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(Fourth Edition)

Geology and Economic Minerals of Canada

BY

Officers of the Geological Survey of Canada

Edited by C. H. Stockwell

GEOLOGICAL SURVEY
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
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PREFACE

Three earlier editions of the Geology and Economic Minerals of Canada were published, the first in 1909, the second in 1927, and the third in 1947. In the past decade much new geological information has become available and the changes in the mineral industry have been remarkable.

Canada's mineral production in 1944 was valued at $485 million, but in 1955 it had more than trebled and was valued at $1,795 million. Newfoundland, which became Canada's tenth province in 1949, provided about $69 million of Canada's total in 1955 and this figure will increase greatly with increased production of iron ore from Labrador. The major change in mineral production, however, comes from oil and gas. The Leduc oil field in Alberta was discovered in February, 1947 and the known fields of Western Canada are estimated to contain about 3 billion barrels of oil and assured reserves of many trillions of cubic feet of natural gas. Crude petroleum, which was well down the list in value of output in 1946, attained first position as a contributor to the Canadian mineral output in 1953, a position it has since held. A further spectacular change is in the development of uranium deposits. In 1947 all the Canadian production came from the Eldorado mine at Great Bear Lake, whereas in 1956 nine mines were producing and others were nearing production. The past decade has been marked also by important developments in base metals in New Brunswick, Quebec, Ontario, and Manitoba; iron ore in Ungava and Ontario; lithium in Quebec; and asbestos in Ontario and British Columbia.

Legislation relating to mining and to the search for oil, introduced some 10 years ago, has been of considerable significance. As the price of gold is fixed, the sharply increasing costs of production became a serious factor in gold mining, but the cost aid provided by the Emergency Gold Mining Assistance Act which came into effect in 1948 has made it possible for many of the gold mines to continue in operation. Certain Federal legislation relating to the drilling for oil, which was enacted in 1944 and remained in force to the end of 1955, afforded considerable tax relief to companies drilling deep test wells under conditions of unusual cost and hazard and was helpful in accelerating the discovery of oil.

Continued changes and development in air transportation have permitted increased geological exploration and mineral discovery in remote areas, especially in the north. New methods of attack on problems relating to geology and mineral discovery, particularly those of geophysics and geochemistry, have come into greatly increased use, leading to important discoveries. There is considerable lag between discovery and production and the full impact of easier transportation and new tools cannot yet be appraised. There is little doubt, however, that Canada's mineral production will continue to expand.

GEORGE HANSON,
Director, Geological Survey of Canada

OTTAWA, June 15, 1956

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INTRODUCTION

(C. S. Lord)

Canada, with a land area of 3,577,163 square miles (Map 1045A, in pocket), is the largest country in the Western Hemisphere and the second largest in the world. Nevertheless, the population based on the June 1, 1956 census, was only 16,081,000, or less than one-tenth that of the United States of America. Furthermore, most of this relatively small population is concentrated south of a line lying slightly north of Vancouver, Edmonton, Winnipeg, Lake Superior, and Quebec City. Thus the Northwest Territories and Yukon Territory lying north of the 60th parallel and having a combined land area of 1,458,784 square miles have population densities of about one and four persons, respectively, per 100 square miles. Vast tracts of Canada are mountainous, rocky, under an Arctic climate, or otherwise not well suited to settlement. About one-half of the total land area is devoid of forests and unsuitable for agriculture.

Physical Features

Canada is naturally divided into five main regions each possessing characteristic geological features and, as a result, more or less distinctive physical features (Figure 1). The largest of these is the Canadian Shield, occupying nearly half of Canada including parts of the Arctic Archipelago. In its central, lowest part, surrounding Hudson Bay, it lies only a few feet above sea-level. Nearly all of the Shield is less than 2,000 feet above sea-level, but in northeast Labrador the Torngat Mountains have elevations of 5,000 to 6,000 feet above the sea, and on Baffin Island mountains rise to elevations of 8,000 to 10,000 feet. Elsewhere most of the Shield has a relief of less than 200 feet. Intense glaciation has left scattered rounded rock outcrops and rocky ridges separated by glacial deposits, muskeg, and myriads of lakes of many sizes and shapes, here and there connected by rivers with rapids alternating with stretches of relatively quiet water. Rock exposures probably total less than 10 per cent of the surface. The northern part of the Shield is devoid of timber, and the treeless ground is permanently frozen except that a thin surface layer generally thaws annually. Ice-caps are found here and there on the Shield in the Arctic Islands.

