cutting war among Canadian producers themselves.

The asbestos mines and mills in the three producing fields of Thetford, Danville, and East Broughton now require for their operation about 18,000 electric horse-power, practically all of which is transmitted at 50,000 volts over a transmission line 110 miles long from Shawinigan Falls on the north side of St. Lawrence river. The line crosses the St. Lawrence between two steel towers 350 feet high and 5,000 feet apart.

Geological Features

The following information regarding the geology is drawn in part from published reports and in great part from an unpublished manuscript by Robert Harvie.

The asbestos deposits are found in the Appalachian region of southern Quebec. As has already been stated, there are three parallel ridges in the Appalachian region having a northeasterly trend, and two broad intervening valleys. The ridges consist mainly of sediments folded in broad anticlines. Taken in order from west to east these folds are named the Sutton, Sherbrooke (or Stoke), and Lake Megantic anticlines. The geological formations consist of quartzites, slates, and limestones, are much altered, and probably belong to all the great geological periods from Precambrian to Devonian, inclusive. With the sediments are associated a variety of igneous rocks, volcanic and intrusive, of basic and acidic composition.

The asbestos deposits occur in a basic igneous intrusive on the eastern flank of the broad Sutton anticline.

The central mass of the anticline is a wide belt of schistose quartzite ranging in colour from white through light grey and greenish grey to nearly black, and consisting on an average of about 60 per cent quartz, 30 per cent sericite, biotite, or chlorite, and 10 per cent feldspar. The formation is cut by a great number of quartz veins varying from a fraction of an inch to several feet in thickness. It is in all probability of Precambrian age.

Lying between this belt of schistose quartzite on the west and the basic igneous rocks of the Black Lake-Thetford Mines area on the east is a belt of light-coloured quartzite forming a part of the east limb of the Sutton anticline. Another area west of Disraeli is underlain by these rocks. If the assumption that the formation on the crest of the Sutton anticline is of Precambrian age be correct, this series of quartzites is probably Cambrian.

Outcrops of a conglomerate that is composed almost entirely of fragments of the quartzite just described have been observed at a number of points. Many blocks of this conglomerate have been observed in the volcanics described in the following paragraph.

Following closely the bands of serpentine rocks in the Thetford Mines-Black Lake area is a series of basic volcanics consisting of red and green tuffs and lavas. The tuffs vary much in texture and colour and the finer-grained phases are highly sheared. The lavas exhibit the common structures observed in rocks of this kind—ropy, amygdaloidal, ellipsoidal, and porphyritic.

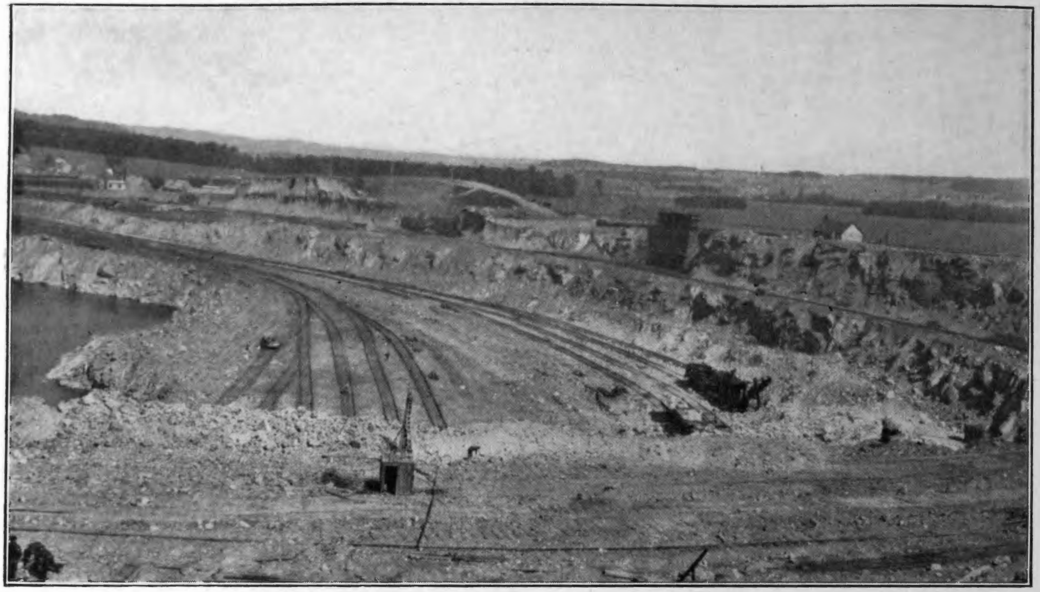
The youngest sediments in the area are black, grey, and greenish, argillaceous slates with a small amount of sandstone and chert. In some localities the slates carry pyrite in abundance. Their contact with the underlying rocks is nowhere visible and in only one exposure is there any suggestion of a basal conglomerate.

The most important rocks of the area are those of the Thetford series. This term is applied to the series of related rocks within which the asbestos deposits are found. These igneous rocks, which compose the "serpentine belt," are found along the eastern limb of the Sutton anticline. For most of its length—over 100 miles—the belt is apparently a steeply tilted sheet or sill that has been truncated by erosion. In the Thetford Mines district, on account of a minor flexure in the limb of the anticline, the Thetford series takes the form of a nearly flat-lying laccolith. This laccolith thins to the east, but in its western part is very thick, the basic part alone having in places a thickness of not less than 1,500 feet.

The Thetford series is composed chiefly of rocks rich in olivine, of the group known as dunites and peridotites, of the serpentine alteration products of these dunites and peridotites, and of smaller amounts of pyroxenite, gabbro, and granite. These rock types have a distinctly stratiform arrangement in the laccolith, which may be ascribed to differentiation after intrusion. The order from bottom to top is: dunite, peridotite, pyroxenite (gabbro), and granites. Whatever may have been the precise nature of the process of differentiation, the mutual relations of the phases indicate the same order for their solidification. Chemically, the transition is from a magnesium-rich magma, through a lime-rich, to an alkaline one. It is estimated that in this district the dunite and peridotite, with the serpentines derived from them, make up over nine-tenths of the volume of the existing portion of the serpentine belt.

The principal group of rocks of the Thetford series, from an economic as well as a quantitative standpoint, consists of dunite and peridotites and the serpentines derived from these. The dunite, composed of olivine with a small percentage of spinel, picotite, and chromite, passes by the accession of pyroxene over into peridotites. The peridotites are: harzburgite or saxonite composed of olivine and orthorhombic pyroxene such as enstatite; wherlite composed of olivine and the monoclinic pyroxene diopside (diallage); and lherzolite composed of olivine and both enstatite and diopside.

On fresh surfaces the dunites and peridotites are commonly of a very dark shade of olive green, passing in some cases into nearly black. Bluish and greenish greys are also common. Serpentinization is widespread and intensive and the mineral serpentine probably makes up about 85 per cent of these rocks. It is produced from the alteration of both the olivine and the pyroxenes. The pyroxenes are more resistant to weathering than olivine and serpentine and on exposed surfaces the grains stand out prominently enough to warrant the name "nail head" structure.



An asbestos pit developed by railway and steam shovels.

An asbestos quarry at Thetford Mines, Quebec.

Chrome minerals are always present in small amounts. Magnetite is present in variable amounts in serpentine. Brucite is found in rocks showing an advanced stage of serpentinization, and magnesite, less abundant than brucite, is also found where alteration is advanced.

Pyroxenites occur in Thetford district chiefly as thin, sheet-like bodies. They are characteristically coarse-grained rocks and are classified according to the variety and proportion of the pyroxenes composing them. Three varieties have been recognized: diallagite and enstatitite, named after their predominating pyroxenes, and websterite in which both diallage and enstatite are present. The pyroxenites are differentiates that were a little later than the peridotites in solidifying, and hence show certain intrusive relations.

Certain rocks in the area have been called gabbros on the basis of their macroscopic characters. Their relations to the other rocks have not been conclusively determined. In places the pyroxenites seem to grade upward into the gabbro, in other places the pyroxenites seem to intrude the gabbro.

Granitic bodies in the form of dykes cutting the other members of the Thetford series are very numerous. These dykes consist in a large measure of quartz and either albite or orthoclase. The larger masses are usually unaltered, but the smaller dykes have nearly all been subjected to great alteration, particularly in the asbestos and chrome pits, and in many cases no remnants of the original minerals are left. The more common alteration products are: zeolites, prehnite, pectolite, diopside, garnet, and vesuvianite. The granite has been considered by many to be the most acid differentiate of the Thetford series. There is an undoubted gradation from dunite through peridotite to pyroxenite, but Harvie expresses doubt as to whether there is a further progression by increasing feldspar through gabbro to granite. Until the intervening stages have been thoroughly investigated it seems impossible to determine the genetic relation of the granite to the other rocks of the sill.

The Thetford series bears an intrusive relation to the Precambrian (?) and Cambrian (?) quartzites. Its relation to the volcanics overlying the Cambrian (?) quartzite is somewhat less conclusive, although it is probable that it is intrusive in the volcanics. The dark-coloured slates that constitute the youngest sediments of the area have nowhere been found intruded by rocks of the Thetford series, and it is believed that they are later in age. There is evidence that the slates are pre-Silurian and it may be that earlier geologists were quite correct in assigning them to the Ordovician system. It follows that the Thetford series is certainly pre-Silurian and probably early Ordovician, if not pre-Ordovician.

The asbestos mined in this district is altogether of the chrysotile variety and occurs chiefly in the serpentinized peridotite. It is an hydrous silicate of magnesium and is simply a fibrous form of the mineral serpentine. It occurs as cross fibre or slip fibre. Cross-fibre asbestos is found in distinct veins cutting the peridotite, the fibres running perpendicular to the walls of the veins. The slip fibre is found along slip faces where serpentine has been sheared. The fibre from Thetford Mines district is nearly all of the cross variety, but in the highly sheared rocks of Robertson and Broughton slip fibre predominates.

The lengths of the veins are roughly proportional to their widths, and individual veins are characterized by great regularity of width. Veins 2 or 3 inches wide may commonly be traced for 50 feet and some for 100 feet or more. They terminate usually by a gradual reduction in width. Most of them follow the rectangular system of jointing which occurs throughout the dunite and the peridotite. Minor veins are found, however, in all attitudes unrelated to the rectangular system of jointing. The veins have clearly defined walls and are invariably accompanied by a band of pure serpentine on each side. The proportion between the asbestos and this serpentine seems to be fairly constant, the width of the asbestos vein being a little more than one-sixth of that of the serpentine. In places, probably because of particularly abundant jointing, the serpentine zones are so closely spaced that the whole rock is serpentinized and veins occur seemingly anywhere in this mass. In a few localities it commonly happens that instead of a single large vein in the serpentinized zone there is a large number of parallel small veins, or a large single vein, by forking, branches into a number of parallel small veins. In this way is produced the material known as ribbon rock.

The fibre ordinarily lies at right angles to the plane of the vein and there is usually a parting approximately at the middle of the vein. The parting is composed mostly of magnetite and occasionally of serpentine. The length of the fibre is, therefore, in most cases, less than the width of the vein and rarely exceeds $2\frac{1}{2}$ inches. The slip fibre does not form veins, occurs with apparently no definite arrangement, and makes up a large proportion of the rock. It is mostly shorter than the average cross fibre.

The question of the origin of the chrysotile has been a puzzling one for geologists and cannot be adequately dealt with in a short article of this nature.

Mining Methods

In the earlier years of the industry the Quebec asbestos deposits were all worked by quarry methods, in open pits, but during the last 18 years other methods have been evolved. Methods now in use may be classed under four main types:

(1) Open-cast quarries from which the broken rock is hoisted by cable derricks. This is the earliest method, modernized and carried out on a large scale; one quarry using this method has a hoisting capacity of 2,000 tons of rock a 10-hour shift.

(2) Open-cast quarrying in which the broken rock is hoisted in trains of cars through an inclined shaft, from the pit bottom. In this case the mine cars may be loaded by power shovels running on tracks or on caterpillars.

(3) "Glory hole," or "milling," methods, a combination of open-cast and underground work, in which the broken rock falls through chutes to an underground drift, along which it is trammed to a vertical shaft and hoisted to the surface.

(4) Quarrying in large, open pits laid out in wide benches. Standard-gauge railway tracks, which enter the pit by a lengthy, graded approach, run along the faces of the bench, the broken rock from which is loaded into railway cars by steam shovels. The loaded cars, in trains, are drawn out of the pit direct to the mill.

The removal of the overburden preliminary to mining is at some of the mines a problem in itself. Recently, for instance, one of the mines contracted for the stripping to bedrock, in order to extend their open-cast pit, of an area approximately 900 feet by 600 feet, covered with clay, sand, and boulder clay to a maximum depth of 80 feet.

Dressing of Asbestos Rock

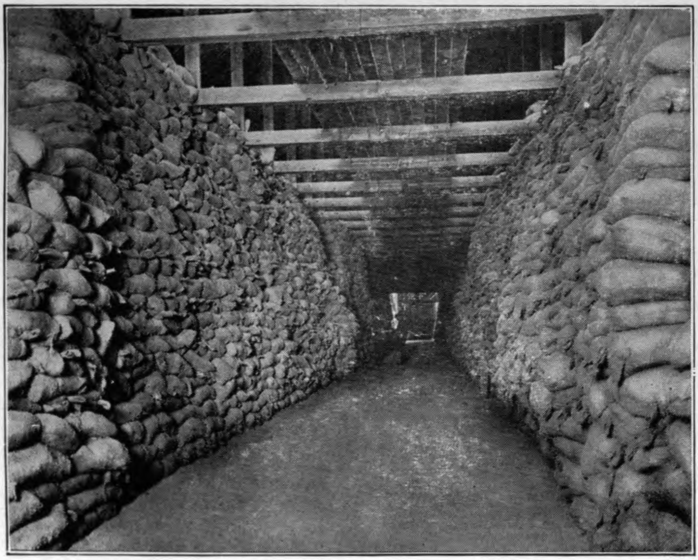
Long fibre, or "crude" asbestos, that is, asbestos half an inch or more in length, is usually separated from the accompanying rock on the floor of the pit by block-holing the larger pieces of rock and cobbing by hand, or at some mines by means of a picking-belt placed after the coarse crushers in the mill. "Crude" is the highest priced material obtained, but it constitutes only a very small part of the total output—5 per cent and less, some mines produce no crude—the proportion varying widely in different quarries and in different parts of the same quarry. At some mines, little or no hand-cobbing is now done, practically all the asbestos-bearing serpentine going direct to the mill for mechanical treatment.

Milling

The milling of asbestos rock to extract the fibre is simple in principle, since in briefest outline it consists merely in the crushing and pulverizing of the enclosing serpentine, with the resulting liberation of the asbestos fibre, by machines that at the same time work up the fibre into light, fluffy masses. The pulverized rock is eliminated by screening and the fluffy asbestos remaining on the screens is picked up by suction devices, working on the same principle as the vacuum cleaner, and is carried by them to suitable collecting receptacles. The details of the practice actually necessary to secure a satisfactory product, however, are complex and troublesome, and involve the use of higaly specialized machines.

The general method of procedure in a typical mill is about as follows, though, naturally, practice differs in different plants.

The mill rock from the quarry and the rejects from the cobbing sheds are dumped into a bin, whence they pass to a jaw crusher of either the Blake or Dodge type. From the jaw crushers the rock passes through rotary driers, to free it from the moisture it contains when it comes from the pit and fit it for subsequent pneumatic operations. On leaving the driers the larger pieces of rock are screened out and put through a second jaw crusher before going to the next machines, usually rotary crushers of either the gyratory or coffee-mill type, which in turn may be followed by crushing rolls.



Asbestos bagged for shipment.

The course of treatment up to this point has for its main object the liberation of the asbestos from the rock by repeated crushings, but to make the fibre amenable to the subsequent treatment it is necessary also that the lumps of asbestos be split into their constituent fibres and fluffed up, so as to be readily acted on by air currents. This operation, as well as further comminution of the small lumps of rock coming from the crushers, is done in special machines called fibreizers, or beaters.

The comminuted material is discharged from the fibreizers on to screens, from which the fluffed asbestos is sucked by fans and blown into collectors or settling chambers. The residue passes on to still other fibreizers, the discharge from which is also thrown on to screens from which, as before, the fibre is lifted and conveyed to settlers by means of fans, and the final sands pass into a hopper beneath the screen.

All the fibre has now been extracted from the rock and collected in the receivers. From the receivers it goes through a series of screens and fans that free it from the last traces of sand, and grade it according to length, ready to be bagged for shipment.

Within the last two or three years a new process, for the wet milling of asbestos, has been devised, and a treatment plant erected on the asbestos fields. The new method is said to possess many advantages over the present dry process, such as higher recovery of fibre, less breakage of fibre, no dust pollution of the air, and economy of fuel for drying, as the fibre only is dried instead of the whole volume of the rock.

The principal grades of asbestos, from the highest to the lowest, in descending order are:

- **Crudes**
  - No. 1
  - No. 2
- **Milled fibres**
  - Spinning fibres
    - Long
    - Medium
  - Sheet fibres
  - Shingle stocks
  - Paper stocks
  - Cement stocks
  - Floats

The "crude" qualities are long fibre that has not been subjected to mechanical treatment; "crude" No. 1 being material of this class more than ½ inch in length. It should be silky and have sufficient tensile strength to allow it to be used in the making of asbestos yarn, tape, cloth, carded fibre, and other asbestos textiles; "crude" No. 2 is generally referred to as mineral less than $\frac{1}{2}$ inch in length that has not been milled and has good tensile strength. It is in many cases mixed with No. 1 in the manufacture of asbestos textiles. Colour is also a consideration in determining the price at which crudes can be sold.

The milled fibres consist as a rule of asbestos ranging in length from $\frac{1}{2}$ to $\frac{1}{20}$ of an inch, the different grades being determined by screen tests. As a rule, mill-stock grades contain only a small proportion of fibre of $\frac{1}{2}$ inch or over.

Standardizing Asbestos Fibre

The testing of asbestos stock to check the grades and ascertain that their length of fibre corresponds to specifications, is standardized, and a knowledge of the methods of carrying out these tests is necessary for an understanding of the significance of the specifications quoted by the trade. The testing apparatus consists of 4 rectangular trays 24 inches long, 14 inches wide, and 5 inches deep, closely fitting on top of one another. The bottom of the upper tray, or No. 1, is a screen made of No. 12 S.W.G. wire with clear openings of $\frac{1}{2}$ inch; tray No. 2 is a 4-mesh screen, or 4 openings to the lineal inch, No. 16 wire; the third tray is 10-mesh or 10 openings to the lineal inch, No. 18 wire; the last and lowest tray has a solid bottom. The nest of four screens is made fast to a frame, to which an excentric with a throw of $\frac{3}{4}$ inch gives a movement of $1\frac{1}{2}$-inch travel. A 16-ounce sample representative of the asbestos shipment to be tested is put on the upper tray, which is covered. The machine is then started running at the rate of 300 revolutions a minute and kept going exactly two minutes. The asbestos remaining on each tray is next accurately weighed and the weights, which determine the grade of the sample, are recorded. For instance, grade 2-9-4-1 means that of the 16-ounce sample, 2 ounces remained on the $\frac{1}{2}$-inch screen, 9 ounces in the $\frac{1}{4}$-inch, 4 ounces on the $\frac{1}{10}$-inch, and 1 ounce went through into the bottom tray. Normally, the greater the proportion of the asbestos remaining in the upper trays, the higher the grade.

Long spinning fibre, used in asbestos textile manufacturing, tests anywhere from 4-7-4-1 down to 1-9-4-2, but the standard tests may be taken as 4-7-4-1 to 2-8-4-2; medium spinning fibres are generally required to test

0-8-6-2 and may be mixed with the better grades for textile manufacturing; magnesia and compressed sheet fibres average 0-5-8-3. These are used in the manufacture of magnesia pipe covering and compressed sheet packing. There are various grades of shingle stocks, each mine having somewhat different ideas of what constitutes a shingle fibre, though the standard shingle stock calls for a test of 0-1½-9½-5. This material, as its name implies, is used in conjunction with Portland cement in the manufacture of asbestos shingles, corrugated asbestos sheeting, and switchboard panels. Paper stock tests on the average 0-0-10-6, and is used for making asbestos paper and millboard or mixing with shingle stock. Cement stock, used in the manufacture of asbestos boiler and roofing cements, and for millboard, may test 0-0-5-11 or 0-0-6½-9½. Floats, or shorts, are sold on colour and used in the manufacture of flooring.

The manifold and increasing number of industrial uses to which asbestos in its various grades may be put are due primarily to its great resistance to heat and to the action of chemicals; to its insulating value, as a poor conductor of heat and of electricity; together with the fact that the longer fibres can be spun and woven into heat-resisting fabrics. A number of these uses have already been mentioned incidentally, but to describe them all would require a treatise by itself. One of the more recently developed, but already most important, outlets for asbestos products is the automobile industry. Asbestos in one form or another is used in a dozen or more parts of the latest models of the motor car, but principally for brake linings. In the United States, the largest manufacturer in the world of asbestos goods though one of the smallest producers of raw asbestos, 50 per cent of the higher-grade asbestos products, manufactured largely from Canadian raw material, are said to be consumed by the automobile.

CHROMITE

Chromite occurs in the dunite of the Thetford series. The mining of this mineral started in 1894 and continued until 1911, with an annual output not exceeding a few thousand tons a year. The high prices paid during the war led to the further exploiting of these deposits and the annual production for four years was two or three times as great as that of any year prior to the war. Operations have since been discontinued, and although lenses of chromite of considerable size, that would yield concentrating ore, are known, it is doubtful if they could be mined with profit at the prevailing prices.

The ore is a segregation in the serpentinized dunite. It varies from grains of chromite widely spaced in a serpentine groundmass to very compact aggregates containing as little as 5 per cent of interstitial matter. The walls of the ore-bodies are ill-defined and irregular. There is a somewhat gradual transition from ore into country rock, and neither chromite nor rock changes its character in the transition. The country rock in the immediate vicinity of the chromite deposits is not in any way different from that occupying large areas in their general vicinity, and in this respect is different from the country rock in the vicinity of the asbestos deposits where bands of complete serpentinization accompany the veins.

Two types of ore-bodies are found, the single lens type and the banded type. In the single lens type the ore of the central part of the lens is usually massive or compact, but grades very quickly into the country rock. A characteristic tail of lean ore runs out in the plane of the lens. In the banded type of ore-bodies the chromite grains are in lineal arrangement, forming bands of which a number may occur close together in parallel position. The banded ore may also form lens-like masses.

The segregations vary in size from merely a few grains up to bodies of tens of thousands of tons. Three bodies have produced over 25,000 tons each and two of them have still large reserves of ore. One deposit was 340 feet deep, about 30 feet in length, and 5 to 50 feet wide. A second deposit is shown by underground workings to be more than 500 feet long, 8 to 60 feet wide, and over 300 feet deep. This is only one lens of a series extending over a known length of 1,400 feet.

AUTHORITIES CONSULTED

General

Cirkel, F.: "Chrysotile Asbestos"; Mines Branch, Dept. of Mines, Canada, Pub. No. 69, 1910.

Fisher, N. R.: "The Quebec Asbestos Industry"; Can. Min. Jour., Aug. 17, 1923, p. 654.

Denis, T. C.: "Geological Sketch and Economic Minerals of the Province of Quebec"; Quebec Bureau of Mines, 1924.

Anon.: "Asbestos and Its Manufactures"; Can. Min. Jour., Apr. 18, 1924, p. 734.

Annual Reports of the Quebec Bureau of Mines: Dept. of Colonization, Mines, and Fisheries, Quebec.

Geological

Dresser, John A.: "Preliminary Report on the Serpentine and Associated Rocks of Southern Quebec"; Geol. Surv., Canada, Mem. 22 (1913).

Poitevin, E., and Graham, R. P. D.: "Contributions to the Mineralogy of Black Lake Area, Quebec"; Geol. Surv., Canada, Mus. Bull. 27 (1918).

ELECTROMETALLURGICAL DEVELOPMENTS ON THE SAGUENAY

The valley of Saguenay river, in the province of Quebec, already far famed for its majestic beauty and its attractions for the hunter and the fisherman; for its big pulp and paper mills; and, in its upper part, for its fertile farm lands; has now been made more famous still by its waterpowers, and as the site of one of the biggest individual industrial undertakings ever planned for Canada. Nearly everywhere, Canada has waterpower in abundance, but the Saguenay-Lake St. John district with its 1,340,000 horsepower of probably the cheapest hydroelectric power obtainable in quantity on the North American continent, has been particularly favoured in this respect, and as a result it has been chosen as the site of the world's largest aluminium-producing plant—a plant which, with its accessories, will eventually cost about $100,000,000; and this despite the fact that Canada has, so far as known, no aluminium ores of her own and affords, comparatively speaking, only a small market for aluminium products. Cheap electric power and contiguity to tide-water were the prime factors that decided the choice. Arvida[1], the model town in which the new industry and its employees will be housed, has been laid out with a 4-mile front on Saguenay river between the present towns of Chicoutimi and Kenogami, and 15 miles from Ha Ha bay, the head of deep-water navigation on the Saguenay, with which it is connected by rail.

Though far surpassing anything previously attempted, this new undertaking at Arvida is not the first of its kind in Quebec, nor the Saguenay the first river in Quebec to furnish cheap power to the aluminium industry. For a number of years, the Northern Aluminum Company, a subsidiary of the Aluminum Company of America, has

[1] The name Arvida is an acrostic formed from the first two letters of the three words Arthur Viming Davis, the president of the Aluminum Company of America.

operated a plant at Shawinigan Falls, Que., for the production of aluminium ingots, alloys, rods, and wire from imported ores, using for this purpose some 45,000 electric horsepower purchased from the Shawinigan Water and Power Company's generating stations on St. Maurice river; and the Montreal Light, Heat, and Power Company exports 80,000 horsepower from their Cedars Rapids plant on the St. Lawrence to the reduction works of the Aluminum Company of America at Messina, in New York state. These amounts, however, are insignificant in comparison with the 800,000 horsepower that the Aluminum Company of Canada, the Canadian branch of the Aluminum Company of America, propose ultimately to use at Arvida.

In addition to a number of smaller waterpowers on its tributaries, there are two very large ones on Saguenay river between the head of navigation at Chicoutimi and the outlet of lake St. John. The upper one, at Grande Décharge falls at Ile Maligne, not far from lake St. John, which is already developed, has a capacity of 540,000 horsepower and ten of its twelve 45,000-horsepower generating units are now installed. Ownership of this plant is divided as follows: the Aluminum Company of America, 53⅓ per cent; the Duke-Price Power Company, the original owners, 26⅔ per cent; and the Shawinigan Water and Power Company, 20 per cent; and of its total output the Aluminum Company of Canada contracts to take 100,000 horsepower for 50 years; the Shawinigan Water and Power Company, 100,000 horsepower for 50 years; Price Bros., for their wood-products plants, 40,000 horsepower for 50 years, and 60,000 horsepower for 10 years; and the Port Alfred Pulp and Paper Company, 30,000 horsepower for 25 years. The control works at the Grande Décharge power development include four dams of concrete masonry and one earth dam in addition to the power-house.

The second waterpower, which the Aluminum Company itself is now developing, is at Chute-à-Caron, about 20 miles below Ile Maligne. The dam will be at Chute-à-Caron, and the water will be carried in a flume to a power-house to be built near the mouth of Shipshaw river, about 4 miles down the Saguenay, opposite Arvida on the other bank of the stream. The Chute-à-Caron generating station will have ten turbines of 80,000 horsepower each, or a total capacity of 800,000 horsepower, all of which it is proposed shall be used in and about the proposed aluminium plants. These will include a plant for the purification of the bauxite ore—which is now done at St. Louis, Mo., U.S.A.—and fabricating plants, in addition to the actual reduction works.

Bauxite will be brought in ocean steamships from the company's mines in British Guiana to a port at the head of tide-water on the Saguenay—a port that will be open seven or eight months in the year—and transferred thence the few remaining miles to Arvida by the company's railway.

On the townsite of Arvida, which has an area of 8½ square miles, it is proposed to build, in addition to the works, 1,000 houses for the accommodation of workmen and their families.

It will be several years before all the construction called for by the plans can be completed, but delivery of aluminium metal began in 1926 and it is expected that by 1928 the output will be at the rate of 180,000 tons per annum, or 90 per cent of the world's present consumption. Until power from Chute-à-Caron is available operations will be carried on with power from Ile Maligne, a transmission line some 3 miles in length having already been built from there to Arvida.

With its big aluminium works at Arvida and its many pulp, paper, and saw-mills at Bagotville, Chicoutimi, Jonquière, Kenogami, and St. Joseph d'Alma, the valley of the upper Saguenay is likely to become one of the busiest hives of industry in Canada. The establishment of a zinc reduction plant to use some of the surplus power available in the district has also been mooted, and it is not impossible that copper from Rouyn district will some day be refined there.

AUTHORITIES CONSULTED

Quebec Bureau of Mines: Report on Mining Operations in the Province of Quebec in 1925, pp. 13-14 (1926).

Lee, W. S.: "Hydro-electric Development of the Saguenay River"; paper presented at the Annual Convention of the Am. Inst. of Elect. Eng. at Saratoga Springs, June 24, 1925.

Westman, L. E.: "Saguenay River Developments from the Standpoint of Power, Pulp, and Paper, and Electro-metallurgy"; Can. Chem. and Met., Nov., 1925, pp. 245–250.

Wake, H. R.: "Building the City of Arvida"; Eng. Jour., Nov. 26, 1926, pp. 461-64.

TÉMISCAMINGUE-ABITIBI MINING DISTRICT (ROUYN)

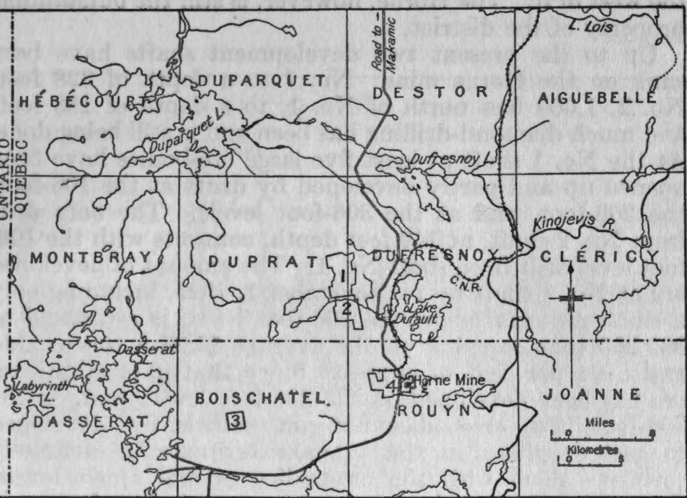
The stretch of country some 100 miles long and of indefinite width in western Quebec, popularly known as the Rouyn gold-field, from the name of the township in which the most important discoveries have been made, lies just east of the Quebec-Ontario boundary, in the southern fringe of Quebec's largest area of undeveloped agricultural lands (part of the great northern clay belt). It includes the eastward extension of the zone of gold-bearing rocks that has given rise to the Kirkland and Larder Lake gold camps in Ontario.

The first discovery of gold in the Rouyn-Abitibi gold-field was made in 1906, at lake Fortune, at the western extremity of the field; on what is now a part of the property of the Lake Fortune Mining Company; in Boischatel township, not far from the Ontario boundary. A second discovery was made, in 1911, at the eastern end of the field, on the eastern shore of lake de Montigny in Dubuisson township. Both were the direct result of that wave of active prospecting that, following the discoveries at Cobalt and Porcupine in Ontario, sent prospectors wandering through the country far and wide. Considerable work was done on, and in the vicinity of, both these early finds, but the results were not startling and the district was remote, so little came of it; and it was not until late in 1922 and early in 1923 that a new set of discoveries, made in Rouyn township a little west of the half-way point between the earlier finds, set the outside world agog. In 1923, 1924, and 1925, prospectors and scouts sent out by Canadian, American, and British mining companies scoured the field and in spite of the paucity of rock exposure—for the country is a flat one and largely clay-covered —many other finds were made; and, more important still, development of some of the earliest discoveries showed that a permanent field had been found.

The first discoveries in Rouyn township were chiefly in the vicinity of Osisko (Tremoy) and Pelletier (Lorenzo) lakes, and were mostly gold-quartz lodes; but among them was one, on the northwestern shore of Osisko lake, of quite another character—a gossan-covered hill that, having been noticed, will be left for the present, to deal with the gold quartz, and return to later—just as did the prospectors by whom it was discovered.

Aeroplane view of Rouyn.

The gold-quartz lodes, the presence of which first attracted attention to Rouyn district and which were, at first, almost exclusively the object of the prospector's search, are quartz-bearing, mineralized, schisted zones in the country rock. A great many very promising discoveries of this type of deposit have been made throughout the district, but despite their early promise development has so far failed to reveal in any of them considerable bodies of workable ore, so that interest in them has somewhat waned. Particularly so in view of what, in the mean-



MAP 6. Plan showing the chief copper-gold-zinc properties near Rouyn. 1, Waite-Montgomery; 2, Amulet Mines, Ltd., Group A; 3, Alderson-McKay claims; 4, Noranda Mines, Ltd.

time, has been shown to exist in the gossan-covered hill previously spoken of, which has now become the Horne mine.

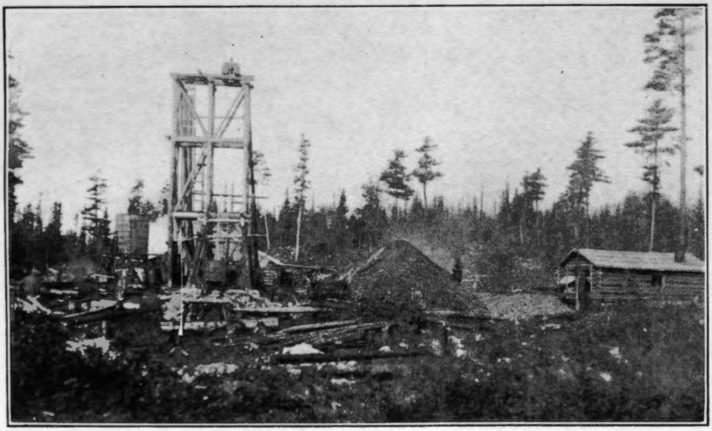
Surface trenching on the Horne prospect in 1923 revealed the presence beneath the gossan of bodies of gold-copper-bearing sulphides rich enough and of sufficient extent to enlist the aid of capital for their development. Diamond-drilling followed, with such encouraging results that in 1924 in addition to continued drilling the sinking of two shafts was begun. By September, 1924, the No. 1

shaft had reached a depth of 100 feet, all the way in solid sulphides—pyrrhotite and chalcopyrite—rich in gold and copper; and diamond-drilling had indicated the presence of a number of valuable ore-bodies.

Needless to say that, from this time on, most of the activity in the camp was directed to the search for bodies of sulphides instead of quartz veins; and, in 1925, at least three other important deposits of this class were found, in the order of their discovery: the Amulet, the Waite-Montgomery, and the Alderson-MacKay. The first two lie a few miles northwest of the Horne and the third to the west of it. The Horne, however, is still the outstanding property of the district.

Up to the present two development shafts have been sunk on the Horne mine: No. 1 to a depth of 328 feet; No. 2, 1,000 feet north of No. 1, to a depth of 158 feet; and much diamond-drilling has been and is still being done. At the No. 1 shaft at least five large ore-bodies have been opened up and partly developed by drifts at the 106-foot, the 206-foot, and at the 306-foot levels. The only drift from No. 2 shaft, at 140 feet depth, connects with the 106-foot level drift from shaft No. 1. The amount of developed ore at No. 1 shaft up to November 1, 1925, including only a small amount below the 206-foot level, is estimated at 982,265 tons carrying on the average $5.25 a ton in gold and 5·94 per cent of copper. Since that date additional ore has been developed on the 206-foot level; and, on the 306-foot, five ore-bodies not yet sufficiently developed to include them in the tonnage estimate or definitely correlate them with the ore-bodies on the upper levels. From what is already known, however, it is safe to say that the total ore-reserves at No. 1 shaft down to the 306-foot level will greatly exceed those that can already be quantitatively estimated. Ore has also been obtained in at least one drill-hole at a depth of over 700 feet, but development below the 306-foot level has been temporarily postponed in order that effort may be concentrated on getting the mine in shape for production. With this in view, a central shaft for the exploitation of the property as a whole is now being sunk and equipped.

In addition to essentially gold-copper ores, a body of zinc ore—sphalerite—practically free from copper, has been found on the Horne. Found first in a diamond-drill hole, it has now been opened up in a crosscut from the 140-foot level of No. 2 shaft, where it has a width of 65 feet,



No. 1 shaft at the Horne mine, September, 1924.

over which it averages 10·6 per cent zinc; for 32 feet of this width the average zinc content is 24 per cent. It is known to have a vertical dimension of at least 170 feet and will be further developed to determine its exact size.

The sulphide bodies at the Horne, as well as those at the Amulet and Waite-Montgomery, do not so far as known occur as veins or lodes in the ordinary acceptance of those terms, but as irregular masses scattered through the country rock. Their sulphide constituents are pyrrhotite, pyrite, chalcopyrite, and sphalerite; though the relative proportions in which these occur vary widely in different deposits and in different parts of the same deposit, as does also the gold content. In some parts the sulphides are solid and massive, forming direct smelting ore; in others, disseminated through the country rock, forming concentrating ores.

The Horne Copper Corporation, the operating subsidiary of Noranda Mines, Ltd., the owners of the property, is now preparing, at the Horne mine, the foundations for a copper smelter of the reverberatory type, capable of handling daily 1,000 tons of ore. The smelter, which will probably be in operation before the end of 1927, will treat not only Horne ore, but also serve as a customs smelter. It is expected that the Amulet, Waite-Montgomery, and Alderson-MacKay properties will be in a position to furnish considerable quantities of custom ore by the time the smelter is finished.

Electric power for the operation of both the smelter and the mines in the Rouyn camp is supplied by the Canada Northern Power Corporation from their generating station on Quinze river about 50 miles away. A transmission line has been built and power is now being delivered to the camp. With the advent of the railway and adequate power the development of the camp will proceed rapidly.

To provide for the needs of the community that will grow up around their plant, the Horne Copper Corporation have set aside 1,600 acres of land for a townsite, and have also obtained from the Quebec legislature the authority necessary to enable them to develop this along the lines of a model town.

Rouyn, the fourth and youngest of the large mining camps that have sprung up in Northern Ontario and Quebec within the last twenty-five years, affords to the visitor an instructive comparison between the conditions that must be met in a pioneer community and those obtaining in the older camps.

Geological Features

Geological formations of earlier and later Precambrian age underlie the area. The younger rocks consist of the rather flat-lying sediments of the Cobalt series and are separated by a great unconformity from the folded and disturbed formations of earlier age. The earlier rocks consist of the Timiskaming and Keewatin series with igneous intrusions of various types. The Timiskaming series is sedimentary and rests with pronounced unconformity upon the Keewatin series, which is composed mostly of lavas.

Table of Formations

Quaternary	Post-glacial	Clays, silts, sands
	Glacial	Boulder clay, stony and gravelly morainic deposits
Huronian	Cobalt series	Conglomerate, greywacke, arkose, argillite
	Great Unconformity	
Pre-Huronian	Pre-Huronian intrusives	Basaltic diabase Later gabbro Syenite Hornblende-mica lamprophyre Syenite porphyry Granite Older gabbro
		Folding
		Diorite porphyry Amphibolite Hornblende lamprophyre
	Timiskaming series	Conglomerates, greywacke, and basalts
	Unconformity	
	Keewatin	Basalts, andesites, dacites, rhyolites, and tuffs

The Timiskaming series forms a belt 10 or 12 miles wide extending east from near the Interprovincial Boundary to Bell river through the southern parts of Dasserat, Boischatel, Rouyn, Joanne, and other townships to the east, and through Dufay, Montbeillard, Bellecombe, Vaudreuil, etc. North of this belt of Timiskaming sediments the country to some distance beyond the Canadian National railway is underlain in great part by the Keewatin series.

The Keewatin series consists almost wholly of acidic and basic lava flows—rhyolite, trachyte, dacite, andesite, and basalt. The basalts form the bulk of the Keewatin rocks and are mostly dark olive-green rocks to which the name greenstone has been fittingly applied. The andesite resembles the basalts, but is somewhat lighter in colour. These basic rocks are as a rule more altered than the acid lavas. Many of them are of great thickness and in the central part are medium grained. The acid lavas are green-white to grey-white in colour, are invariably fine grained, and many are porphyritic. Amygdaloidal textures are common and good pillow structures occur in many places. Banded with the lavas are numerous beds of tuffs and agglomerates mineralogically like the lavas with which they are associated.

The Keewatin rocks have been subjected to intense folding, faulting, and alteration. They dip at high angles and have an approximate east and west strike.

The Timiskaming series consists mainly of conglomerates and greywackes. The conglomerate belt, which is about a mile wide in the west and thins very much towards the east, lies next to the Keewatin lavas, with greywacke intervening in some places. It has undergone varying degrees of shearing, but is commonly fairly schistose. The boulders are rounded or subangular and vary from a few inches to more than a foot in diameter. They consist of granite, syenite, syenite-porphyry, volcanics, and greywacke.

The greywacke which forms the greater part of the Timiskaming series is highly metamorphosed and most of it is a typical schist. The strata dip at high angles to the north and may be overturned.

Bands of sediments are found within the Keewatin area in Duparquet, Destor, Cléricy, La Pause, and other townships. It has not yet been determined beyond all doubt whether they are to be correlated with the Timiskaming or whether they are a part of the Keewatin series.

The Keewatin lavas and Timiskaming sediments are cut by acid and basic igneous intrusives of great variety. They take the form of dykes, bosses, and masses of irregular outline and vary greatly in their age relations. Hornblende lamprophyres, amphibolites, diorite porphyries, gabbros, granites, syenite porphyries, porphyritic syenites, feldspar, and quartz porphyries are found.

Gabbroid rocks of two ages are found. The older, a true diorite, occurs mainly in the western part of the area, forming large, irregular masses and dykes in the Keewatin rocks. It is younger than the Keewatin lavas and older than the syenite porphyry and may have been intruded before the Timiskaming series was folded. The later, a gabbro, forms well-defined dykes cutting the Keewatin and Timiskaming series and the granite of the region and extending for many miles across the country. Both commonly stand up as ridges. The older is more basic, somewhat finer grained, and weathers to a dark green tint, whereas the weathered surfaces of the later are commonly brownish. In many places, however, it is difficult to distinguish between the two without the use of a microscope.

The belt of Timiskaming series is cut off to the south by a large granite batholith. Great thicknesses of the Timiskaming series were stoped away and partly or completely dissolved in the fluid granite and the fusion of the two has produced a great variety of rock types. Small dykes of granite cut the Timiskaming series, but have not been broken up or rendered schistose by the folding movements of this series and it is concluded that the granite intrusion took place after the folding. Bodies of granite variable in outline are found in irregular distribution through the Timiskaming and Keewatin series. Some of these are closely related to the diorite described in the preceding paragraph, and are probably older than the large body of granite lying to the south.

In the western part of the area dykes and irregular masses of syenite porphyry form an interesting and closely related set of intrusives, with large variations in composition and slight differences in age. They all cut both the Timiskaming and Keewatin series, and the earlier gabbroid diorite, but are cut by the later gabbro. Latest of all intrusives is a very fresh-looking, very fine-grained, black diabase, forming dykes rarely more than a few inches in width.

In the western part of the area a belt of the Cobalt series of Huronian age, approximately 2 miles wide, stretches east from the Interprovincial Boundary for a distance of 17 or 18 miles. The series is composed of large quantities of conglomerates interbedded with greywackes and impure quartzites, together with some fine-grained, blackish greywacke or argillite.

Glacial deposits and bedded sediments laid down in lakes formed at the edge of the retreating ice-sheet are widespread. The bedding is caused by variation in the character of the material, due to seasonal changes.

Development work is being conducted on a great number of properties in western Quebec, but descriptions will be given of only two or three.

Horne Claims

The Horne sulphide deposits are near the northwest corner of Osisko lake, south of the mouth of a small creek entering the lake from the west. The principal discoveries have been made on the top of a rocky knob, about 1,000 feet in diameter, that rises some 150 feet above the level of the lake. The rocks are andesites and rhyolites intruded by very fine-grained altered gabbro. The rhyolites or andesites are fine-grained, light grey rocks, finely porphyritic, with phenocrysts of quartz and feldspar up to 1 mm. in diameter, and contain quartz, in varying amounts up to 5 per cent or 6 per cent, chlorite secondary after hornblende, 20 per cent to 25 per cent, and the remainder mainly oligoclase, $Ab_{85}An_{15}$. In addition there are cherty phases that probably represent silicified ash beds, are very white and glassy in appearance, and contain as much as 70 per cent of quartz, the rest mostly sericite probably secondary after feldspar. The gabbro forms a number of irregularly-shaped, dyke-like intrusives, with a general north-south strike.

All the valuable ore-bodies have been found in the andesites. There is mineralization in the rhyolites and rhyolite tuffs, varying in concentration from scattered grains to wide veins of massive sulphide, but this sulphide is practically pure pyrite, carrying no copper and only low values in gold. In the andesites the primary sulphides are pyrrhotite with a minor quantity of pyrite, and zinc blende in places, and chalcopyrite replaces the first-formed pyrrhotite to produce a copper ore.