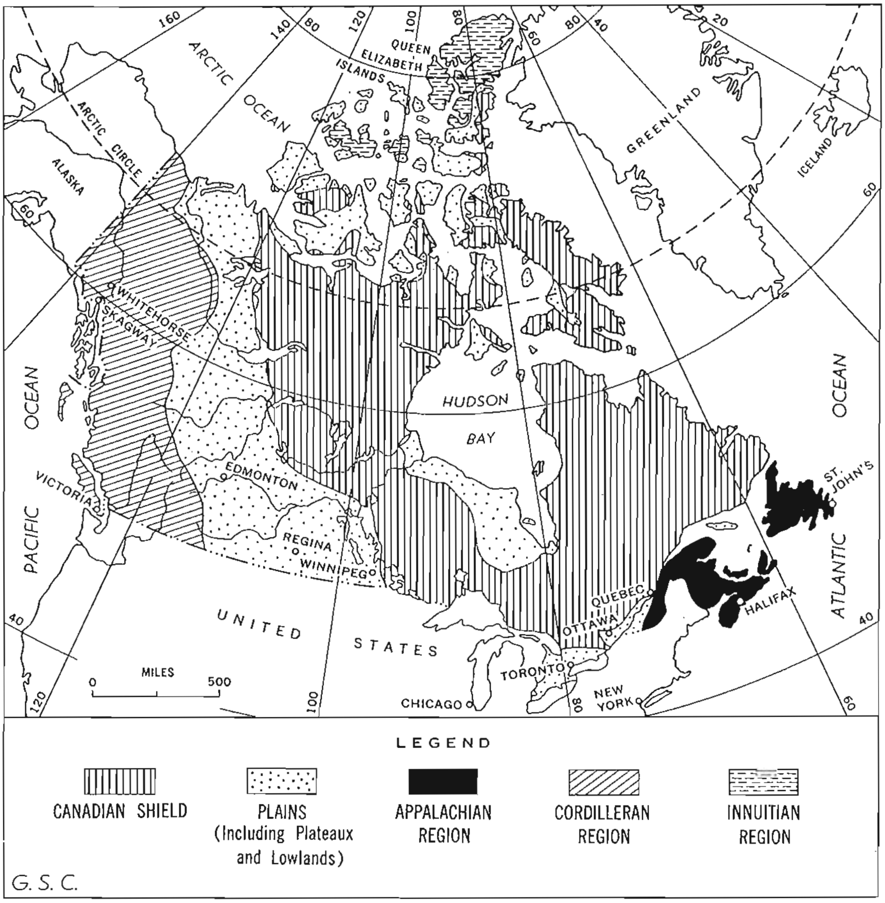

FIGURE 1. Main physiographic and geological regions of Canada.

The Plains region, a second main unit, includes the Interior Plains, St. Lawrence Lowlands, Hudson Bay Lowland, and the lowlands, plains, and plateaux of the Arctic Islands. The Interior Plains flank the Canadian Shield on the west and extend from the 49th Parallel to the Arctic Ocean. Their gently rolling surface, broken by rare questas and buttes, slopes imperceptibly upward away from the Shield until, at an elevation of about 4,000 feet above the sea, it merges with the hills of the Cordilleran region. Their southern part is a treeless prairie, one of the great agricultural areas of Canada.

The plain-like surface of the St. Lawrence Lowlands, which border the Canadian Shield on the south between Lake Huron and Quebec City, is interrupted near the outlet of Lake Ontario by a southerly tongue of the Shield known as the Frontenac axis. West of this axis the surface slopes gently southwesterly, the outstanding exception being the northeasterly facing Niagara escarpment.

The Hudson Bay Lowland is a low swampy plain sloping gently out of the southwestern shores of Hudson Bay and James Bay.

Parts of many of the Arctic Islands are rolling, treeless lowlands or plains sloping gradually inland from the sea but, particularly in the eastern part of the archipelago, sea-cliffs rise abruptly 500 to 1,500 feet to deeply incised plateau surfaces which inland attain still greater heights.

The third main division, the Cordilleran region, lying between the Interior Plains and the Pacific Ocean or Alaska, comprises three northwesterly trending units: a western system of mountains, and a central system of plateaux and mountains, together comprising the western Cordillera; and an eastern system of mainly mountains, making up the eastern Cordillera. In British Columbia the eastern and western Cordillera are separated by an unusually deep and persistent valley called the Rocky Mountain Trench. The highest peaks are very little over 12,000 feet above sea-level except in the St. Elias Mountains where one peak, Mount Logan, is 19,850 feet high, and several others are only slightly lower. The mountains of the eastern Cordillera present a general saw-tooth appearance, whereas, in many places in the ranges of the western Cordillera jagged peaks are interspersed with more rounded or fairly level, upland surfaces. The valleys are forested, except some in the far north, but innumerable peaks rise well above timber-line. Parts of Yukon are underlain by permanently frozen ground. Snow-fields, ice-fields, and alpine glaciers are common, particularly near the coast where a few valley glaciers extend to, or nearly to, sea-level.

Southeast of the Canadian Shield and east of the St. Lawrence Lowlands is a broad belt of mountainous country known as the Appalachian region, the north-eastern end of the Appalachian Mountain system that extends southwest to Alabama in the United States. It occupies New Brunswick, Nova Scotia, Prince Edward Island, the Island of Newfoundland, Gaspé Peninsula, and part of the Eastern Townships of Quebec. The highest hills are found in the Shickshock Mountains of Gaspé Peninsula, and these rise to heights of more than 4,200 feet above sea-level. Elsewhere, only scattered mountains and uplands exceed elevations of 1,500 to 2,000 feet.

The fifth main division, the Innuitian region, extends southwest from northern-most Ellesmere Island to Prince Patrick Island in the northern Canadian Arctic, and consists mainly of mountains and ridges, some of which may rise as high as 10,000 feet.

Geological Investigations

In view of the combination of vast area, the relatively small population concentrated mainly in the extreme south, and other factors, it is perhaps not surprising that very large areas are incompletely explored and difficult of access except by aircraft.