In that part of the deposit that has been best exposed by trenching, it can be seen that the lavas have been sliced, and in places converted almost into a schist, prior to the deposition of the sulphides. The result of the fracturing, on both a large and a small scale, has been to break up the mass of rock so as to form a series of unfractured lenses separated from one another by bands of highly shattered material.

The lenses are of all sizes from 2 or 3 feet in length upward. The sulphides have been introduced along the channels afforded by the fracturing, and have replaced the shattered material in greater or less quantity, depending apparently on the extent of the shattering, and the number of channels accordingly available to them. The unshattered lenses contain little or no introduced sulphide.

Waite-Montgomery

H. C. Cooke gives the following notes:

The Waite-Montgomery property lies close to the eastern side of Duprat township and about 4 miles from its south boundary. The property was staked in March, 1925, and ore discovered, rather by accident, beneath the upturned root of a fallen tree in a muskeg. Trenching during the summer showed that the ore forms a large mass over an area at least 100 by 200 feet. The geological examination indicated that the exposed ore is a part of a larger sheet, lying nearly flat, with a gentle dip to the southeast. Late in the autumn a drill was brought in to determine the thickness of the sheet. The owners do not wish to make public the results of the drilling as yet, but I may say that they show the ore-body to be of great value. The average of 30 channel samples from the surface gave 17·3 per cent copper, 3·6 per cent zinc, 2·8 ounces of silver per ton, and 40 cents gold per ton."

Alderson-MacKay

Late in the fall of 1925 the firm of MacKay and Alderson made a discovery in Boischatel township that bids fair to rank with the two already described. The claims, Nos. M.L. 1953 and T 2990, are just north of the centre line of the township and 3 miles from its west boundary. Three veins have already been discovered, while dip-needle observations suggest that still others may be found. The southernmost vein is about 20 feet wide, strikes north 60 east, and has been traced 150 feet. It carries 8 per cent copper and about $1.50 in gold and silver. Two hundred feet north there is a second vein striking north 78 degrees east, which is 15 feet wide and has been traced about 250 feet. It carries 5 per cent copper. Eight hundred feet still farther north is the third vein, also about 15 feet wide, and traced for some 250 feet. It strikes north 80 degrees west, and averages about 7 per cent copper and $2 in gold and silver. In all of these the ore is a mixture of the sulphides pyrite, pyrrhotite, and chalcopyrite, replacing a lava of about the composition of a trachyte; the gangue is the unreplaced part of the rock itself.

Amulet

The Amulet property lies across the Duprat-Dufresnoy line about 2 miles south of the Waite-Montgomery. It is underlain by a flow of very acid, hard, massive rhyolite lying almost flat, the dips being less than 20 degrees. Resting upon this are patches of a moderately basic rock called dalmatianite or "spotted dog" because it is filled with rounded nodules about the size of marbles, that weather to a lighter colour than the matrix. These patches are remnants of a large, single flow, most of which has been removed by erosion. No ore-bodies are found in the rhyolite, but the dalmatianite, wherever found, contains more or less ore in the form of replacement deposits. The primary ore minerals consist mainly of pyrrhotite with some pyrite and a good deal of zinc blende. The pyrrhotite has been replaced to a greater or less extent by chalcopyrite.

AUTHORITIES CONSULTED

General

Quebec Bureau of Mines: Recent Annual Reports.
Noranda Mines Ltd.: Annual Report for 1925.
Parsons, A. B.:" An Excursion into Rouyn"; Eng. and Min. Jour. Press, Oct. 30 and Nov. 6, 1926.

Geological

Wilson, M. E.: Geol. Surv., Canada, Mem. 39 (1914).
Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1922, pt. D (1923).
James, W. F.: Geol. Surv., Canada, Sum. Rept. 1922, pt. D (1923).
Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1923, pt. C No. I (1924).
James, W. F.: Geol. Surv., Canada, Sum. Rept. 1923, pt. C No. I (1924).
Harvie, R.: Geol. Surv., Canada, Sum. Rept. 1923, pt. C No. I (1924).
James, W. F., and Mawdsley, J. B.: Geol. Surv., Canada, Sum. Rept. 1924, pt. C (1926).
Cooke, H. C.: Can. Inst. Min. and Met., Bull. 169, pp. 627-640 (May, 1926).

ONTARIO

Ontario is the chief mineral-producing province in the Dominion and is specially noted for its gold fields at Porcupine and Kirkland Lake; its Cobalt silver mines with their by-product metals, cobalt, nickel, arsenic, bismuth, and antimony; and its Sudbury nickel mines with their accompanying output of copper and platinum-group metals. Galena also is mined and worked up into pig lead at Galetta, near Ottawa.

In the field of non-metallic minerals, reputedly the largest single deposits known in America of talc, feldspar, mica, and graphite, are being mined in southeastern Ontario; and actinolite, fluorspar, garnet, gypsum, pyrite, and quartz at various localities in the province. Petroleum and natural gas are produced in southern Ontario; where also large salt beds are being worked, and chemical plants based on the use of brine from these beds are in operation at Amherstburg and Windsor. Gypsum mining and the manufacture of gypsum products are important industries near Paris.

At Hamilton and at Sault Ste. Marie there are large iron and steel works, dependent, however, on the United States for their supplies of ore and fuel.

In building materials, there is a large production of Portland cement, bricks, and other clay products, as well as building stone, sand, gravel, and lime.

IRON AND STEEL INDUSTRIES

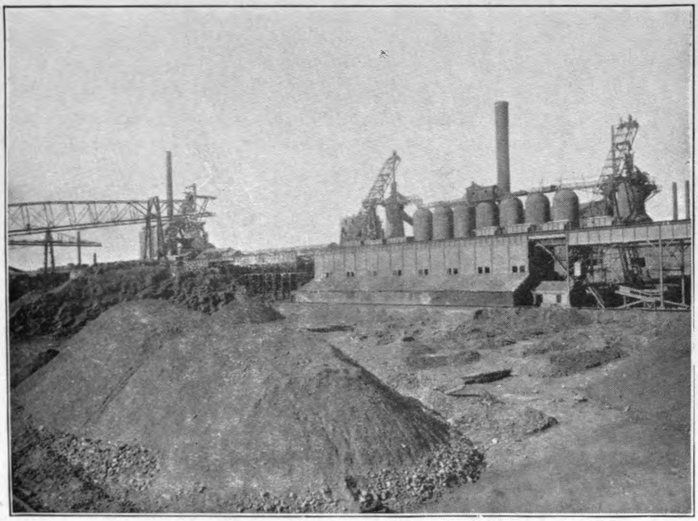
Algoma Steel Corporation

The present company was incorporated in Ontario in April, 1912; the entire capital stock is owned by the Lake Superior Corporation, a United States organization. The works of the corporation are located at Sault Ste. Marie, Ontario, at the foot of navigation on lake Superior, a location which facilitates the assembling of the raw products from various ports on the Great Lakes.

This company owns iron ore properties in Ontario, north of lake Superior, but these are not now being worked, present operations being based on Lake Superior iron ores purchased in the open market.

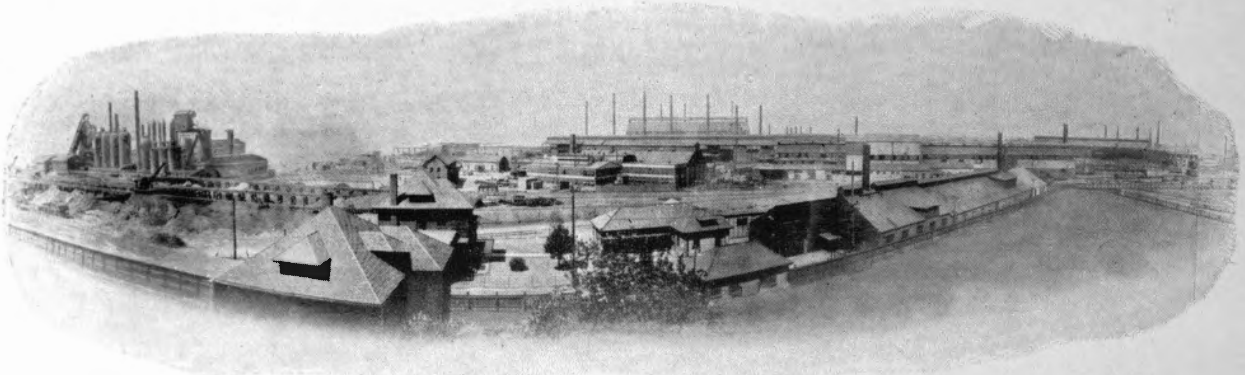
Coal for the coke-ovens is obtained from mines in West Virginia, controlled by the company through subsidiaries.

PLATE XVII



Blast-furnaces and stockyard of the Algoma Steel Corporation, Sault Ste. Marie, Ont.

PLATE XVIII



Works of the Steel Company of Canada, Hamilton, Ont.

Limestone is obtained from quarries at Fiborn and Ozark in upper Michigan, also worked by a subsidiary company which also owns limestone properties on the Canadian islands east of Sault Ste. Marie, but these properties are not at present operated.

The Algoma Steel Works, at Sault Ste. Marie, Ontario, are provided with four blast-furnaces having an annual capacity of 500,000 tons of various grades of pig iron. The coking plant consists of 110 Koppers by-product ovens, and 50 Wilputte by-product ovens. This plant has an annual capacity of 625,000 tons of coke. In connexion with it there is a by-product plant having a capacity of 8,000 tons of ammonium sulphate per annum. The tar recovery amounts to about 30,000 tons. This is delivered by pipe-line to the adjacent works of the Dominion Tar and Chemical Company, for refining.

The steel plant is provided with eleven stationary basic open-hearth furnaces and a 300-ton mixer. The capacity is 420,000 tons of ingots per annum. There is also a duplexing department equipped with one 20-ton Bessemer converter; four cupolas; one 200-ton mixer and one 150-ton tilting furnace, with an annual capacity of 180,000 tons.

The rolling mill is equipped with modern machinery and has an annual capacity of 445,000 tons of rails and structural shapes, and 55,000 tons of merchant bars, angles, rail fastenings, and similar products. Plans are under way to enlarge the capacity of the plant for the production of finished products.

The principal products of the corporation are bessemer, basic, malleable, and foundry pig irons; steel ingots, blooms, and billets; rails, structural shapes up to 15-inch channels, and beams, splice bars, tie plates, merchant bars, iron castings, coke, benzol, sulphate of ammonia, and tar.

Steel Company of Canada

The Steel Company of Canada was incorporated by Federal charter on June 9, 1910, to take over the assets of a number of separate companies located at several industrial centres in Ontario and Quebec. The company also owns a controlling interest in several subsidiary companies which consume steel products. The company operates branches in Hamilton and controls subsidiary plants in London, Brantford, Toronto, Belleville, Gananoque, and Montreal.

The principal plant for primary products is at Hamilton, where are assembled iron ores from the Lake Superior mines, coal from mines in the United States, and limestone from local sources. This plant is equipped with two blast-furnaces capable of producing annually 290,000 tons of basic, foundry, and malleable pig iron. The coking plant consists of 80 Wilputte by-product ovens, with an annual capacity of 365,000 tons of coke. The ovens are provided with a benzol recovery plant capable of producing annually 2,190,000 gallons of light oil, and with a plant for recovering by-product ammonia as the sulphate.

The steel plant is provided with eleven basic open-hearth furnaces and one 100-ton mixer. The fuels used in the open-hearth are coke-oven gas, tar, and producer gas made in six Morgan producers. The capacity of the plant is 300,000 tons of ingots per annum.

The rolling mill is equipped with modern machinery and has a capacity of 260,000 tons of blooms, billets, and sheet-bars, per annum. There are three sheet-mills with accessory furnaces for heating the sheet-bars; two cold mills; a 6-box annealing furnace, and a spike shop for producing railway spikes. The capacity of this part of the plant is 150,000 tons of hot-rolled products, including wire rods, merchant bars, light structural shapes, agricultural implement shapes, and similar stock.

Rolled products only are produced by the Ontario Works at Hamilton, which has an annual capacity of 700,000 tons.

Wire and wire products are produced by the Canada Works at Hamilton, which has a capacity production of 32,000 tons per annum.

Miscellaneous hardware and small parts are produced by the Brantford, London, Toronto, Belleville, Gananoque, and Montreal plants. The products of the company include: various grades of pig iron, steel ingots, blooms and billets, sheet-bars, scrap bar, iron or steel merchant bars, tie plates, fish plates, steel axles, forgings, horseshoe bars and horseshoes, black sheets, black and galvanized wrought iron pipe, nail plate and cut nails, wire rods, plain, galvanized, and tinned wire, wire nails, tacks, staples, and similar products, barbed wire, fencing and other wire goods, spikes, bolts, nuts, rivets, and washers, machine screws and wood screws, drop forgings, and carriage hardware.

Sudbury Nickel

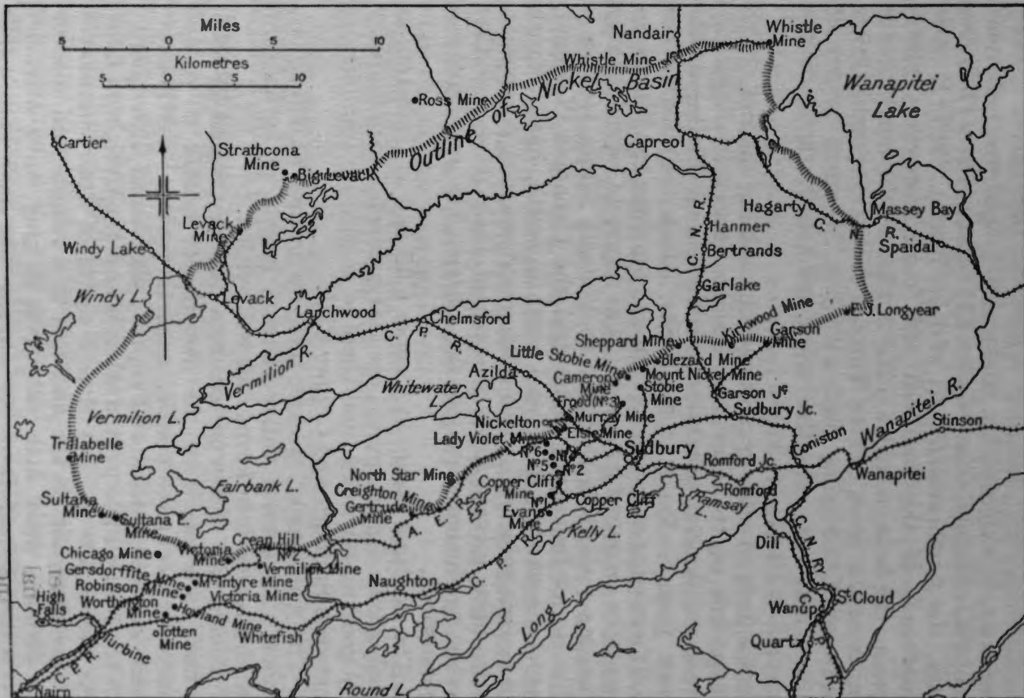
Sudbury, the business centre of the nickel mining industry, is a thoroughly modern, well-built town of about 9,000 inhabitants, situated about 35 miles north of Georgian bay, the northeastern part of lake Huron. It is a little southeast of the southern and most important nickel range, the nearest mines being 2 miles to the north, and 3 miles to the west. From Toronto it can be reached by a journey of 260 miles north and from Montreal by one of 439 miles west, on either the Canadian National or the Canadian Pacific railways.

Six lines of railway traverse the mining district. The main line of the Canadian Pacific crosses it diagonally from southeast to northwest, with a branch running southwest from Sudbury to Sault Ste. Marie, parallel to the southern edge of the nickel field and touching the Worthington mine on one of its offsets. The Algoma Central railway running west from Sudbury to Victoria Mines touches a number of important mines and the Canadian National, which crosses the field from north to south, has a branch to Garson mine. The two mining and smelting companies, also, have private lines to some of their mines, so that every producing mine in the district has excellent rail connexions.

The smelting plants at Copper Cliff and at Coniston, as well as many of the mines, are also connected with Sudbury by good motor roads, and there is an electric tram service between Sudbury and Copper Cliff.

The whole nickel district includes an area of 550 square miles. Its central valley consists largely of agricultural land, divided into farms and well settled.

Nickel was first reported from Sudbury region in 1856, when, as a result of the disturbance caused to a land surveyor's compass needle, magnetic pyrites—pyrrhotite—carrying some nickel and copper, was found disseminated in the rock a little west of what is now the Creighton mine. As nickel was at that time a metal of little commercial importance and as the find was in a remote and roadless wilderness, what little attention it may have attracted soon died down; for a few days it may have been a mild topic of scientific discussion, but that was all. It was not until 1883, when the Canadian Pacific railway was being built through Sudbury district and chalcopyrite was disclosed in a rock-cutting on the railway right-of-way at



Map 7. Key map of Sudbury nickel field.

what later became the Murray mine, that serious attention was given to the mineral possibilities of the region. Prospectors were swarming over the district by 1884 and the discovery in the rock-cutting was soon followed by many others elsewhere. The Elsie, Frood, Worthington, and Lady Macdonald mines were found in 1884; the Copper Cliff, Stobie, Crean Hill, Evans, and Blezard in 1885, in which year also the Creighton mine was rediscovered; the Victoria in 1886; the Vermilion, also rich in gold, in 1887—all of them taken up for copper alone, the presence of nickel in the ores not having yet been recognized. The Garson mine was found in 1891; the Kirkwood and the Gertrude in 1892. The first discovery on the northern range was the Levack mine, first found in 1887, but not opened up until 1913, followed by the Whistle, also in 1887, and the Strathcona in 1889.

The first serious attempt at mining was made in 1886, at the Copper Cliff mine, where the Canadian Copper Company, later to become the International Nickel Company, made an open-cut in the side of a steep, gossan-covered hill. The surface ore carried 15 to 20 per cent copper and, as the names of the mine and the company indicate, it was regarded as copper ore only. Until 1887 no one had any idea that the ore contained any metal other than copper, but in that year a shipment of about 1,200 tons of ore sent from Copper Cliff to the Orford Copper Company's works at Constable Hook, New Jersey, to be smelted, having presented difficulties in its manipulation, an investigation was made, and these were found to be due to that "spirit of the mine" which the old German miners blamed for inciting their copper ores to bad behaviour — that is to say, to the presence of nickel. A smelter was built at Copper Cliff and blown in December 24, 1888 —the first in the district. The direct descendant of this pioneer plant is the modern town of Copper Cliff with its extensive metallurgical plants, spacious company offices, hospital, schools, clubhouse, and residences for officials and workmen.

In September, 1890, a furnace was built on the site of the original discovery, at the Murray mine, by H. H. Vivian and Company, of Swansea, Wales, into whose hands the property had passed; a second furnace was added a year later; and a third in 1892. Mining and smelting were carried on with more or less success until 1894, when this plant was closed down permanently.

About the same time the Dominion Mineral Company operated a smelter at the Blezard mine, on ore from that mine and the Worthington, but it was closed down in July, 1895, and the buildings have now disappeared.

About 1900, a smelter to make high-grade matte without preliminary roasting of the ore was built at the Mount Nickel mine by the Great Lakes Copper Company, but the process was a failure and operations ceased in 1901.

It was not until 1899 that the second of the two powerful corporations that now share the Sudbury nickel industry between them, the Mond Nickel Company, entered the field, by the purchase of the Victoria mine. There they erected a smelter which was in operation from 1901 to 1913, when their centre of operations was removed to Coniston, where a large modern plant had been built more convenient to the present ore supply.

In 1916 the British America Nickel Corporation, a strong British-Canadian company formed to produce nickel from Sudbury ores by the Hybinette electrolytic process, after purchasing the Murray, Elsie, Lady Violet, Gertrude, and other mines, started the building of a large, modern smelter at Nickelton, near the Murray mine. The matte from the smelter, which was blown in, January, 1920, was sent to a large electrolytic refinery that the company had meantime built at Deschênes, Que., on Ottawa river, to be converted into pure electrolytic nickel and copper. The depressed condition of the nickel industry forced the company to shut down mine, smelter, and refinery in 1921. Operations were resumed for a short time in 1923, but the corporation went into liquidation in 1924, and in the following year its chief assets passed into the hands of the International Nickel Company.

Forty years ago, when nickel mining in Canada commenced, the world's consumption of that metal was only about 1,000 tons per annum, largely obtained from New Caledonia ores refined in France; and its uses were few, chiefly as a component of nickel-silver and coinage alloys and for nickel-plating—even yet the market for nickel is a much narrower one than that for iron, copper, and other of the useful metals—and no processes were then known either for the extraction of the metal from ores like those of Sudbury or for the separation of copper from nickel. Consequently, the pioneers in the Canadian nickel industry were confronted with the problem of first finding a method of treating their ores and then of marketing the product. The difficulties, though great, were finally overcome, and the Sudbury nickel industry, from a weak and precarious infancy, has grown to be one of the big metal industries of the world. But, of all the companies that entered the field, only two survive: the International Nickel Company, whose history is contemporaneous with, and inextricably involved with, that of the Sudbury nickel industry; and the Mond Nickel Company, who had solved the first part of the problem, the treatment of the ore, before they entered the mining field. These two companies now supply nearly 90 per cent of the world's nickel, and their combined annual output in 1918, the year of maximum production, was 46,000 tons, or 46 times as much nickel as the whole world produced when the Sudbury mines were discovered. The present rate of production (1925) is a little under 37,000 tons of nickel, to which must be added 20,000 tons of copper, the proportion of copper to nickel in the blast-furnace matte being on an average roughly 4 to 7. Gold, silver, platinum, palladium, rhodium, ruthenium, iridium, and osmium are also recovered in considerable quantities from Sudbury ores.

Unique among the Sudbury deposits is the International Nickel Company's Vermilion mine. Wire gold was found freely distributed through the gossan and upper part of the deposit, so that it was at first regarded as a gold mine. Sperrylite, an arsenide of platinum, was first recognized in the gossan of the Vermilion mine by F. L. Sperry, chemist of the Canadian Copper Company, after whom it was named. The gossan was also found to contain palladium; and both platinum and palladium occur in the solid ore as well. The deposit is a small one as Sudbury deposits go, but in addition to being much richer than the others in the precious metals, its nickel and copper content runs much higher than that of the other mines—the nickel doubtless on account of the abundance of polydymite in the ore. Its production has been small, only a few thousand tons, containing 6·64 per cent nickel, and 6·89 per cent copper, that have been treated separately.

As a general average the Sudbury nickel ores probably run not over 3 or 4 per cent of nickel with copper in smaller proportion, though the relative proportions of nickel and copper may locally be reversed.

Estimates of the reserves of the Sudbury area remove any anxiety regarding the future supply. In 1916, the Royal Ontario Nickel Commission concluded that reserves of proved ore could conservatively be put at 70,000,000 tons and that it was safe to say that proved, probable, and possible ore together exceeded 150,000,000 tons. At the same time, the International Nickel Company's published estimate of their ore reserves was 57,000,000 tons in three mines only. Quite recently in a public utterance, a high official of that company stated that diamond-drilling had proved an ore-body containing 100,000,000 tons at the International Nickel Company's Frood, or No. 3, mine, thus making it one of the largest known sulphide ore-bodies in the world. The average content of the ore mined from open-cuts at the Frood was 2·05 per cent nickel and 1·45 copper.

GEOLOGICAL FEATURES

The nickel-copper producing area of Sudbury is underlain by rocks of Precambrian age. Formations of the earlier and later Precambrian are represented and there are few areas of equal extent in which such a variety is exposed.

The rocks that are regarded as most important from an economic point of view because of their probable genetic relation to the ore deposits, and that have attracted most attention because of their scientific interest, are those that make up the Sudbury norite-micropegmatite sill.

The sill outcrops in a band in the form of an ellipse, with a major axis of 36 miles and a minor axis of 16 miles. The average width of the southern part of the band is 3·1 miles and of the northern part 1·9 miles, and the total average width is 2·5 miles.

The outer edge of this elliptical band of igneous rocks is basic; the inner edge acidic.

> The least altered phase of the basic portion of the eruptive is represented by what may be referred to as norite. The rock is sometimes called a quartz hypersthene-gabbro; but for general purposes the former name is preferred. The microscopical examination shows the rock to be an eruptive of rather exceptional character and interest. It belongs to the general family of gabbros, but with distinct traces of, and, at times, well-marked, diabasic or ophitic structure. The prevalence and usual preponderance of hypersthene or enstatite show its close affinity with the norites, while it contains, which is very exceptional for such a rock type, an abundance of original quartz. In fact, many specimens could be secured which contain nearly as much quartz as an ordinary hornblende granite.

The rock has suffered considerable alteration and the pyroxenes have been changed to hornblende and uralite.

The acid phase of the inner edge of the eruptive is granitic in composition. On freshly exposed surfaces the rock is usually dark coloured and shows small, reddish or yellowish phenocrysts of feldspar. Orthoclase is the predominant feldspathic constituent, but plagioclase is usually more or less abundant. Biotite is the prevailing ferromagnesian mineral.

One of the most noteworthy points in connexion with this gneissoid rock is the prevalence and abundant development of micropegmatite or granophyre, and also the fact that plagioclase and quartz are most frequently the component minerals forming the graphic intergrowth.

The rock is commonly spoken of as a micropegmatite.

Geologists are not in agreement on the nature and extent of the differentiation of this igneous mass. Observations have been made that would indicate, in some places at least, a gradual transition in chemical and mineralogical composition from norite to micropegmatite. One observer, however, "found no indication of a regular 'composition gradient' in either norite or granophyre, considered separately, while the transitional zone between them has all the characters of a hybrid rock." Another states "there is no sharp line of demarcation between the acidic and basic portions of the nickel-bearing eruptive, but the change, though gradual, is usually sharp enough to enable a boundary to be placed between these two types with tolerable accuracy." Another states that "there is a considerable amount of acid material scattered throughout the base of the norite. In places it is a typical granite, although often it resembles the norite except that it has a larger percentage of quartz and acid feldspars. It has been observed in several of the drill-holes and as irregular patches in outcrops of norite in eastern Garson township." One of the most important contributions to this subject is that made by T. C. Phemister, who finds that the norite and the micropegmatite are two distinct intrusives. He states that "the 'norite' typical of the southern range has its most basic facies from half to three-quarters of the total width of its outcrop from the basal contant"; that the micropegmatite "becomes more acid towards its contact with the 'norite';" that although with one exception no sharp contacts between the two rocks were observed, the transition zone never exceeds about 80 yards where dynamic metamorphism has not obscured the relationships; and that the norite near the micropegmatite has suffered metamorphism.

The dip of the outer edge of the norite toward the centre of the ellipse varies from place to place and may average about 45 degrees. At several points on the southern outer edge, however, the contact with the adjacent rock is about vertical, or dips slightly away from the centre of the ellipse, and the dyke-like nature has been pointed out. Nothing definitely is known about the dip of the inner edge.

Certain resemblances exist between the norite-micropegmatite sill and the Nipissing diabase sills of the silver-mining districts of Cobalt, South Lorrain, and Gowganda, and it is not improbable that they are of the same age and origin. They are regarded tentatively as Keweenawan in age.

For convenience of description the other rocks of Sudbury district will be divided into two groups: (1) those underlying and located outside of the elliptical band of norite-micropegmatite; and (2) those overlying and located within the band of norite-micropegmatite.

Outside the band of igneous rocks is to be found a great variety of sedimentary and igneous rocks, conglomerates, quartzite, greywacke, greenstone, granite, and gneiss.

A series of greenstones of various compositions are found widely distributed to the south and east of the norite. They are of igneous origin and both volcanic and intrusive phases are represented. At the east there are well-banded Keewatin schists made up in large part of volcanic tuffs. It is not improbable that some of the greenstones, also, are of Keewatin age. Some are associated with a later series of quartzite, greywacke, and arkose, the Sudbury series, and may be of the same age as the Sudbury series or later. The greenstones have been intruded by granite; in places they are literally cut to pieces by granite dykes, and in other places a banded gneiss has been formed by the injection of parallel dykelets of granite through the greenstone.

The Sudbury series, the most striking series of sedimentary rocks in Sudbury area, forms a wide band extending northeast and southwest, south of the norite mass. It consists of three formations: the Copper Cliff arkose with a thickness of 2,000 feet; the McKim greywacke, 7,000 feet, and the Wanapitei quartzite, 20,000 feet.

The Copper Cliff arkose, which is well exposed in a range of reddish hills in the vicinity of Copper Cliff mine, is made up of grains of quartz and feldspar that are not generally well rounded and cannot have been transported far by wind or water. The feldspars have suffered very little decomposition, and as all the material is fairly fresh looking, and distinct stratification is rarely seen, this rock is difficult to distinguish from granite. In some places there has been a good deal of recrystallization, and long blades of green hornblende have developed. In places it is much brecciated, the brecciation probably having been produced at the time of the intrusion of the norite.

The McKim greywacke is distinctly of sedimentary origin and presents on weathered surfaces beautiful sedimentary structures—fine stratification with small-scale crossbedding and ripple-marks. It varies considerably in composition, but always has some gritty particles of quartz and feldspar in a grey groundmass of finer material. As a rule, the rock is banded with fine and coarse layers, the bands varying from ½ inch to 2 or 3 inches in thickness. The fine-grained parts are slaty, and many contain pseudomorphs after staurolite, some small like rice grains, but some reaching 5 or 6 inches in length. The pseudomorphs now consist of quartz and sericite. The formation strikes northeast to east and has a nearly vertical dip.

The Wanapitei quartzite consists of well-rounded grains of quartz with a few bits of feldspar embedded in a matrix of secondary quartz and sericite. It has distinct bedding in rather thick layers, and occasional crossbedding. On the weathered surface it resembles a pale grey sandstone. The strata strike northeast and have an average dip of 45 degrees to the southeast. They have been intruded by granite, and close to the granite the materials are recrystallized into a schistose rock. *Lit par lit* structure is common near the contact.

The Wanapitei quartzite has been correlated with the Huronian Mississagi quartzite of the north shore of lake Huron.

On the north shore of Ramsay lake east of Sudbury there is a small area in which conglomerates are exposed resting unconformably on the Sudbury series. The age has not been determined. A great deal of the north band of norite is in contact with granites and gneisses, the exact ages of which have not been determined. They are older, so far as is known, than the norite-micropegmatite. An area of granite runs from Copper Cliff southwest to near Crean Hill as a band from 1 to 2½ miles wide. For more than half of this distance it is in contact with the norite. Geologists do not agree as to the relative ages of these two contiguous, igneous rocks. The subject is one of considerable importance, for on this depend some of the arguments advanced regarding the theory of the origin of the nickel-copper deposits.

Within the band of norite-micropegmatite lies a series of sedimentary rocks known as the Whitewater series. They are nonfossiliferous and probably of late Precambrian age. They occupy what is commonly known as the Sudbury basin, the outcrops forming elliptical belts concentric with the band of norite micropegmatite. They consist of: (1) the Trout Lake conglomerate with a thickness of 450 feet; (2) the Onaping tuff with a thickness of 3,800 feet; (3) the Onwatin slate with a thickness of 3,700 feet; and (4) the Chelmsford sandstone with a thickness of from 800 feet to 1,500 feet.

Deposits of mixed zinc, copper, and lead sulphides have been found at a number of places in this sedimentary series of rocks, and extensive exploratory operations are now being carried on in them a short distance west of Sudbury for the purpose of developing commercial ore-bodies.

It is remarkable that the Whitewater series lies only within the band of norite-micropegmatite and that not even a trace of the Trout Lake conglomerate is found at the outer edge of the intrusive. The Whitewater series has generally been regarded as forming a synclinal basin with an average dip toward the centre of about 30 degrees. The suggestion has also been offered that these sediments are preserved as a down-faulted block.

The ore of the nickel-copper deposits consists almost wholly of three minerals, pyrrhotite, chalcopyrite, and pentlandite. Several other minerals occur, but they are in comparatively insignificant quantities. Pentlandite is the nickel-bearing mineral and chalcopyrite is the copper-bearing mineral. Pentlandite is not as a rule readily distinguishable in hand specimens from the pyrrhotite with which it is associated.

The ore-bodies carry a certain amount of rock. Fragments of the country rock varying from microscopic

View of the interior basin from the inner edge of the nickel eruptive.

specks to great blocks 15 feet or more in diameter and consisting of granite, greenstone, norite, greywacke, and schist are embedded in a matrix of sulphides; even the most massive ore is not free from these fragments. The cleanest ore is mined from the Creighton deposit, but even from this ore from 10 to 16 per cent of rock is hand-picked. The hand-picked product still contains 18 to 21 per cent of silica. The included fragments and the wall-rock are to some extent impregnated with sulphides in the form of stringers or blebs. The blebs are about the size of peas and produce the "spotted rock" which is found at all the deposits. Usually the process of impregnation or replacement is accompanied by little or no alteration of the rocks.

The shape of the commercial ore-bodies is for the most part rudely lenticular, the Creighton, Murray, Garson, Levack, and numerous other deposits having lenticular outlines. Other commercial ore-bodies, like the Victoria and Copper Cliff, have the form of irregular cylinders or tubes. Some bodies are distinct veins.

Two classes of deposits with regard to location relatively to the norite mass are recognized: (1) marginal deposits, which occur at the contact of the norite with the adjacent rock; and (2) offset deposits, which lie at some distance from the main norite mass in norite dykes or other rocks.

Marginal Ore-bodies

The ore deposits occur for the most part along the outer, basic, contact of the norite-micropegmatite, but the commercial ore-bodies are rarely found in the norite. On the contrary, they occur largely in the rocks adjacent to the norite, there being a comparatively small quantity of commercial ore met with in this rock. Examples of ore-bodies which occur wholly or mainly in the rocks adjacent to the basic edge of the norite are the Crean Hill, Creighton, Levack, and Whistle. The Creighton is found about at the contact, while the Levack ore-body is wholly in the underlying granite gneiss at an average distance of about 175 feet from the contact of the norite measured at right angles to the dip of the contact. While it is true that little commercial ore occurs in the norite, there is at times light, non-commercial mineralization in this rock, impregnating or replacing large masses, the sulphides often being found in the form of blebs about the size of peas, giving rise to what has been called 'spotted' norite. The notable example of this non-commercial variety of mineralization is met with at the Creighton, where a zone three-quarters of a mile long and about 600 yards wide is thus mineralized. It may be repeated, however, that the commercial ore-bodies are found almost wholly in the rocks adjacent to the norite—not in the norite.

The deposits described in the preceding paragraph are known as 'marginal deposits.'

Offset Ore-bodies

The second class of deposits has been called 'offset' deposits. The offsets are mineralized dykes. There are four main occurrences of the offsets, namely, Worthington, Copper Cliff, Frood, and Foy. In the case of the first three it may be pointed out that they cannot be traced directly into the norite or so-called nickel eruptive, although they are believed by many to be of the same age as this eruptive. This relationship has not been proved nor disproved. The offsets have a maximum length of 6 miles and a width of from a few feet to 700 or 800 feet.

The marginal and offset deposits occur along extensive and well-defined lines that have either a northwest-southeast or northeast-southwest direction. These directions constitute lines of crushing, brecciation, and shearing. It has so happened, in the case of the marginal deposits, that the lines of disturbance occur along the contact of the basic edge of the norite-micropegmatite and adjacent rocks, largely in the latter, thus accounting for the occurrences of the ore-bodies in this position. The disturbances referred to have broken the rocks along their path into crush-conglomerates and crush-breccias. The ore occupies or fills the spaces between the rock fragments composing these disturbed zones. The ore also impregnates or replaces the rocks in the form of irregular veinlets, masses, and in disseminated grains.

There are two main theories to account for the origin of the ores. One, known as the magmatic segregation theory, is to the effect that the separation of the nickel, copper, and iron sulphides was part of a process of differentiation in the magma of the norite-micropegmatite sill in which gravitation played a large part, so that the heaviest ingredients, the ores, sank to the lowest points, and were succeeded upward by norite, which in turn merged upward into granite. Upholders of this theory admit that there was subsequent rearrangement of the ores by solution and redeposition.

The other theory is that the ores were deposited from heated solutions circulating through crushed, brecciated, fissured, and sheared zones. In the marginal deposits the crushing took place mainly in the rocks adjacent to the norite and to a less extent in the norite itself; in the offset deposits the crushing took place largely in the dykes.

The origin of the ores will probably remain a controversial subject for many years. Whatever theory is propounded must take cognizance of the fact that the sulphides were introduced after the norite had solidified, and that the deposits are found at or near the contact of the norite with the adjacent rocks.

MINING METHODS

Both the ore-bodies and the enclosing rocks of the Sudbury area are hard, so that the problem of extracting the ore is a simple one; elaborate systems of timbering, caving, or slicing are unnecessary.

The first mining was done by open-pit methods, the ore being handled by derricks; later, when the pits became deep, shafts were sunk alongside them, and connected with them by levels, through which the ore was trammed from the pit floor to be hoisted to the surface in skips. The Evans, Frood, Stobie, Crean Hill, Kirkwood, North Star, Victoria, Blezard, Murray, Creighton, and other mines have all at one time or another been worked open-cast. The Creighton pit, 670 feet long and 400 feet wide at surface, and 300 feet deep, is the largest of these.

When all the ore that could be economically and safely mined by open-cast methods was removed, the shafts were sunk deeper, and underground methods were adopted, below a floor left in the bottom of the pit. The general method used underground is overhand stoping in shrinkage stopes, details being varied to suit the size, dip, and configuration of the ore-body. If the ore-bodies be narrow, drifts are timbered and the ore broken on the timbers; in large stopes, pillars are left and the back kept arched while the ore is being removed. Dry-wall drifts are used in wide ore-bodies in some mines. Pillars, which are left in the larger stopes, are drawn later.

Previous to exploitation, magnetic surveys of the ore-bodies are sometimes made. These are followed by diamond-drilling, to determine the configuration, grade, and tonnage. From the information thus obtained definite plans for the winning of the whole deposit can be made well in advance of actual working.

International Nickel Company

Nearly, if not quite, all the ore now being treated by the International Nickel Company comes from its Creighton mine, the world's biggest operating nickel mine, situated 6 miles west of Copper Cliff, the site of the company's smelter and the general offices of its mining and smelting departments.

The Creighton, which first shipped in 1900, has already a production of 11,000,000 or 12,000,000 tons to its credit, with known reserves sufficient to keep it going for many years at the present rate of some 700,000 tons per annum. It was first worked as an open-pit; later, when increasing depth made this system dangerous, underground methods were adopted. First, underground quarrying followed as working progressed to depth, by shrinkage stoping with dry walls; shrinkage stoping with underdrifts chiefly in ore; to the present method of shrinkage stoping with main drifts in the foot-wall, crosscuts in ore, and the use of rib pillars that are finally drawn.

Ore is trammed by storage battery locomotives, dropped through an ore-pass to underground crushers at the loading stations, whence it is hoisted to surface in 9-ton skips.

Little pumping is required; and natural ventilation supplies ample air for the deepest workings—now over 2,000 feet deep vertically.

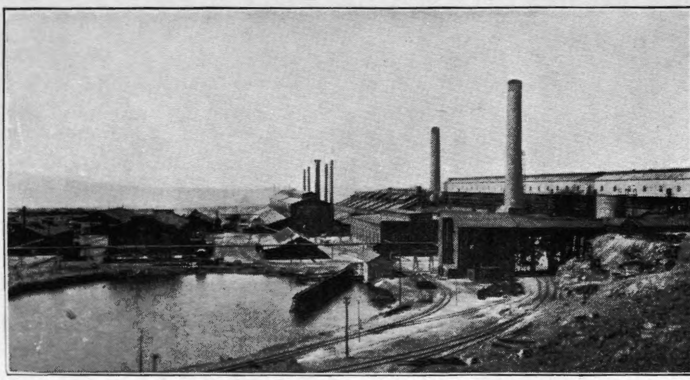
In the rock house at the shaft-head the ore is further crushed, hand-picked, and screened to two main products, coarse and fines. About 15 per cent of the material hoisted is sorted out as waste rock; of the remainder about 60 per cent leaves the rock house as coarse, and 40 per cent as fines. A typical analysis of the ore would show 1·5 per cent copper and 4 per cent nickel.

The subsequent treatment of the ore includes roasting, smelting in blast or reverberatory furnaces, and the enrichment of the furnace matte by blowing in basic converters. A portion of the ore is roasted in wedge roasting furnaces and charged to reverberatory furnaces, but most of it is roasted in the open air in large heaps, each containing about 5,000 tons of ore. The heap-roasted ore is loaded by steam shovels onto railway cars for the smelting plant. Here, mixed with a certain proportion of unroasted ore, coke, and flux, it is charged into the blast-furnaces, from which it issues in the form of slag, and a matte carrying 25 to 27 per cent combined copper and nickel.

The reverberatory charge also consists of both roasted and green ore and, in addition, flue dust. It yields a matte of about 16 per cent in copper and nickel.

Matte from both blast and reverberatory furnaces is charged molten, with quartz and mine rock as flux, into large, magnesite-lined Pierce-Smith converters. In these it is blown until the matte contains 79 or 80 per cent copper-nickel and only 0·3 to 0·5 per cent iron, the balance being sulphur.

PLATE XX



The International Nickel Company's smelter at Copper Cliff.

The finished converter matte is cast in moulds and shipped either to the company's refinery at Port Colborne, Ontario, or to their plant at Huntington, West Virginia, for the manufacture of Monel metal and malleable nickel.

The company's mines and smelters are electrified throughout with power brought from their own generating plant at High falls on Spanish river, at Turbine, about 28 miles from Sudbury. The rated capacity of the generating station is 21,300 horsepower. Power is transmitted to the mines and smelter at 33,000 volts and there stepped down to 2,200; 550; and 110 volts for various uses.

Port Colborne Refinery. The International Nickel Company, in 1918, completed at Port Colborne, in southern Ontario, a magnificent refinery for the production of nickel and copper from their Sudbury mattes. The plant is situated on the shore at the east end of lake Erie, just east of the entrance to Welland canal, on a site 330 acres in extent and having a frontage of nearly a mile on the lake. There is deep-water frontage to meet the requirements of lake transportation, and railway facilities are provided by a branch line of the Canadian National railways.

The plant is designed to secure maximum efficiency by means of the latest mechanical and metallurgical appliances, and the layout is such as to reduce to a minimum the labour required for operation. The works include a complete power plant, a water supply system, a separate sewerage system, an electric conduit distribution system for power and lighting, as well as piping systems for steam, oil, and compressed air. All piping and cables are carried underground, so that there are no obstructions between the buildings.

The metallurgical processes employed include both chemical and electrolytic, one advantage of the latter being that the platinum metals in the matte are recovered; when the Orford, or wet, process is used for the production of shot and ingot nickel, the precious metals content of the matte is lost. There are four blast-furnaces for smelting nickel-copper matte, four converter stands, eleven roasting furnaces, and three refining furnaces. One of the most modern Cottrell electrostatic precipitation plants for the treatment of flue gases is provided, consisting of seven treaters conveniently placed in relation to the main flue, so that any portion of or all the gases can be subjected to the process or discharged directly to the chimney.

The total capacity is: 48,000 tons of matte, producing 24,000 tons of refined nickel and 12,000 tons of refined copper per annum. The electrolytic refinery has recently been enlarged to a capacity of 1,000,000 pounds of refined nickel a month.

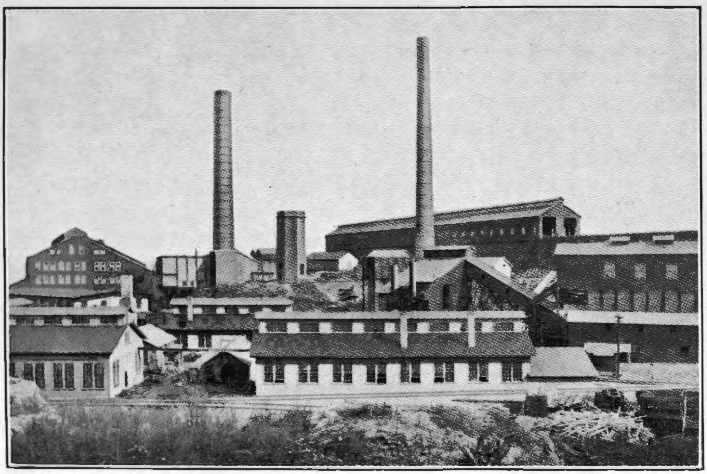
Mond Nickel Company

The smelting plant of the Mond Nickel Company is at Coniston, 8 miles east of Sudbury. It is served by three railway lines, the main lines of the Canadian National and the Canadian Pacific, and also by the Toronto-Sudbury branch of the Canadian Pacific. These railways afford connexion with all the company's mines in the district, of which the principal are the Garson, Levack, Frood Extension, and Worthington. Victoria mine, the company's pioneer mine and the site of their first smelter, was abandoned in 1923 and the machinery moved to the Frood Extension; the smelter had already been replaced by the present Coniston plant in 1913. The Victoria at the time of its closing was the deepest mine in Canada—3,000 feet or more—and had produced 864,459 tons of ore.

The Mond Company's chief producer at present is the Garson mine, 10 miles northeast of Sudbury, which began shipping in 1908; the Levack mine, about 30 miles west of Coniston, acquired in 1913, is one of the Mond Company's most important nickel deposits, some 8,000,000 tons of ore having already been proved in it; the Frood Extension, about 2½ miles north of Sudbury, adjoins the International Nickel Company's big Frood mine. It was acquired by the Mond Company in 1911 and diamond-drilling has indicated that it will become a very large and important mine. It is being equipped with the most modern mining machinery, as the bulk of the ore lies at great depth. Garson ore runs about 2·4 per cent nickel and 1·7 per cent copper; Levack, about 3·2 nickel and 1·5 copper; Worthington, 3·00 nickel and 3·46 copper; ore taken from the surface at the Frood Extension yielded nickel 2·15 per cent and copper 2·22.