The Geological Survey of Canada, one of the oldest organizations of its kind in the world, was organized in 1842 to map, study, and report on the geology of

Canada. In this task it has been aided to varying degrees by geological surveys conducted by nine of the ten provincial governments but, because these organizations generally confine their efforts to detailed studies of small areas, many of which are first mapped on reconnaissance scales by the Geological Survey of Canada, the task of completing the initial geological mapping of the ten provinces has remained overwhelmingly the duty of the Federal organization. Furthermore, Northwest Territories and Yukon, together comprising about 40 per cent of Canada, are under Federal jurisdiction, and there the Geological Survey of Canada is the sole government organization engaged in geological mapping.

After more than a century of effort, nearly three-quarters of Canada is unmapped geologically, even on reconnaissance scales. Such a pace is clearly unacceptable when, as today, the frontier no longer advances gradually from south to north but spreads from a constantly increasing number of isolated points that spring up at unforeseen localities throughout the north, and sound long-term plans for national development and more detailed geological work await the completion of the initial geological reconnaissance. Present top priority objective is, therefore, to complete the preliminary reconnaissance geological mapping at the earliest practicable date. Various resulting modifications in geological methods during recent years, particularly the successful adaptation of helicopters to a variety of survey conditions, have already greatly increased the rate and efficiency of mapping (Plate I, Frontispiece). As a result, it is reasonable to expect that the preliminary geological reconnaissance of Canada will be essentially completed, to acceptable standards, within the next twenty-five years.

Geology and Mineral Deposits

Canadian Shield

During the long ages of Precambrian time great accumulations of sedimentary and volcanic strata were formed in what is now the Canadian Shield (Figure 1). These were subjected to mountain-building processes, and large bodies of granites and other igneous rocks were formed in the roots of the mountains. These ancient mountain ranges were worn down by erosion, seas encroached over the resulting lowland, and the cycle of deposition, mountain building, intrusion, and erosion began anew. In at least some parts of the Shield these processes were repeated several times, and it appears that no one process occurred throughout the Shield at any one time, but that mountain building, for example, took place in one region while another was covered by sea and undergoing a stable period of deposition. It may thus be that this cycle was repeated many times during the immensely long Precambrian time, although not all cycles were necessarily operative in any one place. As a result of this long complex history, the Shield now consists mainly of granite and granitoid gneiss, some of Archæan and some of Proterozoic age, but includes also remnants and patches of volcanic and sedimentary rocks of Archæan and Proterozoic age. The region has been a stable mass since Precambrian time, and although it has been partly or completely below the sea for long intervals since that time, it has not been folded by Cambrian or later mountain-building movements. A post-Cretaceous, probably late Tertiary, uplift was followed by Pleistocene glaciation. The elastic rebound that followed the retreat of the ice is still continuing and the lakes and streams of the Shield have not yet adjusted themselves to the new conditions. The result is the present disorganized drainage pattern.

The Archæan (Early Precambrian) strata occur as scattered troughs and basins of severely deformed and altered volcanic and sedimentary rocks. Some of these bodies are more than 100 miles long and many miles wide. They are formed of rocks older than the surrounding granites, and are remnants of former extensive formations that were partly destroyed by intrusions and partly removed by erosion. The common rock types include basic to intermediate volcanic rocks (greenstone), banded chert with iron oxide (iron-formation), greywacke, and slate. In places the volcanic rocks predominate; elsewhere the sedimentary formations are more abundant. Before the end of Archæan time these ancient formations were folded by mountain-building movements and intruded by granitic rocks. They were deeply eroded before the first Proterozoic (Late Precambrian) rocks were deposited. It has not been demonstrated that this closing period of orogeny and erosion took place everywhere within the Shield at the same time.

Unconformably overlying these Archæan formations and some of the granite that intrudes them are extensive bodies of relatively undeformed volcanic and sedimentary rocks of Proterozoic age. Available dates, determined by radioactivity methods, indicate that the oldest rocks mapped as Proterozoic are all younger than those mapped elsewhere as Archæan. Proterozoic rocks differ from the Archæan formations in having an abundance of clean sandstone and quartzite, limestone and dolomite, and graphitic sedimentary rocks. The Proterozoic assemblage is divisible into two or more units separated by one or more unconformities. The older strata are cut by granitic intrusions and, in most parts, the youngest known Precambrian intrusions are diabase.

In the southeastern part of the Shield, in the area known as the Grenville sub-province, is a complex of more or less granitized sedimentary gneisses associated with large amounts of crystalline limestone and a little lava. The age of this complex is not known with certainty. Although the sedimentary and derived metamorphic rocks are shown as Archæan on the latest geological map of Canada (Map 1045A), the occurrence of crystalline limestone is unusual within strata of that age. Moreover, age determinations made on minerals from pegmatites that cut the Grenville show that the intrusions range in age from 800 to 1,100 million years and, therefore, indicate the possibility of a Proterozoic age. Rocks similar to the Grenville complex are found on Baffin Island, in Manitoba, and in other parts of the Shield.

Within recent years it has been shown that the Shield may be conveniently divided into five or more geological provinces, each with a characteristic assemblage of rock types, structures, and mineral deposits. The outlines of these provinces and of their sub-provinces cannot, however, be defined everywhere until much more geological mapping has been done.