A recent innovation at several of the Mond Company's mines is the substitution of magnetic cobbing machines for hand-picking. By means of this new apparatus—a continuous belt passing over magnets of varying intensity—not only is a saving in labour effected, but the grade of the waste rock is lowered and cleaner ore is sent to the smelter.

PLATE XXI



The Mond Nickel Company's smelter at Coniston.

Ore from the different mines is delivered by the railway companies to Coniston, where the Mond Company itself operates about 10 miles of standard-gauge track, locomotives, and switching engines. Here, it is sintered on Dwight-Lloyd, straight-line sintering machines—heap roasting has been abandoned by the Mond Company—smelted in blast-furnaces, and the resulting furnace matte blown to high-grade converter matte in large Pierce-Smith basic converters.

The charge fed to the blast-furnaces consists of raw ore, sintered ore, metal-bearing scrap, limestone, and coke, in proper proportions, these being delivered to the smelter bins in cars drawn by electric locomotives. Each blast-furnace has a capacity of 400 to 500 tons of ore a day.

The matte from the furnace runs into a settler to separate it from the slag, whence it is tapped into ladles of about 10 tons capacity, lifted by electric travelling cranes, and poured into the converters, each of which holds about 40 tons of matte. Fine, raw ore is also charged to the converters. Air blown through the molten mass oxidizes the sulphur, which passes off as sulphur dioxide gas; and the iron, which, combining with the silica of siliceous copper ores added as a flux, goes off as slag. The resulting converter matte, containing now some 41 per cent nickel and an equal amount of copper, 17 per cent sulphur, and less than 1 per cent of iron, is poured into ladles, thence into moulds to solidify. It is then crushed, barrelled, and sent to the company's refining plant at Clydach, Wales, for final treatment.

A certain proportion of the ore as received at Coniston is concentrated in a flotation mill attached to the plant before being melted.

The sulphur dioxide fumes from the converters, after purification, are used for the manufacture of sulphuric acid by the contact process, in a plant built by the company in 1925, which is capable of producing 25,000 tons of acid a year. This is the first attempt in Sudbury district to turn to profitable account the sulphur fumes which when poured into the air give rise to annoyance, litigation, and expense. The Mond Nickel Company must also be given the credit of being the first to make a commercial success of the use of Bessemer converters for the concentration of low-grade furnace mattes.

Like those of the International Nickel Company, both the mines and smelter of the Mond Nickel Company are electrically equipped throughout. The company has two generating stations having a combined capacity of 9,600 horsepower, operated through a subsidiary, the Lorne Power Company, and situated near Nairn, 40 miles west of Coniston, on Vermilion and Spanish rivers. Electricity is also purchased under long-time contract from the Wanipitae Power Company for operation of part of the Coniston plant. As a reserve against future needs water-power rights at High falls on Onaping river, close to the Levack mines, have also been acquired.

In addition to building a number of villages contiguous to their mines, the Mond Nickel Company has, by planning and laying out a town on an excellent site at Coniston, done much to ensure the comfort of its employees. Coniston comprises a clubhouse, boarding house, public library, two schools, churches, stores, etc., besides houses for the staff and employees; all on company land and many of them built and owned by the company.

In addition to works in Sudbury district and a refinery in Wales, the Mond Nickel Company also operates a rolling-mill plant at Clearfield, Pennsylvania, for the manufacture of nickel alloy (Mond alloy) and malleable nickel products.

USES OF NICKEL

A volume might be written on the uses of nickel and the history of their development; and a detailed list alone would fill several pages.

In 1903, consumption of nickel could be grouped under four main headings, viz.: plating; nickel-silver; coinage; and nickel-steel, chiefly used for armour plate. Today this list can be extended to eleven major headings—of which armour plate is no longer one—that is to say: structural nickel-steels, nickel silver, coinage and copper alloys, nickel-plating, heat-resisting alloys, the Edison storage battery, malleable nickel, ferro-nickel alloys, nickel cast-iron, nickel cast-brasses and bronzes, hydrogenation of oils.

There are in the United States and Canada alone about 300 companies using substantial amounts of metallic nickel in the manufacture of intermediate nickel products, of which there are more than 60 different compositions and types—nickel steels and alloys—in commercial use. These products are used by perhaps 10,000 manufacturers who may be considered the ultimate consumers. One of the largest fields for the use of nickel today is, of course, the automobile industry.

AUTHORITIES CONSULTED

General

Report of the Royal Ontario Nickel Commission: Ontario Dept. of Mines, 1917.
Staff of the International Nickel Co.: "The Mining and Smelting Operations of the International Nickel Company of Canada"; Trans. Can. Min. Inst., vol. XXIII, pp. 19–111 (1920).
The Mond Nickel Company: Brochure published by the company in 1918.
Merica, P. D.: "The Nickel Industry"; Bull. Can. Inst. Min. and Met., Feb., 1926, pp. 173–212.
Orr, J. A.: "Notes on Present Mining Practice at Creighton"; Bull. Can. Inst. Min. and Met., June, 1926, pp. 725–736.
Hall, O.: "Mining Methods at the Mond Nickel Company's Mines"; Trans. Can. Min. Inst., vol. XXII, pp. 180–186 (1919).
Wotherspoon, W. L.: "International Nickel Company's Refining Works at Port Colborne, Ont."; Eng. and Min. Jour. Press, Mar. 8, 1919, pp. 429–435.
Gibson, T. W.: "Nickel; The Mineral Industry," 1925, pp. 504–512.
Mines Branch, Ottawa: Metallurgical Works in Canada, List No. I-I, Sept., 1926.

Geological

Bell, R.: Geol. Surv., Canada, Ann. Rept., vol. V, pt. F (1893).
Walker, T. L.: Quart. Jour. Geol. Soc., vol. 53, pp. 40–66 (1897).
Dickson, C. W.: Am. Inst. Min. Eng., Trans., vol. 34, pp. 3–67 (1903).
Barlow, A. E.: Geol. Surv., Canada, Ann. Rept., vol. XIV, pt. H (1906).
Coleman, A. P.: Ont. Dept of Mines, vol. XIV, pt. 3 (1905).
Campbell, W., and Knight, C. W.: Econ. Geol., vol. 2, pp. 350–366 (1907).
Howe, E.: Econ. Geol., vol. 9, pp. 505–522 (1914).
Roberts, H. M., and Longyear, R. D.: Can. Min. Inst., Trans., vol. 21, pp. 80–126 (1918).
Wandke, A., and Hoffman, R.: Econ. Geol., vol. 19, pp. 169-204 (1924).
Phemister, T. C.: Ont. Dept. of Mines, Ann. Rept., vol. XXXIV, pt. 8 (1926).

COBALT SILVER

The town of Cobalt, the commercial and business centre of one of the world's most famous silver-mining districts, lies about 330 miles north of the city of Toronto, Ontario, from which it can be reached by a comfortable night's journey in a Pullman car.

The Cobalt silver district, as that expression is commonly used, includes not only the Cobalt area proper, an area of about 5 square miles including and immediately surrounding the town of Cobalt, that has furnished more than 90 per cent of the production of the whole field; but also a stretch of country some 70 miles in length, scattered over which at a number of places silver ores, similar in composition and occurring under practically identical geological conditions with those at Cobalt, have at different times been found. Next to Cobalt proper, the chief producing locality is South Lorrain township, about 16 miles southeast of the town of Cobalt; then Gowganda,

MAP 8. Key plan of Cobalt silver area proper.

about 55 miles to the northwest; other localities in which silver ores have been obtained include Casey, Cane, and Auld townships; and at Shining Tree, Bay lake, Maple mountain, Elk Lake, and Wendigo.

No mining district in Canada has attracted more world-wide attention or has had a more romantic and remarkable history than the Cobalt silver fields. Discovered by chance in the autumn of 1903 (it is unnecessary here to go into the popularly accepted details of the first discovery—many of them apocryphal), in a country that was at the time a wilderness frequented only by lumbermen and trappers, in the course of construction of a railway to open up agricultural land farther north, the first finds did not attract the attention they deserved. The veins were small and narrow and the ore, though apparently rich, was different from anything with which Canadian miners and prospectors were then familiar. The half-contemptuously expressed opinion of many "old-timers" was that the deposits were of small importance and would soon "peter out." When, however, attention was drawn to the number of new veins being discovered almost daily, and the returns were received from the first shipment of ore made in 1904, opinion changed, and it soon came to be realized that a camp was in the making that promised to surpass the wildest hopes of the most optimistic prospector.

The total production of 1904 amounted to only 206,875 ounces of silver, that of 1905 to 2,451,356 ounces, but this had nearly all been taken by hand from shallow surface pits, so small that it seemed impossible that they could have been capable of yielding the wealth with which they were credited. It was about this time that every visitor to the camp was taken for a stroll over Nipissing's "silver sidewalk," and an orgy of the wildest speculation soon followed.

Meantime, production rapidly increased until a maximum annual output of 31,507,791 ounces of silver was attained in 1911. Since 1911, there has been a gradual decline that has been halted in recent years by increased production from the outlying camps. For several years past, production has hovered around 10,000,000 ounces annually, in the neighbourhood of which figure it seems likely to remain for some time to come, since the declining production of Cobalt proper is being offset by increasing production from the South Lorrain and Gowganda areas.

The richness of some of the ground at Cobalt may be judged by the fact that to the end of 1924 the Nipissing Mining Company had produced a total of 69,500,000 ounces of silver and paid $26,000,000 in dividends; and the Coniagas Mining Company, from one 40-acre claim alone, 32,000,000 ounces that yielded $11,500,000 in dividends.

At one time in its history there were some thirty mines producing simultaneously in the Cobalt camp. These have now (1925) been reduced to thirteen—with four others in South Lorrain and three in Gowganda, making twenty producers for the whole field, as against forty-one when prosperity was at its height. The distribution of the output in 1925 was as follows: Cobalt proper, 6,197,753 ounces; South Lorrain, 3,099,664 ounces; Gowganda, 1,345,978 ounces.

Incidentally it may be remarked that South Lorrain's present prominence in the productive field is the result of the resuscitation of what was practically an abandoned and discredited camp—a story in itself.

The total silver production of the entire Cobalt district, from the time of its discovery in 1903 to the end of 1925, amounts to some 364,697,865 fine ounces, of which the Cobalt area proper has furnished 340,088,826 ounces; South Lorrain, 13,028,302 ounces; Gowganda, 8,411,331 ounces; and Maple mountain, Casey, Elk Lake, and other localities the remainder. In addition to that from silver, there is also a considerable profit from the accompanying by-product metals cobalt, nickel, and arsenic—in fact the quantity of cobalt that is recovered from the silver ores is sufficient to make Canada one of the world's two chief present sources of the metal cobalt.

A comparison of the yield in silver of Cobalt district, with that of some other of the world's great silver camps, is interesting, and has been set out, approximately, in the following table.

District	Silver production in metric tons	Years
Potosi, Bolivia	over 30,000	Since 1545
Guanajuato, Mexico	over 15,000	" 1558
Zacaticas, Mexico	14,000	1548–1832
Cobalt, Canada	11,358	1904–1925
Freiberg, Germany	5,243	1163–1896
Comstock, Nevada	4,820	1859–1889
Pachuca, Mexico	3,500	1522–1901

Power

In every new mining camp the question of an adequate supply of power at a reasonable cost is a matter of keen solicitude; in central Canada remote from coal-fields it becomes one of paramount importance, that in every instance has ultimately been solved in the same way, that is, by the development of some of the waterpowers with which the country almost everywhere abounds.

In the earliest and somewhat primitive plants at Cobalt, wood cut on the mining claims and burned under steam boilers temporarily filled all power requirements; then, when available supplies of wood were exhausted, coal was used, imported from the United States at an exorbitant cost; and, finally, when the mines had reached to a point that warranted large capital expenditures, hydroelectric power was developed. At the present time Cobalt and South Lorrain are served by two hydroelectric plants on Montreal river and one on Matabitchuan river, having a combined capacity of 21,300 horsepower; and by a 5,000-horsepower, hydraulic, air-compressing plant, on Montreal river, that delivers compressed air to the Cobalt mines through some 29 miles of steel pipe-line; all owned or controlled by the Canada Northern Power Corporation.

Geological Features

The description of the geology of the Cobalt camp is extracted largely from the article on Cobalt area by Willet G. Miller prepared for the Guide Book used on the Excursion of the International Geological Congress, 1913.

Rocks of the earlier and later Precambrian ages are represented. They consist of the Keewatin series, which was intruded by a granite known as the Lorrain granite, the Cobalt series of sediments of later Precambrian age, and diabase dykes and sills intruding the Keewatin and Cobalt series and known as the Nipissing diabase.

The Keewatin rocks, of the Cobalt area proper, fall into four groups: (1) basalts, (2) diabases and other basic rocks, (3) acid intrusives, (4) sediments. Of these the basalts are the most common. The diabases are also of common occurrence, although they are not so widely distributed as the basalts. The acid intrusives are of infrequent occurrence in the Cobalt area. They include felsite, feldspar-porphyry, and quartz porphyry. The sediments grouped with the Keewatin include iron formation (jaspilyte, chert, and greywacke), graphitic schists, and slates.

Many of the basic, igneous rocks of the Keewatin have been rendered schistose and their original character cannot now be definitely determined.

The acid intrusives of the Keewatin are on the whole younger than those of more basic composition. Certain diabases are intrusive into the basalts and iron formation.

No granite, or granite gneiss, older than the Lorrain granite, occurs in the immediate vicinity of Cobalt.

The Keewatin series is intruded by lamprophyre dykes and by a coarse-grained, biotite granite with a characteristic pink colour, named the Lorrain granite.

The Cobalt series of fragmental rocks is of importance since the greater proportion of the mineral-bearing veins of the camp are found in this series. It contains rocks varying from types that are uniformly fine in grain to those that carry boulders several feet in diameter. The fragments composing these rocks are of great variety and represent the erosion products from all the older Pre-cambrian series of the region, the Keewatin, the Timiskaming, and the intrusives of various kinds.

The surface of the region in the period immediately preceding the deposition of the Cobalt series was uneven, and the hills were probably higher and the valleys deeper than those of the present surface. The thickness of the series, therefore, varies considerably from point to point. In the vicinity of Cobalt it rests on a weathered surface of one or other of the older formations. Most commonly the underlying series is the Keewatin, and fragments of the older rocks are found in situ at the contact.

Normally the basal conglomerate and breccia pass gradually upward into fine-grained, delicately banded, slate-like greywacke. The components of the greywacke are so fine in grain that they cannot be distinguished except by examination of thin sections under the microscope. When thus examined, they are found to consist, for the most part, of angular fragments of quartz and feldspar, which are usually quite fresh and undecomposed. The feldspar consists of orthoclase, microcline, and the more acidic soda-lime varieties. Grains of glassy volcanic rocks, and of iron ore and other material, have also been observed. Chlorite and other decomposition products are present. Under the microscope certain thin sections of the greywacke resemble volcanic ash. It has not been proved, however, that there was contemporaneous volcanic activity.

The greywacke, like the other members of the Cobalt series, usually lies in an almost horizontal position. Ripple-marks and wave-marks are numerous and mud-cracks have also been observed. Normally the greywacke passes upwards into quartzite more or less impure and the latter into conglomerate, but in places the quartzite is lacking and the greywacke is succeeded by conglomerate. Where the members of the series are complete, as at some points on lake Timiskaming, the conglomerate appears to be succeeded conformably by what has been called Lorrain arkose and quartzite.

A cobalt-silver vein.

The quartzite succeeding the greywacke as a rule has no great thickness, in many places not more than 20 or 30 feet. In places it is interbanded with greywacke.

The most striking rock of the Cobalt series is the conglomerate overlying the quartzite. It has for convenience been called the second conglomerate, to distinguish it from the one lying at the base of the series. The great variety of pebbles and boulders found in this rock attracts attention. They consist, as has already been pointed out, of fragments of all the earlier geological formations of the vicinity. Considerable controversy has been waged over the origin of the rock, one school of geologists claiming that it is a typical glacial tillite and another school that it is of torrential or other origin.

The Nipissing diabase is one of the most important rocks of the camp, since it is generally conceded by geologists that the ores had their origin in the magma from which the diabase was derived. It occurs as a sill, the thickness of which is about 1,000 feet, and dips on the whole at a low angle to the southeast. At Cobalt much of the sill has been removed and the diabase occupies about one-half the surface of the productive area. The rock has an ophitic texture, and primary quartz is almost always present usually associated with feldspar in micrographic intergrowth. In Elk Lake and Gowganda areas the Nipissing diabase is cut by narrow dykes of aplite or granophyre, thought to represent the residual and more acid material of the diabase magma.

The most important minerals in the veins are native silver, smaltite, niccolite, and related minerals. Some dyscrasite, argentite, pyrargyrite, and other compounds of silver are also found. The arsenides and sulpharsenides have yielded large quantities of white arsenic and have been for many years the most important source of the world's supply of cobalt. The veins occupy narrow vertical fissures or joint-like cracks in rocks of three ages; the Cobalt series, the Keewatin series, and the Nipissing diabase. More than 80 per cent of the silver has been obtained from veins in the Cobalt series. This is due probably to the Cobalt series being more brittle than the igneous rocks and consequently fracturing more readily.

After the intrusion of the Nipissing diabase sill, which, on the whole, dips at a low angle from the horizontal, and penetrates both the Cobalt series and the Keewatin, disturbance, probably due chiefly to the contraction of the sill on cooling, caused fissures and joint-like cracks to be formed. These openings were made in the rocks of the hanging-wall of the sill, in those of the foot-wall, and in the sill itself.

Ore-bearing waters, working through or along the zone of weakness produced by the sill, deposited their burden in the fissures and cracks. The minerals first to be deposited were essentially cobalt-nickel arsenides, and related compounds, and dolomite or pink spar. The fissures and cracks were ultimately filled with these minerals. Then there was a slight disturbance of the veins, re-opening the ore-filled fissures and cracks, or fracturing the material deposited in them.

In the interval, between the filling of the fissures and cracks with cobalt-nickel ores and the fracturing of the veins thus formed by a secondary disturbance, the character of the material carried by the circulating waters had changed. Silver was then the characteristic metal in solution and it was deposited, along with calcite, in the cracks and openings in the fractured veins. There may have been some silver deposited in the earlier period of vein filling and doubtless cobalt-nickel minerals were deposited after the secondary disturbance, but the latter minerals belong characteristically to the first generation and the silver minerals to the second.

There are several factors governing the formation of ore-shoots. In a general way it may be said that the dominating factor is the Nipissing diabase sill. Ore-shoots are found only in the vicinity of the diabase as it exists today, or as it existed prior to its partial erosion. Mineral veins occur both above and below the diabase sill, but approximately 90 per cent of the total mineral output has been obtained from the lower contact.

Next in importance in the deposition of silver ore-shoots appears to be the influence of contacts. There are three contacts along which ore-shoots have been found: the contact between the Keewatin and the Cobalt series, the upper contact of the Nipissing diabase with the intruded rocks, and the lower contact of the Nipissing diabase.

The contact between the Keewatin and the Cobalt series controlled the deposition of a very large proportion of the ore. It may be said that all the ore-shoots in the Cobalt series follow along its contact with the underlying Keewatin and do not rise as a general rule more than 100 to 200 feet above the contact. One of the most striking examples of this is the Meyer vein in the Nipissing and Trethewey mines. This ore-shoot has a length of about 1,600 feet, lies in the Cobalt series, and rises an average height of about 110 feet above the Keewatin.

Faults existing prior to mineralization have been in some cases a controlling factor. In places they have acted as dams or barriers in confining the occurrence of ore-shoots to certain areas, and in other places silver ore has been deposited within the faults themselves. Vein systems have also been found in the Cobalt series above or near depressions or troughs in the Keewatin.

Mining Practice

The mining methods employed at Cobalt present few features of special interest. Overhand stoping in shrinkage stopes is the practice commonly followed. The wall-rocks are for the most part hard and sound, so that little timber is required for their support, and pumping is not a serious item of cost, except perhaps in a few places where workings have been carried close under the bottoms of small lakes.

The veins themselves, though extremely rich, are very narrow, ½ inch to 8 or 10 inches as a rule, except at intersections where they may become much wider; but the adjacent wall-rocks are in many cases impregnated with silver for a considerable distance from the vein and thus constitute milling-rock—the ore on which the camp now chiefly depends—so that stopes have in some cases to be carried very wide, in one case over 80 feet.

The ore-shoots are shallow, most of the silver mined having come from depths not greater than 300 feet. The greatest depth at which workable ore (in this case a good grade of mill rock) has been encountered is a little less than 1,000 feet, though at another mine a few thousand ounces of silver is reported to have been taken from a depth of 1,600 feet.

In exploring new ground the diamond-drill is much used, and is of the greatest value for the preliminary determination of the sub-surface geology; on account of the characteristic narrowness of the veins and the comparatively small extent of the individual ore-shoots, however, it is not conspicuously successful in actually locating ore-bodies. For this, shaft sinking and drifting, guided by the geological information obtained from preliminary drilling, are necessary. Operations of this kind are not only costly, but highly speculative; nevertheless, the possible reward if success be achieved is so great that much work of this kind is now being carried out in Cobalt district by some of the oldest and most experienced mining companies.

ORE TREATMENT

The ores of Cobalt district are remarkable not only for their high silver content, but also for the assemblage of complex minerals they contain. Silver is, of course, the metal of outstanding value, but cobalt, arsenic, and to a smaller extent nickel, are important by-products; in some shipments of concentrates copper, also, has been paid for and a little bismuth in refinery residues.

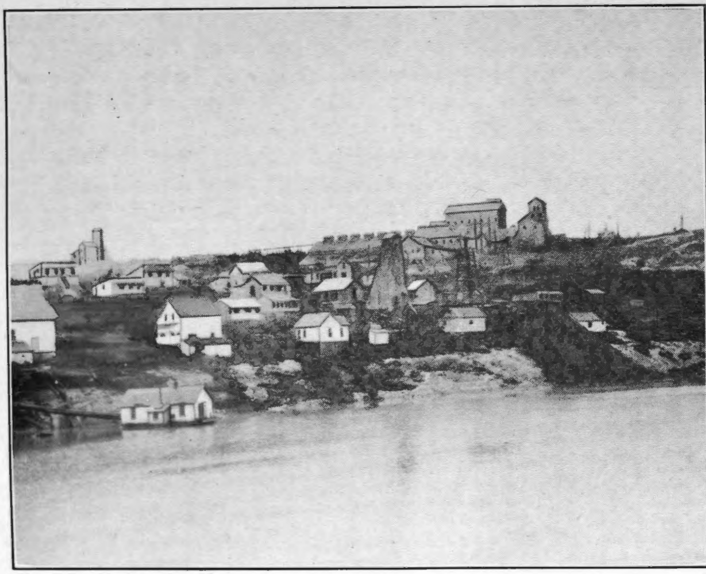
Fully 97 per cent of the silver occurs native, in forms ranging from the finest, filmy leaf to large slabs and irregular masses. In some veins it is found nearly pure in a calcite gangue; in others it is intimately mixed with smaltite, niccolite, breithauptite, and a host of other minerals. About 3 per cent of the silver is chemically combined with sulphur, arsenic, antimony, and bismuth, most abundantly as argentite, then as proustite and pyrargyrite.

For the first three years after the discovery of the camp attention was directed entirely to the recovery of high-grade material, and no attempt was made to win the low-grade ore. Thus, the 208,875 ounces of silver shipped in 1904 was contained in 158 tons of ore and the 2,451,356 ounces in 1905, in 2,144 tons; or an average of 1,309 ounces of silver in every ton of the ore mined in 1904, and 1,143 ounces in 1905. In 1906 the average was 1,013 ounces. Much of the ore was sacked underground as it was picked out of the broken muck, and the remainder was hand-sorted in simple washing plants.

As, however, the high-grade ore is found in narrow veins and cracks that are extensive neither in length nor depth, and, though exceedingly rich in silver, carrying, in places, 15,000 ounces or more a ton, are soon worked out, it was not long before it became evident that the early predictions of a short life for the Cobalt camp would be fulfilled unless means were found for the profitable treatment of low-grade ore also.

The first milling plant, which had a capacity of only 15 tons of ore a day, was built by the McKinley-Darragh-Savage Mines, Ltd., in the summer of 1907; then followed the Buffalo and others in quick succession, until at one time or another a total of eighteen mills, having a combined daily capacity of 2,100 tons, have been engaged in treating low-grade material; and the relative position of high-grade and low-grade in the production records is the complete reverse of what it was in the earlier years. Today, in most of the mines, high-grade ore is merely incidental, and production depends largely on the recovery made from low-grade ore by milling processes. Well over 50 per cent of the total production to date has been in the form of concentrates, bullion, and residues from the treatment of low-grade ores, and there is little doubt that

PLATE XXIII



The Nipissing mill, looking across Cobalt lake.

the continued working of the low-grade ores will extend the productive life of the camp indefinitely.

The first method of treatment was by gravity processes, which were later supplemented, and partly replaced, by cyanidation, and these are still the two general methods of outstanding importance in the camp. Flotation, introduced comparatively recently, has also been found useful for the treatment of very low-grade material, usually the tailings from other processes that in many cases carry as little as 3 to 5 ounces of silver to the ton. The first attempts to cyanide the very complex and refractory Cobalt silver ores were not very successful, and the remarkable efficiency of the method as now carried out is the result of much experimenting and painstaking research, for which too much credit cannot be given to the little band of men by whom it was carried out—the work of Cobalt metallurgists has probably done more to advance the hydrometallurgy of silver than that of any other body of men of equal number. Practice in the several plants now in operation is largely standardized, though there are naturally still individual variations in the details of procedure and the machines employed.

Broadly speaking, the milling and metallurgical treatment of the Cobalt ores falls under two general heads, "low-grade" and "high-grade"; the "low-grade" mills treating crude mill-rock from the mines and the "high-grade" mills treating rich concentrates from the low-grade mills, together with rich, hand-sorted ore. The residues from the "high-grade" treatment, which still carry a little silver together with considerable cobalt, arsenic, and nickel, are sold to smelters and refiners for final treatment, most of the residues going to the Deloro Smelting and Refining Company's plant at Deloro, Ont. Owing to difficulties that stand in the way of treatment locally, flotation concentrates are also sold to smelters outside the camp.

There are two companies in the Cobalt camp, the Nipissing Mines, Ltd., and the Cobalt Reduction Company, now operating "high-grade" mills for the extraction of silver by wet methods. These produce for sale, in addition to silver bullion, residues and flotation concentrates.

AUTHORITIES CONSULTED

General

Knight, C. W.: "Cobalt and South Lorrain Silver Areas"; Ontario Dept. of Mines, Ann. Rept., vol. XXXI, pt. II (1924).
Miller, W. G.: "The Cobalt Nickel-arsenides and Silver Deposits at Timiskaming"; Ontario Dept. of Mines, Ann. Rept., vol. XIX, pt. II (1913).
Reid, F. D., Denny, J. J., and Hutchison, R. H.: "Milling and Metallurgical Practice in the Treatment of Silver Ores at Cobalt"; Ontario Dept. of Mines, vol. XXXI, pt. II (1924).
Bateman, G. C.: "The Cobalt Silver District"; Can. Min. Jour., June 20, 1924, pp. 595-597.
Various recent Reports and Bulletins of the Ontario Dept. of Mines.

Geological

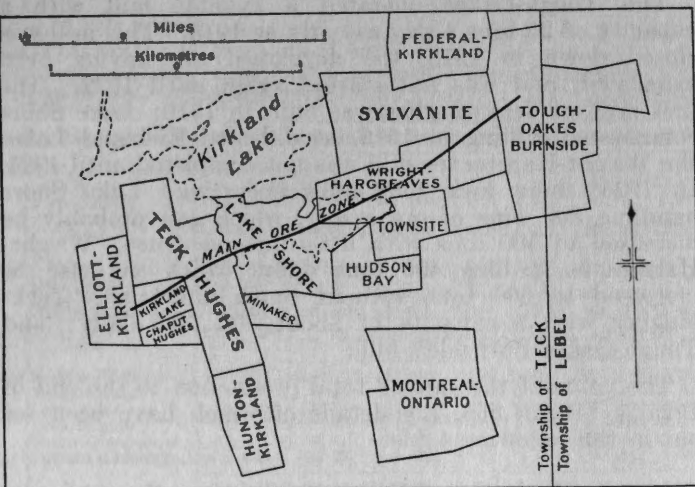
Miller, W. G.: Ontario Dept. of Mines, Guide Book No. 7, pp. 51-102 (1913).
Collins, W. H.: Geol. Surv., Canada, Mem. 33 (1913).
Whitehead, W. L.: Econ. Geol., vol. 15, pp. 103-135 (March, 1920).
Whitman, A. R.: Econ. Geol., vol. 15, pp. 136-149 (March, 1920).
Burrows, A. G.: Ontario Dept. of Mines, Ann. Rept., vol. 30, pt. 3, (1922).
Bell, J. M.: Inst. Min. and Met., Bull. 209-210 (February and March, 1922).
Knight, C. W.: Ontario Dept. of Mines, Ann. Rept., vol. 31, pt. 2 (1924).
Bastin, E. S.: Econ. Geol., vol. 20, pp. 1-24 (January-February, 1925).

KIRKLAND LAKE GOLD-FIELD

Kirkland lake is Ontario's second most productive gold-field. Though smaller than Porcupine it has attracted much attention during the past few years on account of the richness of its ores and the remarkably favourable results that have attended its development at depth.

It lies about 60 miles southeastward from Porcupine and is 392 miles by rail from Toronto. It is connected with Swastika station, about 4½ miles to the southwest, on the Temiskaming and Northern Ontario railway, both by a short branch line of railway and by an excellent macadamized highway over which fast motor buses are operated—part of the main trunk-road system of the district of Timiskaming. The town of Kirkland Lake has about 2,500 inhabitants and is provided with good telephone and telegraph services and with hotels.

The first discoveries made in this vicinity were in 1906, during the boom days of Cobalt, when many claims were staked for gold around Swastika and northeasterly to the lake now known as Kirkland. Most of these claims were abandoned later, but one property, at Swastika, continued working and by 1911 had produced some gold. This, together with the success being obtained at Porcupine, aroused new interest in the older finds to the east, with the resultant discovery, in 1911, of gold near the shore of



Map 9. Key plan of the chief gold mines at Kirkland lake.

Kirkland lake on what is now a part of the Wright-Hargreaves mine. In January, 1912, gold was also found three-quarters of a mile northeast of Kirkland lake on the Tough-Oakes claims. No great excitement was caused, however, until 1913, when the shipment of two carloads of ore taken from an 8-inch vein on the Tough-Oakes brought returns of $8,960 in gold in the first car, and $8,073 in the second. Active prospecting by surface trenching now became the rule, with the consequent discovery of promising veins on a number of properties, viz.: the Burnside, later merged with the Tough-Oakes; the Robbins, now Sylvanite Gold Mines; Wright-Hargreaves; Oakes, now Lake Shore; Teck-Hughes; Wettlaufer, or Orr, now merged with Teck-Hughes; Wood-McKane, now Kirkland Lake; and Hunton.

By midsummer, 1914, hydroelectric power had been brought into the new camp, from Charlton; and in March, 1917, the Northern Ontario Light and Power Company (now a subsidiary of the Canada Northern Power Corporation) completed an electric transmission line from Cobalt, a distance of 65 miles, and a large sub-station was built at the Kirkland Lake terminus. With ample power available for all purposes, active mining was commenced on numerous properties.

The Tough-Oakes operated a cyanide mill with a capacity of 25 tons a day as early as 1915. This mill was closed down in 1918, the developed ore having been exhausted, and was not started again until 1922. The first mill on Teck-Hughes was built in 1916; Lake Shore commenced milling in 1919, as did also Kirkland Lake; the Wright-Hargreaves mill was not completed until 1921. In 1925, there were four mills operating; Lake Shore handling 300 tons of ore a day, which can probably be increased to 500 tons with little inconvenience; Wright-Hargreaves, milling 400 tons daily, which can also be increased to 500 tons without much alteration; Teck-Hughes with a capacity of about 300 tons daily; and Tough-Oakes Burnside's mill.

The value of the camp's total production to the end of 1925 is $19,237,556, the details of which have been set out in the following table:

Production of Gold and Silver from the Kirkland Lake Area

Year	Mine	Ore milled, tons	Gold		Silver		Total value gold and silver	Extraction per ton
			Ounces	Value	Ounces	Value		
				$		$	$	$
1913	Tough-Oakes........	2,220	3,164·05	64,376	3,890	2,225	66,632	30.01
	Wright-Hargreaves..	3	42·77	884	404	242	1,126	......
	Total...........	2,223	3,206·82	65,260	4,294	2,498	67,758	30.47
1914	Tough-Oakes........	3,734	5,523·62	114,153	6,634	3,490	117,643	31.24
1915	Tough-Oakes........	26,196	26,658·23	551,069	8,922	4,470	555,539	21.21
1916	Tough-Oakes........	39,865	33,991·32	702,760	13,051	8,864	711,625	17.85
1917	Teck-Hughes........	11,257	3,181·46	65,752	1,154	969	66,722	5.44
	Tough-Oakes........	38,695	16,383·60	383,593	5,256	4,237	342,830	8.86
	Total...........	49,952	19,565·06	404,346	6,411	5,206	409,552	8.20
1918	Lake Shore..........	16,749	20,031·01	415,229	1,188	1,184	416,413	24.86
	Teck-Hughes........	14,774	3,869·29	79,949	669	620	80,570	5.45
	Tough-Oakes........	22,000	6,619·52	136,827	3,006	2,855	139,683	6.35
	Total...........	53,523	30,519·82	632,006	4,864	4,660	636,667	11.81

Production of Gold and Silver from the Kirkland Lake Area—Continued

Year	Mine	Ore milled, tons	Gold		Silver		Total value gold and silver	Extraction per ton
			Ounces	Value	Ounces	Value		
				$		$	$	$
1919	Kirkland Lake......	11,324	2,675·05	55,780	378	482	56,262	4.97
	Lake Shore..........	11,081	12,695·72	262,421	932	932	263,354	23.77
	Teck-Hughes........	18,387	8,156·37	168,607	930	983	169,590	9.22
	Total............	40,792	23,527·14	486,809	2,241	2,397	489,207	11.99
1920	Kirkland Lake......	40,812	13,795·13	285,170	1,852	1,730	286,900	7.03
	Lake Shore..........	19,779	24,291·89	502,113	1,723	1,621	503,734	25.47
	Teck-Hughes........	30,646	11,909·65	246,194	1,507	1,562	247,757	8.08
	Total............	91,237	49,996·67	1,033,478	5,083	4,914	1,038,392	11.38
1921	Kirkland Lake......	43,966	11,677·75	241,379	1,665	1,037	242,416	5.51
	Lake Shore..........	21,817	23,896·46	493,939	2,024	1,336	495,276	22.70
	Teck-Hughes........	34,693	15,582·00	322,028	1,304	890	322,918	9.31
	Wright-Hargreaves..	36,053	22,617·50	467,503	2,066	1,247	468,751	13.00
	Total............	136,529	73,773·71	1,524,850	7,060	4,511	1,529,362	11.20
1922	Kirkland Lake......	37,489	10,813·64	223,517	1,279	878	224,396	5.98
	Tough-Oakes[1].......	16,108	5,144·26	106,331	1,870	1,149	107,481	6.05
	Lake Shore..........	24,279	22,737·17	469,977	1,974	1,363	471,340	19.41
	Teck-Hughes........	41,194	28,779·86	594,879	2,321	1,615	596,495	14.48
	Wright-Hargreaves..	66,181	36,748·81	759,585	44,702	3,167	762,752	11.52
	Ontario Kirkland[2]...	6,496	483·25	9,988	142	93	10.082	1.55
	Total............	191,747	104,706·39	2,164,281	12,291	8,266	2,172,547	9.83
1923	Kirkland Lake.......	45,449	10,746·66	222,153	1,471	949	223,102	4.91
	Tough-Oakes[1].......	1,803	579·75	11,984	293	189	12,174	6.75
	Lake Shore..........	23,203	26,430·57	546,368	1,917	1,231	547,599	23.60
	Teck-Hughes........	38,314	53,954·67	1,115,342	4,074	2,621	1,117,963	29.17
	Wright-Hargreaves..	79,242	36,369·82	751,781	4,968	3,197	754,978	9.52
	Total............	188,011	128,081·47	2,647,629	12,725	8,188	2,655,818	14.79
1924	Kirkland Lake......	8,091	2,235·86	46,219	452	293	46,512	5.75
	Lake Shore..........	56,168	53,053·48	1,096,712	4,224	1,860	1,098,572	19.56
	Teck-Hughes........	44,209	49,350·06	1,020,166	4,116	2,859	1,023,025	23.14
	Tough-Oakes Burnside..............	8,430	2,280·81	47,148	582	399	47,547	5.53
	Wright-Hargreaves..	84,487	52,464·78	1,084,447	6,412	4,278	1,088,725	12.88
	Total............	201,393	159,384·99	3,294,693	15,789	9,690	3,304,381	16.47
1925	Lake Shore..........	104,765	94,456	1,952,611	8,890	6,109	958,720	
	Teck-Hughes........	55,220	48,077	993,857	4,518	3,086	996,943	
	Tough-Oakes Burnside...............	34,152	12,625	260,973	3,047	2,091	263,064	
	Wright-Hargreaves..	147,939	92,286	1,907,557	8,520	5,845	1,913,402	
	Total............	342,076	247,444	5,114,998	24,975	17,131	4,132,129	

[1] Production from the Tough-Oakes mine was by the Kirkland Lake Proprietary (1919), Limited, during 1922 and 1923. The property was transferred August 31, 1923, to the Tough-Oakes Burnside Gold Mines, Limited.

[2] This property was later amalgamated with Montreal Kirkland under the name Montreal-Ontario, which has since been re-named Kirkland Rand.

The dividends paid by the three chief producing companies to the end of 1925 amount to over $3,000,000; Lake Shore Mines, Ltd., have paid $1,620,000; Wright-Hargreaves, $1,375,000; and Teck-Hughes has more recently been added to the list of dividend payers.

Geological Features

The most important geological formations in the Kirkland Lake camp are the Keewatin lavas, the Timiskaming sediments, and intrusions of lamprophyre, hornblende syenite, and feldspar porphyry.

The Keewatin rocks consist largely of ellipsoidal, amygdaloidal, and spherulitic lavas, with alternating flows and dyke-like masses of diabase, some rusty carbonate rocks, and narrow bands of iron formation. The lavas have been so greatly altered that it is difficult to classify them. In the fresher samples of fine-grained greenstone a basaltic texture can be observed showing rods of plagioclase set in a groundmass of pyroxene or hornblende which is generally altered to chlorite.

Lying unconformably on the Keewatin lavas and closely interfolded with them is a band of Timiskaming sediments. They lie in a broad syncline extending in a general northeast and southwest direction with an average width of about 2 miles.

In this series of rocks there are recognized various bands of conglomerate, slate, greywacke, and quartzite, all in a highly inclined attitude, usually dipping to the south. These have been greatly altered to schist with a cleavable structure developed along the bedding planes of the sediment.

Conglomerates predominate. They contain a great variety of pebbles including various greenstones, diabase porphyry, felsite, quartz, an occasional granite, and numerous fragments of iron formation. Some of the fragments of iron formation are of bright red jasper which gives the rock a very striking appearance. The conglomerate alternates with narrow bands of greywacke and other fine-grained sediments. The marginal bands of sedimentary material are more highly altered than those near the centre of the series and much of this rock has been reduced to fine-grained, glossy schist.

The greywacke is composed of angular fragments of quartz, orthoclase, plagioclase, chlorite, and other minerals, with considerable carbonate scattered through it. It is readily recognized as of sedimentary origin. The impregnation by much carbonate or sericite aids in distinguishing it from the greywacke of the later Precambrian Cobalt series.

Both the Keewatin and the Timiskaming series have been impregnated with carbonate solutions. They are, generally, rusty weathering owing to the oxidation of the iron in the carbonate to ferric oxide. The alteration of rocks by carbonization is widespread in northeastern Ontario. It is observed in Porcupine, Kirkland Lake, Larder Lake, and other areas. H. C. Cooke has described the phenomenon as observed at Larder lake, where in some places the alteration to carbonate rocks has been extreme. The completely carbonated rock commonly known as dolomite is composed almost entirely of lime-magnesium-iron carbonate or ankerite, and all variations in composition are to be found between the completely altered products and the unaltered country rocks. Keewatin basalt, Timiskaming basalt, black slate, sandy greywacke, conglomerate, and diorite porphyry have all suffered alteration, and the transition from unaltered rock to pure dolomite has been traced in each case. Horses of altered and partly altered country rock occur within the larger dolomite bands. The bands of dolomite are found adjacent to pegmatite and quartz porphyry dykes and in rocks cut by veins and stringers composed of quartz and carbonate, and it is thought that the dolomitization was effected by aqueous solutions of juvenile origin.

The Timiskaming sediments have been intruded by lamprophyre, syenite, and feldspar porphyry. There is a close association of these three types of rocks in different outcrops in the vicinity of Kirkland lake, and extending southwesterly and northeasterly from this locality. They occur either as broad, stock-like masses or narrow dykes, with their longer axes in a northeast-southwest direction. They are all evidently from the same parent magma. The lamprophyre is normally a black to dark grey rock, in many places showing phenocrysts of ferromagnesian minerals such as augite, hornblende, or mica. The syenite is a red rock that is found associated with the lamprophyre in broad masses or narrow dykes. It consists largely of orthoclase feldspar with scattered grains of ferromagnesian mineral altered to chlorite, calcite, and secondary feldspar. The latest of the three intrusives is the feldspar porphyry. It also occurs in narrow dykes and broad, stock-like masses that may be nearly the width of a mining claim. It is, as a rule, characterized by the presence of conspicuous phenocrysts of red feldspar, and is, generally, of a bright red or pink colour.

Exploration in Kirkland Lake area has revealed an important ore zone running northeasterly and southwesterly along the southern expansion of Kirkland lake. Along this zone, a group of mines has been developed over a distance of 2½ miles.

In this zone, operations have shown a major fracturing along which the principal properties are located. It is believed that after the intrusion of the porphyry and syenite, faulting took place in lines roughly parallel with the long axes of the intrusions, accompanied by fracturing and crushing of the porphyry and other rocks with the formation of the veins or lodes along these fracture planes. The principal or major fracturing can be traced across a number of properties where ore-shoots are being developed at widely separated points, but evidently along one system of fracturing. This fracturing has crossed all the different rocks in this zone, including feldspar porphyry, syenite, lamprophyre, and conglomerate.

The fault-planes along which the ore deposits have been formed dip to the south, usually at a high inclination, 80 degrees to 85 degrees, although locally there are rolls in the fault-planes that are steeper or flatter than the average dip. A fracture zone will contain several fault-planes, which often form the boundaries of ore, and at many mines development has been carried on with regard to two prominent fault-planes called foot-wall and hanging-wall planes. These planes are from a few feet to 40 feet or more apart, the ore sometimes occurring over this whole width, or, as is more frequent, near one or the other wall, depending on subsidiary slip or fault-planes. The ore will also at times extend beyond the recognizable fault-planes or so-called vein boundaries.

The faulting and fracturing of the rock has permitted the circulation of mineral-bearing solutions with accompanying vapours, which have partly filled any open fissures and partly replaced the country rock in the fracture zone. The amount of vein quartz in the ore deposits is relatively small as compared with the mineralized porphyry or other rock through which the fractures have extended. In addition to irregular masses of quartz, several feet in width, that occur along the veins, there are numbers of narrow, irregular quartz veins, a few inches in width, penetrating the porphyry or other rock, together with mineralized or replaced rock, which make up the ore-body. In consequence of the irregular distribution of quartz in the veins, the working faces along drifts on the veins vary greatly in appearance, sometimes showing considerable quartz and at other times almost entirely mineralized porphyry or other rock with minute veinlets of quartz intersecting it.

The mineralization of the veins has extended over a long period, since there has been repeated fracturing along the mineralized zone. The primary quartz is greatly brecciated and fragments of quartz and porphyry have been displaced along the fault-planes. Movement along the walls in the ore-bodies is evidenced by grooving and slickensided surfaces in the direction of movement.

Strictly speaking, the ore-bearing deposits should be called lodes, as they are composite veins formed under strong compressive forces, with the solutions following openings along fracture-planes in an irregular manner and partly replacing the country rock adjacent to the fractured planes. The stringers and masses of quartz intermingled with the fractured porphyry or other rock generally lie in the direction of the vein or lode, but are often connected by transverse stringers. The replacement character of the ore is frequently recognized by masses of quartz spotted with remnants of red porphyry; this ore has a faint, reddish colour due to the included porphyry. In other cases, masses of ore are bright red porphyry or syenite, with very thin seams of quartz that are hardly recognizable. The lenses of quartz are sometimes several feet wide in portions of an ore deposit and contain much visible gold, together with tellurides, pyrite, copper pyrites, molybdenite, etc. Some of the ore shows very little vein quartz, and specimens of altered red syenite from the Lake Shore mine have been found to contain grains of gold in the secondary minerals, calcite and sericite, intermingled with the original feldspars of the rock.