The known and potential mineral resources of the Shield are larger and more diverse than those of any of the other principal geological regions of Canada, although a notable deficiency is a complete lack of mineral fuels. Nor is the prominent position of this region surprising in view of its tremendous size, its very long and correspondingly complex geological history, and the deep erosion that has exposed the roots of the ancient mountain ranges. The value of minerals produced in the Shield in 1955 amounted to about 45 per cent of the Canadian total. About 77 per cent of Canada's metal production was derived from the same region. In the same year it supplied about 88 per cent of the copper, 92 per cent of the gold, 83 per cent of the iron ore, and all of the nickel, platinum and platinum group metals, uranium, and cobalt produced in Canada. Nearly all the mines of the Shield lie within 300 miles of its outer margin. It is commonly believed, however, that this distribution results from the relative accessibility of the outer fringe, and the consequent more thorough geological mapping and prospecting. It has not been demonstrated that valuable mineral deposits are less abundant in the interior parts of the Shield. Most of the known deposits of metallic minerals lie within the troughs, basins, and patches of volcanic and sedimentary Archæan and Proterozoic rocks that occur scattered more or less widely throughout the granitic rocks and gneisses.

As already indicated, erosion in the Archæan parts of the Shield has cut down to the roots of the ancient mountain systems, and, consequently, the common types of mineral deposits found there are those formed at moderate to great depths. Such are most gold-quartz veins, large copper-zinc deposits, quartz veins containing tungsten, and pegmatites containing beryllium and lithium. Not only do the mines of the Archæan commonly have ores of the moderate to deep-seated type, but many of the mines themselves are very deep, and in Canada and throughout the world, average much deeper than mines in younger rocks.

Associated with Proterozoic rocks are a group of distinctive deposits, many of them highly productive or potentially so. The great copper-nickel-platinum deposits at Sudbury are associated with a body of norite and micropegmatite, and the silver-cobalt ores of Cobalt with a diabase sill. Late Proterozoic lava flows and sills of basalt and diabase in various parts of Canada contain copper. Most of Canada's known deposits of iron ore or potential ore, some of shipping grade and some requiring beneficiation, occur in Proterozoic formations in Labrador, northern Quebec, and western Ontario. A variety of uranium deposits, some of them of very substantial size, have been found and developed during recent years along the western and southern borders of the Shield. They occur mainly as hydrothermal vein deposits in or near fault zones, as disseminated pitchblende and its alteration products in brecciated syenite, and as parts of a quartz-pebble conglomerate formation. The latter deposits are among the largest known reserves of uranium ore in the world.

The Grenville province not only differs geologically from much of the remainder of the Shield, but contains a characteristic assemblage of mineral deposits. Valuable mica and feldspar deposits occur in some of the abundant pegmatites. Graphite is common in crystalline limestone and has been mined. Contact metamorphic magnetite orebodies are being mined or prepared for mining. Uranium orebodies are associated with certain unusual pegmatitic bodies. Brucite is being mined from Grenville limestones, and dolomite provides the raw material for the production of magnesium.

Very large tonnages of ilmenite occur as magmatic segregations in the anorthosites of southern Québec. Potentially productive deposits of niobium (columbium) have been found recently in complexes of carbonate rocks and alkaline intrusions. Chrysotile asbestos is being recovered in northern Ontario from the ultrabasic parts of a differentiated sill that cuts Archæan formations.

Plains Region

Sedimentary strata of the Plains region, ranging in age from Cambrian to early Tertiary or younger, overlap the Shield on all sides, except on the northeast where it meets the Atlantic Ocean. In general, they dip very gently away from the Shield, have not been affected by mountain-building movements, and, with minor exceptions, are devoid of intrusions. The Plains are interrupted on the north, west, and southeast by mountain systems. Most of the rocks were laid down in the sea, in water of moderate to shallow depth. During some of the more recent periods, however, fresh- or brackish-water deposits accumulated in considerable volume. Reefs of organic origin are found in Devonian strata of the Interior Plains and in Silurian formations of the St. Lawrence Lowlands. It is probable that some of the Palæozoic and Mesozoic strata formerly extended over parts of what is now the Canadian Shield.

The most important known and potential mineral deposits of the Plains are oil, natural gas, and coal, although other characteristic deposits include common salt, gypsum, and potash salts. Mineral deposits have been extensively explored and exploited in the St. Lawrence Lowlands and in the Interior Plains of Manitoba, Saskatchewan, Alberta, and British Columbia. Much less exploration has been done in other parts of the Plains, and these parts have not produced significant quantities of fuels or other mineral products. The value of crude petroleum produced in Canada in 1955 exceeded that of any other mineral product and amounted to about 16 per cent of the nation's total mineral production. Nearly all of this petroleum came from the Interior Plains, but a little was derived from the St. Lawrence Lowlands. Most of the natural gas produced came from the same parts of Canada, and the Interior Plains afforded about 30 per cent of the nation's coal production.