The oldest mineral in the veins, apart from the rock-forming minerals, is a coarsely crystalline quartz. As a rule this quartz has been broken up, and other minerals deposited in the fracture-planes. Of these there is quartz in many cases of a somewhat darker colour than that first deposited. Carbonates, chlorite, iron pyrites, and copper pyrites occur in the veins. Galena and zinc blende are found in small quantity. Molybdenite has been deposited abundantly in fractures, usually as a thin film, and graphite has been recognized in some of the ore. Several tellurides have been recognized. Although the gold-bearing solutions were emitted subsequent to the intrusion of the porphyry it is likely that the two are genetically connected. The cooling of the intrusive was apparently accompanied by shrinking and faulting and displacement in the porphyry itself and in the adjacent rocks, and the gold-bearing solutions that deposited their burdens in the fissures and other fractures probably represent the end product of the intrusion of the acid rocks.

Mining Practice

The producing mines are strung out in line along the fault zone for a distance of about 2½ miles, with Kirkland Lake mine at the western extremity of the row, then Teck-Hughes, Lake Shore, Wright-Hargreaves, and finally Tough-Oakes-Burnside at the east end. In this fault zone the ore occurs in irregular shoots of various sizes, and of both high and low grades, in lode, or composite vein, deposits of the gold-telluride type. The ore-shoots vary in width from 3 to 60 feet and some of them show great persistence both in length and depth; in grade, they average from $5 to $30 and more a ton. Ore is now being mined at depths of over 1,300 feet, and has been shown to persist to 2,000 feet and more. As work progresses in the different mines evidence of the great value of the deposits increases and a long future for the camp is assured.

Mining methods are comparatively simple in the Kirkland Lake camp and are in general similar in all the mines. Entry is by vertical shafts of two to four compartments, timbered with square sets, off which levels are run at intervals of 100 or 125 feet. All the shafts are equipped with electrically driven, double-drum hoists. Due to the dip of the ore zone, about 85 degrees to the south, crosscuts from the shafts are necessary to reach the veins. Drifts are run in the ore, and the ore is mined above them by overhand stoping in shrinkage stopes. Both timbered stope bottoms with built-in chutes, and solid-rock stope floors with box-hole chutes, are in vogue, but the latter is becoming the more general practice as it is the safer and saves timber—except for lagging and minor supports, for which local material can be used. A considerable part of the timber consumed in the camp comes from British Columbia. Stope walls as a rule do not scale badly enough to cause serious dilution of the ore, but some rich ore has been encountered in bad ground, that will probably require special methods for its working.

As a rule, the ore is hand-trammed from the stope chutes to the shafts in one-man end-dump cars, which are hoisted in cages to the surface. But electric locomotives for main underground haulage, and hoisting in skips from ore pockets at underground loading stations will probably soon be the practice in all the larger mines.

None of the underground workings are what would be called "wet," but considerable volumes of water have to be handled, since many of the fault-planes which cut the ore zone form drainage channels from the surface.

Carbide hand-lamps are used by the miners, but travelling ways are usually electrically lighted.

Labour and living conditions are good. Many of the companies have built houses at the mines for their married employees, and clean, comfortable quarters are provided for the single men.

Teck-Hughes new shaft house.

Milling Practice

The milling, like the mining, of Kirkland Lake ores, presents few features of note that are out of the ordinary.

At the present time the universal practice in the camp is "all-sliming" cyanidation, the various mills differing from each other only in minor details. The general sequence of operations is as follows:

(a) Coarse crushing in either Blake, Farrell, Telsmith, or Buchanan crushers.

(b) Grinding in rolls or in ball mills.

(c) Fine-grinding in cyanide solution, in tube mills in closed circuit with classifiers.

(d) Continuous agitation, thickening, and counter-current decantation.

(e) Precipitation with zinc dust, followed by filter pressing, and refining in bullion furnaces.

Teck-Hughes employs 5-stage crushing and grinding, i.e., jaw crusher, gyratory, rolls, ball mill, and tube mill; Lake Shore does preliminary crushing in a gyratory, followed by rolls; Wright-Hargreaves uses two jaw crushers in series. All have ball and tube mills. The product of the tube mills is handled, except in one case, in a Dorr classifier in closed circuit; Lake Shore has 15-foot bowl-classifiers, whereas the other mines have the older duplex machine. Overflow from the thickeners is clarified in leaf vacuum filters and goes thence to the precipitation tanks; the underflow is pumped through a series of thickeners, and washed by counter-current decantation. Teck-Hughes and Wright-Hargreaves now have Oliver vacuum filters treating the discharge from the last tank before it goes to waste, and Lake Shore is installing the same type of equipment.

Zinc dust is used altogether for precipitation. The precipitate is treated with acid to remove excess zinc, melted, and cast into bars of about 850 fine, which are sold to the Royal Mint at Ottawa.

The presence of tellurides in the Kirkland Lake ores has made special treatment necessary in some cases. To reduce the amount of gold going into the tailings, the Wright-Hargreaves management has introduced a flotation machine into the ordinary cyanide circuit after the tube mills and classifiers; by means of which the rich tellurides are cut out of the pulp as a flotation concentrate.

This concentrate, which is of small bulk, is then treated separately with bromine salts to destroy the tellurides, and turned back into the circuit at the agitators. At the Teck-Hughes mine sodium peroxide added to the pulp in the agitators has been used for the same purpose.

Though, of course, much smaller than the big Porcupine gold mills those of Kirkland Lake are second to none in efficiency, neatness, and compactness, and for the inquiring, but uninformed, visitor afford perhaps a better opportunity for quickly obtaining a general conception of the method of extracting gold from its ores by cyanide treatment. In these smaller, compact mills, a larger number of the long series of operations through which the ore passes can be kept under observation at the same time, and the sequence of events more closely followed, and the mind is not distracted by a vast network of strange and complicated machinery, as in the larger mills.

AUTHORITIES CONSULTED

General

Hopkins, P. E.: "Ontario Gold Deposits"; Ontario Dept. of Mines, Ann. Rept., vol. 30, pt. II (1922).

Orser, E. H.: "Kirkland Lake: Ontario's Second Gold District"; Eng. and Min. Jour. Press, Feb. 20, 1926, pp. 317–323.

Anon.: "Gold Mining at Kirkland Lake"; Can. Min. Jour., May 21, 1926, pp. 525–534.

Mueller, W. A., Grant, J. E., and Heath, C. L.: Paper read at meeting of Amer. Inst. of Min. and Met., Feb., 1926.

Forbes, D. L. H.: "The Use of Sodium Peroxide in Cyanidation at the Teck-Hughes Gold Mine"; Eng. and Min. Jour. Press, Mar. 10, 1923, pp. 440–441.

Geological

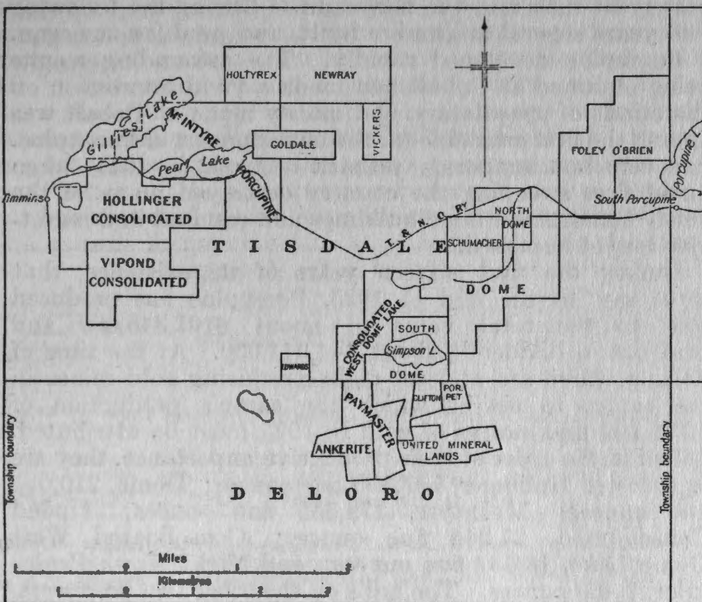
Cooke, H. C.: Geol. Surv., Canada, Mem. 131 (1922).

Burrows, A. G., and Hopkins, P. E.: Ontario Dept. of Mines, Ann. Rept., vol. 32, pt. 4 (1925).

Tyrrell, J. B., and Hore, R. E.: Roy. Soc. Canada, Trans., Third series, vol. 20, pt. 1, sec. 4, pp. 51–63 (1926).

PORCUPINE

Ontario is Canada's greatest gold-producing province and Porcupine Ontario's most productive gold-field; the largest of its gold mines, the Hollinger, ranks with the great gold mines of the world, both in quantity of gold produced and in tonnage of ore treated. Timmins, the business and commercial centre of the Porcupine goldfields, a well-built town supplied with all modern conveniences and having a population of 15,000 or more, is situated on a branch of the Temiskaming and Northern Ontario railway, about 485 miles north of Toronto; and



Map 10. Key plan of the chief productive mines at Porcupine.

can be reached from that city by a comfortable railway journey of about 20 hours' duration.

The first discovery of gold at Porcupine was made in 1908 and was indirectly a consequence of the silver discoveries made at Cobalt about five years previously. The host of prospectors attracted to northern Ontario by the wonderful finds made at Cobalt, gradually and naturally, as the older field became more thoroughly explored, spread northwestward through the country traversed by the newly constructed railway between Cobalt and Cochrane; and in the course of its advance a number of finds were made, of which the most important has proved to be Porcupine.

Though the first discovery of gold at Porcupine was made in 1908, it was not until the following year that the spectacular finds were made that were later to develop into the three largest mines in the camp, the Hollinger, McIntyre, and Dome—all within a few days of one another. It was these finds, made in 1909, that caused the first great rush into the new camp. During the following two years several mills were built, and production began.

Porcupine developed rapidly. The astounding results being obtained at Cobalt had made a vivid impression on the minds of speculators, and money made at Cobalt was among the first available for the development of Porcupine. A severe but temporary setback occurred in 1911, when forest fires sweeping the country destroyed many of the newly constructed mine buildings and resulted in a regrettable loss of human life.

During the first sixteen years of its existence, that is to say to the end of 1925, Porcupine has produced gold to the total value of about $161,346,000 and paid out in dividends about $44,944,000. At the time of writing, there are at least eight producing gold mines in the camp, to six of which the camp's production of 1,196,199 fine ounces of gold in 1925 must be attributed. Listed in the order of their productive importance, they are as follows: Hollinger, 757,306 fine ounces; Dome, 210,051 fine ounces; McIntyre, 178,556 fine ounces; Vipond Consolidated, 27,244 fine ounces; Consolidated West Dome Lake, 13,582 fine ounces; and Night Hawk Peninsular, 9,460 ounces. The mills on the other two producers, the Ankerite and the Paymaster, were not put into operation until 1926, so that their production records will first appear in the returns for that year. With the Ankerite and Paymaster definitely added to the list of producers, and with the other properties adding largely to their productive capacities, to say nothing of the favourable underground developments on such properties as the Coniaurum, a greatly increased rate of output will doubtless have been attained before the present article has left the hands of the printer. The Hollinger is being quickly put in shape to mine and mill 8,000 tons of ore per day, as compared with less than 6,000 tons at present; the McIntyre will probably greatly increase its present output of about 1,400 tons as soon as the new central shaft can be connected with the older workings and properly equipped for hoisting; and the Vipond has construction under way that will increase its milling capacity from 150 to 300 tons a day. In the case of the Dome only, does any immediate increase in production seem at all unlikely.

The present position of Porcupine among the gold-producing districts of the world, a position that is likely to be materially improved in the not far distant future, can be seen at a glance in the following table of annual outputs of a number of the world's chief gold-producing regions:

Output Expressed in Millions of Dollars

Origin of output	1913	1915	1919	1920	1921	1922	1923	1924	1925
	$	$	$	$	$	$	$	$	$
World	459·9	468·7	365·8	337·0	330·2	319·4	367·8	389·2	394·0
Transvaal	182·0	188·0	172·2	168·0	167·7	145·1	189·1	197·9	198·4
United States	88·9	101·0	60·3	51·2	50·1	47·3	50·2	50·6	48·0
Canada	16·6	19·0	15·9	15·8	19·1	26·1	25·5	31·5	35·9
Ontario	4·6	8·5	10·5	11·7	14·6	20·7	20·1	25·7	30·2
Porcupine	4·3	7·5	9·9	10·6	13·1	18·4	17·3	22·1	24·7
Kirkland Lake	**0·06	0·55	0·49	1·0	1·5	2·2	2·7	3·4	5·4
Mexico	19·3	6·6	15·2	15·3	14·2	15·5	16·2	16·5	16·3
Australia	—	—	—	—	15·6	15·9	14·9	14·2	11·6
California	20·4	21·4	17·4	14·8	15·7	14·7	13·4	13·2	13·1
Rhodesia	14·1	18·9	12·3	11·4	12·1	13·5	13·4	13·0	12·0
West Australia	27·1	25·0	15·2	12·8	13·7	11·1	10·4	10·0	9·1
India	11·2	11·5	10·5	10·3	9·7	9·0	7·9	8·2	8·1

Maximum world production	$468,700,000 in 1915
Maximum United States production	101,000,000 in 1915
Maximum Transvaal production (estimated)	205,900,000 in 1926

** First production in 1913.

The three principal mines are: the Hollinger Consolidated and the McIntyre Porcupine near the town of Timmins, and the Dome, 3 miles to the southeast. The ore-bodies of the camp are of large size, low to medium in grade, and of the lode, or composite, type in structure, containing much mineralized schist. No. 5 vein on the McIntyre has an ore-shoot 1,500 feet long that continues for at least another 100 feet in Hollinger ground. No. 1 vein on the Hollinger averages 10 feet in width for a length of over 1,000 feet. Hollinger's No. 84 ore zone is 900 feet long. There are many ore-shoots in the camp 500 feet in length. The persistence of ore in depth has been proved to at least 4,000 feet by diamond-drilling, though, of course, the areal extent at these deep levels has still to be determined; the lowest workings in the camp, between 2,500 and 3,000 feet in depth, show no falling off in either grade or quantity.

The ore, which is mostly one of the darker shades of grey, is quartz and mineralized schist. Iron pyrites is the most abundant sulphide mineral in it, though chalcopyrite, galena, and zinc blende also occur, usually in the richer parts; and pyrrhotite is quite common at the Dome. Other associated minerals are: calcite, dolomite, scheelite, tourmaline, graphite, feldspar, chlorite, and sericite.

Power

The motive power almost universally used in the Porcupine gold mines and mills is electricity, derived from waterpower supplied by the Canada Northern Power Corporation, a power company that controls through its subsidiaries, in the aggregate, some 71,500 fully developed electric horsepower, that can be readily increased as need arises to over 111,000 horsepower. In addition to Porcupine, it serves the silver-mining camps at Cobalt, South Lorrain, and Gowganda; the Kirkland Lake gold-mining camp; and the new copper-gold camp at Rouyn in Quebec. It obtains its power from seven hydroelectric developments, six of which are in Ontario—on Mattagami, Montreal, and Matabitchuan rivers, and the seventh—and largest—on Quinze river in Quebec. The high-tension transmission lines from the various generating stations have an aggregate length of between 400 and 500 miles, and are so interconnected that an ample supply of electric power can be delivered as needed at any point on any of the lines.

Geological Features

With the exception probably of a few diabase dykes the rocks exposed in Porcupine area are of early Precambrian age. The oldest are Keewatin and consist predominantly of lavas of various compositions, together with tuffs, iron formation, and carbonate rocks. They are extremely metamorphosed and altered to schists. Resting unconformably upon them is a series of greywacke, slate, quartzite, and conglomerate, known as the Timiskaming series. These early Precambrian formations are intruded by rocks of various types, basic, intermediate, and acid. The most important of these intrusives are the quartz and feldspar porphyries found near the large ore deposits. In general the porphyry masses have been altered to schists, but their attitude has probably undergone little change since the time of intrusion. Burrows gives the following table of formations:

Table of Formations

Pleistocene	
Glacial and Recent	Boulder clay, stratified clay, sand, gravel, peat
Precambrian	
Keweenawan	Olivine diabase
	Intrusive contact
Matachewan	Quartz diabase
	Intrusive contact
Algoman	Granite, granite porphyry, quartz porphyry, feldspar porphyry. The presence of later granites in the surrounding areas has not been proved.
	Intrusive contact
Haileyburian (?)	Serpentine
	Intrusive contact
Timiskamian	A series of sediments consisting of conglomerate, greywacke, slate, and quartzite. In places much impregnated with carbonate and rusty weathering.
	Unconformity
Keewatin	A complex of basic to acid lava flows: basalt, andesite, dacite, rhyolite; volcanic fragmental tuffs, and agglomerate, now altered to grey and green schists.
	Carbonate schist, carbonate-talc-chlorite schist, iron formation, slates

The Keewatin rocks, as previously mentioned, consist mainly of lava flows. They are folded, rendered schistose, and greatly altered in composition. Owing to the large proportion of secondary minerals it is nearly impossible to state definitely what the original rocks were. Undoubtedly many of the lavas had the composition of basalt or andesite and exhibit pillow structure. Primary quartz is present in some of the lava, indicating a quartz andesite or dacite and it is probable that a variation from basalt to dacite may be found in individual flows. Most of the flows are very similar in appearance and have many features in common—ropy and fragmental surfaces, amygdaloidal facies, pillow structure, fine-grained bottoms, and medium-grained uniform interiors. They are usually of a dark to light green or grey colour on the weathered surface. They have suffered extreme metamorphism by chloritization, carbonization, and sericitization.

The structural features of the lavas have by detailed field work been determined in some areas. A broad, synclinal structure in Tisdale township is described as follows:

Lying to the west of the Dome mines there are a number of lava flows with their tops facing north. On the line between the West Dome and Apex properties there are five complete flows and portions of two others shown in a width of 1,000 feet. Most of these are narrow, being less than 150 feet in width, but the south flow itself is probably over 1,000 feet in width. The flows here, as exposed on their upturned eroded edges, strike nearly east and west in a broad curve and can be followed for 1¼ miles westerly from the Dome. They then bend to the north with some faulting or flattening of the contacts between individual flows, and on lots 7 and 8 of Tisdale township the flows face the east. Farther north, the flows swing to the northeast and can be traced across the Schumacher-South Porcupine road to the vicinity of the Newray mine, beyond which they are concealed by drift to the Davidson mine, where they again change their strike to nearly southeast and can be followed almost to the north end of Porcupine lake. On the north limb of the fold, the flows face in a southern direction. The contact of the flows in the east part of the north limb shows an overfold, so that the bottom of a succeeding lava flow lies under the top of the older one at an angle of 80 degrees north. Farther west, near the Newray mine, the contact dips to 70 degrees to 80 degrees southeast. The structure as indicated by the lava flows is the southwest end of a syncline which pitches to the northeast. The structure is further emphasized by the occurrence of infolded strata of Timiskaming sediments which disappear towards the west, having been eroded from the southwest end of the syncline.

The Timiskaming series of conglomerate, greywacke, slate, and quartzite rests unconformably upon the Keewatin rocks. The unconformity is marked by a difference in the attitude of the two series and by the inclusion of fragments of the Keewatin rocks in the basal conglomerate of Timiskaming. The most prominent band of these rocks starts just northwest of the Dome mine and extends in a northeastern direction to Nighthawk lake. The general structure of the series is that of a synclinorium. Numerous contacts between the Timiskaming and Keewatin rocks, revealed on various levels of the Dome mine, indicate a strong anticlinal structure at this point, in which the Timiskaming sediments lap around the underlying Keewatin lava. The structure pitches north 60 degrees east at 40 degrees.

Greywacke and slate occur in greater volume than the other members, and the series compares with the older formations in its profound metamorphism, being bound up with the Keewatin in the schistose complex of ancient rocks which are favourable for the location of gold deposits.

The most important intrusive post-Timiskaming rock is the light grey, quartz porphyry which occurs commonly in the form of stocks, and in fewer cases in the form of dykes.

One of the most important stocks of porphyry is that which partly underlies Pearl lake and extends southwesterly to the Hollinger. This mass is about 5,000 feet long and 1,400 feet wide. Work on the Hollinger at different levels has indicated an eastern rake of about 55 degrees, while at a deeper level on the adjoining McIntyre similar conditions are found. Other smaller masses in the vicinity of the larger one show similar eastern pitch, and the structure is important in that the location of many of the ore-shoots is controlled by the attitude of the porphyry intrusions. The porphyry intrusion at the Porcupine Crown mine, along the east side of which a productive vein was located, dips to the east, passing to the Vipond mine at depth.

The porphyry is recognized by its rather white colour, the presence of "eyes" or phenocrysts of glassy quartz, and a satin-like sheen due to the presence of minute blades of sericite. Recognition is less common of crystals of acid plagioclase near albite in composition. The phenocrysts of quartz vary up to an eighth of an inch in diameter and are more abundant in some masses than in others. The feldspar phenocrysts are hard to recognize in hand-specimens, being clouded by sericite and carbonate, but in certain masses, like that at the Porcupine Crown mine, they are very conspicuous. The quartz and feldspar phenocrysts are set in a very fine-grained groundmass of light-coloured, clear minerals, presumably quartz and feldspar. The groundmass is, however, obscured by abundant sericite and carbonate and some chlorite.

Although some of the porphyry is extremely altered to schist, particularly in the vicinity of the Hollinger, McIntyre, and Dome mines, the great deformation of the Timiskaming and Keewatin rocks probably occurred before the intrusion of the porphyries. The Keewatin lavas were folded and possibly eroded before the deposition of the Timiskaming sediments. Further folding involved both lavas and sediments, producing the major synclinorium and inducing schistosity. The porphyry rose into the schists from the east to the west, the direction being influenced by the structure of the intruded rocks. The intrusion further altered the surrounding rocks, increasing the amount of schistosity, and forming shear zones favourable to the location of gold deposits. The intrusion also intensified the circulation of carbonate solutions, since many schists show a higher percentage of carbonate where they surround the porphyry masses than elsewhere.

The gold deposits occur in close proximity to the quartz porphyry stocks of Tisdale township, and apparently a close genetic relationship exists between the two. It is thought that the gold solutions ascended after the porphyry was solidified and apparently after it had become somewhat schistose, and that they had their origin in the magma of underlying granitic rocks from which the porphyry itself emanated.

The gold deposits are composite in their structure. They consist of quartz and mineralized schist in varying proportions, being either linear or in irregular masses in which the length may not be much greater than the width. Where linear, the deposits can be called lodes and not simply veins. Where a number of more or less parallel lodes occur in a width of several hundred feet, the structure is a lode system. Lodes are often branching over part of their distance and may be called a lode series. The word 'vein' is in general use at the mines to describe an ore deposit. The deposits are not the filling of open fissures, such as are often connected with veins formed near the surface. They do not show the crustification or banded character of the filling of open fissures by slow movement of mineralizing solutions. Occurring in schistose rocks which have been further sheared, many irregular lines of weakness were developed, allowing for varied entrances of the quartz into the schist. The quartz has been injected under heavy pressure and is pegmatitic in character, much like the intrusion of a rock magma. J. E. Spurr, from a study of the structure of the quartz, has referred to the injections as vein dykes. Along these lines, L. C. Graton, in a description of the Southern Appalachian gold deposits, states: 'It is even possible that the vein-forming solutions representing the final product of emanations from a granite magma were injected under heavy pressure into the surrounding rocks along lines of weakness and so, like pegmatite dykes, made spaces for themselves by opening their own fissures.'

Such a mode of formation would readily explain the irregular form assumed by the quartz masses in the Porcupine deposits. For example, veins on the Hollinger, McIntyre, and other mines are linear for several hundred feet and very irregular in detail. The quartz sometimes occurs over the width of a vein in lens-like mass, and again in narrow stringers, varying greatly in dip and strike. Stringers may run diagonally into the wall-rock, dying out away from the lode. The schist adjacent to quartz masses constitutes a part of the lode, in fact, in most of the deposits, it is the greater portion. Where the quartz veins are numerous and closely spaced, the whole of the intervening rock mass may be well impregnated with iron pyrites. Where large, the quartz mass may carry strips and irregular blocks of mineralized schist. A rough banding often results from parallel strips of schist in the quartz. From the larger masses of quartz, narrow, often irregular, bands or dykelets of quartz extend into the schist in a most complex arrangement. Veinlets of quartz are seen distinctly cutting across the schist; others run nearly with the schist; while the larger masses of quartz frequently parallel the schistose structure. In an ore deposit, it is common to find repetition of lenses of quartz and schist offset to the left when one is looking in the direction of the lode.

While a certain amount of fracturing was present at the beginning of ore deposition, the deposits were the result of enlargement by metasomatic replacement. The quartz, which was the avenue of mineralization, also silicified the surrounding schist. It is found in the grey or black schist as small blebs with the iron pyrites crystals, and in minute vague veinlets. The alteration of the rock is well shown along separate quartz veins, which extend into the wall-rock. Here, there is often a space of a few inches of the wall-rock where the rock is mineralized with pyrite and carbonatization and silicification are pronounced.

The primary quartz in the deposits has been much fractured. Granulation is frequently apparent along the margins of quartz grains, and such minerals as calcite, sericite, and chlorite are frequently observed in the crushed areas. Metallic sulphides and gold are often observed prominently with the minerals in the fracture planes. A favourable location for concentration of ore minerals is also along the contact of quartz and schist. Small fragments or strips of country rock are often enclosed in the quartz with a concentration of gold in or around them. It should be noted that where cracks have been produced in a quartz vein and subsequently filled with minerals from solution, secondary quartz can with difficulty be distinguished from the primary quartz. Hence it is not always possible to say whether visible gold in such a vein occurs in the original or later quartz.

Some sections were examined in which gold appeared to be encased in the unfractured quartz grains, but the occurrence is much less prominent than when found in the fracture planes.

Gold occurs almost wholly in the native form and rarely in combination with tellurium.

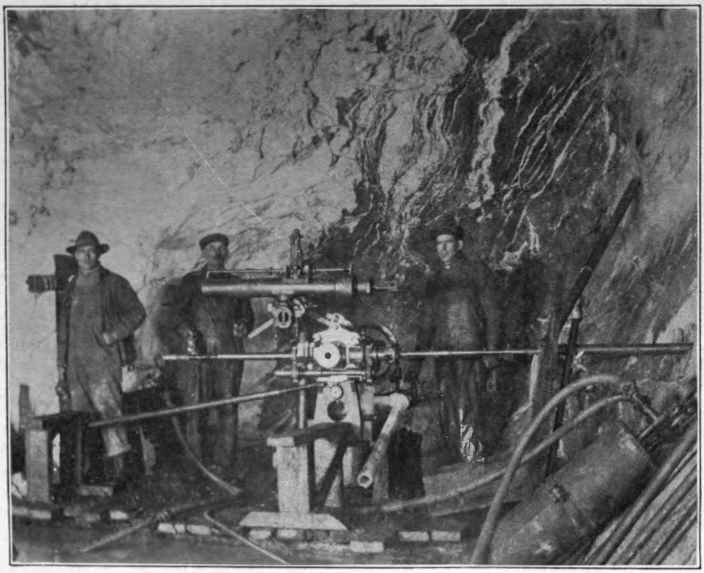
The most productive part of the Hollinger property is a zone about 1,200 feet wide extending from the south of Miller lake in a northeast direction toward Pearl lake. The veins are numerous; for example, No. 12 crosscut on the 550-foot level intersected ten vein structures in 800 feet. Nearly all the veins have a general northeast-southwest strike. Although they are quite linear and traceable for many hundreds of feet, many are connected and show a chain-like arrangement. The veins occur mainly in the Keewatin rocks. The porphyry has not proved important as an ore bearer except near its contact with the Keewatin. The relative location of the porphyry and volcanic schist varies from level to level and consequently ore-shoots found to the west of the eastward-pitching porphyry pitch downward toward the east or are followed by other ore-shoots in this direction.

One of the most productive veins of the area is the No. 5 of the McIntyre-Porcupine mine. This occurs along a persistent fracture and is a replacement deposit consisting of silicified and pyritous lava with some vein quartz. At the surface, and to about the 1,000-foot level, much of the southwest claim of the McIntyre property is underlain by the porphyry which extends west into the Hollinger property. The porphyry has a strong easterly pitch and the zone of Keewatin lavas below it favoured the deposition of gold. No. 7 vein was encountered by diamond-drilling in the porphyry at a depth of about 1,250 feet. It extends downward into the volcanic schist, where it carries good values and has been found to continue to great depth. Other veins have been located to the south of this and below the porphyry.

The geology of the Dome mine is more complex than that of the properties near Pearl lake, because the Timiskaming series, in addition to the Keewatin series and the quartz porphyry, is involved.

The major features consist of an asymmetrical anticline followed by a synclinal trough on its south side. In the anticline, the Keewatin rocks outcrop to the west of the large open-pit and pitch north 60 degrees east at 40 degrees under the Timiskaming sediments. To the north, the contact inclines gently northward; whereas on the south side, it is almost vertical, and the sediments in the syncline are carried to great depth. The south side of the syncline is intruded by quartz porphyry. The top of the pitching Keewatin in the anticline is called the crest-line, and it is along this, partly in the Keewatin but mostly in the overlying sediments and in the deep sedimentary trough to the south, that most of the great ore-bodies of the Dome occur. A few deposits occur entirely in the Keewatin, and two have been stoped in the quartz porphyry. The early workings consisted of 'glory' holes, extending over a length of 900 feet and up to 300 feet wide, carried below the 100-foot level. . . . Over thirty separate ore-shoots have already been determined in various parts of the mine. They are large, irregular lenses which are very wide in proportion to their length, varying from 15 feet to 150 feet in width, with length up to 600 feet; in depth, they have been followed up to 800 feet. They consist of mineralized schist, sediment, volcanic or porphyry, with a proportion of vein quartz. The quartz is very irregularly distributed in the schist, and, while occurring in large masses in some of the deposits, as in the crest-line types, the percentage is small in proportion to the total ore mined, being estimated at from 10 to 15 per cent. The most favourable rock has been found to be the conglomerate and greywacke of the Timiskaming series, which in parts of the area are overlain by easterly dipping slates which have not been permeable for ore solutions. Some of the best ore has been obtained from deposits just below the slates, which are encountered at different levels when the workings are extended easterly.

PLATE XXV



Underground in the Hollinger mine.

Mining Practice

The methods of ore extraction in general use at Porcupine do not in themselves present features of special interest; the most striking thing is the large scale on which they are carried out. The total length of underground passages on the congeries of veins that constitute the Hollinger mine, for example, is more than 100 miles; 13 miles of sinking, drifting, crosscutting, and raising, were done in 1925 alone. Some very large excavations also have been made for the installation of machinery underground. The ore-bodies, which are vertical, or nearly so, and of which the walls are strong enough to stand without undue crushing while stopes are being mined or emptied, are well adapted to shrinkage stoping, which is the customary practice in the camp—usually in flat-backed stopes. In opening up drifts for stoping, both timbered and solid backs are used to protect the levels, the solid backs being especially desirable where the stopes are wide. Hollinger practice where timbered backs are used is to take down the roof of the drift to a height of 17 feet, then 12- by 18-inch stulls of British Columbia fir are set at 7-foot 3-inch intervals and supported on spruce posts. Four-inch lagging laid on the stulls forms the bottom of the stope onto which the ore is broken. Where solid backs are used, box-holes at intervals are raised in the roof of the drift, and their tops connected. The box-holes are next chambered out to the full size of the stope, leaving a rock sill 15 to 20 feet thick over the drift or crosscut that serves as an outlet for the ore.

In the early history of the Dome mine a lenticular mass of low-grade ore 1,000 feet long and in places 275 feet wide was mined in open-pits by the "glory hole" method; and a similar method is now under consideration for parts of the Hollinger ground where large masses of the country rock are sufficiently mineralized to constitute low-grade ore.

Filling of the big, empty Hollinger stopes is now being carried out, the filling material—sand and gravel—being brought by aerial tram from deposits 3 miles north of the mine.

A piece of work of special interest in the camp is McIntyre Porcupine's new central shaft which, when finished, will be the deepest mine shaft in Canada. This is a six-compartment shaft 20 feet 4 inches by 13 feet 8 inches, outside the timbers, which will be sunk to a depth of 4,000 feet. When connexions have been made with the present workings it will be the McIntyre's main hoisting shaft.

All the mines are equipped with double cylindrical drum-hoists for the handling of ore and waste, though some single drum-hoists are used for men and supplies. These, like most of the other machinery in the camp, are commonly electric-driven. The two largest hoists in Canada are installed at the Hollinger Consolidated Mines central shaft. These have each a capacity of 560 tons of ore an hour from a depth of 3,200 feet, or 12,440 tons a day, which is more than double the present mill capacity. A third giant hoist, for the new McIntyre Porcupine shaft, is being built in England.

Electric locomotives of the storage battery type are used for underground haulage on the three biggest mines, and in addition, on the Hollinger, electric trolley locomotives on all levels below the 425-foot.

So far artificial methods of ventilation have not been generally necessary, though with rapidly increasing depth of working they are gradually being installed. The underground temperature ranges from 42° to 48° F. winter and summer, and the mines are neither wet nor very dusty.

The diamond-drill is a much-used piece of machinery in the Porcupine mines, both for exploration and exploitation. The drilling of the walls of workings is necessary to avoid concealed parallel ore-bodies, to locate faulted veins, and, in many places, on account of the irregular nature of the ore-bodies, to obtain the information necessary to direct the stoping properly.

Close sampling also is necessary for checking operations, as well as for the estimation of reserves.

Milling Practice

The gold in the Porcupine ores yields readily to cyanide treatment and this, with supplementary amalgamation on two mines, is the general practice. The method of cyanide treatment adopted is that known as "all sliming," the sequence of operations being:

Coarse crushing.
Coarse grinding.
Fine grinding.
Agitation in tanks with cyanide solution.
Counter-current decantation or vacuum filtration.
Precipitation with zinc.
Refining and melting.

In the machines used and in the details of procedure there are, however, considerable variations.

Hollinger Practice

In the Hollinger mine the ore is crushed to 8-inch size underground, in a mammoth 48- by 60-inch jaw crusher installed on the 1,550-foot level; dropped thence to a loading pocket at the 1,700-foot level, and hoisted, in skips, to the surface. It next passes through Gates gyratory crushers and Traylor rolls until all will pass a 1½-inch ring. Then it is distributed to rod, ball, and stamp mills for wet crushing, in cyanide solution. Following the rod, ball, and stamp mills, fine grinding is done in tube mills in closed circuit with duplex Dorr classifiers —approximately 63 per cent of the overflow from which will pass through a 200-mesh screen. The overflow from the classifiers is next thickened in Dorr thickeners, the overflow from which, after clarification, is sent to the gold-solution tanks; the thickened pulp is agitated in Dorr agitators for 16 hours and then run over Deister concentrating tables. The table concentrate is reground in tube mills in closed circuit with a classifying thickener; the reground concentrates, after passing through another thickener, the overflow from which after clarification also goes to the gold-solution tanks, are sent to Dorr agitators; and after agitation in 1·5 cyanide solution rejoin the tails from the Deister tables and proceed with them to a battery of Dorr thickeners for washing by counter-current decantation, followed by filtration on Oliver filters. The barren filter cake is repulped with water in a beater and pumped to a tailings disposal site.

A part of the overflow from the first classifiers, consisting of minus 200-mesh material, is thickened, agitated, and, without concentration, sent direct to Moore filters.

In a recent addition to the mill twenty steel Pachuca tanks have been substituted for the Dorr agitators used throughout the older part of the plant.

The overflow from the thickeners following the classifiers is clarified in square-leaf filter presses and then subjected to vacuum treatment, after which the gold is precipitated by the addition of zinc dust and the precipitate caught on paper-covered canvas in Merrill filter presses. The paper with the precipitate is fluxed, smelted in a lead blast-furnace to base bullion 180 to 200 fine, which is next cupelled in an oil-fired reverberating furnace. The final bullion is 810 fine in gold and 140 fine in silver.

Dome Practice

At the Dome, the ore is crushed underground to 8-inch size in 36- by 54-inch jaw breakers, placed on the 850-foot and 1,450-foot levels. After being hoisted to the surface it goes first to a Gates gyratory crusher which reduces it to 4½ inches, then to 10 by 36-inch jaw crushers which bring it down to 1¾ inches, followed by rolls that further reduce it to 1-inch size. The discharge from the rolls, along with the undersize from the gyratory crusher, is then screened in trommels, the coarser material sent to stamp mills, and the finer to ball mills. Seventy-five per cent of the ore is ground by the ball mills; the stamps crush the remainder. The combined pulp from the stamps and ball mills goes to Dorr classifiers, the rake discharge of which goes to tube mills for further grinding, then rejoins the overflow and passes with it over amalgamating plates and corduroy blankets.

After passing the plates and blankets the pulp goes to concentrating cones, the overflow from which is finished product so far as grinding is concerned. The underflow passes to Dorr classifiers, feeding tube mills. The discharge of the tube mills is passed over amalgamating plates and blankets, after which it is again elevated to the classifiers. The classifier overflow passes back to the concentrating cones via the first set of amalgamating plates.

The gold amalgam from the plates is retorted, then smelted direct without refining, the resulting bullion assaying 990 fine in gold and silver combined. The concentrate caught on the blankets is ground in barrels, with steel balls, and mercury is added shortly before the grinding is finished. The barrels are then discharged to a settler where the amalgam is caught. Of the total gold in the ore, about 28 per cent is caught on the amalgamating plates, about the same proportion on the corduroy blankets, and 41·5 per cent is extracted in the subsequent cyanide treatment; making the total recovery 97·7 per cent of the gold in the ore.

The overflow from the concentrating cones, i.e., the fully ground product, runs to Dorr thickeners, where the pulp comes into contact with cyanide for the first time, both fresh and working cyanide solution being added. Cyanide extraction is effected by agitation of the pulp in Pachuca tanks. From the Pachucas it goes to storage

The McIntyre Porcupine mine and mill.

tanks, from which it is drawn intermittently into Merrill slime presses. Washing is performed by forcing barren cyanide solution through the filter cake. The residues from the filters are sent to Dorr thickeners, the thickened discharge of which is sent to waste, and the overflow used for further sluicing.

The pregnant solution coming from the filter presses is clarified by filtration through a sand bed, deoxygenated by the Crowe vacuum process, and the gold precipitated by zinc dust. The gold precipitate is treated with sulphuric acid to remove zinc, calcined at a low red heat, and smelted direct in pots in a reverberatory furnace. The resulting bullion is 984 fine, in combined gold and silver.

McIntyre Practice

At the McIntyre the ore coming from the mine is crushed to pass a 3½-inch ring in a gyratory crusher, then sent through two sets of rolls, in series, which further reduce it so that all will pass a 1-inch ring. This ends the dry crushing.

The discharge from the rolls is next ground, in cyanide solution, in Hardinge conical ball mills. The discharge from these, which is all minus 8-mesh with 25 or 30 per cent below 200-mesh, goes to Dorr duplex classifiers, in closed circuit, with tube mills to regrind the oversize. The pulp overflowing from the classifiers (93·6 per cent of which will pass a 200-mesh screen) goes to primary thickeners, the overflow from which is clarified, freed from oxygen by the Crowe vacuum system, and precipitated with zinc dust.

The underflow from the primary thickeners goes to Dorr agitators, followed by thickeners in which the pulp is washed by counter-current decantation, the discharge of the last tank going to the tailrace.

Vipond Practice

The ore as it comes from the mine is put through a Gates gyratory crusher, followed by rolls set to ½ inch. This constitutes the primary crushing plant. At the mill the ore is crushed in cyanide solution in Hardinge ball mills, the oversize from which is returned to the mills for regrinding; the undersize goes to Hardinge pebble mills operating in closed circuit with Dorr classifiers. The overflow from the classifiers is passed to a Dorr tray thickener with a Weber pulp-sealed boot, the overflow from which is clarified in a leaf filter, then put through a Crowe vacuum apparatus, precipitated with zinc dust, filtered in Merrill presses, and the resulting precipitate smelted direct. The thickened pulp from the tray thickener is given the usual cyanide treatment in Dorr agitators followed by a four-step counter-current wash, and then sent to waste.

West Dome Lake Practice

The ore from the mine passes over a bumping-table to a 9- by 15-inch jaw crusher, crushing to $1\frac{3}{4}$ inches. Wet grinding next is done in a Hardinge ball mill, or a ten-stamp mill when the ball mill is down. The discharge from the ball mill or the stamps, as the case may be, passes to a Dorr classifier, the oversize from which is ground in a tube mill running in closed circuit with amalgamating plates and the Dorr classifier. Amalgamation is used in the tube-mill circuit only, and catches 60 or 65 per cent of the gold and silver in the ore.

The classifier overflow goes to a Dorr thickener, the pulp from which goes to Pachuca tanks, where cyanide and barren solution are added to maintain a specific gravity of 1·49. Two agitators in series follow the Pachuca tanks and these are followed by Oliver filters. The residue on the filters is sent to waste; the filtrate is clarified and then sent to zinc boxes to be precipitated. The barren solution from the zinc boxes is used for filter wash.

Though the history of Porcupine contains as yet no record of extraordinary difficulties overcome, the reputation of the camp for efficiency in both mining and metallurgical practice is high, and in regard to these it need not fear comparison with other gold-mining districts throughout the world. Costs already compare favourably with those in other districts and will show further reductions in the future. They cannot be expected to reach their lowest during the period of expansion through which the mines are now passing.

Map 11. Sketch map showing the relative positions of Sudbury, Cobalt, Porcupine, Kirkland Lake, and Rouyn.

AUTHORITIES CONSULTED

General

Burrows, A. G.: "The Porcupine Gold Area"; and

Cole, G. E., Longmore, E. L., Dowsett, C. W., and Dorfman, A.: "Porcupine Mining Methods and Milling Practice"; Ont. Dept. of Mines, Ann. Rept., vol. XXXIII, pt. II, 1925.

Hollinger Mine Staff: "Mining and Milling Methods at the Hollinger Mines"; Trans. Can. Inst. of Min. and Met., vol. XXV, pp. 52–80 (1922).

McIntyre Mine Staff: "Mining Operations at the McIntyre Porcupine Mines, Ltd."; Trans. Can. Inst. Min. and Met., vol. XXV, pp.81-108 (1922).

Webster, A. R.: "Hydro-electric Development for Gold and Silver Mines in Northern Ontario"; Ont. Dept. of Mines, Bull. No. 46, 1923.

Annual Reports of the mining companies.

Geological

Spurr, J. E.: Eng. and Min. Jour. Press, vol. 116, No. 15, pp. 633-638 (Oct. 13, 1923).

Robinson, H. S.: Econ. Geol., vol. 18, No. 8, pp. 753–771 (Dec.,1923).

Feilding, R. C.: Inst. of Min. and Met., Bull. No. 231 (Dec., 1923).

Dougherty, E. Y.: Econ. Geol., vol. 20, No. 7, pp. 660–670 (Nov., 1925).

MANITOBA

Metal-bearing rocks in Manitoba are found in the northern part of the province, in localities as yet somewhat remote and inaccessible to cheap transportation. Metal mining, consequently, is just commencing and the present mineral output is almost entirely non-metallic, principally structural materials and clay products. There is a very considerable gypsum mining industry 170 miles north of Winnipeg, the raw material being brought to that city for calcining and milling. Limestone from quarries at Tyndall, 25 or 30 miles from Winnipeg, is well known throughout Canada as a handsome and durable building stone.

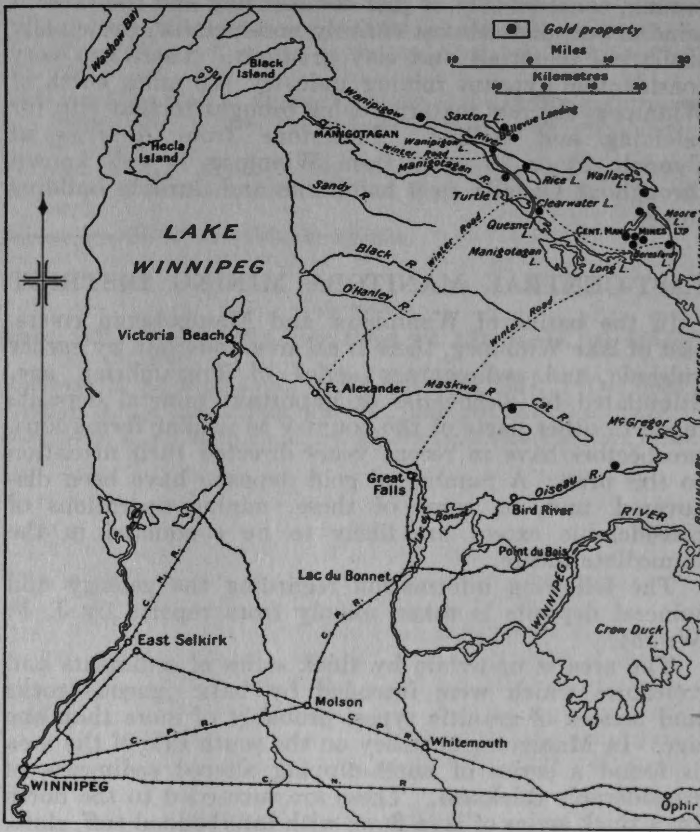
EAST-CENTRAL MANITOBA MINING DISTRICT

In the basins of Wanipigow and Manigotagan rivers, east of lake Winnipeg, there is an area underlain by earlier volcanic and sedimentary series of Precambrian age. Stimulated by discoveries of important mineral deposits made in other parts of the country in similar formations, prospectors have in recent years directed their attention to this area. A number of gold deposits have been discovered, and, on some of these, mining operations of considerable extent are likely to be conducted in the immediate future.

The following information regarding the geology and mineral deposits is taken mainly from reports by J. F. Wright.

The area is underlain by thick series of sediments and volcanics which were intruded by basic igneous rocks and masses of granitic types, probably of more than one age. In Manigotagan valley on the south side of the area is found a series of north-dipping altered sediments of considerable thickness. These are succeeded to the north by a thick series of lava flows with interbedded tuff, slate, chert, and iron formation. To the north of the lavas and along Wanipigow valley lies a second, less-altered, sedimentary series which is in part contemporaneous with the lavas, and possibly in part younger.

The lavas of the volcanic series are fairly massive, fine-grained to dense rocks, and show pillow structure and other evidence of volcanic origin. A light-coloured acidic group and a dark-coloured basic group are recognized, and in many places members of the two groups are interbedded. They consist of a great variety of types—rhyolite, trachyte, dacite, andesite, and basalt. Basic and acidic intrusives, very similar to the lavas in appearance, cut the volcanic rocks as dykes, sills, and small bosses. Of local



Map 12. Key map of east-central Manitoba mineral district.

distribution in these volcanics are cherts, slates, volcanic tuffs, and iron formation in long, narrow bands or lenses.

The formation intermediate between the volcanic and sedimentary series to the south consists of a succession of greywacke beds with thin lava flows and pyroclastic beds. Coarse, fragmental rocks predominate near the sedimentary series; tuffs and cherty beds near the volcanic series.

The rocks of the sedimentary series along Manigotagan valley fall into two divisions: a fine-grained, argillaceous group, and a coarse-grained, sandy group. About 10 miles southeast of Long lake these two groups are separated by a mass of conglomerate and grit over 1,000 feet thick. This gradually thins out to the west, and at the east end of Long lake argillite is followed directly by arkose and greywacke.

The argillite and slate are fine-grained, black, or dark grey, fissile rocks having in places a well-developed, slaty cleavage. The argillite has been traced northwest and found to be the equivalent of the biotite schist and garnet gneiss which form a belt extending northwestward from Manigotagan lake.

The coarse-grained, sandy group is found in great thickness east of Long lake. It consists of thick, massive beds of arkose with a number of beds of quartzite, chert, and conglomerate near the transition into the argillite group to the south. Greywacke is abundant in that part of the group lying nearest to the volcanic series.

The second series of coarse sediments is typically exposed in the vicinity of Rice lake and along Wanipigow valley. They dip to the north, and the succession from south to north is quartzite with thin beds of conglomerate, quartzite with thin slaty beds, thick-bedded quartzite, and massive arkose.

Basic intrusives in the form of dykes, small bosses, and masses of irregular shape cut the volcanics and the sediments. They vary greatly in composition, the most abundant type being hornblende gabbro, which in many places is altered to amphibolite. Granitic intrusives are widespread. Except for a few small diabase dykes they are the latest rocks of the area, and intrusives of different ages may be represented. Massive, gneissic and porphyritic types of varied mineralogical composition are found.

Gold Quartz Deposits

The known gold quartz deposits of the east-central Manitoba gold-field occur in fractured and sheared zones cutting massive granite, granite porphyry, granodiorite, and the lavas and sediments near the contacts with these intrusives. Both in the granitic intrusives and in the older formations, the sheared zones are parallel to the intrusive contact, and where this contact bends there is a concentration of quartz deposits. The deposits of greatest known economic importance occur near or around the ends of wide, sill-shaped areas of granite porphyry, or coarse-grained dioritic phases of the granitic intrusives.

The shear zones are characterized by many pinches and swells along their entire length, and are only partly replaced by quartz, various sulphides, and gold. The quartz and sulphides in some places display a banded or ribbon structure.

It is thought that in their final stages of intrusion the wide, sill-shaped masses of granitic magma thrust and shoved aside the country rock, and caused the formation of openings or easily replaceable zones by intense fracturing, both in the country rock and in the nearly consolidated intruding rocks. The residual solutions carrying quartz, pyrite, arsenopyrite, chalcopyrite, and gold, from the granitic magma, were concentrated along these zones. The known mineral association of the deposits is not typical of the gold quartz deposits formed in close association with granitic intrusives, but is more typical of those deposits formed under conditions of intermediate temperature and pressure at some distance from the granitic intrusives. But, since some of the deposits are in the granitic intrusives themselves, and the fracturing of the granitic rocks took place after they had consolidated, it is evident that these particular deposits, if they are associated with the granitic intrusives, must have been formed at a very late stage in the history of the intrusion.

In English Brook area, where discoveries have been recently made, auriferous quartz veins are found at the contact of granite and elongated inclusions of older lavas and also within shears in the granite.

Mr. Wright has furnished the following notes on recent developments.

During the summer of 1926 fairly extensive development was in progress on the Kitchener group of the W. A. D. Syndicate, and on the Cryderman property of the Mining Corporation of Canada, Ltd. Less extensive developments were also in progress on several other properties, and a few prospectors were busy searching for new veins or doing assessment work on their claims.

The Kitchener and adjoining group of some twenty-five claims lie about 4 miles northeast of the east end of Long lake. In July the holdings in this district of the W. A. D. Syndicate and of the Anglo-Canadian Explorers, Ltd., were amalgamated and taken over by the Central Manitoba Mines, Ltd. The three main veins at present exposed in the Kitchener group are known as the Kitchener, Tene 6, and Hope. On the Kitchener vein a vertical three-compartment shaft has been sunk 375 feet, and at the end of August about 2,000 feet of drifting and crosscutting had been completed on this level together with a winze 75 feet and a raise 90 feet. Over 1,000 feet of drifting and crosscutting had also been completed on the first and second levels. This vein has been diamond-drilled to a depth of 700 feet. The Kitchener vein extends westward under swamp to the adjoining Growler mineral claim and, at a point approximately 1,600 feet west of the Kitchener shaft, an inclined shaft was sunk 125 feet along the vein, and a raise will be extended from the 375-foot level to meet this shaft.

The country rock immediately south of the Kitchener vein is andesite pillow lava containing a number of chert beds varying in thickness from 10 to 125 feet. North of the vein the rock is hornblende gabbro, intruded between an andesite flow and an adjoining chert bed. The contact of hornblende gabbro and chert is slightly undulatory and this contact zone was later intruded by masses of irregular outline and dykes of a fine-grained, grey, feldspar porphyry. The quartz vein is for the most part in chert, hornblende gabbro forming the foot-wall, and porphyry in many places forming the hanging-wall. The general strike of the chert bed and quartz vein is north 83 degrees west (magnetic), with an average dip of between 55 and 60 degrees south, but there are local variations of 20 or 30 degrees both ways from this average. The quartz in parts of the underground workings is distributed in the form of a single definite vein, but much of the ore-body consists of a number of closely spaced, narrow quartz veins or stringers, and jointed chert. The average width of the ore-body is between 3½ and 4½ feet and the average reputed values between $10 and $15 a ton in gold. The larger proportion of the quartz is dark and carries pyrite and chalcopyrite, but no free gold has been noted.

On the Tene 6 mineral claims, and approximately 3,300 feet east of the Kitchener shaft, a body of quartz was discovered in the autumn of 1925 and preliminary prospecting was commenced at this point in August, 1926. This quartz body is along a heavily drift-covered depression and just north of a small hill of hornblende gabbro. The stripping completed by August exposed the quartz 90 feet along the strike and across an average width of 19 feet. On the surface this quartz lens cannot extend over 100 feet farther west and may extend between 200 and 250 feet to the east. A vertical shaft was commenced in August near the east end of the exposed outcrop and at a depth of 25 feet the vein was 21 feet wide and averaged about $35 a ton in gold.

On the Hope mineral claim, and approximately 1,700 feet east of the Tene 6 workings, another shear zone in hornblende gabbro and varying from 4 to 30 feet in width has been exposed by surface trenching for 680 feet along a strike of north 85 degrees west (magnetic). A continuation of this shear zone is probably represented 700 feet eastward by a similar shear exposed 150 feet along the strike and outcropping along the south side of a large spruce swamp. If this be so, the Hope shear is at least 1,500 feet long. In this shear zone only the more schistose parts of the hornblende gabbro have been replaced by the quartz, which is distributed irregularly in narrow veins and lenses. Chalcopyrite is the abundant sulphide and some free gold has been found. The values are reported as not being so consistent as, and the average less than, those of the Kitchener vein.

The Cryderman property, discovered in May, 1925, is about 3 miles northwest of the northwest end of Moore lake. In the summer and autumn of 1925 considerable surface trenching, and a small prospect shaft 40 feet deep, were completed on this property. Between April and June, 1926, a large vertical shaft was sunk 250 feet, and early in September 1,000 feet of drifting and crosscutting were completed on the first and second levels. The country rock is andesite pillow lava cut by hornblende gabbro, and quartz, and feldspar porphyry dykes. North and east of the shaft the andesite has been jointed and sheared along two nearly parallel zones and the quartz is distributed as lenses and masses of irregular outline along these zones. The general strike of these zones is north 55 degrees west (magnetic) and the dip of the southern vein is 60 degrees south; the northern vein appears to dip steeply to the north. The southern vein is fairly well exposed for 420 feet along the strike; one quartz lens near the east end is 42 feet wide. The quartz is white, with only minor amounts of a dark variety, and has been jointed; coarse, free gold was noted along some of the joint-planes. The underground development shows the shear to persist and to contain considerable white quartz, but the gold values are local and no single large ore lens was encountered. Surface trenching has exposed four outcrops of sheared andesite, impregnated with quartz carrying free gold, within a distance of 2,500 feet northwest of the shaft and along the projected strike of the developed deposits, but outcrops in the intervening areas indicate that the shear zone cannot be continuous, at the surface, throughout this distance.

No developments were in progress west of Beresford lake in the summer of 1926. In 1924 and 1925 the Anglo-Canadian Explorers, Ltd., did considerable development and diamond-drilling on the Oro Grande and adjoining Solo mineral claims. At the same time the W. A. D. Syndicate completed quite extensive surface explorations along a number of veins west of Beresford lake. These two companies have since united their interests and for the present are concentrating their efforts on the Kitchener group. Several new discoveries were made during the summer of 1926 near Gem and Slake lakes in the southeast end of the district, but not enough prospecting had been completed in August to indicate the presence of any considerable tonnages of gold ore. On the Eldorado group, southeast of the southwest end of Halfway lake, two prospect shafts were each sunk 50 feet on the vein and considerable surface trenching completed. This vein is along a narrow, shear zone in a greyish, granitic intrusive and the quartz bodies are narrow and lenticular but carry free gold. On the San Antonio mineral claim, along the north shore of Rice lake, considerable stripping was completed along a jointed and slightly schistose zone in hornblende gabbro. No development was in progress at the Selkirk property where between 1922 and 1924 the Selkirk Gold Mining Company completed underground development to a depth of 535 feet along a shear zone in granite. The quartz lenses were found to be small and not closely spaced, and the gold values were erratic.

The Central Manitoba Mines, Ltd., are now building a 150-ton mill which they hope to have completed in 1927. Power for the mill will be obtained from the Manitoba Power Company's plant at Great Falls on Winnipeg river, 40 or 50 miles distant. This will entail the building of a high-tension transmission line into the gold-fields. The availability of electric power will, no doubt, stimulate development on many other prospects in the district.

AUTHORITIES CONSULTED

Moore, E. S.: Geol. Surv., Canada, Sum. Rept. 1912, pp. 262–270.
Dresser, J. A.: Geol. Surv., Canada, Sum. Rept. 1916, pp. 169–175.
Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1921, pt. C.
Wright, J. F.: Geol. Surv., Canada, Sum. Rept. 1922, pt. C, pp. 45–82.
Wright, J. F.: Geol. Surv., Canada, Sum. Rept. 1923, pt. B, pp. 86–104.
Wallace, R. C.: "The Mineral Resources of Manitoba"; Industrial Development Board of Manitoba, Winnipeg, 1925, pp. 23–27.
Wentworth, H. A.: "Recent Mining Development in the Central Manitoba Mining District"; Can. Inst. of Min. and Met., Bull. 162, pp. 941–949 (Oct. 1925).

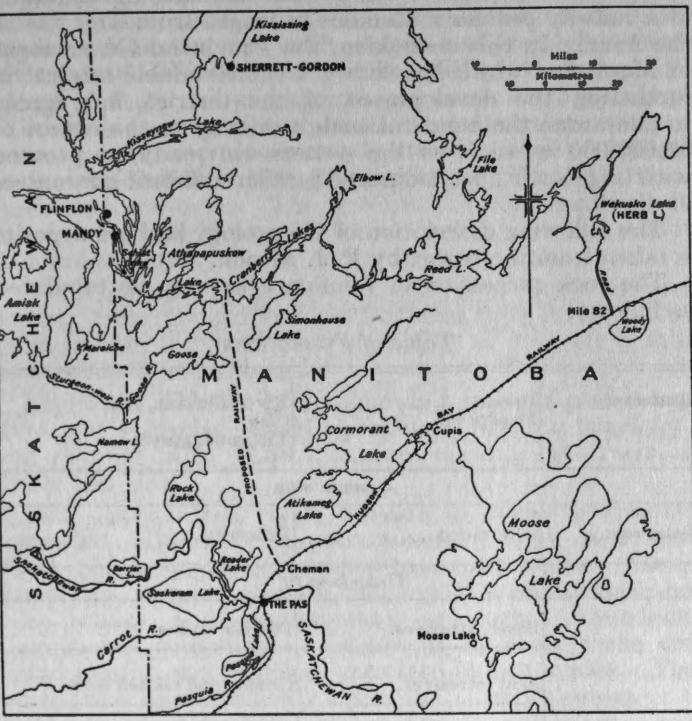
THE PAS MINING DISTRICT

In Manitoba and eastern Saskatchewan 50 miles north of The Pas there is a belt of mineralized ancient Precambrian volcanics and sediments having an east and west extent of over 100 miles and a width of great variability. Other areas of similar rocks of much smaller extent are found farther to the west in Saskatchewan and farther to the east in Manitoba. These mineralized belts have in recent years attracted considerable attention on the part of prospectors and miners, with the result that very promising discoveries have been made, mining operations have been conducted on a moderate scale, and prospects of the development of mining and metallurgical operations on a large scale are probable in the near future. The two most important bodies of ore yet discovered are known as the Flinflon and Mandy bodies of sulphide ores of copper and zinc.

The Flinflon copper-zinc deposits are situated on Flinflon lake, on the boundary between the provinces of Manitoba and Saskatchewan, and are, in an air-line 68 miles, northwesterly, from The Pas on the Canadian National railway, the chief distributing centre for the district.

The summer route for supplies for the Flinflon is by way of The Pas up Saskatchewan river to Sturgeon Landing by shallow-draft steamboat, then by portage road 16 miles from Sturgeon Landing to lake Athapapuskow, followed by a further 40 or 45 miles by gasoline boat or canoe to the head of Schist lake about 4 miles by wagon road from the Flinflon camps. In winter the property is reached by a sleigh road about 90 miles long, from The Pas.

The deposit was discovered in 1915 and diamond-drilling was started in March of the following year. Since that date some forty-four drill-holes having an aggregate



Map 13. Key map of The Pas mineral district.

length of 25,664 feet have been put down, and two shafts over 500 feet apart have been sunk on the ore-body, one to a depth of 300 feet the other to 210 feet, and some cross-cutting and drifting have been done to confirm the diamond-drill records to these depths. Owing to the low price of copper, the low grade and complex character of the ore, the isolated situation of the deposits, and the large capital expenditure necessary to put the property on an operating basis, exploitation of the Flinflon deposits has been long delayed, but now appears to be in sight.

A pilot plant of sufficient capacity to treat about 25 tons of ore a day has been erected on the Flinflon mine and if the results obtained in this preliminary plant are such as to indicate the commercial feasibility of the undertaking a complete plant will be built and large-scale operations will follow. This will involve the building of a railway probably 85 miles in length from The Pas to the mine. In this connexion, the Provincial Government of Manitoba, which has shown a commendable interest in furthering the development of the district, has agreed to guarantee the bonds of such a railway to the extent of $3,500,000 as soon as the owners are ready to proceed with large-scale operations and furnish sufficient guarantees of development.

The following description of the geology and ore deposits is taken from the report by F. J. Alcock.

The rock succession in Flinflon area may be tabulated as follows:

Table of Formations

Quaternary......	Recent..................... Pleistocene................	River alluvials, peat Clay Till, sand, gravel
	Unconformity	
Palæozoic.......	Ordovician...............	Dolomite
	Unconformity	
Precambrian....	Basic intrusives..........	Dioritic dykes
	Acid intrusives...........	Granite and related rocks
	Basic intrusives...........	Lamprophyre Amphibolite Gabbro Peridotite
	Upper Missi series.........	Arkose Conglomerate
	Unconformity	
	Acid volcanics and intrusives	Flows, quartz porphyry and rhyolite porphyry dykes, and fragmental volcanic rocks
	Basic volcanics and intrusives	Basic lavas, tuffs, agglomerates, irregular intrusive bodies, and derived schists.

Among the most important formations from a standpoint of economic geology is the series of basic volcanics. It consists dominantly of lava flows, but beds of fragmental rocks are fairly common. The massive flow rocks, on account of their prevailing greenish tone, commonly receive the name greenstone. In composition the greenstones present considerable variation; most of them are apparently basalts, but rocks of intermediate composition, such as andesites and quartz-andesites, are very common. Many of them are porphyritic and some of the porphyritic varieties approach rhyolite in composition. Others have an ophitic structure and are to be classed as diabase or quartz diabase. Amygdaloidal and ellipsoidal structures are common. The greenstones are found both massive and schistose, the former being more abundant in Flinflon area.

The fragmental rocks show all degrees of coarseness and sorting, from fine-grained, well-banded tuffs formed from volcanic ash, to coarse beds consisting of volcanic bombs as much as 3 feet in length.

Associated with the greenstones is a series of acid intrusives and volcanics—quartz porphyry, rhyolite porphyry, and rhyolite tuffs. The intrusives occur in the form of dykes and sills.

The Upper Missi series consists of clastic sediments somewhat altered. The commonest variety is arkose which passes by metamorphism into mica gneiss. Sandstones are found that pass similarly into quartzites and mica schists, and conglomerates are locally abundant. Greywackes consisting of fragments of basic rocks are found locally, and in places pass into biotite schists. The series rests unconformably upon the older volcanics.

Of later age than the Upper Missi series is found a series of small intrusions of basic rocks—lamprophyre, gabbro, and peridotite. Of still later age and of widespread distribution are intrusives of granitic types, some of which are typically massive granite, others gneissic, and others porphyritic. In composition there is a range of granitic, syenitic, and dioritic varieties. These acid intrusives may have been the source of the solutions from which economic minerals were deposited in the greenstones.

Of still later age than the granitic types are a few basic intrusions in the form of dykes.

All the rocks so far described are of Precambrian age. They are concealed at the south of Flinflon area by flat-lying Ordovician dolomite.

The two bodies of ore to be described are the copper-zinc sulphide ore-bodies known as the Mandy and the Flinflon.

Flinflon Ore-body

The Flinflon ore-body is situated on the shore of the southeastern bay of Flinflon lake. It crosses the Interprovincial Boundary into Saskatchewan, but most of it lies in Manitoba.

General Character

The ore-body lies in greenstone. To the northeast of the deposit the greenstone is massive and amygdaloidal, showing its flow origin. The ore-body strikes north 30 degrees west. Some banded tuffs associated with flow rocks, on the summit of Flinflon hill east of the wagon road, strike north 12 degrees west. The deposit dips from 60 to 70 degrees to the northeast and the boring records show that it pitches at a low angle to the south. Dykes of quartz porphyry were encountered by the drill; one of these dykes forms the hanging-wall of the ore-body for some distance. The ore-body is a fairly regularly shaped lens, tapering gradually to the northeast, and ending rather bluntly to the southwest. . . . . The total length of the ore-body on the surface is 2,593 feet; at a depth of 900 feet it has a length of over 1,000 feet. It has a greatest width of 400 feet, but this includes some bands of unmineralized greenstone, which occur in the ore-body. The largest of these masses forms the prominent ridge along the strike of the ore-body between the two shafts. At a depth of 900 feet the ore-body has narrowed to 35 feet. It has been calculated that there are over 16,000,000 tons of ore without including the unmineralized horses of country rock or the ore below the 900-foot level.

Mineralogy

The principal minerals in the ore-body are pyrite, sphalerite, and chalcopyrite. Assays show that gold and silver are present. Arsenopyrite, galena, and magnetite have also been recorded, and small amounts of native copper have been found in the upper part of the deposit. Quartz is present in places between grains of pyrite, and as local veinlets traversing the sulphides. Calcite is rare, but occurs in places with the quartz.

The ore consists of two fairly distinct types, known respectively as the solid sulphide variety and the disseminated ore. The solid sulphide variety consists chiefly of very fine-grained, pale-coloured pyrite, containing sphalerite, chalcopyrite with some rare fragments of schist, and some quartz and calcite. In places there is a distinctly banded effect where the sphalerite and chalcopyrite form narrow bands in the pyrite. The sphalerite is dark in colour, and on the weathered surface assumes a bluish tarnish, probably due to the development of a film of covellite. The disseminated ore consists of country rock,

Flinflon No. 2 shaft.

chiefly chlorite schist, inpregnated with sulphides. The solid sulphide variety forms the central part of the lens, though in places it extends to the hanging-wall, whereas the disseminated ore is largely confined to a zone along the foot-wall. Disseminated ore is also found on the hanging-wall in the upper part of the deposit, but the copper content is here less than in the disseminated ore on the foot-wall. In places, as shown in both plane and section, disseminated ore forms a zone on either side of the central solid sulphide type. Boundaries between the disseminated and solid sulphide types are, as a rule, fairly distinct, though in places a gradation between the two varieties is found. Contacts between the solid sulphides and the horses of unmineralized rocks are also, as a rule, quite sharp. In places the disseminated variety of ore runs as high as 3 to 5 per cent copper, though the ore-body as a whole averages only approximately 1·9 per cent copper. The sphalerite is more abundant on the hanging-wall side than elsewhere in the deposit. The average zinc content for the whole ore-body is about 3·8 per cent. The gold and silver values are, respectively, 0·074 and 1·04 ounces a ton. Galena is rare in the ore-body, but it has been found lining vugs in the country rock.

Origin of the Deposit

The deposit was, clearly, formed by replacement. The presence of unsupported masses of rock in the ore-body, some of them schistose with the plane of the schistosity parallel to that of the wall-rock, and the character of the disseminated ore, consisting, as it does, of country rock partly replaced by sulphides, can be explained only by this method of formation. It is clear also that replacement was along a shear zone. The country rock away from the ore-body and the horses of rock in the ore-body consist of massive greenstone. On the other hand the rock containing the disseminated ore and the minor rock inclusions in the ore are largely chlorite schist. At the end of the crosscut from the No. 2 workings, quartz porphyry, probably a dyke, forms the hanging-wall of the deposit. The greenstone was apparently more easily sheared than the harder porphyry. The sheared rock was in turn more easily replaced than those which were less altered; the amount of shearing, therefore, was apparently the chief factor that facilitated the replacement and hence determined the size and shape of the ore-body.

The source of the solutions which caused the replacement is an interesting problem. There are two possible sources: (1) the basic igneous intrusives of post-Missian age; and, (2) the granite of the region. In favour of the former possibility it may be said that, locally, the basic intrusives were found to contain pyrite of apparently primary origin, and at one place the lamprophyre across from the Flinflon ore-body was seen to contain chalcopyrite, this, however, in a narrow zone suggesting later infiltration. In places, also, the Missi arkose in the neighbourhood of Beaverdam lake was found to contain pyrite near the contact with the lamprophyre intrusion. The position, also, of the two known ore-bodies of the region, the Mandy and the Flinflon, in a zone adjacent and parallel to the zone of basic intrusives, suggests a possible genetic relationship with them.

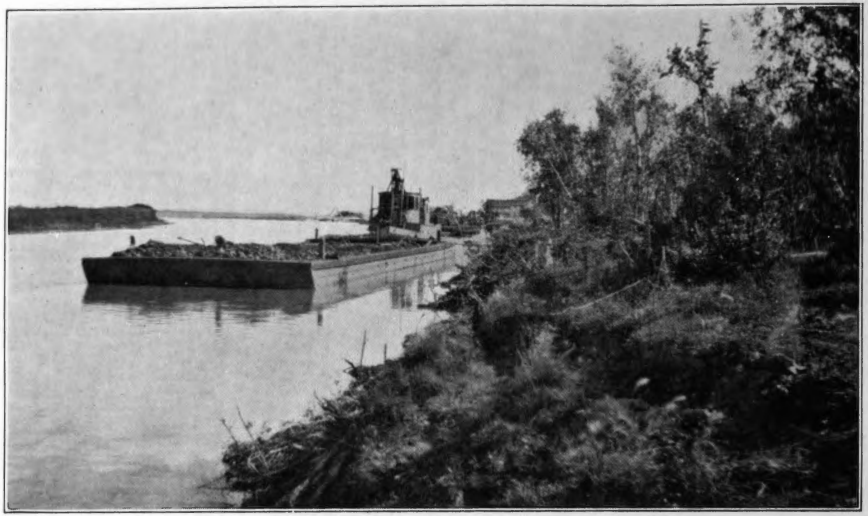
It has usually been considered, however, that the mineralizing solutions came from the granite. The chief argument in favour of this conclusion is the presence of quartz in the ore-body, showing that the solutions which caused replacement must have been siliceous and hence were more likely to have come from a granitic magma than from a basic one. Quartz is found interstitially between grains of pyrite and as small stringers cutting the ore. At the east end of the crosscut from shaft No. 2 on the 100-foot level very siliceous bands occur in the disseminated ore. On the surface of the deposit, just east of the unmineralized horse of greenstone, is also found a siliceous rock. It is light and porous, like pumice, and consists of quartz. It is apparently a replacement of country rock by quartz and sulphides, from which the sulphides were subsequently leached out.

Aside from these occurrences of silica, the presence of gold and silver in the ore is suggestive of an origin from the granite. The gold-bearing veins of the region are clearly attributable to the closing phases of the intrusion of the granite batholiths, and it is probable that the sulphides were derived from the same source. Evidence from certain other sulphide bodies in the region points to the same conclusion. On the north arm of lake Athapapuskow, deposits of pyrite and chalcopyrite are found at several places, associated with greenstone and acid porphyry rocks. In this region no basic intrusives of post-Missian age are known to occur. There is also a great deal of quartz associated with these sulphide occurrences, and the source of the deposits is, clearly, the adjacent granites. It seems highly probable, therefore, that the Mandy and Flinflon ore-bodies are attributable to the granite intrusives rather than to the lamprophyres and associated rocks.

The solutions which brought the ore were hot. The wall-rock near the sulphide zone contains much sericite. Some of the more badly altered rock, near the ore-body, consists only of sericite, quartz, and pyrite. Irregular masses of talc, also, have been found in the chlorite schist and in the sericite schist of the foot-wall. It is to be concluded, therefore, that the deposition of the ore was the result of the replacement of a sheared zone in volcanic rocks by solutions from intermediate to high temperatures given off from the granite intrusives. The shearing took place during the period of folding that accompanied the granite intrusion, and the replacement occurred towards the close of the period of intrusion. The solid sulphide ore was formed first. Towards the close of the period of mineralization the solutions were relatively richer in copper and gave rise to the disseminated ore on either side of the solid sulphide mass.

Mandy Ore-body

The Mandy ore-body is situated on the northwest arm of Schist lake, 3½ miles southeast of the Flinflon ore-body. It was located in 1915. In 1916 it was found by diamond-drilling that there were 25,000 tons of massive chalcopyrite averaging about 20 per cent copper, with additional



Barge with Mandy ore, at Cumberland lake.

gold and silver values to the amount of $5 a ton, and about 180,000 tons of lower grade ore consisting of mixed copper, iron, and zinc sulphides, running from 5 per cent to 8 per cent copper, 20 per cent to 30 per cent zinc, and gold and silver to the value of $5 a ton.

The body of massive chalcopyrite was mined out and shipped to Trail, B.C., to be smelted. The amount and value of copper produced were as follows:

Year	Lbs.	Value
1917	1,116,000	$ 303,329
1918	2,339,751	576,234
1919	3,348,000	625,775
1920	3,062,577	534,604
Total	9,866,328	2,039,942

In addition to the copper, the ore averaged $5 a ton in gold and silver.

The profitable working of the remaining material awaits the establishment of a local treatment plant and railway transportation; the future of the Mandy is thus closely bound up with that of the Flinflon, the quantity of ore in sight at the Mandy alone being scarcely sufficient to warrant the capital expenditure necessary to equip the property for economical operation. The method of treatment found best suited to the Flinflon ore will probably be the most satisfactory for that of the Mandy mine also.

The ore lens is in a band of schist with massive greenstone on both sides. The lens is 225 feet long and has a maximum width of 40 feet. It is rather irregular in shape and its longer axis parallels the strike of the schist and the greenstone bands. The ore at the south end is mainly chalcopyrite and that at the north end mainly pyrite. The central lens of chalcopyrite had a maximum width of 12 feet on the surface and a length of 100 feet. On the 100-foot level it widened to over 18 feet. It was surrounded by sphalerite and pyrite. The zone of sphalerite ore shows a well-banded structure, and a rough banding is to be seen also in the pyrite zone. Chalcopyrite and sphalerite are intimately intergrown in many places and commonly occur as a matrix cementing pyrite grains, filling fractures in pyrite, or, less commonly, replacing pyrite. The sphalerite is massive, shows no signs of cleavage or crystal faces, and is of a dark colour with a metallic lustre quite different from ordinary blackjack. Locally, chalcopyrite and sphalerite form a well-banded variety of ore, but in this type chalcopyrite is present in the sphalerite bands and sphalerite in the chalcopyrite bands. Galena is found in small quantities.

The lens lies in a zone of chlorite schist which, under the microscope, is seen to be a mass of secondary minerals. The actual wall-rock is in places a sericite schist. The chief peculiarities of the rock adjacent to the lens, as contrasted with the country rock away from the ore-body, are the complete removal of the feldspars, the increase in the amount of secondary quartz and carbonates, the presence of sericite and sulphides, and the presence of rutile. This alteration was effected undoubtedly by hydrothermal solutions.

It is concluded that the Mandy ore-body was formed in a sheared zone in volcanic rocks. Solutions, probably derived from the granite, deposited pyrite in the shear zone replacing the schistose rock. Later movement took place during the period of deposition, and towards the end of this period the solutions became relatively richer in copper and zinc. Towards the end of the period, chalcopyrite deposition was dominant, and the central lens of chalcopyrite and the chalcopyrite veins cutting the sphalerite zone were formed.

Auriferous quartz veins have been found at a number of points throughout the mineralized belt in Manitoba and Saskatchewan, particularly in the vicinity of Amisk and Wekusko lakes. Mining for gold has been carried on to a limited extent on Wekusko lake.

On Cold lake, about 30 miles north of the Flinflon property, a discovery of a body of copper-zinc sulphides has been made, and a considerable amount of work has been done to determine its extent and value.

AUTHORITIES CONSULTED

General

Wallace, R. C.: "The Mineral Resources of Manitoba"; Industrial Development Board of Manitoba, Winnipeg, 1925, pp. 20–21.

Anon.: "The Flin Flon Mine"; Can. Min. Jour., Nov. 27, 1925, pp. 1090–1091.

Geological

Bruce, E. L.: "Amisk-Athapapuskow Lake district"; Geol. Surv., Canada, Mem. 105 (1918).

Alcock, F. J.: "The Reed–Wekusko Map-Area, Northern Manitoba"; Geol. Surv., Canada, Mem. 119 (1920).

Alcock, F. J.: "Flinflon Map-area, Manitoba and Saskatchewan"; Geol. Surv., Canada, Sum. Rept. 1922, pt. C.

SASKATCHEWAN

The mineral industry in Saskatchewan is small and confined entirely to non-metallic materials.

Coal (lignite), the chief mineral product, is mined near Estevan in the southern part of the province. Refractory clays are dug to some extent; and there is also a small output of natural sodium sulphate obtained from alkali lakes; and of volcanic ash for use in cleaning and polishing compounds.

REFRACTORY CLAY INDUSTRY

Clays suitable for the manufacture of common brick and tile are of general occurrence in nearly all parts of Canada, but known deposits of the higher grades of clays—clays suitable for the manufacture of pottery, vitrified wares, and articles having high heat-resistant qualities—are much less common. Saskatchewan has probably a greater variety of clays, in larger quantities and inclusive of the higher grades, than any other Canadian province, and, as the country becomes more thickly populated, there will, without doubt, grow up in southern Saskatchewan—and in neighbouring parts of the adjoining province of Alberta, where high-grade fuel in the shape of bituminous coal and natural gas is cheap and plentiful—a very important ceramic industry. In order to assure the best and most competent guidance for the future development of its clay industry the Saskatchewan Provincial Government, in conjunction with the University of Saskatchewan, has entered on a careful survey of the clays and of the ceramic possibilities of the province, and has established at the Provincial University a course in ceramic engineering under a highly trained specialist—the first of its kind to be undertaken by a Canadian University. In connexion with this, a complete equipment of clay-working machinery and kilns has been installed for the testing of clays and allied materials.

Among the known and tested deposits of Saskatchewan clay a number have been found suitable for use wholly or in part in the manufacture of:

Pottery or *Light Ware.* Whiteware, granite ware, electrical porcelain, sanitary ware, wall and floor-tile, yellow ware, and stoneware.

Heavy Ware. Sewer-pipe, hollow-ware, paving brick, building brick, terra-cotta, and roofing-tile.

Refractories. Locomotive-tile, stove linings, fire-proofing, fire-bricks and shapes.

All the clays of Saskatchewan are transported clays; residual clays are not known to occur in the province. Their winning is a simple matter; nearly all can be worked by open-pit methods and even the high-grade refractory clays are so well exposed that underground mining will not be necessary for a long time to come. The chief localities in which high-grade clays have been dug are at Clay Bank, Willows, and East End, in southern Saskatchewan.

At Clay Bank on the Avonlea-Gravelbourg branch of the Canadian National railways, the Dominion Firebrick and Clay Products Company, manufacture a number of special lines of refractories, including flue and furnace linings, linings for straw and coal-burning engines, locomotive arch tile, etc., from clays dug in the neighbourhood.

White-burning ball-clays and clays of the semi-refractory type dug at Willows, 74 miles south of Moose Jaw on the Weyburn-Lethbridge branch of the Canadian Pacific railway, are shipped to Medicine Hat, Alberta, where they are used in the manufacture of whiteware and stoneware by Medalta Potteries, Ltd., and Alberta Clay Products, Ltd., as well as for sewer-pipe, refractories, etc. Ball-clay from Willows has also been used in Ontario potteries.

From the vicinity of East End, about 103 miles west of Willows on the same line of railway, clay for the manufacture of stoneware, sewer-pipe, and other vitrified clay products is also shipped to the clay-working plants at Medicine Hat. The reason Medicine Hat has been selected as the place of manufacture for so much of the Saskatchewan high-grade clays is on account of the abundant supply of cheap natural gas.

Stoneware from the Medicine Hat potteries, made from Saskatchewan clays, finds a market in all populated parts of Canada.

Geological Features

Southern Saskatchewan is underlain by nearly flat-lying shales and sandstones of Cretaceous and Tertiary age, mantled to a very great extent by deposits of Pleistocene and Recent age.

Fire-clay beds at Twelvemile lake, Saskatchewan.

The Pierre shale of Upper Cretaceous age is the oldest and most widely distributed of the formations exposed in the southern part of the province. It is of marine deposition and consists of dark grey, clay shale, which in places becomes sandy towards the top. The shales are rendered friable by exposure and always weather to a very sticky gumbo. Towards the end of Pierre time there was apparently a shallowing of the sea, anticipation as it were of the shallow-water conditions that prevailed during the deposition of the Fox Hills sandstone.

The Fox Hills sandstone rests conformably upon the Pierre, was deposited in the shallowing Pierre sea, and is the most recent of the marine formations of the Great Plains of Canada. It is a fine-grained, friable sandstone or unconsolidated sand and on the weathered surfaces is stained yellow or brown by iron oxides formed by the decomposition of ferromagnesian silicates. It is found at the base of such elevations as Wood mountain and Cypress hills. In the former it is not over 75 feet thick and in the latter is 150 feet.

These sediments are succeeded upward by three formations, the Estevan, Whitemud, and Ravenscrag, and these are overlain in places by the Cypress Hills formation of Oligocene age.

Beds of the Estevan group are exposed in the Souris valley from Halbrite to Estevan; in the Big Muddy valley from the International Boundary to the forks; in the Dirt hills at Clay Bank, and south of Wood mountain. They do not occur in the Frenchman River plateau, Swift Current Creek plateau, or in the Cypress hills.

In general the beds are fairly uniform in appearance, but the individual beds are seldom continuous for any distance; they thicken and thin from place to place. The colours are commonly grey to dark grey on fresh exposures, but weather to yellowish grey and light grey on exposure. They have a very high content of colloidal matter and vegetation has difficulty taking root on the exposures. As a result the outcrops are often weathered to bad land topography. None of the beds is hardened to any extent, except an occasional sand bed.

The Estevan beds are of the greatest importance economically to the province of Saskatchewan, because they carry workable seams of lignite. They are correlated with the Lance formation. Regarding the transition from the Cretaceous to the Tertiary, Rose writes in part as follows:

The evidence collected in this area is of interest also in its bearing on the Cretaceous-Tertiary boundary problem. The period was one of transition. . . . . Deep-sea conditions are represented by the shale deposits of the Pierre. A change to shallow-water conditions gradually took place as the Pierre sea retreated southward, and the marine Fox Hills sands were deposited. At the same time a Tertiary flora developed on land and when the Cretaceous sea finally withdrew, at the end of the Fox Hills epoch, its place was taken by freshwater lakes and swamps in which the clays, sands, and lignite of the Lance were deposited. However, this gradual change from the marine Pierre-Fox Hills to the freshwater Lance, with its Tertiary flora, was not accompanied by the extinction of the Cretaceous fauna. The marine forms in the sea which had retreated southward were still of Cretaceous types and in the lakes and swamps of the Lance, Cretaceous reptiles still persisted, as is evidenced by the remains of turtles and dinosaurs. The final extinction of the reptiles marks the end of the Lance, and was followed by the deposition of the typical freshwater Tertiary deposits of the Fort Union formation.

The Whitemud beds are refractory white clays which extend interruptedly west from Souris valley to the Alberta boundary and north from the International Boundary to the escarpment west of Elbow. These clays are relatively pure and refractory and stand out in striking contrast to the impure clays and sands above and below.

The relation of the white band clays to the underlying formation changes somewhat from west to east. In the Frenchman River valley near East End the white clays appear in contact with the Pierre and Fox Hills, but going east to the Wood Mountain country, particularly along the Big Muddy valley, a dark grey, lignite-bearing series, the Estevan beds, appears below the white band and continues towards the Manitoba boundary. In the Souris valley near Halbrite, and farther north near Yellow Grass, there are small outliers of the white band on top of the lignite-bearing Estevan beds.

The white refractory sands and clay represent the waste from the weathering of granitic rocks similar to the Precambrian of Manitoba to the east. The physical characters of the clays of the white band suggest that the source of the material was from the east. Those beds found in the Souris valley near Halbrite and Yellow Grass, in the Dirt Hills at Clay Bank and Mitchellton, and in the Lake of the Rivers valley near Willows, are decidedly more refractory and pure than those to the west in the Cypress Hills district. It is to be expected that the nearer the source the purer and more refractory will be the material. The eastern beds are true fire-clays, while those of the west are semi-refractory and stoneware clays.

The principal formation of the higher elevations of the area is the upper part, or Ravenscrag beds, of the Fort Union. It appears over the white band in all the elevations east as far as the Coteau. In the northern part of the Souris valley it has been completely removed by erosion, but near the boundary at Roche-Percée it appears overlying the Estevan horizon to a depth of about 100 feet. It consists of grey and yellow clays, silts, and sands, with many workable beds of lignite.

The Ravenscrag division contains beds of red and buff-burning clays that are valuable mainly for the manufacture of common brick and fire-proofing.

The Cypress Hills beds of Oligocene age cap all the higher elevations of the western plateaux extending from the west end of the Cypress hills to the east end of the Swift Current Creek plateau, a distance of about 140 miles. Their deposition was preceded by an erosion interval. Towards the west they rest upon Fort Union formation, whereas east of East End coulée they overlap the Fort Union and are underlain by the Fox Hills sandstone and Pierre shale. The formations consist of calcareous clays, silts, quartz sands, and conglomerates. The conglomerates are a striking feature of the formation, and are composed of pebbles derived from the quartzites of the Rocky mountains.

The Whitemud formation is of great economic interest to Saskatchewan, for in it are found the high-grade clays that are shipped to Medicine Hat for the manufacture of sewer-pipe, pottery, etc., and that are used at Clay Bank for the manufacture of fire-brick.

In Cypress Hills area the clays are not so refractory as those farther east, but are of the earthenware and stoneware types. The formation is 20 to 50 feet thick, is well exposed in the valley of Frenchman river, and outcrops conspicuously within a mile of the Canadian Pacific railway between South Fork and Palisade, a distance of 15 miles. The clays show considerable local variations in quality, but Frenchman river supplies an excellent water for washing during all seasons of the year. Owing to the horizontality of the beds and the open nature of the exposures the recovery of the clays is comparatively simple.

In Lake-of-the-Rivers area the Whitemud formation is well exposed along the Canadian Pacific railway. Four miles east of Willows there is a large exposure within a few hundred yards of the railway, and at Readlyn and Verwood there are other exposures not far from the railway. The clays are plastic and more refractory than those of East End. Besides these light-burning clays there are others of the stoneware type, and semi-refractories suitable for sewer-pipe, terra-cotta, and ordinary fire-brick for stove linings.

Fire-clays are found in Dirt hills 30 miles south of Moose Jaw. Here some of the most refractory clays of western Canada have been exposed by several extensive landslides on the north face of Dirt hills. Other deposits in the area lie at a greater distance from the railway. There are also large exposures of refractory clays in Blue hills several miles west of Dirt hills.

AUTHORITIES CONSULTED

Davis, N. B.: "Report on the Clay Resources of Southern Saskatchewan"; Mines Branch, Dept. of Mines, Canada, Pub. No. 468 (1918).

Molloy, T. M.: Fourth Annual Report of the Bureau of Labour and Industries of the Province of Saskatchewan, Regina, 1924, pp. 8–23.

Anon.: "An Alberta Ceramic Industry"; Can. Min. Jour., Mar. 20, 1925, pp. 294–296.

Anon.: "New Clay Products Industry Making Progress"; Can. Chem. and Met., April 1924, p. 86.

Rose, Bruce: Geol. Surv., Canada, Mem. 89 (1916).

ALBERTA

No metallic minerals are produced in Alberta. The chief mineral output is coal, of which Alberta is at present producing more than any other Canadian province. Alberta also leads all the other provinces in the production of petroleum and natural gas.

The chief producing oil-field is in Turner valley, 40 miles southwest of Calgary, where high-grade crude naphtha is extracted from "wet" natural gas by a process of absorption. A little heavy petroleum is being obtained, also, in the Wainwright field, about 125 miles southeast of Edmonton.

The chief productive gas-fields are the Medicine Hat, Bow River, and Foremost, supplying the cities of Medicine Hat, Lethbridge, and Calgary; the Turner valley, supplying Calgary; and the Viking field supplying Edmonton through a pipe-line 80 miles long.

A start has been made in the working of salt beds and huge bituminous sand deposits near McMurray in the northern part of the province.

TURNER VALLEY AND OTHER OIL- AND GAS-FIELDS OF WESTERN CANADA

Few subjects have aroused greater interest in Canada in the last two years than the oil possibilities of the Prairie Provinces. A great deal of money has been spent in boring. These operations have been attended in part with success and in part with failure. The area to be tested is of vast extent and lack of success at a number of points has not deterred companies from further exploration.

The following notes are taken mainly from manuscript articles by G. S. Hume.

The Prairie Provinces are underlain almost wholly by shales and sandstones of Cretaceous age which extend from the escarpment in Manitoba west to within the Rocky mountains. They are overlain by sediments of Tertiary age in southern Saskatchewan and in a synclinal trough in central Alberta extending from the International

Boundary north to beyond North Saskatchewan river. In Manitoba they rest disconformably upon Devonian limestone which is succeeded downward by Silurian and Ordovician sediments deposited upon a Precambrian shelf; in north-central Saskatchewan and northern Alberta, also, they lie directly on the Devonian; in the mountains and foothills, the Cretaceous formations are succeeded downward by sediments of Jurassic, Triassic, Permian, Carboniferous, and earlier age.

Since the oldest Cretaceous sediments are believed to be continental, it is assumed that there was a pre-Cretaceous period of erosion in which the area now occupied by the plains was above sea-level. Probably the sediments of Jurassic, Triassic, Carboniferous, and Permian ages were bevelled off during this period of erosion and may have been entirely removed over areas where they formerly extended.

In the sediments deposited at the base of the Cretaceous, sands predominate, and in some areas conditions were favourable for the formation of coal deposits.

It is not assumed that the Lower Cretaceous sediments over the whole plains area are exact equivalents, but it is probable that sediments now found in one portion of the plains may represent only part of the time represented by sediments found in other portions.