The Interior Plains of central Alberta contain the largest known oil fields in Canada. The oil is found in beds of Upper Devonian, Mississippian, Lower Cretaceous and Upper Cretaceous age. Very large reserves of natural gas in Alberta and northeastern British Columbia will permit export by pipeline to metropolitan areas of Eastern Canada and the Pacific coast. Bituminous sands of Lower Cretaceous age outcrop for about 120 miles along the Athabasca River in the Fort McMurray area of Alberta. Extensive coal deposits occur in Cretaceous and Paleocene rocks of the Plains of Western Canada.

Common salt and gypsum occur in various places in the Plains, in Silurian or adjacent strata. Very large deposits of the potassium salts, sylvite and carnallite, are associated with Devonian strata in Saskatchewan.

Millions of tons of lead-zinc ore of obscure origin occur in Middle Devonian crystalline dolomite on the south shore of Great Slave Lake, and minor occurrences of galena and sphalerite have been noted in similar rocks at other widely scattered places in the Plains.

Cordilleran Region

The Cordilleran region includes all mountain-built strata west of the Plains, and the Foothills that lie between the mountains and the Plains. It extends northwestward through Canada, embracing most of British Columbia, a small part of Alberta, all of Yukon, and a small part of Northwest Territories. It swings westward into Alaska, and to the south occupies the western United States. The region is on the site of a great basin of sedimentation where seas and freshwater basins existed during much of the time from Proterozoic to late Mesozoic and early Tertiary. The mountains of the western Cordillera have been carved in a complex assemblage of sedimentary, volcanic, and plutonic rocks. Great thicknesses of sedimentary strata that range in age from late Precambrian to early Mesozoic are exposed. With these are large amounts of lava flows and volcanic fragmental rocks, mainly late Palæozoic and Mesozoic in age. These strata were folded and intruded by granitic rocks at different times, mainly in the Mesozoic era. The mountains formed at that time were eroded to a fairly flat surface, exposing deep-seated granitic rocks in many places, most notably the large and complex Coast Range batholith along the western mainland of British Columbia. Tertiary lava flows were followed by uplift, and this in turn by deep late Tertiary dissection.

The mountains of the eastern Cordillera were formed from a great thickness of sedimentary strata ranging in age from Proterozoic to Tertiary. The strata consist chiefly of limestone, quartzite, and shale, which have a total thickness estimated at about 68,000 feet in the Rocky Mountains. Sedimentation continued, at least in places, until early Tertiary time, long after the main period of folding of the mountains to the west. Thus the Rocky Mountains and other ranges of the eastern Cordillera are still in the first stage of erosion which accounts for their characteristic saw-tooth appearance. With scattered minor exceptions they do not contain exposed igneous intrusions.

In 1955 the Cordilleran region afforded about 51 per cent of the silver, 86 per cent of the lead, 51 per cent of the zinc, 6 per cent of the asbestos, and all of the antimony and nearly all of the tungsten produced in Canada, as well as substantial amounts of coal and oil. Most of the productive or known valuable mineral deposits are in southern British Columbia, southwestern Alberta, northwestern British Columbia, and southwestern Yukon, a factor probably to some extent the result of the longer and more intensive search that these more accessible areas have received.

The western Cordillera has been folded, faulted, extensively intruded by igneous rocks of a variety of ages and compositions, and deeply eroded to expose these intrusions. It thus contains a great variety of, mainly, metallic mineral deposits laid down under widely different conditions of temperature and pressure, as illustrated by deposits of magnetite, or scheelite, or cinnabar, or tellurides of gold and silver. Substantial coal deposits occur in basins of Lower Cretaceous, Upper Cretaceous, and Tertiary age.

The eastern Cordillera although extensively folded and faulted has not experienced the very deep erosion required to lay bare its roots, which might contain extensive intrusions and mineral deposits. On the other hand, mainly along the eastern Foothills and flanks, geological conditions have resulted in important accumulations of coal, oil, and gas. Most of the coal mined comes from Lower and Upper Cretaceous beds, but some is from Tertiary strata. Some of the Cretaceous formations have been folded sufficiently to raise the grade of the coal to high bituminous rank. Coking coal occurs here and there. Petroleum and natural gas are found in four major fields, three in the southern Foothills of Alberta and one in the Mackenzie River Valley. One of these, Turner Valley, was in its peak year of 1942 the largest producer in Canada.

Appalachian Region

The Appalachian region is underlain by a strongly folded and faulted assemblage of sedimentary and volcanic rocks ranging in age from Archæan to Triassic. Extensive deformations occurred at the close of the Ordovician period and in Devonian time. Both these disturbances, in general, produced structures that trend northeasterly. The Appalachian revolution, so effective in forming the Appalachian Mountains of the United States, was relatively ineffective in this northern region. Intrusions are widespread. They range in composition from granite to peridotite, and most were emplaced in Devonian time.

The Appalachian region has been notable mainly for non-metallic mineral deposits, and coal and iron ore. Recent discoveries and developments, however, promise to increase greatly the relative importance of copper, lead, and zinc production. In 1955 the region afforded about 61 per cent of the coal (by value), 90 per cent of the asbestos, 81 per cent of the gypsum, 83 per cent of the barite, and more than 99 per cent of the fluorite produced in Canada.

The Pennsylvanian strata contain bituminous coal, and Mississippian formations have deposits of gypsum, salt, barite, petroleum, natural gas, and oil shale. The Devonian intrusions were responsible for almost all the metalliferous and many of the non-metalliferous deposits. The Ordovician or Devonian ultrabasic rocks of the Eastern Townships of Quebec, of Gaspé Peninsula, and of Newfoundland, carry asbestos and chromite. Very large deposits of copper, lead, and zinc are generally ascribed to the influence of Devonian granitic intrusions. Oolitic hematite deposits, believed by many to be of sedimentary origin, have been extensively mined from Ordovician rocks on the Island of Newfoundland. Manganese occurs in a variety of deposits.

Innuitian Region

The Innuitian region is underlain by moderately to intensely folded rocks ranging in age from Precambrian to Tertiary. These consist mainly of sedimentary strata, with some metamorphic and volcanic rocks. The region has experienced several periods of folding. Granitic to ultrabasic intrusive rocks have been found in the northern part of the region, and basic dykes are common in some other parts.

Numerous occurrences of coal are known. These are mainly of low rank and range in age from Devonian to Tertiary. Anhydrite-gypsum is exposed in the central parts of domes and folds at many places in the northwest part of the region. Geological conditions make it reasonable to expect that valuable accumulations of petroleum and gas may be found.

Mineral Production

The annual value of Canada's mineral production rose from $10 million in 1886 to a maximum of $1,795.3 million in 1955 (Table I). The value of annual production considerably more than trebled during the decade ended 1955, and during the same period the index of the physical volume of mineral production more than doubled (Table II). The total value of mineral products during this decade about equalled that of the previous 45 years. The most notable gain of the decade was in the annual value of crude petroleum production which rose from a very minor position in 1945 to first place among all the minerals in 1954; its value of output in 1955 was $305.6 million. The principal products, in order of total value since about 1886[1], have been gold, coal, copper, nickel, petroleum, zinc, asbestos, lead, and silver (Table III). These products are listed below, with the production in the year of maximum output.

Gold	5,345,179	fine ounces	1941
Coal	19,139,112	tons	1950
Copper	651,987,423	pounds	1955
Nickel	349,856,997	pounds	1955
Petroleum	129,440,247	barrels	1955
Zinc	866,714,038	pounds	1955
Asbestos	1,063,802	tons	1955
Lead	436,990,488	pounds	1954
Silver	32,869,264	fine ounces	1910

[1]Newfoundland figures are included as of 1949.

In 1955 the value of each of the following products exceeded $1 million: cadmium, cobalt, copper, gold, iron ore and ingots, lead, magnesium and calcium, nickel, platinum and platinum group metals, pitchblende (mainly uranium), selenium, silver, tungsten concentrates, and zinc; asbestos, barite, fluorspar, gypsum, magnesitic dolomite and brucite, nepheline syenite, peat moss, quartz, salt, sodium sulphate, sulphur, and titanium dioxide; coal, natural gas, and petroleum; clay products, cement, lime, sand and gravel, and building stone. The