In the Lower Cretaceous are the Kootenay and lower Blairmore formations of southwestern Alberta, the McMurray, Clearwater, and Grand Rapids formations of Athabaska River area, the Loon River and Peace River formations of the east Peace River area, the Bullhead Mountain and possibly younger formations of the western Peace River area, and (possibly) the basal Cretaceous sands of Manitoba.

The Lower Cretaceous was followed by thick shale deposits of Colorado age with a marked thickening from east to west. In the Peace River area the Dunvegan sandstone is a non-marine member of the Colorado, but elsewhere the sediments are mostly marine shales with some sand members near the base. The Montana deposits following the Colorado began in certain places in Alberta as marine shales, but were quickly followed by a great thickness of deposits of the Belly River, a delta deposit with marine members. The total thickness of the Belly River is very variable—from less than 1,000 feet in certain parts of eastern and southern Alberta to 10,000 to 11,000 feet in the foothills southwest of Edmonton.

In southern Alberta the Belly River deposits are followed by marine Bearpaw shales, which in turn are followed by the extensive and coal-bearing beds of Edmonton and equivalent age. In central Alberta it has been shown that a disconformity separated the Edmonton from the overlying Paskapoo formation of Tertiary age, but it is not known what relationship this unconformity has to the Lance formation of southeastern and southwestern Saskatchewan. The Lance formation has dinosaurs later in age than the Edmonton, and Lance dinosaurs are known in the Estevan beds of the Cypress hills. The relationship of the Lance to the formation in central Alberta is not clear.

The succession of strata varies considerably from point to point. The succession for the Turner Valley oil-field, which is the most important field, is given in the following table of formations.

Table of Formations

Age		Formation	Lithology	Deposit	Topographic features	Thickness in feet	Remarks
		Paskapoo	Light, ash-coloured, massive sandstone beds, greenish clays and shales	Freshwater	Eroded into irregular hills and depressions	4,000±	In certain places a conglomeratic sandstone with quartzite pebbles up to 3 inches in diameter is exposed at what is considered the base of the Paskapoo. Below the conglomeratic sandstone are green clay shales presumed to be Edmonton. The division is not made on fossil evidence
Cretaceous	Montana	Edmonton	Dark green clays with hard, greenish sandstones. A carbonaceous horizon at base	Brackish water	Forms a broad depression along upturned beds east of Turner valley and extending northwestward to Priddis	1,300	
		Bearpaw	Black shales, carbonaceous in places	Marine	....	....	Not definitely known to be present in Turner Valley area
		Belly River	Light green clays and shales, light grey and greenish, massive and thin-bedded, sandstones. A coal seam at the top of the formation	Brackish water	Upturned beds form ridges which form prominent features of the topography	1,800 to 1,900	

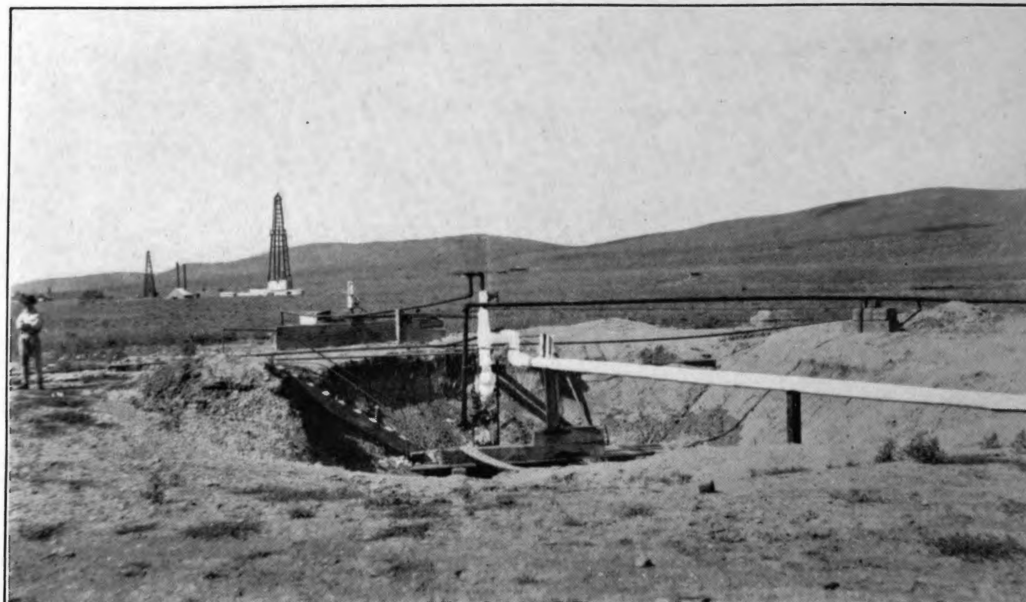
Colorado	Benton.......	Blue-black shales with several thin sandstone members	Marine	In contrast with the Belly River rocks these are easily eroded and form valleys	2,400	Fossils from the upper part of the Benton are presumed to be Montana in age. Lower down, Colorado fossils are common
	Blairmore....	Thin-bedded, variegated shales, massive and thin-bedded, green and grey sandstones	Land and freshwater (Plants)	Form ridges...........	According to Slipper Blairmore is 950 feet and the Kootenay is 400 ±, Hume thinks it is somewhat less	In Blairmore area there are two floras, an upper or dicotyledon belonging to the Upper Cretaceous, and a lower cycad flora. Only the lower so far has been found in Turner valley
	Kootenay....	Coal, black shales, and hard sandstones	Continental	Does not outcrop in Turner Valley area	....	A conglomerate varying in thickness occurs at the base of the Blairmore. It has not yet been recognized in well samples from Turner valley
Jurassic	Fernie........	Mostly dark, calcareous shales	Marine......	Does not outcrop in Turner Valley area	400 to 500	
?	Royalite.....	Limestones and dolomites	Marine......	Does not outcrop in Turner Valley area	?	The age is not definitely known. Fossils from a core sample of Illinois-Alberta well, at 3,811 feet, although poorly preserved, are considered by E. M. Kindle to be late Palæozoic

In the foothills the strata have been subjected to close folding and faulting. East of this area lies a broad syncline in which Tertiary sediments are preserved. The syncline narrows towards the International Boundary and is here succeeded to the east by an anticline on which has been developed the Kevin-Sunburst oil-field of Montana. In Canada the arch plunges downward to the north and on it are the Bow Island and Foremost gas-fields; farther down the dip the Medicine Hat-Redcliff gas-field has been developed.

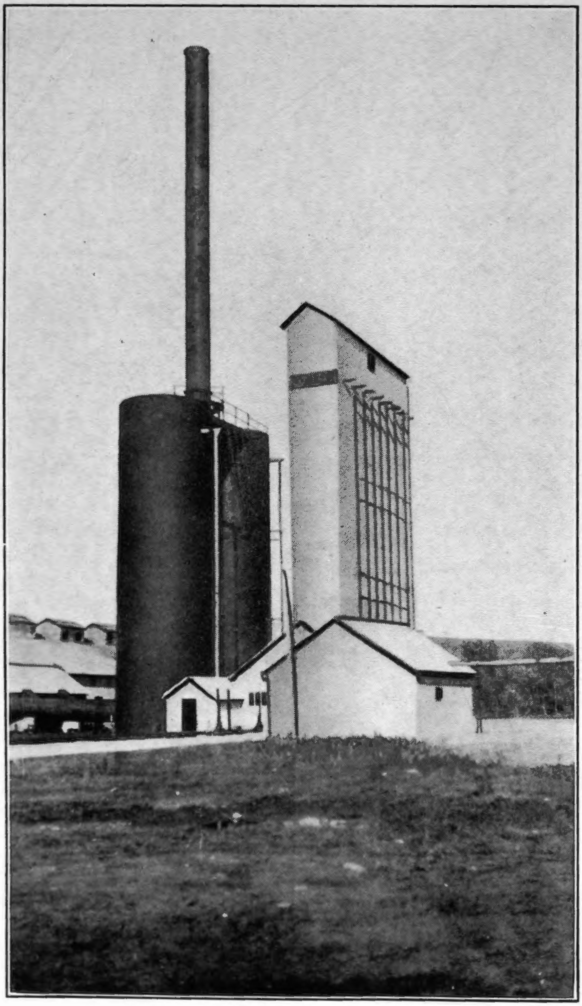
In east-central Alberta the eastern edge of the syncline is thought to be a line from Misty hills south of Monitor to a point west of Viking. West of this the strata dip southwest into the syncline, whereas east of this the dip is in the same direction but more gentle in character. This slight southwesterly dip of the strata continues east to the Alberta-Saskatchewan boundary in the vicinity of Battle river. East of this there is a gentle easterly dip of the strata which continues nearly to Battleford. On this broad structure minor folds have been induced that have favoured the accumulation of natural gas and petroleum, such as the Hawkins fold, the Fabyan fold, the Viking fold, the Wainwright-Battle River fold, and the Ribstone-Blackfoot fold.

The Turner Valley oil-field which lies in the foothills southwest of Calgary is the most important. Light oil was struck in 1913 and since then production has been continuous. In October, 1924, a very heavy flow of wet gas was struck in limestone in Royalite Well No. 4, at a depth of 3,740 feet. Since the opening of this well 500 barrels a day of light oil have been extracted from the gas. It is piped to the refinery at Calgary. The gas is purified and also piped to Calgary. The strike in Royalite Well No. 4 has aroused new interest in the oil possibilities of Alberta. Boring operations have been actively conducted in Turner Valley field and at other points in the foothills and on the plains. Strong flows of wet gas have been encountered in two or three wells from which a good quantity of oil is obtained, but none equals the Royalite Well No. 4.

A table of formations for this field, with descriptive notes, has already been given. The strata are closely folded. The Benton is the lowest formation exposed in the field, the lower formations which are met in drilling being exposed in the hills and mountains to the west. The

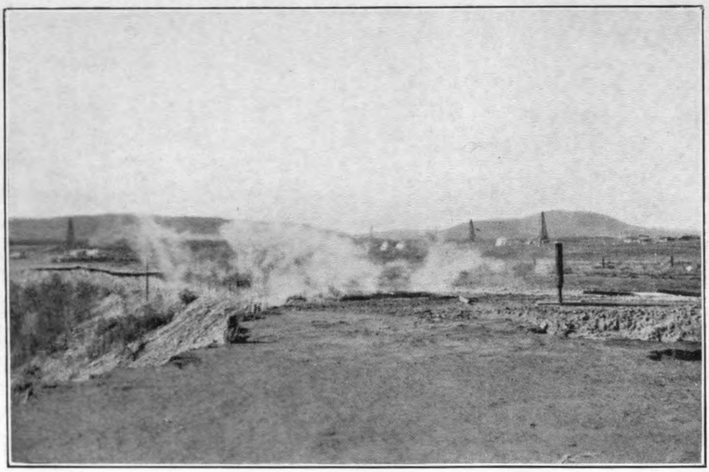


Royalite No. 4 well, Turner valley.



Purification plant, Royalite No. 4 well.

PLATE XXXII



Burning waste gas from Royalite No. 4 well.

Benton forms the crest of the strong anticlinal fold and has been eroded to form Turner valley, from which the fold derives its name; the harder Belly River beds form two parallel ridges on the flanks of the fold.

The oil obtained before the discovery made in 1924 came from different horizons in the Cretaceous sediments; the heavy flows of wet gas, from which the greater production of the last two years has been made, come from a dolomitic limestone that underlies Fernie shales of Jurassic age. This is the deep oil stratum that is now being sought in the boring operations in the foothills. The inclination of the strata varies greatly within short distances horizontally and it is probable that it varies also with depth. The apparent thickness of uniform strata thus changes from point to point. This makes it extremely difficult to interpret the logs of wells and to predict the depths at which oil-bearing horizons will be struck.

Brief notes follow regarding the gas- and oil-fields in other parts of Alberta, sufficient to indicate the results of borings made at points widely distributed throughout the province.

The Bow Island gas-field was for many years the main source of supply of natural gas for Calgary and a number of smaller centres of population. The productive horizon is near the base of the Colorado shales, which is reached at depths ranging from 1,900 to 2,200 feet. Three wells have initial open flows of 29,000,000 cubic feet, 23,000,000 cubic feet, and 15,000,000 cubic feet a day, and the average wells had initial capacities of 7,000,000 to 12,000,000 cubic feet.

In the Foremost field, which lies south of the Bow Island field, a number of wells have been drilled that have shown an initial capacity of 10,000,000 to 20,000,000 cubic feet a day. The gas comes from near the base of the Colorado formation.

The Medicine Hat-Redcliff gas-field has been producing large quantities of gas since 1908. The initial flow of the wells was from 2,000,000 to 4,000,000 cubic feet a day. The main producing stratum is the Milk River sandstone which is reached at depths of 1,000 to 1,200 feet.

The Viking gas-field supplies the city of Edmonton, 80 miles distant. The gas-bearing horizon is near the base of the Colorado formation and is struck at depths of 2,100 feet to 2,400 feet. The initial flow of the wells is 2,000,000 to 9,000,000 cubic feet each.

The Fabyan field is 150 miles southeast of Edmonton and 8 miles west of the Wainwright-Battle River oil-field. Two wells have been drilled. One gave a flow of about 10,000,000 cubic feet of gas a day and a small amount of heavy oil. The other is a gas well. The productive horizon lies near the base of the Colorado shales. The Hawkins fold lies a short distance to the west.

The Wainwright-Battle River oil-field is 4 or 5 miles north of Wainwright. A number of wells have been drilled and oil has been struck at two horizons, one in the sands at the base of the Colorado shales and the other in sands assumed to be of Lower Cretaceous age.

In a boring on the Ribstone-Blackfoot anticline gas was struck at a depth of 1,400 feet and an oil-sand at 1,900 feet. It is assumed that the gas horizon is in the Colorado formation and the oil-sand in the Lower Cretaceous.

A heavy flow of gas was struck in a boring made thirty years ago on Athabaska river near the mouth of Pelican river. The gas occurs in the southwestward extension of the Lower Cretaceous McMurray formation, which contains the bituminous sand. A number of wells drilled on lower Peace river north of the town of Peace River struck small quantities of oil and gas in the Loon River formation of Lower Cretaceous age. At Pouce Coupé a flow of 10,000,000 cubic feet of gas a day was struck at a depth of 1,675 feet.

The oil and gas prospects of a great part of Saskatchewan and Manitoba depend on the folding to which the sediments have been subjected. Since the whole area is mantled by extensive deposits of glacial origin, so that outcrops are rare except along stream valleys, structural features are difficult to determine.

AUTHORITIES CONSULTED

Malcolm, W.: Geol. Surv., Canada, Mem. 29 (1913).
Clapp, F. G., and others: "Petroleum and Natural Gas Resources of Canada"; Mines Branch, Dept. of Mines, Canada, 1914.
Dowling, D. B.: Geol. Surv., Canada, Mems. 53, 93, 116 (1914–1919).
Stewart, J. S.: Geol. Surv., Canada, Mem. 112 (1919).
Slipper, S. E.: Geol. Surv., Canada, Mem. 122 (1921).
Hume, G. S.: Geol. Surv., Canada, Sum. Rept. 1923, pt. B; Sum. Rept. 1924, pt. B.

COAL-FIELDS OF WESTERN CANADA

The coal-fields of Alberta and British Columbia are the most extensive in the Dominion of Canada, and the recovery of coal is one of the most important mining industries of western Canada. The total production for 1925 was 9,083,978 (short?) tons derived as follows:

Province	Kind of coal	No. of mines	Quantity	Value
			Short tons	$
Saskatchewan	Lignite	55	471,965	870,875
Alberta	Bituminous	19	2,145,635	8,423,909
	Sub-bituminous	27	570,654	1,731,267
	Lignite	307	3,152,742	9,866,308
British Columbia	Bituminous	39	2,742,252	11,720,373
Yukon	Bituminous	1	730	7,172

Geological Features

The coal-bearing formations of western Canada are of Cretaceous and Tertiary age; no seams are known to occur in the sedimentary formations of Carboniferous age.

Shales and sandstones of Cretaceous age extend from the escarpment in western Manitoba west to the Rocky mountains, resting, in the east, on formations of Devonian age and, in the west, on formations of Jurassic age. They are overlain in part by shales and sandstones of Tertiary age, the latter forming the more elevated parts of southern Saskatchewan and filling a broad, synclinal trough extending through central Alberta from the International Boundary north to beyond North Saskatchewan river.

The Cretaceous formations consist of a series of sediments which were deposited alternately under marine and continental conditions. Marine sediments are most abundant in the east and freshwater and brackish-water sediments are most abundant in the west. Between the two lies an area in which there is considerable interfingering of marine shales and freshwater or brackish-water sandstones. The Cretaceous coal seams lie, therefore, mainly in the province of Alberta, although borings at a few points in Saskatchewan show that conditions existing in this area during a small part of Cretaceous time favoured the formation of coal seams. Cretaceous sedimentation extended westward into the area now occupied by the Rocky mountains and coal seams are found in the fault-blocks of these mountains for long distances north and south on the Alberta side of the Interprovincial Boundary and in the south on the British Columbia side.

In the mountains and foothills the seams are usually tilted at high angles and their edges are exposed at the surface. Eastward the coal horizons are buried under a great thickness of sediments in the synclinal trough of Alberta. The coal-bearing formations that come to the surface to the east of the syncline assume a nearly horizontal position, as do also the lignite-bearing sediments of southern Saskatchewan.

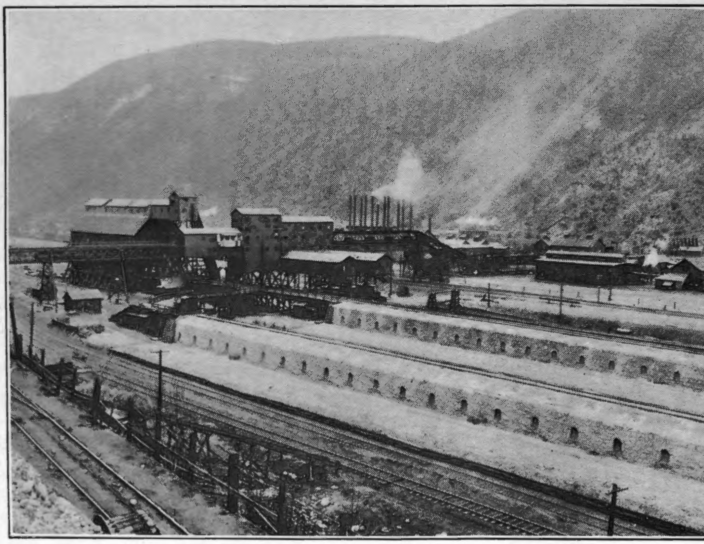
There are three important coal horizons in Alberta. One lies at the base of the Cretaceous in the Kootenay formation; one lies in the Belly River series in the Upper Cretaceous; and one in the Edmonton formation at the top of the Cretaceous. In southern Saskatchewan the main lignite beds are found in the Estevan formation, which is included by some geologists in the Cretaceous and by others in the Tertiary.

The older coal seams of the Prairie Provinces carry in general a better grade of coal than the younger. Mountain-building movements which took place subsequent to the laying down of the coal beds and which resulted in the thrusting up of the Rocky mountains have apparently had a marked effect on the grade of the coal. Coals found in the mountains and foothills are of much better grade than coals found at the same horizon in undisturbed areas farther east. This point is well illustrated by a series of typical proximate analyses of Belly River coal taken in order from east to west across the southern part of Alberta.

Area	Moisture	Ash	Volatile matter	Fixed carbon	B.T.U. per lb.
Redcliff	26·2	7·4	27·6	38·8	8,320
Taber	15·0	10·6	31·9	42·5	9,940
Lethbridge	10·2	9·3	35·8	44·7	10,980
Pincher	6·9	16·5	33·6	43·0	11,190

The Kootenay coal-fields lie in the western part of Alberta and in the southeastern part of British Columbia

PLATE XXXIII



Michel colliery and coke ovens.

and stretch with interruptions from the International Boundary to Peace river. It is the coal of Kootenay age that is found in the Crowsnest area on both sides of the Interprovincial Boundary, in the Highwood, Cascade, Nordegg, Mountain Park, Brûlé, Smoky River, and Peace River areas.

In the Fernie basin of southeastern British Columbia the Kootenay strata are found in the mountains east of Elk river and form a broad, flat syncline extending 35 miles in a north and south direction and varying in width from 4 to 13 miles. At Morrissey, 23 seams totalling 216 feet of coal are found in 3,676 feet of measures; at Fernie, 23 seams totalling 172 feet of coal are found in 2,250 feet of measures; and at Sparwood, 23 seams totalling 173 feet are found in 2,050. On the Alberta side of Tent mountain, which is on the Interprovincial Boundary, seams of 6, 15, 5, 7, 40, and 15 feet are found in 550 feet of measures. In Blairmore area, Alberta, three seams 16, 10, and 8 feet thick are found in 565 feet of measures and six seams 10, 17, 3½, 3½, 17, and 6 feet are found in 277 feet of measures. A tunnel driven 2,250 feet across the steeply-dipping measures on the headwaters of Sheep creek southwest of Calgary cuts thirteen or fourteen seams of coal ranging in thickness from a few inches to 39 feet, of which at least seven are workable. The number of workable seams in the Kootenay formation varies greatly in different localities, but the sections given above suffice to show that the reserves of the high-grade coals in this formation are very great.

The Kootenay coals vary from bituminous to semi-anthracite. Nos. 1 to 5 of the table (page 160) are analyses of Kootenay coals.

The coal-fields of the Belly River series are found in the foothills of western Alberta and in south-central Alberta. The most productive areas are Lethbridge and Taber, in the southern part of the province, and Coalspur and Saunders areas in the foothills west of Edmonton.

Nos. 6 and 7 of the table of analyses indicate the character of the coal.

The third important coal-bearing formation in Alberta is the Edmonton formation at the top of the Cretaceous. Mining is conducted on the seams that are found on the east limb of the broad syncline which runs north and south through the province. The complete section of the Edmonton formation in east-central Alberta is 1,224 feet thick, with fourteen coal seams having an aggregate thickness of approximately 62 feet. The coal is a lignite (domestic). The areas of greatest production are Drumheller, Edmonton, Pembina, Carbon, and Tofield. Nos. 8 and 9 of the table are analyses of the coals of the Edmonton formation.

Lignite seams are found in the Estevan formation of southern Saskatchewan and have been worked for many years. The Estevan formation lies either at the top of the Cretaceous or the base of the Tertiary. The most important mines are in the southeastern part of the province. The character of the lignite is shown by analysis No. 10 of the table. Saskatchewan has large fuel reserves in these lignite seams.

Coal-fields are dotted over the province of British Columbia from the south to the north and from the extreme east to the large islands off the coast. Some are small, others are of considerable extent; together they make up a resource of great magnitude. Reference has already been made to the Kootenay coal measures of Fernie basin in the southeast part of the province, and to those of Peace river.

The British Columbia coal seams are of Lower Cretaceous age, as in the case of those of Bulkley River valley and of Groundhog area at the head of Skeena river; of Upper Cretaceous age as in the case of the Nanaimo and other coal-fields of Vancouver island and Graham island; and of Tertiary age as in the case of the Princeton, Tulameen, Nicola, Chu Chua, and Hat Creek coal-fields.

The Cretaceous coals are in general bituminous, but anthracite seams are found in Groundhog basin. The Tertiary coals range from lignite to bituminous. In some places the grade of the coal has been improved by the folding of the strata and by the heat from lava flows which have spread over some of the fields.

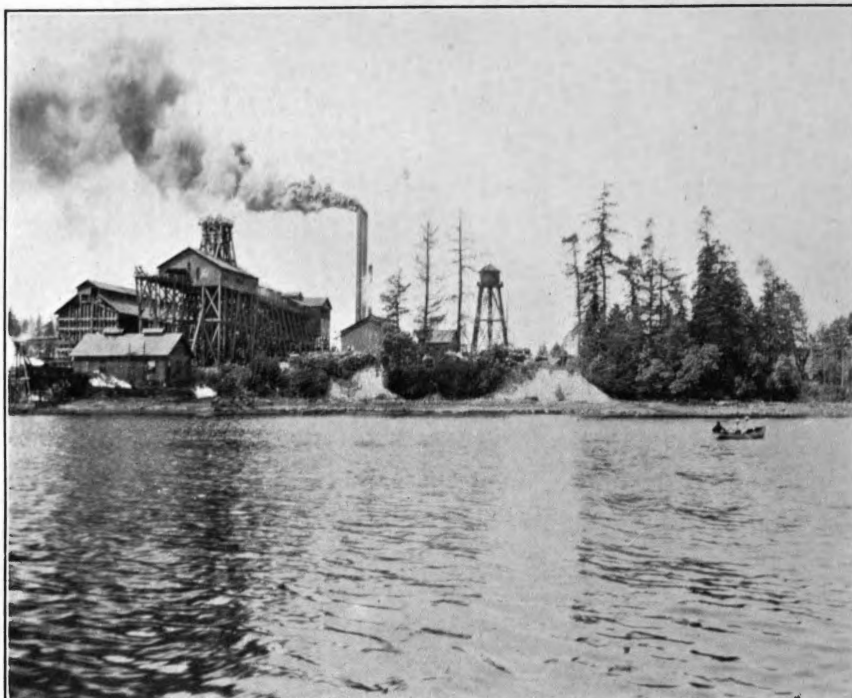
The Nanaimo coal-field gives a greater production than any other field of the province. The productive area is only about 65 square miles, but the area known to be underlain by coal is somewhat larger. The measures are moderately disturbed and have a general low dip to the northeast, with a few, large, open folds and many smaller ones. There are three seams, the Wellington, Newcastle, and Douglas. They are remarkably persistent, but vary greatly in thickness and quality. In many places a variation as great as from 2 or 3 feet of dirty, slickensided coal to 30 feet of clean coal occurs within a lateral distance of

100 feet. The coals of the various seams are much alike and are high volatile, bituminous coals of fair quality. An analysis is given in No. 11 of the table.

The rocks of the Nicola coal-basin are of early Tertiary age and consist of sandstones, shales, and conglomerates which dip at angles varying from 10 to 40 degrees. In places the strata have been folded into anticlines and in other places faulted. The basin has an area of 40 square miles, all of which, however, does not appear to be underlain by coal. The coal is low-carbon bituminous; No. 12 of the table is an analysis.

The Tulameen coal-basin is roughly oval in shape. It has a length of nearly 3⅓ miles, and its greatest width is about 2¼ miles. The area covered by the coal-bearing rocks, which are Tertiary in age, is 3,700 acres, and the area occupied by the coal itself is about 3,254 acres. About one-third is covered by a flow of lava. On the southwest side of the basin the sediments dip to the northeast and on the northeast side they dip to the southwest. The average dip around the edge of the basin is about 40 degrees. The coal is classed as bituminous, but it varies in physical and chemical properties from one part of the field to another. An analysis is given in No. 13 of the table.

	Mine	Proximate analyses				Ultimate analyses						B.T.U. per lb.
		Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Ash	Sulphur	Nitrogen	Oxygen	
1	Crow's Nest Pass Coal Co., Michel colliery.....	1·2	10·1	23·8	64·9	75·2	4·6	10·1	0·6	1·3	8·2	13,330
2	McGillivray Creek Coal and Coke Co., Carbondale mine...............	0·9	17·3	24·4	57·4	70·4	4·3	17·3	0·7	1·0	6·3	12,240
3	Canmore Coal Co., No. 2 mine, Canmore..........	0·9	5·4	14·0	79·7	85·2	4·2	5·4	0·9	1·3	3·0	14,470
4	Canadian Pacific railway, Bankhead colliery.	0·5	9·7	8·2	81·6	82·3	3·7	9·7	0·5	0·9	2·9	13,760
5	Mountain Park Coal Co., Mountain park..........	0·8	8·0	28·3	62·9	79·2	4·8	....	....	....	....	13,890
6	Yellowhead Pass Coal and Coke Co., Coalspur......	4·2	10·2	37·0	48·6	66·7	4·6	10·2	0·2	....	....	11,550
7	Canadian Pacific railway, Galt No. 6 mine, Lethbridge..............	8·9	9·7	33·7	47·7	63·5	5·5	9·7	0·5	1·5	19·3	10,980
8	Rosedale Coal and Clay Products Co., Rosedale	13·9	5·1	33·8	47·2	61·0	5·4	5·1	0·5	1·4	26·6	10,570
9	Midland Collieries, Ltd., Drumheller.............	12·5	8·2	31·6	47·7	59·9	5·2	8·2	0·5	1·3	24·9	10,120
10	Saskatchewan Coal, Brick, and Power Co., Shand mine....................	26·9	9·6	27·8	35·7	45·6	5·8	9·6	0·4	0·8	37·8	7,640
11	Canadian Collieries (Dunsmuir), Ltd., Wellington Extension colliery.......	1·1	10·0	39·7	49·2	72·1	4·8	10·0	0·4	1·2	11·5	13,020
12	Middlesboro Collieries, Ltd., Merritt............	3·9	14·0	37·6	44·5	64·6	5·3	14·0	0·9	1·2	14·0	11,230
13	Tulameen area, Granite creek...................	....	14·0	32·4	53·6	70·1	4·4	14·0	1·9	....	....	



The Western Fuel Company's Northfield colliery on Vancouver island.

BRITISH COLUMBIA

Coal mining has been carried on in British Columbia for nearly a century, records showing an average annual production of about 5,500 tons from 1836 to 1865, from the coal seams on Vancouver island. From 1865 onward the annual output slowly increased, with occasional fluctuations, until in 1910 over 3,300,000 tons were produced. Since 1910, owing to a variety of causes, not the least of which is the increased use of cheap oil fuel on the Pacific coast, the annual outputs have been below this maximum; that for 1925 being somewhat less than 2,750,000 tons.

All the coal being mined in British Columbia is bituminous, though lignite and anthracite also occur in the province. The chief coal-mining centres are Nanaimo and Comox, on Vancouver island; Fernie, in Crowsnest Pass district, in the southeast corner of the province; and Princeton, in the southern interior. Over three-quarters of the output comes from the Vancouver Island and Crowsnest Pass collieries.

The market for the Vancouver Island mines is provided by the domestic and manufacturing requirements of Pacific Coast cities, and of ocean-going steamers calling at these ports. It is these collieries, therefore, that suffer most from the competition of California crude oil fuel.

The market for the East Kootenay, or Crowsnest Pass, coal-field is provided primarily by the railways operating in this part of British Columbia and in the northern parts of the adjoining states of Montana and Washington; and by the steamboats, mines, and smelters of the district. A considerable proportion of the coal sold is exported to those two states, British Columbia being the largest exporter of coal of any of the Canadian provinces. Coke made at the Crowsnest Pass mines is largely for domestic consumption—chiefly by the Trail smelter—but about 27 per cent of it is exported to the United States. The East Kootenay collieries come into direct competition with Alberta collieries just over the Provincial Boundary line, mining the same grade of coal, under similar conditions, in the same coal-field.

The output of the Nicola-Princeton coal-fields is smaller than that of either Vancouver Island or East Kootenay districts and is largely absorbed by the local railways, though a small part finds its way to Vancouver, on the coast.

The larger of the British Columbia collieries are well equipped with up-to-date appliances. A considerable portion of the coal produced in the province is machine-mined, and electric power is used for various purposes underground as well as on the surface at a number of the mines. Coal miners as well as coal-mine officials are required to hold certificates of competency; only permitted explosives and safety lamps (usually of the electric type) are allowed to be used underground; and there are strict regulations regarding ventilation and the treatment of coal dust. Mine-rescue stations and instructors in mine-rescue work are maintained in the chief coal-mining districts.

ALBERTA

Coal mining in what is now the province of Alberta dates, practically speaking, from the completion of the Canadian Pacific railway about forty years ago, but the rapid expansion that has made it the chief coal-producing province of the Dominion did not start until the beginning of the present century. In 1901, the output for the North West Territories (Alberta and Saskatchewan) was only 346,649 short tons; in 1920 and again in 1923 it was not far below 7,000,000 tons. In 1925 it had dropped back to 5,883,394 tons (Alberta Government figures) made up of the following grades: 3,156,359 tons domestic (lignite) coal; 2,145,200 tons bituminous; and 581,835 tons of sub-bituminous. The chief centres for the mining of domestic (lignite) coals in Alberta, in the order of their productive importance, are Drumheller, Lethbridge, and Edmonton. The chief bituminous fields are the Crowsnest (the eastern extension of the East Kootenay field of British Columbia), Mountain Park, Nordegg, and Cascade, of which the Crowsnest is the most important. Sub-bituminous coal is mined chiefly at Coalspur, east of Jasper National park. Anthracite coal was formerly mined at Banff, in Cascade district.

Coal-mining problems in Alberta range from the winning of flat-lying lignite seams in the prairie country, some of which can be stripped of their overburden of soil and worked open-cast, to the more difficult operations involved in working in disturbed mountain strata. As in British Columbia, the larger collieries are well-equipped in every way and electric power is much in use. Also, as in British

Columbia, the safety of mining operations is controlled by a staff of Provincial Government inspectors having wide regulatory powers, and all coal-mining operations must be in charge of certificated officials. The Alberta Government further requires all operators of coal mines to register a trade name for the coal taken from their mines and no coal is allowed to be sold or shipped except under its registered name. Every coal dealer selling Alberta coal, is required also, to state on every bill, weigh-ticket, or invoice issued by him, the name of the mine and district from which derived, and the registered name and size of grade of coal sold.

AUTHORITIES CONSULTED

Annual Reports, Minister of Mines, British Columbia, 1924 and 1925.
Annual Report, Mines Branch, Alberta, 1925.
"Report on the Mining and Metallurgical Industries of Canada, 1907-08"; Mines Branch, Dept. of Mines, Canada, Pub. No. 24.
"Mineral Industries of Canada"; Mines Branch, Dept. of Mines, Canada, Pub. No. 611, 1924.
Porter, J. B., and Durley, R. J.: "An Investigation of the Coals of Canada"; Mines Branch, Dept. of Mines, Canada, 1912.
Dowling, D. B.: Geol. Surv., Canada, Mems. 53, 59, and 69 (1914-1915).
Clapp, C. H.: Geol. Surv., Canada, Mem. 51 (1914).
MacKenzie, J. D.: Geol. Surv., Canada, Mems. 87 and 88 (1916).
Allan, J. A., and others: "Reports on Various Coal Fields of Alberta," published by the Scientific and Industrial Research Council of Alberta.
Lignite Utilization Board: First general report, 1924.

MAP 14. Sketch map of southeastern British Columbia, showing the relative positions of the chief silver-lead-zinc mines with reference to Trail and the Crowsnest coal-field.

BRITISH COLUMBIA

The province of British Columbia has long been the chief source in Canada of lead, zinc, and copper; and now leads also in the production of silver. Most of the lead and zinc come from the Sullivan mine, the output of which is, however, supplemented by that of numerous smaller mines most of them situated in the Kootenay districts in the southeast corner of the province; large mines at Britannia Bay, Anyox, and Allenby account for most of the copper. The Sullivan mine is the largest silver producer, followed by the Premier in Portland Canal district. Gold is mined in both placer and lode deposits; placer chiefly in Atlin, Cariboo, and Quesnel districts; lode gold at various points, though the chief production is from Portland Canal district, in which is situated the Premier mine, the largest gold producer in the province. Gold and arsenic are mined at Hedley; and a little platinum is recovered from gold placers in Tulameen river.

British Columbia's chief non-metallic mineral product is coal; but gypsum, fluorspar, pyrites, soapstone, quartz, magnesium, sulphate, sodium carbonate, and pulpstones are also produced, as well as structural materials and various clay products.

SULLIVAN MINE AND CONCENTRATOR

The Sullivan mine, which is owned by the Consolidated Mining and Smelting Company of Canada, is the source of the greater part of the raw material treated in the company's lead and zinc plants at Trail. It is about 2 miles from Kimberley, which lies at the end of a short branch line, about 19 miles long, joining the main line of the Crowsnest Pass division of the Canadian Pacific railway, at Cranbrook. It is distant from Trail a little over 200 miles, by rail.

First discovered in 1892, when it was located as a lead mine, the Sullivan had, in its early days, a somewhat chequered career. The Kimberley branch line of the Canadian Pacific railway was built to it in 1899; and in 1903 its owners commenced to build a lead smelter to treat its ores at Marysville, 5 miles below

Kimberley, on Mark creek. However, on account of the high zinc content of much of the ore, serious metallurgical difficulties were encountered. Though some of these were successfully overcome and a total of about 75,000 tons of ore smelted, it was found that lead could not be produced at a profit and in 1907 both mine and smelter were closed down. In 1909 the Consolidated Mining and Smelting Company took a lease and bond on the property and immediately and successfully set to work to improve the grade of the ore both by selective mining and by the installation of additional sorting facilities. At the same time, underground developments and diamond-drilling convinced the company's officials that the mine contained not only high-grade zones, the ore from which could be profitably smelted for lead in a suitable furnace with a properly proportioned charge, but that there was a very large tonnage of complex ore which would be valuable if a satisfactory process for its treatment could be devised. Consequently, the option was exercised in 1910 and the Sullivan mine passed into the hands of the Consolidated Mining and Smelting Company of Canada. At the same time a number of other mining claims adjoining the Sullivan group were acquired, so that the property now includes 8,147 acres of Crown-granted mineral claims in addition to ungranted claims and large surface holdings.

For the next few years mine development was directed to the discovery of ore sufficiently high in lead and silver and low enough in zinc to be smelted with the equipment then available at Trail. By 1914 the Sullivan had become the biggest lead mine in the Dominion, a distinction to which is now added that of being one of the biggest in the world.

The early workings in the Sullivan ore-bodies were all carried on from adits and shafts located in the upper parts of the deposits, chiefly from an adit 3,600 feet long, known as the 1,000-foot level, situated about 4,500 feet above sea-level, but by 1915 it was decided that the ore reserves indicated by diamond-drilling warranted a more ambitious scheme of development. Consequently, in June of that year an adit was started from the valley of Mark creek, at a point 3,900 feet above sea-level, to open up the ore-bodies 600 feet below the deepest of the upper workings. In 1919, a raise from this lower adit, started at a point 7,100 feet from the portal, reached the south ore-body, from which shipments of ore by this route have continued ever since. The adit was meantime continued, to develop the north ore-body, and now is over 2 miles long.

The south ore-body, which has been developed over a depth of about 700 feet from the 3,900-foot, or lower, adit, has an average width of 30 or 40 feet; the north ore-body, which is now also being developed, has a width in places of over 200 feet. Characteristic ore is a fine-grained mixture of zinc blende, galena, pyrite, and pyrrhotite, the average mill-feed running 11·0 per cent lead, 10·5 per cent zinc, 36·5 per cent iron, and silver 3 ounces to the ton. The company does not publish estimates of ore reserves; but a statement made in 1923 would indicate that at that time they amounted to at least 10,000,000 tons, and it is known that subsequent development has added largely to this amount. The present output of the mine is over 1,100,000 tons a year and narrow workings now total over 16 miles in length.

Geological Features

Kimberley area is underlain by the Aldrich formation of Precambrian age. This formation consists of a series of quartzites, argillaceous quartzites, and argillites, the argillaceous quartzites forming about three-quarters of the whole series and occurring in beds having an average thickness of 1 foot. According to a rough estimate the total thickness of the formation is 8,000 feet. Under the microscope the argillaceous quartzite is seen to consist of small, angular, interlocking grains of quartz, cemented together as a rule by argillaceous material which is altered to a net-work of sericite needles. Small, striated feldspars occur as grains in most of the specimens examined. Muscovite and biotite are quite abundant and small garnets are found. The metamorphism of the Aldrich formation has been for the most part very slight. Garnetiferous mica schist passing on all sides into normal argillaceous quartzite has been observed.

The Aldrich formation has been intruded by a series of sills known as the Purcell sills. These sills range in thickness from 2 feet to 2,000 feet and vary in composition from a hypersthene gabbro to a very acid granite. Only a very small amount of contact metamorphism has been induced in the Aldrich formation by the intrusion. The Purcell intrusives have not been observed in the vicinity of the

Sullivan mine. The ore deposit occurs in the argillaceous quartzites of the Aldrich formation, which here form the eastern limb of a large anticline.

Near the mine the beds strike approximately north and south and dip to the east at angles averaging about 23 degrees. While possessing many of the features of a regular vein, the ores are essentially replacement deposits in the argillaceous quartzites. Irregularities of foot- and hanging-walls are prevalent, but in general the deposits are conformable to the beds.

The ore, which in places has attained a thickness at right angles to the dip of approximately 240 feet, is usually a very fine-grained mixture of galena, zinc blende, pyrite, and pyrrhotite. The blende is of the variety known as marmatite, represented, in this case, by the formula FeS, 5ZnS. Microscopic examination shows that the iron sulphides crystallized first and the galena last.

The ore as developed occurs in two zones which, for convenience, have been called the south and north ore-zones. In the upper levels, between these ore-zones, the replacement is composed entirely of pyrite, while in the lower workings it consists of a fine-grained, massive pyrrhotite. The maximum length of the pyrite zone is 800 feet.

Subsequent to the replacement period a moderate folding took place, which resulted in some fissuring, and, in places, a readjustment of the outlines of the ore-bodies, as well as a rearrangement of the minerals composing them. Some faulting occurred at this later period, the lines of fracture striking about north and south. The greatest displacement shown is about 150 feet, but it has had no appreciable effect on the ore-body.

While the two ore-zones do not vary greatly in the ratio of lead to zinc, both have produced ores of fairly high grade in each metal. In the same working-face, it is not unusual to find clean galena, zinc blende, and pyrrhotite, as well as the usual intimate mixture.

Mining Methods

In the earlier mining, in the upper workings, both glory-hole methods and underground stopes with square-set timbering were employed, but as depth was gained and the hanging-wall became stronger a pillar-and-room system of mining was adopted. At first, when the selective mining of lead ore was the principal aim, "zincy" material was left to form pillars; but after the shipping of zinc ore began, the size of the pillars was reduced, and an attempt was made to leave as pillars parts of the vein below shipping grade. In places where all the ore was workable large timber cribs took the place of pillars.

In the latest method of working adopted in the north ore-body, crosscuts are driven from the main, or 3,900-foot adit into the foot-wall of the ore-body. From these, drifts are carried north and south parallel to the main adit, and from these drifts again, raises at suitable intervals are carried up to, and through, the ore, to the hanging-wall. Pillars 100 feet square and spaced at 300-foot centres are left to support the roof. These will be ultimately recovered in whole or in part by robbing. In the stopes, when the muck will no longer run by gravity, drag-line scrapers operated by compressed-air hoists and having a working radius of about 250 feet are used. The working radius of the scrapers governs the distance between chutes.

The main, or 3,900-foot, adit is 9 by 12 feet in cross-section and for the first 600 feet, which is through loose ground, is supported by concrete posts with steel girders for caps. The mine tracks are laid with 45-pound rails on a 36-inch gauge. Six-ton electric locomotives operating at 250 volts are used for haulage. Storage battery locomotives are used for assembling trains. Air-driven mucking machines are used in driving the main adit.

The mine power-plant, which is situated near the main adit portal, includes a water-driven compressor coupled to an auxiliary steam engine and electrically driven compressors, the whole having a capacity of 15,000 cubic feet of free air per minute. Electricity delivered at 2,200 volts is supplied by the East Kootenay Power Company to an underground sub-station where it is stepped down to the proper voltages for the various mine uses.

Comfortable quarters for employees are provided in a company town, McDougall, near the portal of the main adit, and fine new company offices have been built in Kimberley.

Concentrator

While the mine was being developed the company's research department was busy making exhaustive experiments and tests in order to devise the most satisfactory method of treatment for the complex Sullivan ores, with sufficient success for the commercial production of zinc to be undertaken at Trail in 1916. But it was not until the possibilities of differential flotation were recognized and the company's engineers had worked out a process by this method suited to the Sullivan ores that operations were undertaken on anything like their present scale.

The present Sullivan concentrator, one of the finest plants of its kind to be found anywhere and a monument to the patience and skill of the Consolidated Mining and

Smelting Company's metallurgical staff, was not begun until the results of experimental work allowed full anticipation of all details in connexion with its design, a policy that has been fully justified by the satisfactory operation of the plant from the time it first went into operation in September, 1923.

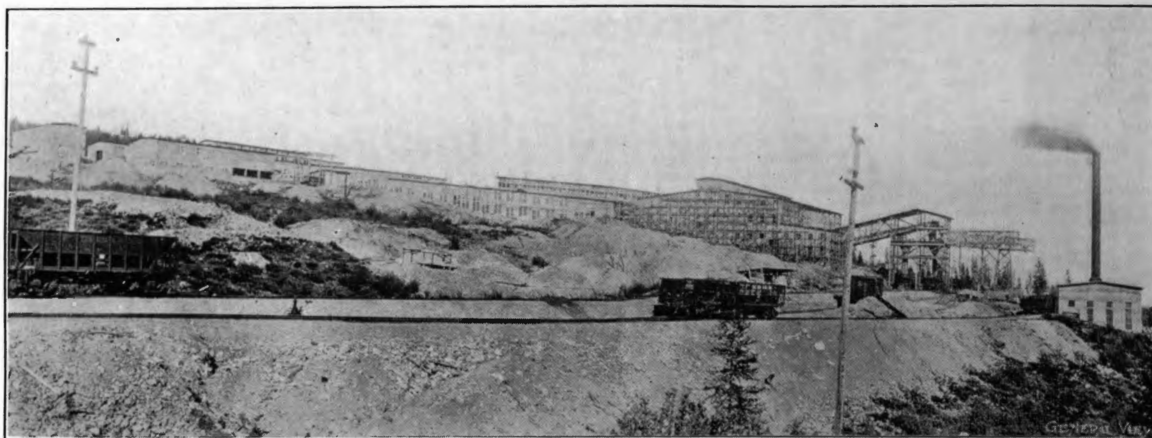
The buildings of steel and reinforced concrete are of excellent proportions throughout and permit of easy access to all the various types of equipment for inspection and repair, as well as room for additions where such are likely to be needed. Originally designed for the treatment of 3,000 tons of ore a day, in actual operation the mill has surpassed expectations. It is now enlarged to handle 4,000 tons—ultimately it will probably be expanded to treat 6,000 tons a day, the present capacity of the coarse-crushing plant at the mine.

The preliminary crushing of the Sullivan ore is all done in a separate plant situated at the portal of the main adit. The ore is first put through jaw crushers which are followed by gyratories set to 2½ inches. From the bins at the coarse-crushing plant it is transported 3½ miles in railway cars to the secondary-crushing plant at the concentrator, on the other side of Kimberley.

At the secondary-crushing plant, the ore, after being weighed, is passed through two sets of rolls, which reduce it to ¾-inch size, sampled, and sent to the fine-ore bin at the top of the mill.

The mill-building proper has an over-all length of 606 feet. Its width is 126 feet for a distance of 181 feet; 78 feet for a distance of 152 feet; 126 feet for 145 feet; 48 feet for 16 feet; and 144 feet for a distance of 112 feet. The average height is 40 feet and the difference in elevation between the primary ball-mill floor and the compressor floor of the thickening bay is 73 feet. Practically all the floors and platforms as well as stairs are of concrete, or steel and concrete. In all cases easy access is provided from the operating floors of any one bay to those of the adjacent bays. The zinc retreatment table, lead-cleaner, and filter operating-floors are continuous for 273 feet, and are on the same level. The total horizontal area of the mill proper, including reagent mixing-shed, sampling-plant, and heating-plant, is 71,532 square feet.

All the outside walls are of 1½-inch gunnite reinforced with steel mesh. The total area of gunnite walls in the mill proper is 43,000 square feet. The window area of



The Kimberley concentrator.

walls and roof is 19,400 square feet, or 14·4 per cent of the total. The roof is of laminated, 2 by 4 wood strips, set on edge, and spiked to nailing strips bolted to the roof trusses.

A skipway on an incline of 1½ inches a foot, extending along the west side of the mill, from the machine shop at the top to the loading tracks at the bottom, serves the entire mill with material. Under the skipway a concrete tunnel 6 feet wide and 6 feet 6 inches high carries all steam, water, flotation-oil, and reagent-solution pipe-lines, as well as the cables carrying electricity from the sub-station to the starting boxes in the mill.

The water supply is brought from the tailrace of the compressor plant at the mine to a distribution house at the mill, through a 16-inch wood-stave pipe-line 16,000 feet long, under a head of 131 feet. Water and soda solution are carried from the distribution house into the mill in pipe-lines laid in the tunnel beneath the skipway and delivered where needed.

The carpenter, machine, boiler, blacksmith, plumber, and electric shops are all under one roof at the upper level of the mill; and, on the same level, there is a warehouse which also contains the office, assay plant, and change room.

Between the warehouse and the mill is a reagent-mixing shed. The reagents are automatically mixed, dissolved, and delivered by gravity through pipe-lines to their destination.

Power is obtained by purchase from the East Kootenay Power Company's plant at Bull river. Nearly all the machines in the mill are driven by individual motors, of which there are 160 in use, ranging from 1 to 200 horsepower. The estimated total power required to operate the mill was calculated to be 3,064 horsepower, but in actual practice 30 per cent less than the calculated amount is found sufficient.

Concentrates are conveyed from the filters to circular, steel loading-bins, one for zinc concentrates, the other for lead concentrates, both of which discharge into railway cars. Provision is also made for the stocking of concentrates.

Mill tailings are laundered to a 40-acre settling-pond.

Nearly all the machinery in the concentrating plant was manufactured in the company's shops at Trail, and plans and designs for most of the machinery were made at Trail by the company's staff. The mill was erected and construction was supervised also by the company's staff.

The prime object in concentrating the Sullivan ores is the separation of the intimately mixed lead, zinc, and iron sulphides. Flotation machines and tables are used for this purpose, in rather intricate combination, the flow-sheet being complicated by the retreatment of some of the zinc concentrates on tables, the lead concentrates in a secondary flotation machine, and the cleaning of the tailing from the zinc machine.

Omitting many details the process may be briefly outlined as follows:

The ore crushed to ¾-inch size is delivered to the mill bins in drop-bottom Canadian Pacific railway cars. From the bins it passes to Hardinge ball mills in closed circuit with Dorr rake classifiers and undergoes a two-stage reduction by means of which it is ground until 85 per cent will pass through a 200-mesh screen and only 0·5 per cent is over 100-mesh. The overflow from the rake classifiers is reclassified in bowl classifiers. It has been found necessary to grind Sullivan ore finer than is usual in ordinary milling practice in order to liberate the different minerals and for the satisfactory operation of the selective flotation process.

The overflow from the bowl classifiers goes to a mechanically agitated, surge tank which feeds the lead flotation machines; the reagents necessary for the lead separation, soda-ash, sodium cyanide, coal-tar creosote, and water-gas tar having been added in the fine-grinding circuit. The pulp is first treated in modified Minerals Separation machines to produce a lead concentrate carrying about 50 per cent lead and 10 per cent zinc. The concentrates from the first lead machines are next treated in cleaning-machines which bring the grade up to 65 per cent lead and 5 per cent zinc, the tailing being returned to the grinding circuit. The final lead concentrates are filtered in American filters and sent to loading bins whence they are taken to the lead smelter at Trail.

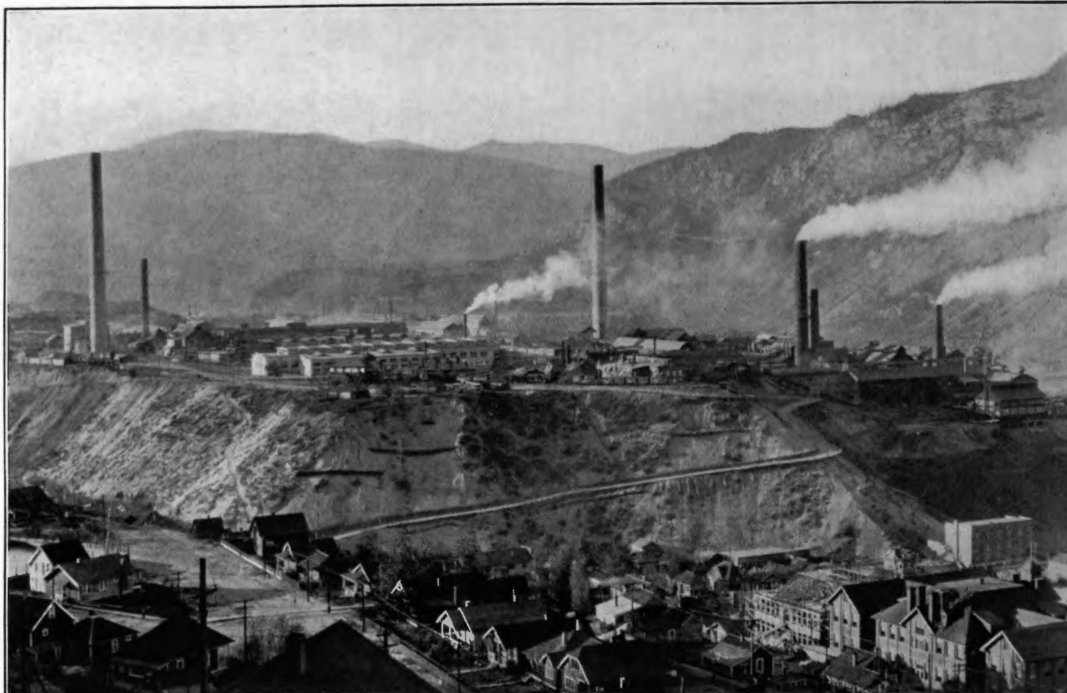
Preparatory to flotation of the zinc, copper sulphate is added to the tailing from the primary lead machines, which forms the feed to the zinc machines. The pulp is then heated to about 25° C., water-gas tar is added, and zinc flotation follows in Minerals Separation machines, which make a lead-zinc concentrate, a zinc concentrate, a zinc middling, and a tailings product. The lead-zinc concentrate is put over Plato and Wilfley tables, making a lead-iron product which is sent back to the fine-grinding circuit, a zinc concentrate, and a zinc iron product. The tailings are sent to a bowl classifier which makes a concentrate, the classifier tailings going to waste. The zinc middlings from the flotation machines, together with the classifier concentrate, and the zinc-iron middling from the tables, are reground in a Hardinge ball mill in closed circuit, with a rake classifier, and are then re-treated in a flotation machine which produces a concentrate that goes back to the tables, and a tailing that goes back to the zinc roughing flotation machines. The zinc concentrate from the primary zinc flotation cells, after joining that from the tables, is thickened in Dorr thickeners, filtered in American filters, and sent to bins for transportation to the zinc plant at Trail. The zinc concentrates will average 42 to 44 per cent zinc and about 3 per cent lead.

TRAIL

Hidden away in Kootenay hills, on the banks of Columbia river, in southern British Columbia, is one of the world's largest metallurgical plants. This plant, owned and operated by the Consolidated Mining and Smelting Company of Canada, is situated on a high bench overlooking the town of Trail at the end of a short branch line of railway that leaves the Crowsnest Pass division of the Canadian Pacific railway at Castlegar, 26 miles west of Nelson. The distance to Vancouver by rail is about 507 miles. Immediately surrounding the works and within the precincts of the company's property is the municipality of Tadanac, made up of dwellings of company officials and employees. Tadanac, in addition to being the name of the town and railway station at the plant, is also the registered trade-mark under which the company's products are marketed.

It is at this great plant that all the silver-lead-zinc, gold, and copper ores of Kootenay district, as well as ores from Boundary district, and a considerable amount from other outside points, are smelted and refined. Started some thirty years ago purely for the smelting of copper ores, it has undergone successive alterations and additions, especially since the successful development of the company's Sullivan mine at Kimberley, until today it is one of, if not quite, the biggest of the world's electrometallurgical plants. It is the source of one-tenth of the world's supply of refined lead, in addition to an important amount of its zinc, and it also produces copper, gold, silver, and antimony.

The first metallurgical works at Trail was a copper smelter built in 1895 by the British Columbia Smelting and Refining Company to treat the gold-copper ores from the neighbouring Rossland mines; to connect it with which a narrow-gauge railway was built. Later, the Columbia and Western railway was built from Trail to West Robson, giving the new smelter rail connexion with the outside world. In 1898, the Canadian Pacific Railway Company bought both the smelter and the railway, and formed the Canadian Smelting Works Company to operate the smelter. In 1899, a lead smelter was added to the works, to treat silver-lead ores from Slocan district, most of which had previously gone to the United States for treatment; and about three years later the patents held by Anson G. Betts for the electrolytic refining of lead were purchased and the establishment of a lead refinery was decided upon. In 1906, the Consolidated Mining and Smelting Company of Canada was formed to take over the interests of the Canadian Smelting Works, with which were now consolidated the War Eagle and Centre Star mines at Rossland and the St. Eugene lead mine at Moyie. Prior to and during this time the plant at Trail was being enlarged and kept abreast of the times, but was still only a gold-copper matte plant and a lead-smelting and refining plant. Purchase of the now famous Sullivan mine, at Kimberley, in 1909, brought with it new problems in the treatment of low-grade lead-zinc ores, which after several years experimentation were finally overcome. The installation of a zinc reduction plant was largely brought about by the urgent need of Great Britain and her allies during the Great War; the building of an electrolytic zinc refinery being undertaken and rushed to completion in 1915 and put in operation in February, 1916. This marked the beginning of a new era for the company, which not only had to devise a method to separate the zinc from the lead in the complex Sullivan ores, but also to solve the many problems connected with the electrolytic refining of zinc, a process then only in the experimental stage. Production of zinc has been continuous since 1916, but it was not until 1920, by which time the problem of



The Consolidated Mining and Smelting Company's plant at Tadanac, B C.

concentrating the Sullivan ore had been solved, that it began to increase rapidly. Since that date the history of Consolidated Smelters, the name by which the company is commonly known, has been one of steady, large-scale expansion.

At present the plant covers 250 acres and includes a lead smelter, a copper smelter, an electrolytic zinc reduction plant, electrolytic lead and copper refineries, a gold and silver refinery, a hydrofluoric and hydrofluosilicic acid plant, a sulphuric acid plant, a bluestone plant, and a copper-rod mill. In addition there are machine shops and foundries in which are manufactured many of the mechanical appliances used in and about the works.

The plant is served by the Canadian Pacific railway, but all interdepartmental transportation is done by electric locomotives running on 18-inch gauge track.

Power is supplied by a subsidiary company, the West Kootenay Power and Light Company, from a hydro-electric generating station, having an installed capacity of 60,000 horsepower, situated at Bonnington Falls on Kootenay river, about 30 miles away. Two transmission lines deliver power at 60,000 volts and two at 20,000 volts, to a central sub-station. Here it is stepped down to 2,200 volts and distributed to departmental sub-stations, where it is again stepped down to 550 volts, which is the standard through the plant except in the zinc plant, refinery, generator rooms, and rod mill where 2,200 volts are used. The total power requirements of the Trail works amount to 52,200 horsepower.

Water for the plant is delivered by flumes from creeks in the vicinity, augmented by a further supply pumped from Columbia river by three 1,500-gallon roturbo pumps each driven by a 200 horsepower motor and delivering against a head of 315 feet.

The estimated tonnage of ore and concentrates treated at Trail in 1925 is: 340,710 tons from company mines; 39,570 tons from customs shippers; or a total of 380,280 tons.

Estimated production for the same year is: 117,504 tons of lead; 48,611 tons of zinc; 950 tons of copper; 4,397,455 ounces of silver; and 21,352 ounces of gold—the whole valued at $29,973,453.

Lead Treatment

By far the greater part of the material treated in the lead smelter is silver-lead-zinc concentrates from the Kimberley concentrator. These concentrates have an average analysis of: lead, 66 per cent; zinc, 6·3 per cent; sulphur, 18·8 per cent; silica, 1 per cent; iron, 7·5 per cent; and carry 20 ounces of silver to the ton. The remainder consists of customs ores and concentrates from different parts of the province, as well as a considerable tonnage of zinc plant residues.

The ores and fluxes are delivered to the works in railway cars and go first to the sampling mill, after which they are either stored or delivered directly to bins serving Dwight-Lloyd sintering machines. The ore is sintered twice; the sinter from the primary machines passing on, after crushing, to a second set of Dwight-Lloyds, the product from which is weighed and sent to the lead blast-furnace bins. The fumes from the sintering machines pass through a Cottrell separator on their way to the stack.

The blast-furnace charge is made up of sinter, settler shells, furnace cleanings, dross, and some oxidized ores, together with coke; and is hauled in V-bottom cars by an electric locomotive, to the furnace.

There are four lead blast-furnaces, 180 by 50 inches at the tuyère line, and 19 feet from tuyère line to feed-floors. Each has a rated average capacity of 315 tons of charge a day. The lead bullion from the blast-furnaces is conveyed to a drossing plant by overhead electric cranes. The slag is granulated and washed to the slag dump in launders. The furnace fumes pass through a Cottrell treater on their way to the stack.

In the drossing plant, the bullion is first treated in a reverberatory furnace, after which it is cast into anodes and the dross sent on to a second reverberatory, the products from which are: a copper matte or speiss, a lead-oxide slag, and lead bullion. The lead anodes, weighing about 360 pounds each, are placed in rack cars and hauled by electric locomotives to the lead refinery.

The refinery has a capacity of 350 tons of refined lead a day, and has the distinction of being the first refinery to use the Betts process for the electrolytic purification of lead—this process having been developed from the laboratory to the commercial stage at the Trail plant. Briefly outlined, it is as follows: The lead anodes are immersed in an electrolyte containing 11 to 13 per cent hydrofluosilicic acid and 6 to 9 per cent of lead, to which about $\frac{2}{3}$ pound of glue a ton of refined lead is added to ensure a smooth, compact deposit. The cathodes are thin sheets of pure lead. The electrolytic tanks, of which there are 956, each holding 24 anodes and 25 cathodes, are arranged in cascades of seven, 5 inches apart and with a drop of 3 inches between tanks. The average current density is 14·5 amperes per square foot of cathode area and the voltage drop between electrodes is 0·23 to 0·5 volts. The power used in the whole plant is 2,800 kilowatts; and the floor area of the tank room is 84,968 square feet. The sheet-lead cathodes on which the refined lead is deposited are withdrawn every four days, washed free from electrolyte, and dumped into melting kettles. The anodes last about eight days. The melted cathode lead is treated with compressed air to remove a little antimony and tin; and is then pumped by a centrifugal pump to the moulds, where it is cast into pigs, 99·99 per cent pure. The anode scrap is melted and re-cast; the anode slimes containing the gold, silver, and impurities go to the silver refinery.

Copper Treatment

At present the chief sources of copper ores for the Trail works are the Granby Mining, Smelting, and Power Company's mine at Allenby and the Consolidated Company's Rossland mines, concentrates from the former being treated under contract at Trail. The small tonnage derived from the Rossland mines arrives at the smelter as crude ore; the material from Allenby is flotation concentrates which require sintering before being smelted in the blast-furnaces. Briefly, the plant includes a sampling mill equipped with Vezin samplers and gyratory crushers, and Dwight-Lloyd sintering machines for the preliminary treatment of copper concentrates. There are three copper blast-furnaces; two 12-foot converters of the Great Falls type; a reverberatory refining-furnace; and an anode casting machine.

In the copper refinery, which has a rated capacity of 60 tons of refined copper a day, the usual electrolytic refining practice is followed. The copper anodes from the smelter are suspended in an electrolyte of sulphuric acid and copper sulphate. The cathodes are melted and cast into ingots for shipment, the anode scrap going back to the converters, the impure electrolyte to the bluestone plant, and the anode slimes to the silver refinery. The tank room contains 426 tanks, occupying 24,650 square feet, and consuming 400 kilowatts of power; the melting plant covers 4,500 square feet.

In connexion with the copper refinery there is a 50-ton copper-rod mill.

Silver Refinery

In the silver refinery the lead and copper tank-room slimes are dried and roasted in chambers heated by waste gases, then melted for the production of doré metal in three small, magnesite-lined reverberatory furnaces, in which the base metals, lead, copper, antimony, and bismuth, are eliminated by oxidation. Antimony in the form of oxide is collected in settling-chambers and recovered as a by-product; antimonial lead is also made by re-treatment of the slag from the first melting. The finished doré metal from the third furnace is 950 to 970 fine and contains 1·5 to 2·5 per cent copper. It is parted by the ordinary sulphuric acid method and the resulting gold and silver melted and cast into bars for shipment.

Zinc Plant

At the zinc plant all the zinc concentrates made at the Sullivan concentrator at Kimberley are treated, as well as custom zinc ores and concentrates. The custom ores are treated in a separate unit of the plant.

The Sullivan zinc concentrates, which have an average analysis of: zinc 43·5 per cent; lead 5·3 per cent; sulphur 33·2 per cent; silica 1 per cent; iron 19·0 per cent; and carry 2·2 ounces of silver to the ton, are first fed to 17 Wedge mechanical roasters of the seven-deck type, in which the zinc sulphide in the ore is oxidized and thus made soluble in dilute sulphuric acid.

The fumes from these roasters pass through a flue 420 feet long, nearly 29 feet wide, and 18 feet high, to a Cottrell treater, and thence to a reinforced-concrete stack 409 feet high and 21 feet inside diameter—the tallest reinforced-concrete chimney in America. The hot, roasted ore is conveyed to the leaching plant by spiral-screw pipe-conveyers.

The leaching method followed at Trail may be described as a double-circuit, continuous counter-current process. There are two distinct leaching circuits, the "acid" and the "neutral." The hot calcines entering the plant go into the "neutral" circuit where they are added to solution that has already had most of its acid neutralized in the "acid" circuit. As there is not enough acid left in it to combine with all the soluble zinc in the fresh calcines, it now becomes alkaline and precipitates ferric iron, antimony, arsenic, and some of the other impurities it may contain while taking zinc from the calcines into solution. The solids from this "neutral" circuit go next to the "acid" treatment, where they are leached with acid (electrolyzed) solution returned from the electrolytic tanks, to ensure the complete solution of all soluble zinc. To complete the round, the now partly neutralized acid solution goes next to the "neutral" circuit where, as already said, it meets fresh calcines and becoming alkaline drops some of its impurities; then into the electrolytic tanks where it becomes re-acidified; and finally back to the acid circuit again.

The solids are settled out from the solution in the acid circuit and, after filtering and washing, are stock piled, to be smelted later in the lead blast-furnace, the leached residue containing on the average: 10·9 per cent lead; 19·1 per cent zinc; 37·0 per cent iron; 2·4 per cent silica; and carrying 4·8 ounces of silver to the ton.

The effluent solution from the "neutral" circuit, before it goes to electrolysis, is treated with zinc dust and filtered, to remove any copper and cadmium present.

The plating out of the zinc is done on aluminium cathodes, and is carried out in three large, reinforced concrete buildings. In these the purified solution, or electrolyte, containing about 8 per cent sulphuric acid and a little glue, flows through a number of cells each containing 17 lead anodes and 16 aluminium cathodes carrying a current density of 26 or 27 amperes a square foot; the drop in voltage between electrodes is about 3·5 volts. The zinc deposited on the aluminium cathode sheets is stripped off every 48 hours; 20 to 30 pounds of zinc being deposited in that time. One man can strip some 8,000 pounds of zinc a day.

The zinc sheets stripped from the cathodes are stacked on small cars, taken to the melting room, and charged about 7 tons at a time to a reverberatory furnace. The melted zinc, freed from dross, is ladled out, cast into moulds, and is then ready for shipment as the well-known "Tadanac" brand, 99·956 per cent pure zinc.

The power requirements of the zinc plant amount to 28,000 kilowatts.

AUTHORITIES CONSULTED

Staff of the Consolidated Mining and Smelting Company of Canada, Ltd.: "Development of the Sullivan Mine and the Processes for the Treatment of Its Ores"; Trans. Can. Inst. Min. and Met., vol. XXVII, pp. 306-370 (1924).
The Consolidated Mining and Smelting Company of Canada, Ltd.: Annual Report for 1925.
O'Brien, M. M.: "Sullivan Mine and Mill Described"; Eng. and Min. Jour. Press, Nov. 6, 1926, pp. 749–750.
Minister of Mines, British Columbia: Annual Reports:
1923, pp. 200–204 and 301–302.
1924, pp. 293–294.
1925, pp. 226 and 370.
Schofield, S. J.: Geol. Surv., Canada, Mem. 76 (1915).

SLOCAN

The Slocan and contiguous mining divisions in West Kootenay district—that is to say the country lying about 30 miles north of the city of Nelson between and adjacent to Slocan and Kootenay lakes—have the distinction of being among the oldest lode-mining districts in British Columbia. Most of the mines are readily accessible from Nelson by steamer, or steamer and rail, the district between Kootenay and Slocan lakes being traversed by the Kaslo, Sandon, and Nakusp branch of the Canadian Pacific railway. Sandon, situated in a narrow, mountain valley between Kootenay and Slocan lakes, is the chief centre of mining activity; and Kaslo on Kootenay, and New Denver and Silverton on Slocan lake add, to mining, attractions that appeal to the tourist and the fruit-grower.

A great part of Slocan area is underlain by sedimentary rocks having in general a northerly to north-westerly strike and a southwesterly dip. The general structure is complicated by folds which strike in a northwesterly direction and by a tendency of the strata to dip away from intrusive granitic bodies. The area is in part underlain by a granitic mass intrusive into the sediments; by dykes and cupolas given off from the granitic batholith, and by a series of schistose, basic igneous rocks in the east that form a northwesterly trending belt some distance west of Kootenay lake.

On the west shore of Kootenay lake is a belt of sedimentary rocks 2 miles wide, formerly designated the Shuswap series, but more recently given a local name, the Ainsworth series. This series consists of mica schists, quartzites, siliceous limestones, thin bands of hornblende schists, and garnetiferous mica schists. It is cut by numerous intrusions of aplite, fine-grained granite, quartz porphyry, and pegmatite.

West of the Ainsworth series and exposed in Blue ridge lies a series of sediments named the Milford series. They are described as consisting mostly of "slate or fissile argillite interbedded with chert and fossiliferous limestone." These sediments may be monoclinal and conformable with the Ainsworth series to the east and the Kaslo schists to the west, or they may be synclinal in structure with a flinty, quartzite formation standing out in relief along the axis of the fold. On this point geologists are not in accord.

On the west slope of Blue ridge lies a belt of altered rocks known as the Kaslo schists. The belt varies in width from ½ mile in the southern part of the area to 3 miles in the northern part. It consists mainly of basic igneous rocks and is described as "sheared and mashed hornblende and augite porphyrites, tuff, breccia, serpentine, talcose schist, diorite, and gabbro, with interbeds of dolomite, quartzite, and squeezed conglomerate." There is a difference of opinion as to whether the igneous rocks of the Kaslo schists are all intrusive or whether they are in part extrusive.

The sedimentary rocks lying west of the belt of Kaslo schists and extending to Slocan lake are known as the Slocan series. Fossil evidence points to the Mesozoic age of these rocks. The following description is taken from a paper by C. E. Cairnes:

> The mineral deposits of the area are mostly located in the Slocan series. This series comprises sediments ranging from limestone to fine conglomerate, with intermediate limy, argillaceous, and sandy beds. These sediments include massive, blocky rocks and others which are notably fissile and slaty.
>
> The Slocan series, as represented in this area, might be divided into four roughly parallel zones or belts characterized by an abundance of certain rock types. West of the zone of volcanic rocks there is, first of all, a belt up to half a mile or more wide composed almost entirely of black, fissile slates. This belt is exceptionally poor in mineral deposits. Adjoining it to the southwest and overlying it is a zone with a maximum width of about 4 miles. This zone also contains a large

proportion of slaty rocks, but is characterized by a great number of limestone beds varying up to 200 feet or more in thickness. Most of the fossil collections were made from these limestone beds. The zone has comparatively few mineral deposits, although a few important properties are located in it, their ore deposits being characteristically replacements of limestone along series of parallel cross-fractures in the limestone. Such ore deposits occur at the Cork-Province, Lucky Jim, and Whitewater Deep properties. The third zone occupies a wide strip through the central portion of the Slocan series and includes the uppermost horizons in that series. It is abundantly mineralized and is characterized partly by a great variety of thinly interbedded rock types, including sandy, argillaceous, and limy strata, but more particularly by the great number of associated porphyritic intrusives, most of which trend with the enclosing formations. These 'porphyries', as they are generally called, are regarded as of extreme importance, probably, not so much from a genetic, as from a structural, point of view. They have opened channels for rising metalliferous solutions; have bolstered up the ground much after the fashion of reinforcement in concrete and thereby preserved the lines of fissuring; and have provided strong, confining walls for the ore deposits or furnished good hanging-walls for the mineral deposits to bank against. These minor intrusives are by no means confined to this third zone in the Slocan series, but are particularly characteristic of it and have afforded greater assistance to the formation of ore deposits here than elsewhere in the series. Among the more important properties in this third or 'porphyry' zone are the Payne, Surprise, Last Chance, American Boy, Noble Five, Reco, McAllister, and Silver Glance mines.

West of this and extending to Slocan lake is the fourth zone. This is the broadest zone of all. The rocks consist chiefly of strong, massive types including blocky argillites, quartzites, and feldspathic sandstones, all of which may be more or less calcareous. They are intermediate in age between the rocks of the second and third zones and are also exposed between the second and third zones. Some of the largest ore-shoots in the district have been discovered in this broad fourth zone, including the Standard, Slocan-Star-Silversmith, Ruth, Queen Bess, Hewitt, Van Roi, and Bosun mines.

Intrusive into the sedimentary series is a granitic batholith known as the Nelson batholith. It is exposed throughout a large part of West Kootenay and consists mostly of quite fresh rock varying from granite through granodiorite to quartz diorite. The northern contact crosses the southern part of Slocan area and apparently plunges at a low angle beneath the rocks of the Slocan series. Its presence, at comparatively shallow depths beneath the area now occupied by this series, is inferred from the occurrence of granitic stocks which are probably satellitic to the main batholith.

The ore deposits were formed by the deposition of economic minerals in fissures or zones of fracture and by replacement of the country rock.

The deposits occurring in fissures in the granitic rocks, and the sediments near the contact, carry high-grade silver minerals and are worked primarily for their silver content. The vein matter is composed largely of quartz, with minor quantities of lead and zinc minerals. The veins and replacement deposits farther from the contact carry the important argentiferous lead and zinc ores of the camp. The gangue forms a smaller proportion of the vein matter than in the case of the deposits found in the granitic rocks and consists commonly of siderite, although calcite is, in some cases, the chief gangue mineral. Between the two classes of mineral deposits no hard and fast line can be drawn. In fact there appears to be strong evidence of a zonal arrangement of mineral deposition, both with depth and laterally, with respect to the batholithic contacts.

The veins in which the argentiferous lead and zinc deposits are found occupy fault fissures mainly, although a few are localized by master joints. The fault-fissures cut across the bedding of the Slocan series and.............

die out in a gradual distortion of the slates or by abutment against other faults. More rarely the displacement has been absorbed by movement along bedding-planes. In a few places, as at the Sovereign mine, the fault-fissures follow narrow dykes, thus being localized along lines of previous rupture. In such cases the fissure usually follows one wall of the dyke, though rarely it may angle across the dyke. The mineralization has taken place by both filling and replacement in the fissures.

Replacement is greatest in the limestone beds, and bodies of irregular outline varying from 1 to 40 feet in width are formed.

Several wide bodies, connected with each other by narrow bands of ore, may occur along a single fissure. These large swellings may have been localized by cross-fractures that afforded more ready opportunity for the replacing solutions to work outward from the master control fissures.

The veins vary in length up to several thousand feet and in width up to 40 feet.

Some of them are remarkably continuous and straight; others show a tendency to swing from one fault-fissure to another, or from a fault to a joint- or bedding-plane. The veins strike predominantly northeasterly, though a few trend east and west. The dip is almost invariably southerly.

The ore-shoots range in length from a few feet to over 450 feet. Most of them have a pronounced pitch or rake within the vein and are sporadically distributed along the vein both laterally and vertically. Usually the unworkable part of the vein between the shoots is of greater length than the shoots themselves. The shoots contain varying amounts of clean, shipping ore, mixed ore of galena and blende that can be hand-sorted, and mill ore.

In most of the mines the zone of oxidation is negligible and primary sulphides come to the surface or near it.

It is thought that the ores are genetically related to the magma from which the Nelson batholith was derived. It has been pointed out that there are evidences of a zonal distribution of the minerals with respect to the batholith.

The ores in the granodiorite are highly siliceous, zinc is scarce, lead is subordinate, and the chief metal is silver. The minerals are quartz, tetrahedrite, argentiferous galena, with small amounts of sphalerite, ruby silver, chalcopyrite, pyrite, pyrrhotite, calcite, and siderite. The total amount of metallic minerals is small. The ores in the roof sediments near the contact are less siliceous, contain more galena, sphalerite, siderite, and calcite, with less tetrahedrite and ruby silver and about the same proportions of pyrite and chalcopyrite. In the more distant deposits the relative proportion of galena and sphalerite to quartz is greater, siderite and calcite are more abundant, and chalcopyrite and pyrite remain about the same. Tetrahedrite and ruby silver are still present, but the proportion of these minerals with respect to the amounts of galena and sphalerite is much less than in the ores in the granodiorite. In brief, the zonal arrangement here is characterized by increasing amounts of galena, sphalerite, and siderite, and decreasing relative amounts of quartz, tetrahedrite, and ruby silver, outward from the mother rock of the metals. The relative amounts of chalcopyrite and pyrite do not change appreciably, though the latter has been observed by Argall to increase with decreasing galena. Argall also notes that zinc blende increases in proportion to galena as depth is gained, and these pass into siderite and quartz and finally into quartz.

The Slocan country has been celebrated for the production of rich silver-lead-zinc ores ever since the first shipments were made from its mines early in the nineties of the last century. The first discoveries were succeeded by a feverish boom period, the effects of the collapse of which are still visible in the overbuilt business sections of such mining towns as New Denver, Silverton, and Kaslo. Production has fluctuated in a remarkable way, due in part to corresponding fluctuations in the metal market and in part to alternations of bonanza and borrasca in the numerous properties throughout the district. For a time it looked as if the silver-lead camps of West Kootenay had seen their best days, but the persistence of the more optimistic operators, a better understanding of the geology of the ore-bodies, and improvements in metallurgical practice, which have made available grades of ore that were formerly worthless, have changed the whole aspect of affairs, and the outlook for a long-continued period of steady output and prosperity is probably better today than ever before.

The common ore is argentiferous galena associated with more or less zinc blende in a gangue of siderite, calcite, and quartz. The silver values are commonly associated with tetrahedrite; and, in a general way, the ores carry about 2 ounces of silver to the unit of lead. From the metallurgical point of view the shipping products may be divided into silver-lead ores, zinc ores (mostly argentiferous), and dry silver ores.

In the early days of the camp, the zinc blende, which practically always accompanies the galena in greater or less quantity, was more frequently a detriment than an asset, as its presence in silver-lead ores was heavily penalized by the lead smelter, whereas zinc ores or concentrates, even where they could be satisfactorily separated by hand-sorting or the mechanical devices then available, could be sold only to United States zinc smelters, involving payment of excessive charges for freight and treatment. In addition to these drawbacks the lack of continuity characteristic of the high-grade ore-shoots on which most of the mines depend for their profit was another discouraging feature. In contrast with all this, increased knowledge of the geology of the ore-bodies now enables the operator to conduct exploratory work with greater intelligence and to follow his veins through barren ground with more confidence than before; improvements in ore-dressing practice, chiefly the introduction of flotation, have made possible the working of ores that formerly had little or no value. Moreover, the Consolidated Mining and Smelting Company's custom plant at Trail now affords an accessible and a profitable market for zinc ores and concentrates as well as for silver-lead ores. The result is that old workings that have been lying idle for years are being reopened and again made productive. The irregularity of the ore-bodies, however, is not a condition favourable to the development of large reserves, so that in only a few of the mines is there much ore actually blocked out ahead of extraction.

Good roads and trails are general throughout the district, and aerial tramways and small waterpower developments common. In most cases the ores can be won through adits without expensive equipment for hoisting and pumping, and these easy working conditions, together with the richness of some of the small, high-grade ore-shoots, make conditions almost ideal for the lessee and small operator generally, who is probably more in evidence in the Slocan country than in any other area of equal size in Canada. It must not be understood, however, that the district is one of small operators only; a number of companies operate on a large scale. The Silversmith mine at Sandon is the second largest shipper of silver-lead-zinc ores in the province, being exceeded only by the Sullivan at Kimberley, in East Kootenay.

The great number of actually productive properties, the wide range in the scale of operations, and the general character of the ores produced, can be best illustrated by the following schedule covering Slocan and Ainsworth mining divisions.

Shipping Mines in Slocan and Ainsworth Mining Divisions in 1925[1]

Mine	Locality	Tons	Character of ore
Antoine	McGuigan basin	7	Zinc, silver, lead
Apex	New Denver	28	Silver, lead
Bosun	Sandon	723	Silver, zinc, lead
Buffalo	Silverton	23	Silver, zinc
Corinth	Sandon	18	Silver, lead
Galena Farm	Silverton	614	Silver, zinc, lead
Hewitt	Silverton	1,800	Silver, zinc, lead
Lucky Jim	Zincton	6,800	Silver, zinc, lead, gold
Lucky Thought	Silverton	4,250	Silver, zinc, lead
Mammoth	Silverton	5	Silver, lead
McAllister	Three Forks	999	Silver
Mollie Hughes	New Denver	34	Silver, gold
Monitor	Three Forks	182	Zinc, lead, silver, gold
Mountain Chief	Alamo	93	Silver, lead, zinc
Mowitch	Alamo	9	Silver
Number One	Sandon	19	Lead, silver
Queen Bess	Alamo	80	Lead, silver, gold
Rambler	Rambler	3,600	Silver, zinc, lead
Ruth-Hope	Sandon	707	Silver, lead, zinc, gold
Silversmith	Sandon	36,779	Silver, lead, zinc, gold
Surprise	Sandon	153	Silver, lead, zinc
Van Roi	Silverton	4,200	Lead, silver, zinc
Canadian	Sandon	30	Silver, lead
Victor	Sandon	45	Silver, lead, gold

[1] Minister of Mines, B.C., Ann. Rept., 1925.

Shipping Mines in Slocan and Ainsworth Mining Divisions in 1925[1]—Continued

Mine	Locality	Tons	Character of ore
Washington	Sandon	2	Silver, lead
Wonderful	Sandon	3,286	Silver, zinc, lead, gold
Albion	Ainsworth	83	Lead, silver
Blue Bell	Riondel	17,531	Lead, zinc, silver
Cork-Province	Keen creek	2,960	Silver, lead, zinc
Highland	Ainsworth	3,817	Lead, zinc, silver
Liberty	Zwicky	2	Silver, lead
Silver Bell	Keen creek	27	Silver, lead
Silver Hoard	Ainsworth	62	Silver, lead
Spokane-Trinket	Ainsworth	30	Lead, silver
Tariff	Ainsworth	41	Lead, silver
Whitewater	Whitewater creek	414	Lead, zinc, silver, gold
Whitewater Tailings	Whitewater creek	480	Zinc, silver, lead
	Total	89,933	

[1] Minister of Mines, B.C., Ann. Rept., 1925.

AUTHORITIES CONSULTED

"Report of the Commission Appointed to Investigate the Zinc Resources of British Columbia and Conditions Affecting Their Exploitation": Mines Branch, Dept. of Mines, Canada, 1906.
LeRoy, O. E.: Geol. Surv., Canada, Sum. Rept. 1909, pp. 131–133.
LeRoy, O. E.: Geol. Surv., Canada, Sum. Rept. 1910, pp. 123–128.
Drysdale, C. W.: Geol. Surv., Canada, Sum. Rept. 1916, pp. 56–57.
Bancroft, M. F.: Geol. Surv., Canada, Sum. Rept. 1919, pt. B, pp. 39–48.
Schofield, S. J.: Geol. Surv., Canada, Mem. 117 (1920).
Bateman, A. M.: Econ. Geol., vol. 20, pp. 554–572 (1925).
Cairnes, C. E.: Geol. Surv., Canada, Sum. Rept. 1925.
Various Annual Reports of the British Columbia Department of Mines.

COPPER MOUNTAIN AND ALLENBY

The Copper Mountain mine of the Granby Consolidated Mining, Smelting, and Power Company, is situated south of Princeton on the Kettle Valley (Canadian Pacific) railway in the southern interior of British Columbia. It is connected with the railway at Princeton by a branch line 13·2 miles long. The company's concentrating mill is at Allenby, close to Similkameen river, on the same branch line as the mine, from which it is 7·7 miles distant—and 5·5 miles from Princeton.

The following geological notes on the district have been furnished by V. Dolmage:

Allenby, or Copper, mountain is composed of a series of steeply folded, Mesozoic volcanic flows and breccias, which have been largely intruded and highly metamorphosed by several stock-like intrusions of diorite, monzonite, and syenite. There are three principal intrusions, each of which has a type of copper deposit peculiar to itself and differing distinctly from the others. In the eastern part of the mountain is an intrusion of augite gabbro-diorite known as the Voigt stock, along the margin of which are deposits characterized by large quantities of hematite and pyrite associated with chalcopyrite. In the western part of the area is the Copper Mountain stock, composed of gabbro at its margin, but grading towards its centre through augite-diorite and monzonite to syenite, and associated with which are large deposits of copper ore composed mainly of bornite. North and west of these stocks is an irregular mass of syenite and monzonite in which are many smaller deposits of ore consisting entirely of pyrite and chalcopyrite. The bornite deposits are the most important; they constitute the Copper Mountain mine, and are the only ones developed to a producing stage.

The deposits lie on the northeast side of the Copper Mountain stock, at its contact with the metamorphosed volcanic breccias which are here intruded by a number of augite-diorite sills similar to, and probably connected with, the stock. The sills are from 10 to 50 feet thick and are separated by much narrower bands of breccia, thus forming a zone totalling, at its maximum, 500 feet. This zone follows, for a known distance of at least 5,000 feet, a wavy course roughly parallel to the contact of the stock and at a distance from it of 400 to 900 feet. Mineralization is prevalent on both sides of this zone of sills, but virtually all the ore of commercial grade is confined to a band of breccia lying between the sills and the stock.

The breccia is intensely metamorphosed to a distance of 7,500 feet from the contact of the stock. Between the sills and stock the breccia has been converted into coarse biotite gneiss (which, in many places, is composed of 100 per cent black biotite), the foliation of which strikes generally parallel to the contact of the stock. Cutting the gneiss, and to a slight extent the stock also, is a set of small, straight, closely spaced, parallel fractures, dipping vertically and striking at right angles to the contact of the stock. They vary from a minute fraction of an inch to 2 inches in width, averaging less than $\frac{1}{8}$ of an inch, and can seldom be traced continuously for more than 10 or 12 feet. Some are filled with pegmatite carrying bornite, chalcopyrite, and chalcocite, whereas others contain the copper sulphides only. Along the margins of the fractures throughout their length and for a uniform distance on either side of about $\frac{3}{4}$ of an inch, the rocks have been altered to a light grey, slightly greenish, fine, dense material resembling chert, but composed largely of feldspar and sericite. A small amount of sulphide is also disseminated in the coarser phases of the gneiss adjacent to the fracture. Those places where the fractures are sufficiently abundant to cause the copper content to rise to a minimum of 1·83 per cent constitute the ore-bodies of the mine.

After the ore was deposited, it and all the adjacent rocks were intruded by a number of large, white felsite and quartz porphyry dykes, whose only influence on the ore was to replace large quantities of it and to divide it into a number of separate bodies.

The copper occurs largely in the form of bornite and chalcocite.

An average of a large number of analyses of the ores taken from the mines is: copper, 1·77 per cent; silica, 50 per cent; iron, 5·8 per cent; calcium oxide, 9·1 per cent; sulphur, 1·1 per cent; alumina, 19·9 per cent; gold, 0·005 ounce a ton; silver, 0·20 ounce a ton.

The first work on what is now the Copper Mountain mine was done in 1905 by the British Columbia Copper Company, which was later absorbed by the Canada Copper Corporation, but it was not until 1912 that exploration and development began in earnest. Surface trenching and diamond-drilling carried on in this and the following years having disclosed the presence of some large ore-bodies, a temporary mining plant was put in, in 1916, and underground development was started.

By the end of 1917, 114,819 feet of diamond-drilling; 14,798 feet of tunnelling, nine-tenths of which was 9 feet by 10 feet in cross-section; 6,056 feet of raising; 641 feet of sinking; and 25,084 feet of surface trenching had been done at a total expenditure of about $1,250,000, for the purpose of ascertaining the size of the ore-bodies, the average grade of the ore, and the best methods of winning it. It is seldom that a mineral deposit is so thoroughly explored before actual mining begins.

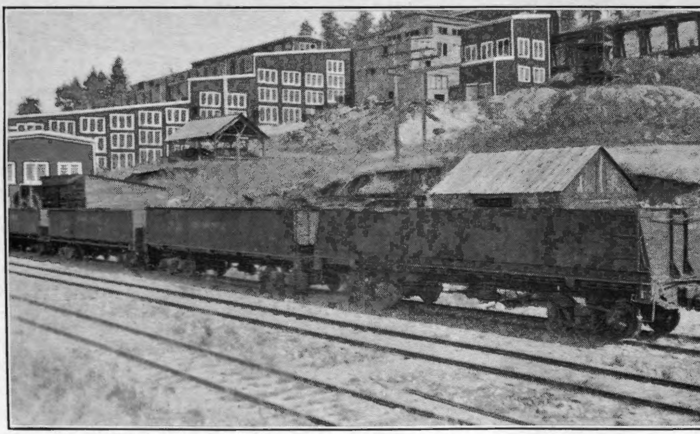
The known ore-bodies lie between 3,236 and 4,220 feet above sea-level, that is they occur over a vertical range of 984 feet. They have been opened by three tunnels: No. 1 at an elevation of 4,073 feet; No. 2 at 3,945 feet; and No. 3 at 3,170 feet. No. 3 tunnel is the main haulage way for all ore broken above this level, a storage pocket above the tunnel being the bottom of a zigzag raise, or ore-pass, 8 feet by 15 feet in section and 804 feet long, put in between the 3,170- and 3,945-foot levels. There is also a vertical manway from the 3,170-foot level to the surface, from which short drifts have been driven at intervals to tap the ore-pass and give access to it in case it should become blocked.

Ore broken in glory holes at the top of the mine runs down through ore-passes to the 3,945-foot level, whence it is trammed by electric motors and dumped into the main ore-pass leading to the pocket on the 3,170-foot level. From this pocket it is next transferred by electric motors to the crushing plant near the No. 3 tunnel portal, on its way to the railway bins, whence it goes by rail to the mill at Allenby. The governing idea in the layout of the mine is to have, as nearly perfect as possible, a gravity system of handling the ore.