TABLE I

Annual Value of Mineral Production of Canada, 1886-1955

Year	Metallics[1]	Non-metallics	Fuels	Structural materials	Total	Value per capita
	$	$	$	$	$	$
1886	2,118,608	1,259,827	4,367,444	2,225,376	10,221,255	2.23
1887	2,073,746	1,209,153	5,080,853	2,707,579	11,321,331	2.23
1888	2,628,292	1,320,585	5,522,016	2,798,001	12,518,894	2.67
1889	3,251,299	1,562,010	5,702,930	3,247,674	14,013,913	2.96
1890	3,614,488	2,392,315	6,745,279	3,761,271	16,763,353	3.50
1891	5,421,659	2,025,195	8,205,228	3,074,534	18,976,616	3.92
1892	3,698,697	1,417,821	7,658,444	3,603,455	16,628,417	3.39
1893	4,630,495	1,249,283	8,771,358	5,133,946	20,035,082	4.04
1894	4,685,852	1,263,803	8,727,095	5,004,408	19,931,158	3.98
1895	6,087,114	1,193,512	8,248,923	4,726,368	20,505,917	4.05
1896	8,030,633	1,207,671	8,658,410	4,327,542	22,474,256	4.38
1897	13,780,314	1,425,093	8,641,016	4,388,550	28,485,023	5.49
1898	21,741,865	1,492,262	9,608,158	5,270,146	38,412,431	7.32
1899	29,282,823	1,610,111	11,872,788	6,168,283	49,234,005	9.27
1900	40,521,807	1,914,690	15,311,479	6,372,901	64,420,877	12.04
1901	41,939,500	2,713,621	14,047,654	6,803,836	65,804,611	12.16
1902	35,924,651	2,730,425	16,359,722	7,896,836	63,211,634	11.36
1903	33,210,147	2,589,302	17,197,317	8,443,747	61,740,513	10.83
1904	30,924,897	2,807,995	17,858,902	8,182,103	60,073,897	10.27
1905	36,946,212	3,468,408	18,756,112	9,608,267	69,078,999	11.49
1906	41,949,563	4,424,882	21,081,724	11,530,528	79,286,697	12.81
1907	42,426,607	5,021,384	26,254,162	12,863,049	86,865,202	13.75
1908	41,774,362	5,188,269	26,954,515	11,339,955	85,557,101	13.16
1909	44,156,841	4,593,142	26,548,109	16,533,349	91,831,441	13.70
1910	49,438,873	5,109,754	32,647,404	19,627,592	106,823,623	14.93
1911	46,105,423	5,659,746	28,746,214	22,709,611	103,220,994	14.32
1912	61,172,753	6,750,980	38,729,694	28,794,869	135,048,296	18.33
1913	66,361,351	7,402,849	41,060,860	30,809,752	145,634,812	19.35
1914	59,386,619	6,165,107	37,302,122	26,009,227	128,863,075	16.75
1915	75,814,841	7,254,732	36,118,839	17,920,759	137,109,171	17.44
1916	106,319,365	10,245,689	43,169,294	17,467,185	177,201,534	22.05
1917	106,455,147	14,566,995	48,787,368	19,837,311	189,646,821	23.18
1918	114,549,152	17,192,967	60,428,979	19,130,799	211,301,897	25.37
1919	73,262,793	16,676,377	59,325,710	27,421,510	176,686,390	20.84
1920	77,939,630	22,260,697	85,767,250	41,892,088	227,859,665	26.40
1921	49,343,232	10,148,665	77,694,017	34,737,428	171,923,342	19.56
1922	61,785,707	10,986,120	71,990,674	39,534,741	184,297,242	20.55
1923	83,764,403	14,097,925	78,465,622	37,751,381	214,079,331	23.41
1924	102,058,235	12,374,278	59,770,024	35,380,869	209,583,406	22.71
1925	116,951,996	14,628,048	57,354,055	37,649,234	226,583,333	24.19
1926	115,090,770	16,643,022	68,743,933	39,959,398	240,437,123	25.61
1927	113,349,051	17,771,709	71,426,516	44,809,419	247,356,695	25.67
1928	131,819,402	19,019,744	74,413,160	49,737,181	274,989,487	27.96
1929	154,282,736	21,245,279	76,787,397	58,534,834	310,850,246	31.00
1930	142,614,237	15,347,391	68,184,485	53,727,465	279,873,578	27.42
1931	120,794,977	11,028,311	54,453,143	44,158,295	230,434,726	22.21
1932	111,943,049	7,839,551	49,047,342	22,398,283	191,228,225	18.20
1933	147,206,959	10,061,071	47,778,436	16,696,687	221,743,153	20.74
1934	194,213,956	10,558,174	54,262,099	19,286,761	278,320,990	25.67
1935	222,139,223	12,579,334	54,824,200	23,215,400	312,758,157	28.56
1936	259,988,203	16,782,608	59,983,320	25,770,741	362,524,872	32.82
1937	335,000,751	22,536,303	65,828,379	34,869,699	458,235,632	41.13
1938	324,064,074	20,122,661	64,803,294	33,878,666	442,868,695	39.42
1939	343,453,866	25,114,106	70,671,328	35,362,759	474,602,059	41.94
1940	382,440,214	26,074,296	78,837,874	42,472,651	529,825,035	46.39
1941	395,193,386	34,532,635	85,141,997	45,373,272	560,241,290	49.06
1942	391,540,411	37,329,163	92,169,291	45,729,807	566,768,672	48.63
1943	356,558,751	38,970,577	92,514,384	42,010,254	530,053,966	44.87
1944	308,111,295	37,431,875	97,291,007	42,984,937	485,819,114	40.57
1945	316,962,810	39,841,422	93,531,276	48,419,673	498,755,181	41.15
1946	290,386,425	43,792,717	102,516,888	66,120,221	502,816,251	40.86
1947	395,069,530	54,742,453	110,481,207	84,576,785	644,869,975	51.25
1948	488,151,055	67,234,304	159,736,260	105,127,246	820,243,865	63.67
1949	538,967,258	64,585,216	183,654,473	113,903,079	901,110,026	66.51
1950	617,238,340	94,721,564	201,193,957	132,296,212	1,045,450,073	74.68
1951	745,588,728	115,706,983	232,854,093	151,333,791	1,245,483,595	88.90
1952	727,904,366	125,047,050	263,582,319	168,808,618	1,285,342,353	89.07
1953	708,880,758	126,039,359	314,181,168	187,202,218	1,336,303,503	90.40
1954	799,916,306	130,523,624	352,959,465	204,982,696	1,488,382,091	96.59
1955	1,007,839,501	144,920,841	414,318,015	228,232,439	1,795,310,796	112.20

[1]Values of pitchblende products not included from 1941 to 1953.

TABLE II

Physical Volume of Mineral Production of Canada, 1922-55
(1935-39 = 100)

Year	Index	Year	Index	Year	Index
1922	38.1	1933	60.7	1944	104.1
1923	42.2	1934	73.6	1945	100.9
1924	43.4	1935	79.5	1946	97.1
1925	47.5	1936	89.2	1947	106.2
1926	54.9	1937	103.8	1948	122.2
1927	58.7	1938	109.4	1949	131.7
1928	64.7	1939	118.0	1950	145.4
1929	67.6	1940	125.7	1951	161.8
1930	63.9	1941	132.0	1952	174.7
1931	59.2	1942	129.5	1953	185.8
1932	59.4	1943	116.1	1954	209.7
				1955	244.0

value of each of the following products closely approached or greatly exceeded $100 million (Table III): copper, gold, iron ore, nickel, and zinc; asbestos; coal and petroleum.