Excavation for the foundations of the 2,000-ton concentrating mill at Allenby was begun in August, 1918. The railway from Princeton was completed to Allenby in 1919, but did not reach the mine until 1920. Hydro-electric power for operation also reached the mine from the West Kootenay Power Company's plant at Bonnington Falls late in 1920. During the same year the concentrator (fine grinding and flotation) was finished and set running for a short time to tune up, but owing to the impossibility of profitable operation at the prevailing price of copper, 13 cents, both mine and mill were closed down on December 9, 1920, and operations were not resumed until 1925.

Meantime, the Canada Copper Corporation, having become involved in financial difficulties, all its properties and assets passed into the hands of the Allenby Copper Company, a subsidiary formed by the Granby Consolidated Mining, Smelting, and Power Company, for the purpose of acquiring them, in 1922. An estimate of the proved ore reserves in the Copper Mountain mine, made by the Granby Company's engineers and geologists at the time of the transfer, was: 5,625,980 tons carrying 1·83 per cent copper, together with small values in gold and silver, with favourable indications that more

PLATE XXXVII



The Allenby concentrator.

ore would be found as operation and development progressed. The new owners proceeded to put the mine in shape and to overhaul the mill, which was found to need some additions and modifications to bring it up to its rated capacity of 2,000 tons of ore a day. However, the continued low price of copper prevented actual commercial production being undertaken until August, 1925. Since that date production has been continuous, though the mine and mill have not been operated to full capacity. Much work of an experimental nature requiring continual changes in the details of the flow-sheet has been carried out to determine the most advantageous procedure to be followed in milling the ore.

The concentrates from the Allenby mill are shipped to Trail, where they are treated in the Consolidated Mining and Smelting Company's plant for the recovery of copper, gold, and silver. Most of the copper at present being produced at Trail is derived from Allenby concentrates.

AUTHORITIES CONSULTED

Annual Reports of the Minister of Mines, British Columbia, 1918 to 1925.

BRITANNIA

The townsite of the Britannia Mining and Smelting Company (a subsidiary of The Howe Sound Company), known as Britannia Beach, is 28 miles north of the city of Vancouver, on the east shore of Howe sound, a navigable arm of the gulf of Georgia. The company's concentrating mill, bunkers, general offices, and townsite being located at tide-water are conveniently situated for the bringing in of supplies to the property by steamship and the dispatch of concentrates to the smelter at Tacoma, Wash. The Mine camp, which is at an elevation of 2,100 feet, is at the mouth of the long adit by which the mine is served, and 3 miles inland from the Beach camp. The whole property, which extends 10 miles eastward from the shore of Howe sound, covers some 25,000 acres of mountainous, heavily timbered country, with many deep-cut gorges, canyons, and water-courses, but few valleys except very narrow ones. Some of the mountain peaks within a few miles of Howe sound reach altitudes of 5,000 feet or more. The company's highest mine workings on Britannia mountain are in the neighbourhood of 4,000 feet above sea-level.

Geological Features

The following notes on the geology of the district are taken chiefly from an unpublished manuscript by H. T. James.

The ore deposits have been formed in one of the roof pendants on the western slope of the Coast Range batholith. The rocks in the immediate vicinity of the mines consist essentially of four major groups, the oldest consisting of carbonaceous sediments and volcanic material, a younger more purely volcanic group, and two intrusive groups including the granitic rocks. The oldest group is composed of at least 3,000 feet of dark-coloured flows, sills, tuffs, and shale. Towards the top of this group in the northern part of the area where the rocks are relatively undisturbed it is possible to distinguish a series of sedimentary rocks consisting of shales with some sandstone and more or less ash. The series is not thick and is recognized as a separate series merely because the rock type is very characteristic. These shales (in the northern section) represent merely a brief return of normal sedimentary conditions after a period of explosive vulcanism. Into the shales are intruded massive, sill-like bodies essentially similar in composition to the sills, tuffs, flows, etc., immediately below. Near the lowest exposed part of the volcanic series, as represented in the northern or undisturbed section of the pendant, small outcrops of other shales are found and they are also invaded by basic porphyries. Possibly these represent the normal sedimentary conditions that were interrupted by the vulcanism. In the southern belt, where the rocks have been tilted to a steep angle, slates are found and again they are associated with the more or less typical rocks of the basic volcanic series. It is probable that these latter slates are the oldest rocks in the area and have been tilted to their present position as a result of thrusting immediately prior to the batholithic intrusion. An estimation of the thickness would be very hazardous on account of the close folding within the slates and the difficulty of solving detailed structural problems.

In the flat-lying series in the north approximately 2,000 feet of the upper volcanic group are exposed. These have a characteristic, light olive-green appearance on a freshly fractured surface, whether the surface examined be of the clastic or wholly igneous phase.

The first group of intrusives is distinctly later than the series already described. These intrusives have been injected as sill-like bodies into the shales in the southeastern part of the area and are locally referred to as "quartz porphyries," although they are not as siliceous as that term would imply. They have been described as the Britannia sills and it is the sheared phase of one member of this group which has been so important as a host to the sulphide deposits of Britannia. Of no less importance is the second group of intrusives, or the granitic rocks of the batholith, for it is to the batholith in general that the original sources of the ore must be referred.

This particular remnant of the ancient roof of the batholith varies from 8,000 to 28,000 feet in width and may be traced for about 12 miles from east to west as a continuous, but very irregular, unit. The irregularity does not disguise a distinct tendency for arms of the pendant rocks to extend in a southeasterly direction from the main east-west "back-bone" of the roof pendant.

In general coincidence with the southeasterly direction of the arms is a direction of major shearing and deformation and it is within the larger and most westerly of the shear zones that the ore deposits have been discovered. The rocks to the northeast of the shear zone are essentially horizontal, but in the shear zone itself and south to the granite, the prevailing dip is 70 degrees to the southwest. A part of the lower, or basic volcanic series, as well as the shales and the Britannia sills, is represented in the belt of steeply dipping rocks. The general flexure has been sufficient to metamorphose the shales to slate, but the more competent igneous rocks have not been altered to schists except along a more localized shear zone within and parallel to the main zone of deformation.

This more restricted shear zone, in which members of the Britannia sills have been altered to chloritic schists, is in the form of a slender arrowhead with the point situated about 3 miles east of Howe sound. From here it extends to the southeast and widens to half a mile at a distance of 2 miles from the apex. Farther to the southeast the shear zone becomes less distinct and less well defined. Along the foot-wall or northerly side of the shear zone, is a more or less continuous band of slates. The ore-deposits are found in the chloritic schist, but very closely related to the slates. Up to the present nothing commercial has been found more than 800 feet away from the slates, and where ore does occur at this distance, no less than twelve veins have been found within the 800 feet.

Surface and underground prospecting have discovered five distinct ore-bodies within the first 7,000 feet of the shear zone, and active development is in progress for another 5,000 feet beyond this. The ore deposits are somewhat regularly spaced along the slate foot-wall and are separated from one another by barren ground. The two most westerly deposits are irregular replacements in the highly silicified schist, and the remaining three are composed of parallel veins whose strikes and dips are, in general, concordant with the schistosity. Silicification has not been intense in these last three, except toward the west end of each deposit.

The mineralogy of all the deposits is exceedingly simple. Quartz or the silicified country rock is practically the only non-metallic gangue mineral. Pyrite is the most abundant sulphide and chalcopyrite is the mineral of immediate economic importance. On the upper levels of the mines at the west end of the shear zone one finds a general distribution of sphalerite and locally small bunches of good zinc ore. Galena, bornite, and tetrahedrite have been observed in the same zone with the sphalerite.

Britannia mine includes five large deposits, named in order from west to east: Jane, Bluff, Fairview, Empress, and Victoria.

The Jane deposit, which was the first to be operated commercially, is some 300 feet long, 250 feet wide, and less than 300 feet deep. The ore contains pyrite, zinc blende, chalcopyrite, and possibly barite, with scattered values in gold and silver.

The Bluff deposit, 900 feet northeast of the Jane, has a maximum length on the 1,200-foot level of 500 feet, east and west, and a width of 250 feet, north and south. It reaches a depth of at least 1,600 feet below the surface. It carries pyrite, chalcopyrite, zinc blende, galena, and argentite in quartz gangue. Gold and silver occur more persistently, but in smaller amount than in the Jane. It is a very massive, highly silicified, and extremely hard deposit.

The Fairview, to the east of the Bluff, is much softer. It covers an area about 1,500 feet long and 500 feet wide in which the schist is heavily mineralized with pyrite and chalcopyrite in lodes from 10 to 70 feet wide. Between the lodes (veins, in local parlance) are bands of varying width, of barren or very low-grade schist.

The Empress is in soft, much-weathered rock, about 1,000 feet east of the Fairview. It has a maximum length of 1,000 feet and is 100 feet wide. Pyrite, chalcopyrite, and chalcocite are its ore minerals and secondary enrichments occur in it.

East of the Empress is the Victoria deposit, in which the schisted zone is heavily mineralized with pyrite and chalcopyrite. The full dimensions of this ore-body have still to be determined, but it will no doubt prove to be of considerable size. It is badly broken up and crushed in parts and is overlain by 150 feet of surface wash which makes it difficult to prospect rapidly. Development work to date has shown that it is at least 900 feet long and 200 feet wide.

Nearly 50 miles of development work has been done in the Britannia mine; and the ore reserves, broken and in place, at the end of 1925 amounted all told to 5,643,712 tons, carrying on an average 2·1 per cent copper. This does not include probable or possible ore; figures for which are not published by the company.

Mining Practice

The ore from the workings on all the deposits is made tributary, through long transfer raises, to a main ore-raise which delivers it to crushers on the 1,700- and 1,800-foot levels, where it is crushed until all will pass through a 2½-inch ring. From the last crusher on the 1,800-foot level the ore is again dropped through the main ore-raise to the main adit, on the 2,200-foot level. From the bottom of the main ore-raise, which is 4,330 feet from the main adit portal, the ore is transported in 17-ton cars drawn by electric locomotives over a switchback railway having a 3 per cent grade, 3½ miles to the top of a rock-raise 1,500 feet deep. It is dropped down this to a second adit, on the 4,100-foot level, again loaded into cars, and hauled by electric locomotives to the mill bins at the portal of the second adit, a further distance of about 4,000 feet.

The electric railway from the main, or 2,200-foot level, adit continues past the mouth of the rock-raise (at the 2,700-foot level) down to Britannia Beach, but no ore is carried on it below the mouth of the ore-pass.

The main adit continues eastward under Britannia mountain some 5,500 feet past the main ore-raise and thus has a total length of nearly 10,000 feet.

It may be well to say here that the datum for mine levels is the top of Britannia mountain, 4,250 feet above sea-level. Levels are measured downward, so that the 2,200-foot mine level, for instance, is approximately 2,050 feet above sea-level, the 2,700-foot, 1,550 feet above sea-level, and the 4,100-foot, 150 feet above sea-level.

When the mine was first opened square-set timbering in the stopes was the rule, but this was discontinued in 1912, on account of the heavy cost and because the ground was amenable to the less expensive method of shrinkage stoping. It has been necessary, however, to return to square-sets in parts of the bad ground that has been encountered in the Victoria deposit.

Most of the ore-bodies stand at an angle of about 72 degrees from the horizontal and are from 10 to 70 feet wide, and as the walls are fairly strong they can be most economically worked in overhand shrinkage stopes. Above the topmost level of the mine a shrinkage system in combination with underhand stoping in glory hole, or open-cast, workings is used, and has been found very satisfactory. Open-cast working can be carried on for about seven months in the year; during the remaining five months, accumulations of snow stop the work. Only a few inches of snow falls at sea-level, but at the top of the mine a depth of 25 feet is not uncommon.

Stopes are opened from drifts driven along the course of the deposit, in the ore. Along the foot-wall side of the drifts, funnel-shaped chute-raises are started at 33-foot intervals and carried up about 25 feet, at which point adjacent raises are connected to form the stope, leaving a strong, wedge-shaped pillar of solid ground over the drift. While the stope is being carried up, a chute at one end of it is, temporarily, kept free from broken ore to afford a means of ingress and egress.

Simultaneously with the cutting of the chute-raises a manway to serve the stope is being driven to the level above. The manway-raises are spaced 300 feet apart along the drift. A 10- or 15-foot pillar is left on each side of the manway, which is thus carried in the solid rock. At 30-foot intervals up the manway-raise, openings are cut through the pillars, on both sides of the raise, to be used successively as entrances to the stope as the broken ore in it increases in height.

The solid roof, or back, in the stope, is drilled by miners standing on broken ore. After each blast, ore is drawn out of the chutes on the level below to lower the height of broken rock in the stope sufficiently to allow drilling operations to be resumed. As the stope progresses toward the level above, each successive by-pass into the manway-raise is used in its turn as an entrance and exit for men and supplies, as well as for the air pipe-line to the drills.

Besides the pillars just above the drift and those surrounding the manway-raises, arch pillars are left between the foot- and hanging-wall where needed. A sill pillar also is left between the upper limit of the stope and the level above. This pillar may be 20 or 30 feet deep, depending on the width of the stope and the condition of the ground. When all the stopes on any specific part of the deposit are completed, part of the pillars may be recovered. The height of the stope between levels varies, but is usually about 150 feet. No timber is used in these shrinkage stopes.

There is an underground vertical, 3-compartment shaft 1,200 feet deep (No. 1) for the passage of men and supplies between the 2,200- and 1,000-foot levels. This shaft is timbered throughout with 12 by 12-inch timbers. In it double-deck cages are operated in balance by a 10-ton capacity, double-drum, electric, geared hoist.

The Britannia Company operates thirty-one electric locomotives, from 3½ to 40 tons, for haulage purposes in the mines, on the railway, and at the townsite at Britannia Beach; this will give some idea of the scale on which operations are carried on.

Milling

The mill-building is an all-steel structure covered with galvanized, corrugated-steel sheeting. Foundations and main floors are of reinforced concrete, and the building is practically fire-proof throughout. It is situated on a steep hillside, has seven distinct floors for the various operations, and rises to an elevation of 210 feet above sea-level. Only one short elevator is used in the entire mill. Though originally designed for the treatment of 2,000 tons of ore a day, as now equipped it can handle over 3,000 tons a day. Selective flotation methods of concentration are employed.

The Britannia ores are replacements of quartz and diorite porphyries containing about 17 per cent by weight of pyrite and chalcopyrite. The ore ranks high in the scale of hardness and its schistose character makes it tend to split into elongated pieces instead of break into cubes. The moisture in the ore as it comes from the mines is 5 to 15 per cent, mainly in the fines, which, consequently, cause considerable trouble by sticking to the rolls, conveyer-belts, etc. To obviate this a washing plant has been installed at the mill ahead of the crushing machinery. In this the fines are washed out of the ore by spraying while the ore is being passed over Hummer screens. It is then dried by jets of compressed air. The undersize, consisting of about 20 per cent of the ore, plus wash water, goes to a drag classifier, the oversize of which is included with the general mill-feed; the slimes go direct to a separate flotation machine for special treatment.

The oversize from the crushing plant goes to a Traylor roll, crushing to $\frac{3}{4}$ inch. The discharge from this roll is kept in closed circuit with Hummer screens delivering oversize to other Traylor rolls, until it is all sufficiently reduced in size to pass a $\frac{3}{16}$-inch opening. Dry crushing is now finished and the ore goes to the storage bins.

The feed from the storage bins is distributed to Dorr classifiers, each operating in closed circuit with a ball mill. The overflow from the classifiers, which contains 20 per cent solids, flows in launders direct to flotation machines of the standard Minerals Separations type. Of these, five act as roughers to one cleaner, the latter taking the concentrates from the former and raising the copper content approximately 4 per cent by recleaning. By the addition of special reagents to the pulp, iron pyrites, as well as gangue, is separated from the chalcopyrite in the flotation machines, and in this way the copper content of the concentrates, which formerly ran only about 12 per cent, has been raised to nearly 21 per cent.

The flotation concentrates are settled in Dorr tanks and then pumped to American disk filters, from which the filter-cake is removed by a beating device.

From the filters the cake is delivered by a conveyer-belt a quarter of a mile in length to a 10,000-ton storage bin. A weightometer installed with the belt gives an accu-

The Britannia concentrator, B.C.

rate daily record of the weight of concentrates produced. The concentrates are also weighed on Merrick scales while being loaded on vessels. A 5-ton gantry crane loading to an apron feeder, which distributes them on a conveyer with hinged boom for tide variation, loads the concentrates into the hold of the steamer. They are then taken to Tacoma, Wash., to be smelted.

Following is a summary of general milling and metallurgical data for the year 1925:

Ore (3 per cent moisture) transported from mine to mill	1,032,596 tons
Dry tons milled	994,113 "
Average grade of ore per cent copper	1·65 per cent
Dry tons concentrates produced	71,755 tons
Ratio of concentration	14·0 per cent
Copper produced	28,002,658 pounds
Gold produced	8,231 ounces
Silver produced	138,076 "
Copper recovery	88·0 per cent
Gold recovery	61·0 "
Silver recovery	75·0 "

The total milling cost averaged 51 cents a ton.

The average analysis of Britannia concentrates in 1925 was:

Copper	20·50 per cent
Iron	27·50 "
Zinc	6·10 "
Insoluble	8·20 "
Sulphur	34·50 "
Gold	0·12 ounces per ton
Silver	2·00 " "

The total milling cost averaged 51 cents a ton.

Power

Until 1924 the Britannia Company relied chiefly on hydroelectric power generated on streams within the boundaries of its own property. These are Britannia, Mineral, and Furry creeks, from which a maximum of 6,000 horsepower is usually available. At some seasons, however, they do not furnish sufficient power and a steam plant has been maintained for use in case of emergency. The installation of the present concentrating mill with its larger requirements, made more power a necessity, so 6,000 additional horsepower is now purchased from the British Columbia Electric Railway Company, which ensures sufficient power at all seasons and obviates the necessity of maintaining an auxiliary steam plant. The additional power is brought direct from North Vancouver to

Britannia Beach by a transmission line about 30 miles long, built for the most part along the shoreline of Howe sound. At the Beach it is stepped down to any required voltage and distributed to the mill and mine.

AUTHORITIES CONSULTED

General

Browning, C. P.: "General Mining and Milling Practice at the Britannia Mine, Howe Sound, B.C."; Trans. Can. Inst. Min. and Met., vol. XXV, pp. 199–211 (1922).
Brewer, W. M.: "Britannia Mining and Smelting Co."; The Minister of Mines, British Columbia, Ann. Rept. 1924, pp. 229–240.
Munro, A. C.: "Milling Practice at the Britannia Mines, Howe Sound, B.C."; Trans. Can. Inst. Min. and Met., 1923, pp. 319–327.
The Howe Sound Company, Ltd.: Annual Report for 1925.

Geological

Schofield, S. J.: Geol. Surv., Canada, Sum. Rept. 1918, pt. B, pp. 56–59.
Schofield, S. J.: Econ. Geol., vol. 21, No. 3, pp. 271–284 (May, 1926).

ANYOX

Anyox, the centre of operations of the Granby Consolidated Mining, Smelting, and Power Company, is situated at the mouth of Hidden creek on Granby bay; an excellent deep-water harbour at the head of Observatory inlet, about 90 miles north of Prince Rupert and 600 from Vancouver. It is accessible to the outside world by boat only.

Here, in addition to its copper treatment plant, the company operates an electric railway, handling some 6,000 tons of material every day; well-equipped iron and brass foundries; extensive blacksmith, machine, boiler, car repair, and carpenter shops; a fully equipped sawmill; a department store; and administers the affairs of a modern industrial town of about 2,500 inhabitants. The unfavourable climate, with excessive rain and snow, has induced the company to go to unusual lengths to accommodate and amuse its employees, so that, as a result, Anyox is an exceptionally comfortable mining town.

The smelter, coke plant, power-plants, and shops are all at the shore; the mine is about 1½ miles inland about 400 feet above sea-level.

In the company's most important mine, the Hidden Creek, two types of deposit are worked, one type consisting of a series of irregular lenses of heavy pyrite, with some copper, lying at the contact of intrusive greenstones with argillites; the other type consisting of chalcopyrite and pyrrhotite, occupying the joint-planes and impregnating shear zones in greenstone. The first type furnishes the smelting ores; the second type, which is not desirable as a direct smelting ore on account of its greenstone content, is first concentrated. According to the company's latest annual report the Hidden Creek ore reserves at the end of 1925 amounted to 8,896,320 tons containing, on the average, 1·77 per cent copper. Chalcopyrite is the only copper mineral of consequence; zinc blende and arsenopyrite occur with it in very small amounts. The value of the gold and silver in the ore varies in the different deposits, from 12 cents a ton to 90 cents a ton.

Substantial reserves are also available at the Copper Mountain, Bonanza, and Outsider mines, the ore-bodies of which, however, are not yet fully delimited.

Only three of the seven Hidden Creek ore-bodies showed any considerable outcrop; the others have been found by diamond-drilling. Practically all the prospecting for new ore, as well as the laying out of development work, is done by means of the diamond-drill, and more than 30 miles of drill-hole have been made to date.

Geological Features[1]

The ore-bodies occur in a large inclusion of sedimentary and igneous rocks in the Coast Range batholith. The inclusion is made up of two formations designated the Bear River formation and the Goose Bay formation. The Bear River formation consists of massive and fragmental greenstones or hornblende schists with a few interbedded layers of fine, argillaceous tuff and impure limestone. There are also thick, massive flows of coarse andesite, some chlorite schist, and a few thin beds of quartz-biotite schist. These rocks are steeply folded. The Goose Bay formation consists of highly metamorphosed, black, brown, and grey, well-bedded sediments, also steeply folded. The sediments are argillites, fine,

[1]Geol. Surv., Canada, Sum. Rept. 1922, pt. A, pp. 9-34.

argillaceous, and carbonaceous sandstones, and a few thin beds of impure limestone. The most abundant variety is a black, very fine-grained, bedded, and banded sediment composed of nearly equal proportions of quartz, biotite, and a black opaque substance that is presumably carbonaceous material. Close to the Hidden Creek mine and other sulphide deposits the rocks have become highly silicified.

The contact of the Goose Bay and Bear River formations lies a mile or so west of Anyox, but there is so much faulting, mashing, and metamorphism that the age relationships of the two formations are difficult to determine. In places the greenstones appear to intrude the argillites; elsewhere the argillites appear to overlie the greenstones. Hanson, who has carried on field work in Salmon River district, 40 miles farther north, and also from Alice arm, Observatory inlet, southeastward to Hazelton, correlates the Goose Bay and Bear River formations with the Hazelton group. He finds the sediments conformably overlying a volcanic series of great thickness. Fossils found in the upper part of the Hazelton group are described as being probably of Jurassic age.

The Coast Range batholith is the main geological feature of the British Columbia coast region from Fraser river to Alaska. It is of great economic importance, since most of the mineral deposits of the coast region are known to have had their origin in the magma from which it was formed. The intrusion took place probably in late Jurassic time. It is composed in the main of light-coloured, medium to coarse-grained, quartz diorite and granodiorite, with small amounts of granite, quartz monzonite, diorite, and hornblende gabbro. Quartz diorite and granodiorite form over 90 per cent of the total exposed bulk of the batholith. They are very similar in appearance and the one in many cases merges into the other.

Quartz diorite is the more abundant variety. It consists essentially of plagioclase ranging from oligoclase to labradorite, of from 10 to 40 per cent of quartz, hornblende, and biotite, with usually a little augite and some orthoclase. Orthoclase is almost invariably present, but seldom forms more than 2 per cent of the rock. The granodiorite, which is the next most abundant rock type, consists of the same minerals and is distinguished from the quartz diorite only by a higher proportion of orthoclase, ranging from 8 per cent to 20 per cent, usually a higher proportion of biotite, and less hornblende. Granodiorite predominates in the territory adjacent to Portland canal and Observatory inlet and is here particularly high in potash feldspar, usually having over 12 per cent and an average of 20 per cent.

Everywhere throughout the district the batholithic and older rocks are cut by numerous dykes of all sizes up to several hundred feet in width. They have a wide range in composition, but none has had any metamorphic effect on the rocks they cut. They are so numerous that in the Hidden Creek mine, at Anyox, over one hundred separate dykes have been mapped.

The ore-bodies lie on or adjacent to the contact between the Bear River greenstones and the Goose Bay argillites. The contacts of these rocks with the batholith lie 4 miles to the north and 5 miles to the south of the principal ore-bodies. The common metallic minerals are pyrite, pyrrhotite, chalcopyrite, zinc blende, magnetite, and arsenopyrite. These constitute nearly 100 per cent of the ore, but Bancroft found also small amounts of galena, and Dolmage found, in some high-grade ore from the No. 1 ore-body, on the 530-foot level, a small amount of native silver, associated with some arsenopyrite, and a very small amount of a soft, grey mineral which is almost certainly argentite.

It is Bancroft's opinion that the ores were formed by the replacement of greenstones and argillites by minerals deposited from solutions which began to circulate towards the close of the intrusion of the greenstones and continued during the invasion and cooling of the Coast Range batholith. It seems probable that at least the great bulk of the ore minerals had their origin in the magma of the batholith.

There are seven ore-bodies. Nos. 1 to 5 are clustered about the apex of a spur of greenstone about 2,500 feet square, which juts out into the argillites in a northeast direction. The sixth ore-body lies 1,300 feet to the southwest on the southeast side of this spur of greenstone. Another ore-body, which is really a separate deposit, but is owned by the same company and known as the Bonanza, is situated 3½ miles to the south, on Bonanza creek, and 3,200 feet from the shore of Granby bay. This deposit is also on a contact between the argillites and a small mass of greenstone less than a mile in diameter.

Ore-bodies 1, 4, 5, and 6 lie on the contact of the argillites and greenstones, where the argillites are much crumpled and the greenstones are especially schistose. Nos. 1 and 5 have developed where the turn in the strike of the greenstone-argillite contact is most abrupt. These ore-bodies are richer where the slate contact overhangs the ore. Ore-bodies 2 and 3 and Bonanza lie in the greenstone, where it is especially schistose, and 2 and 3 are so situated that at the time of their deposition they were probably roofed by slate.

The following dimensions will give some idea of the sizes of the ore-bodies. Ore-bodies 1 and 5 have a combined length on the 530-foot level of about 1,240 feet, with an average width of 150 feet. No. 3 is a faulted block of No. 2 and together they have a combined length of 750 feet with a width of 240 feet. No. 4 ore-body lies chiefly above the 530-foot level. It is triangular in plan, with a length on the 760-foot level of 560 feet. The present workings extend over a vertical range of 800 feet and diamond-drilling has proved the ore-bodies to extend still deeper. They have a maximum size in cross-section on the 530-foot level, below which there is a gradual decrease in size which becomes more marked below the 150-foot level and is coincident with a sudden flattening of the greenstone-argillite contact.

Mining Methods

The Hidden Creek mine is opened up on seven levels, from 100 feet to nearly 250 feet apart vertically. The 385-foot level is the main haulage way for all the ore passing out of the mine. All ore from below the 385-foot (mine elevations are all referred to a datum at sea-level) is hoisted through a vertical four-compartment shaft, or winze, that extends from the 530-foot level below the 130-foot. It is equipped with a 500 horsepower double-drum, electric hoist. There is no direct access to the surface below the 150-foot level. There are about 750,000 tons of ore tributary to the 130-foot level and about 1,750,000 tons tributary to the zero level, but unless diamond-drilling discloses more ore-bodies it is unlikely that development will be carried lower, since present information indicates that the ore below this horizon cannot be profitably worked at present.

All the main underground haulage is done on 36-inch gauge tracks by electric locomotives equipped with automatic side-dump cars. The electric railway connecting the mine with the smelter is also 36-inch gauge.

The ore when it leaves the 385-foot level is passed through one of three 30- by 42-inch Farrell-Blake crushers, set up at the mouth of the level, with large underground storage pockets beneath them leading to the 150-foot level below. Ore is delivered to the smelter from the mine pockets on the 150-foot level in 25-ton hopper bottom cars, hauled by 42-ton electric locomotives.

Actual mining of the ore follows two general systems: (1) shrinkage stoping, in which the stope is carried up on broken ore, just sufficient being withdrawn from the stope each day to allow the miners to work, until the stope is completed to the level above. Some of the stopes worked in this way at Anyox are unusually large; one on No. 2 ore-body is approximately 350 feet long and 150 feet wide, and was carried up 200 feet without timbering of any kind. No timber is used in the stopes or in the drifts underneath them, except for chute mouths; a block of ore 15 to 30 feet thick, pierced by chute-raises, is left to form the bottom of the stope and to protect the drift beneath.

Most of the mining at Anyox, however, is done by a system of underground glory holing. This consists essentially of spiral raises which, starting from the top of a chute-raise swing around, and upward, at a grade just flat enough to permit a man to walk up it. When completed the raise resembles nothing so much as the impression that would be left by a corkscrew on the inside of a hollow cylinder. On each side, at the extremities of the turns in the spiral, connexions are made with manway-raises which are driven through pillars at each end of the stope, to provide ventilation and easy access for powder and steel. When the first spiral is completed, depending on the nature of the ground, either a second spiral is started, interlacing the first, or the first spiral is gradually enlarged. The stope is drawn empty every day and the fall down the irregular chute helps to break up the large slabs of ore. When necessary, a rib of the spiral can be left as a strut across the stope to support any heavy ground. The method has many advantages: safety, since the miner is always working under a shelf of rock, and has no occasion to go out into the middle of the stope where he might be hit by falling ground—access to one or other of the manways is always easy by going around the side of the stope on the grade of the spiral; saving in timber, for no timber is used above the chute-mouth except for ladders and skids in the manway; no appreciable amount of money is tied up in broken ore; and mining can be transferred to any part of the stope, from top to bottom, to change the composition of the ore supply when desired. This last is particularly important at Anyox where the mine is also a mixing plant for the furnaces and control of the composition of the ore is absolutely essential for successful operation.

Three classes of ore are broken in the mine: heavy sulphide ore yields by far the greatest tonnage; pyrrhotite ore with greenstone gangue is second in amount; and the low-grade siliceous envelope surrounding the ore-bodies, which is used to some extent for flux. Each class of ore is kept separate through the crushers and down to the smelter.

Compressed air for the mine is transmitted from compressors at the beach through 1½ miles of 10-inch pipeline.

Smelting

Blast-furnace smelting as carried out at Anyox is semi-pyritic, that is to say it is, strictly speaking, an oxidation process, in contradistinction to the standard method which is a reducing one. The chemical reactions involved are identical with those that take place in a converter when matte is blown to blister copper, though the process is carried on continuously in a different style of apparatus and has the additional duty of liquifying the charge as well as oxidizing and slagging the iron. The blast, which is used in amounts greatly in excess of the requirements for reduction smelting, is the chief governing factor in the success of the process; at Anyox between 26,000 and 32,000 cubic feet of air a minute is forced through each furnace. Heat in the furnace is generated chiefly by the oxidation of the iron, the sulphur in the ore playing a very small part since most of it is distilled in the upper part of the ore column and burns only when it reaches the top of the furnace and comes in contact with the outside air. The thermal balance in pyritic smelting, even under the most ideal conditions, shows only a slight excess of heat over normal requirements, so that in actual operation at Anyox, the introduction of any unusual amounts of rock, or even an excess of fines in the ore upsets the balance and the furnace will freeze up. As an assurance against stoppages of this kind 4 to 6 per cent of coke is added to the charge. Each of the four blast-furnaces at Anyox will normally handle 800 tons of ore in 24 hours. A furnace campaign lasts from 10 to 40 days; whenever the capacity falls to 600 tons a day, the furnace is tapped out, cooled off, freed from accumulated crusts, and then blown in again, this cycle of operations taking only some 24 hours to carry out.

A typical Anyox furnace charge is six parts of heavy sulphide ore, two parts of pyrrhotite-greenstone ore, and one of siliceous envelope, to which is added about 5 per cent of dry coke and a small amount of limestone. Matte and slag are drawn off continuously into a series of forehearths or settlers, the final slag overflow being granulated and washed out to the slag dump; the matte is tapped intermittently into cast-steel ladles and deliverd by a crane to a battery of five, basic-lined converters. In the first two of these—20-foot converters of the Great Falls type—the matte, which as it comes from the blast-furnace carries about 12 per cent copper, is blown to about 35 per cent copper. It is then transferred to three, smaller, 12-foot, converters which it leaves as blister copper 99·0 to 99·1 per cent pure. The blister copper is shipped to New York to be refined.

A small part of the furnace matte instead of being sent to the converters is allowed to solidify, broken up and returned to the furnaces where it acts as a lubricant and equalizer in the charge.

With the exception of a small amount that is granulated to be used as a binder when sintering flue dust, converter slag is poured back into the blast-furnace settlers, just after matte has been tapped and before the settler fills, which gives sufficient time for the low-grade matte to react with the slag and clear it of prills and shots of copper before the slag overflow starts again.

Concentrator

In order to utilize the excess of pyrrhotite-greenstone ore, which as mined can only be used in the blast-furnaces in the proportion of one to three of heavy sulphide ore, a concentration plant was built and put in operation early in 1924. In this a portion of the gangue, and pyrrhotite, and pyrite is removed by a method of selective flotation, and the copper content raised from about 1·5 per cent in the ore to 15 per cent or more in the concentrates. The mill record for 1925 shows: ore treated, 416,298 tons carrying 1·55 copper; concentrates produced, 35,430 tons carrying 15·08 per cent copper; or a ratio of concentration of about 12.

The mill itself consists of three buildings: a crushing plant, a concentrator building, and a dewatering building. In the crusher building, the ore which is received from the mine at about 6-inch size is put through grizzlies to eliminate everything smaller than 2½ inches, the oversize going to gyratory crushers crushing to 2 inches. The gyratory product, together with the undersize from the grizzlies, is then put through rolls in closed circuit with a Hummer screen, the undersize from which goes to the concentrator building.

A recent innovation is the screening out of the fines from the ore sent to the smelter and treating these also in the concentrator.

Here the ore is put through rod mills of the Cole type in closed circuit with a drag classifier, the overflow from which is 70 per cent through 200-mesh. This overflow goes to a 6-cell, rougher flotation machine, from which the tailings go to waste and the concentrates to a 2-cell cleaner machine, making a tailing which is returned to the rod mill and a final concentrate.

The concentrates are then delivered to the dewatering division, which consists of two Dorr dewatering tanks, from which the thickened pulp goes to Oliver filters.

Until recently most of the flotation concentrates were sent to Tacoma, Wash., for smelting, but a sintering plant using Dwight-Lloyd machines is now installed, in which they are sintered, together with flue dust and granulated slag, then sent to the blast-furnaces. The capacity of the concentrator is about 3,000 tons a day, and all the concentrates are now smelted in the company's furnaces at Anyox.

The mill is electrically equipped throughout, and thoroughly up to date in every detail.

The total production of the Hidden Creek property since the smelter was put in blast, in 1914, until the end of 1925, is: 331,187,931 pounds of copper; 3,830,260

The Granby Company's by-product coking plant at Anyox.

ounces of silver; and 72,390 ounces of gold. Production for 1925 was 37,625,733 pounds copper (including that shipped in concentrates); 335,104 ounces of silver; and 7,098 ounces of gold. The ore produced during the same year amounted to 1,163,258 tons, having an average copper content of 1·86 per cent. In addition, the company's by-product coking plant, which treats coal brought from the company's colliery at Cassidy, on Vancouver island, as well as Alberta coal, produced: 882,147 M cubic feet of gas; 526,223 imperial gallons of tar and tar paint; 728,530 pounds of sulphate of ammonia; 38,209 pounds of concentrated ammonia liquor; 109,072 Imperial gallons of motor fuel; 134,927 Imperial gallons of light oil; and 32,800 pounds of naphthalene, besides 57,455 tons of coke.

To supply the power necessary to carry on its undertakings the company has built and operates a waterpower plant of about 13,200 horsepower, as well as a 6,700 horsepower auxiliary steam plant.

For nearly twenty-five years the Granby Company has been mining and smelting its own ores. First, at Phoenix and Grand Forks in south-central British Columbia, where it was able to make a profit on the direct smelting of a one per cent copper ore; and now, since the Phoenix deposits have been exhausted, at Anyox, where it is operating the biggest pyritic smelting plant in the world.

AUTHORITIES CONSULTED

Campbell, E. E.: "The Hidden Creek Mine and Its Operations"; Trans. Can. Min. Inst., vol. XXII, pp. 135–154 (1919).

Clapp, L. R.: "Notes on Anyox Mining and Metallurgical Practice"; Trans. Can. Inst. of Min. and Met., 1923, pp. 328–346.

Minister of Mines, British Columbia: Annual Reports: 1923, pp. 50-52; 1924, p. 50; 1925, p. 73.

Granby Consolidated Mining, Smelting, and Power Company; Annual Report for the year ending Dec. 31, 1925.

SALMON RIVER

Salmon River mining district in northern British Columbia is about 11 miles north of the town of Stewart which is situated at the head of Portland canal, one of the largest fiords on the Pacific coast. It is connected by automobile road with Stewart, which in turn has regular steamer connexion with Prince Rupert and Vancouver.

It lies near the eastern contact of the Coast Range batholith, and is underlain by a series of sedimentary and volcanic rocks of Jurassic age, which have been cut not only by the Coast Range batholith, but by both earlier and later igneous intrusions.

The sedimentary and volcanic rocks constitute an apparently conformable series correlated with the Jurassic Hazelton group of Skeena River valley. At the base is a formation of highly altered, andesitic, massive, and fragmental volcanic rocks to which the name greenstone is commonly applied. The volcanics are of wide distribution and are estimated to have a thickness of 2,000 feet.

The formation passes upward by gradual transition into a formation of fine conglomerates carrying pebbles of the underlying volcanic rocks. Interstratified with the conglomerates are beds of argillite and a persistent, chert-like band of fine-grained tuff. The conglomerate formation is about 300 feet thick, occupies a semi-circular area around the southern base of Slate mountain, and extends northward as a narrow band. It passes upward into a formation consisting mainly of argillites with occasional beds of sandstone and fine conglomerates. These later sediments are more than 1,000 feet thick and are exposed in the valley of Long lake. The tuffs were intruded by a small stock and a series of associated sills of granodiorite porphyry or quartz porphyry which varies from fine grained to porphyritic. As the best ore-bodies lie in the quartz porphyries, these rocks are of great economic importance. After the intrusion of these sills the whole series of volcanics, sediments, and quartz porphyries were tilted into their present position. Subsequent to the deposition of the sediments and the intrusion of the quartz porphyry, came the intrusion of the granodiorite of the Coast Range batholith. The rocks of the Coast Range batholith lie immediately to the west of the area and good exposures are seen in the numerous cuts along the road from Hyder to Elevenmile in Alaska on the way to the Premier mine.

Other intrusives are: (1) augite porphyry, a stock-like mass outcropping just north of Long lake; (2) quartz diorite dykes, numerous in the southern part of the area; (3) "Belt of dykes" in which is included a large number of dyke rocks of various types, ranging from diorites to quartz porphyry, and cutting across the centre of the area in a northwesterly direction; (4) lamprophyre dykes from

Premier mine.

a few inches to several feet in thickness cutting the bedded rocks, the quartz diorite, the augite porphyry, and the primary mineral deposits.

The property of the Premier Gold Mining Company is situated on the western slope of Bear River ridge. In general it is underlain by a series of greenish tuffs usually very fine grained and intruded by a small stock and associated sills and dykes of quartz porphyry. Shear zones cut the tuffs and quartz porphyries, and the most important ore-bodies are found in the part of a shear zone where it cuts the porphyries. Both very high-grade and concentrating ore-bodies of silver and gold minerals are found. The minerals which have been identified are pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, freibergite, polybasite, pyargyrite, argentite, native silver, stephanite, electrum, and native gold. The predominant gangue mineral is quartz with silicified rock.

C. A. Banks describes the ore deposits of the Premier and B.C. Silver mines as follows:

From the very irregular occurrence of the tuff, the manner in which it comes and goes in both a horizontal and vertical plane, and its comparatively small volume as compared with the porphyry, it appears that the occurrences of tuff are ordinary inclusions within a large porphyry intrusion. There are, no doubt, sill-like intrusions in the district, but the area within the present developments of the ore zone is possibly too close to the centre of the intrusion to show any sill structure. The ore occurs in a shear zone, which strikes roughly north 50 degrees east with a dip towards the northwest, varying from 60 to 80 degrees. The zone is nearly straight, and neither the northeast nor southwest limit of it has yet been determined. Judging from its strength, it is probable that it extends considerably beyond its present known limits. The shear zone passes through both porphyry and tuff, but is mainly confined to the former. The porphyry being more brittle than the tuff, the shearing left the former more open than the latter for the deposition of the ore-bodies. It is probably for this reason that the ore occurrences are stronger in the porphyry than in the tuff. The ore-bodies were probably formed by siliceous solutions from the granite batholith, close by, traversing the fractured zone where their load was deposited. In many places these solutions have attacked and replaced the porphyry wall-rock.

The ore occurs in shoots within the silicified portions of the shear zone, and these shoots in general have a rake towards the southwest of about 60 degrees. The ore zone is cut by a number of lamprophyre dykes, which vary in width from a few inches to about 10 feet, and which strike roughly northwest, and have a dip of about 60 degrees to the southwest.

The erosion of the tops of the ore-bodies and the reprecipitation of at least some of the values therefrom, is probably the cause of the heavy enrichment which is found mainly along slips and faults, to a depth of up to 700 or 800 feet below the present surface. The native and ruby silver are probably due to this process of secondary enrichment.

Discoveries have been made also on Big Missouri ridge in the northern part of the area. The mineral deposits are of two types: (1) replacement and impregnation of favourable bands in the tuffs and fine conglomerates constituting complex siliceous ores, with a fine-grained mixture of galena, zinc blende, chalcopyrite, and pyrite in a quartz gangue; (2) fissure veins cutting the banded formations and carrying galena and zinc blende.

The metal-bearing character of the country in the vicinity of Portland canal was first recognized by prospectors during the height of the Klondike rush in 1898. The earliest record of prospecting in Salmon River district was in 1904, when a number of claims were staked there. Some of the chief claims now forming part of the Premier gold mine—later to become the outstanding mine of the district—were staked in 1910; but it was not until 1914 that high-grade ore was found, followed by a rush in 1915-1916, during which all available ground was staked.

Development following the first discovery of high-grade ore in 1914 did not, however, lead to the immediate opening up of commercial ore-bodies and for a time interest in the district waned. But prospecting and development work never entirely ceased, and the discovery in 1917 of a bonanza ore-body in the Premier mine made it famous. In 1919, control of the Premier was acquired by the American Smelting and Refining Company, and the Premier Gold Mining Company was formed to work it. The first dividend, $400,000, was paid in 1921; total dividends to the end of 1925, including $1,600,000 paid in that year, amounted to $8,150,000 on a capitalization of $5,000,000.

The Premier deposits have been opened by tunnels on six levels, the mine workings having a vertical extent of about 1,400 feet. Up to the end of 1925 approximately $19,000,000 worth of ore had been mined; and some 6 miles of underground work and 12 miles of diamond-drilling done. No. 4 tunnel is the main haulage level as this is the level from which the mill is fed. All the ore won below No. 4 level is hoisted to that level through a three-compartment raise equipped with a double-drum, electric hoist, ore pockets, etc., and extending down 550 feet to the No. 6, or lowest, level. Electric storage-battery locomotives are used for tramming.

Milling operations as carried out at the Premier mine consist of coarse crushing, followed by fine grinding in ball mills operating in closed circuit with drag classifiers.

The ball-mill product, after further classification in cones, goes to tables, which produce a high-grade concentrate, and middlings and tails that are reground in a ball mill in closed circuit with a cone. The cone product goes to subaeration flotation machines, and the tailings are cyanided when rich enough to make this profitable.

With the gradual depletion of the very high-grade—probably secondary—ore, which is found chiefly in the upper workings of the mine, and the necessity of relying more and more on the lower grade primary ores to maintain output, the milling capacity has been gradually increased from 100 to 400 tons a day. The estimated ore reserves in the mine at the end of 1925 were: broken ore in stopes, 243,511 tons averaging 0·64 ounce gold and 14·7 ounces silver a ton; assured and probable, unbroken ore down to the 4th level in the present workings, 316,484 tons averaging 0·52 ounce gold and 13·6 ounces silver; and ore indicated by diamond-drilling below the 4th level 146,000 tons averaging 0·39 ounce gold and 3·2 ounces silver. There is also much ground yet to be explored.

Mine and mill products are delivered at deep tide-water by an aerial tramway approximately 12 miles long—one of the longest, if not the longest, tramways in existence for the transportation of ore. The upper terminal of the tramway is alongside the mill, just below the portal of No. 4 tunnel; the lower terminal ends in ore bunkers for first and second class ore, built on the beach at Stewart. The capacity of the tramway is in the neighbourhood of 10,000 tons a month, or better. The products shipped include: first-class shipping ore, sent to the United States Smelting and Refining Company's smelter at Tacoma, Wash.; second-class shipping ore sent to the Granby Company's smelter at Anyox, B.C.; concentrates, and cyanide precipitates sent to the United States Smelting and Refining Company's smelter at Selby, Cal., for treatment.

Power for mine and mill is provided by an hydroelectric installation having a maximum water-wheel capacity of 1,100 horsepower supplemented by 1,620 horsepower developed by semi-Diesel engines, since the capacity of the hydroelectric plant is greatly reduced during the very cold winter months. Oil for the engine plant is stored at the wharf at Stewart in tanks having a total capacity of 1,200,000 United States gallons, or approximately one year's supply, whence it is transported in drums over the tramway to the mine.

th
ha

th
th
th
M
P

H

M

Pr
Ar

M
De
Sc

Ba