Ontario has long been Canada's principal source of mineral products, with Quebec in second place throughout most of the decade prior to 1955 (Tables III and IV). In 1955 about one-third of Canada's mineral output was derived from Ontario, which led all provinces in copper, nickel, gold, platinum metals, magnesium, salt, and nepheline syenite. In value of output Quebec was the source of about one-fifth of the nation's minerals, being first in the production of asbestos, magnesitic dolomite, titanium dioxide slag, and cement, second in copper, gold, and zinc. Alberta, third among the provinces in value of mineral production, supplied about 90 per cent of Canada's crude petroleum output.

In 1955, Canada ranked first in the output of nickel and asbestos, second in gold and zinc, third in silver, and fourth in copper and lead.

Data on mineral production alone fail to represent adequately the importance of the mineral industry in Canada's economy. Mining is probably Canada's principal exporting industry if only raw and partly manufactured materials are considered. Thus, in 1955, the value of exports of raw and partly manufactured materials of mineral origin amounted to about $1,124 million, or more than 25 per cent of the total value of the nation's exports. Fully manufactured exports of mineral origin amounted to another $359 million. Furthermore, in 1955 approximately 21,500 operations, including mines, smelters and refineries, oil and gas wells, and quarries, employed about 130,000 workers, paid out $465 million in salaries and wages, $62 million for fuels, $54 million for electricity, $630 million for process supplies, and $400 million for capital and repair expenditures.

As already pointed out, the index of the physical volume of mineral production rose at an unprecedented rate during the decade ended 1955, the rise being particularly rapid in the last two years of that period (Table II). Likewise, during recent years, the number and variety of large, commercial mineral deposits, including accumulations of oil and gas, found and developed on a major scale, have increased at an unprecedented rate. Others were prepared for substantially increased production rates. Many of these developments can be expected to have marked effects on the quantity and variety of Canada's mineral output in the near future. A greatly increased rate of production of uranium is assured through contracts negotiated between Eldorado Mining and Refining Limited, the Government purchasing organization, and mining companies in the Beaverlodge, Blind River, and Bancroft camps. The potential productive capacity of the oil and gas fields of Alberta and northeastern British Columbia will be realized more fully with the completion of pipelines now under construction to connect these sources with Pacific coast and eastern metropolitan markets. Canada is now among the leading producers of iron ore, and very substantial further increases in the output are readily foreseeable from current developments in Labrador, northern Quebec, and Ontario. Major deposits of copper, lead, or zinc, or combinations of these metals, are being actively explored or developed in such widely scattered places as northwestern British Columbia, the Manitouwadge area of Ontario, the Chibougamau camp of western Quebec, and the Bathurst-Newcastle area of New Brunswick. Potentially productive deposits of niobium (columbium) are being explored or developed near Montreal, and near North Bay, Ontario. Important lithium deposits are being explored in western Quebec, and in Ontario and Manitoba, and Canada's first important lithia production started late in 1955. Shafts are being sunk to potash deposits in south-central Saskatchewan, believed to be among the largest of their kind in the world.

Most of the past and present mineral producers lie south of a line extending westerly from Schefferville in New Quebec, through central Ontario, Manitoba, Saskatchewan, and Alberta, and thence northwesterly through north-central British Columbia to central Yukon—i.e., within a westerly trending strip comprising the southern third of Canada. Thus, in general, the mining frontier lies only a few hundred miles beyond the main centres of population. Most of the main geological regions, on the other hand, trend northerly (Figure 1) and there are no known broad geological reasons for expecting that mineral deposits are less abundant or less rich in the northern parts of these regions than in the southern parts. Thus the concentration of producing properties in the southern third of Canada is attributable to relatively easy access and thorough prospecting. Accordingly, as the northern areas receive their share of attention, they are likely to prove as productive of minerals as have the southern areas. Furthermore, the potentialities of even the southern areas are far from exhausted, as is amply demonstrated by the number, size, variety, and distribution of the mineral deposits found there during recent years by conventional prospecting and by geophysical methods.

Table III

Value of Principal Mineral Products by Provinces, 1955[1] and Accumulative

	CANADA			Newfoundland			Nova Scotia		
	1955	Accumulative	Since	1955	Accumulative	Since	1955	Accumulative	Since
	$	$		$	$		$	$	
Copper	239,394,952	2,531,534,148	1886	2,348,569	12,312,366	1949	811,988	2,306,042	1936
Gold	157,305,152	4,201,524,317	1858	210,596	1,990,584	1949	135,507	26,004,379	1861
Iron ore	110,387,974	349,357,037	1939	45,701,801	113,266,501	1949	—	547,473	1906
Lead	55,786,929	889,610,628	1887	5,043,735	37,516,512	1949	587,423	2,045,964	1936
Nickel	216,433,694	2,472,648,761	1889	—	—	—	—	—	—
Silver	24,625,797	681,334,888	1887	585,000	3,685,782	1949	238,964	857,665	1924
Zinc	116,425,122	1,203,263,766	1898	7,821,450	61,708,086	1949	2,200,380	8,449,339	1936
Asbestos	98,690,514	1,029,433,979	1880	—	—	—	—	—	—
Gypsum	8,455,173	131,805,228	1874	212,800	509,274	1952	6,452,218	64,211,706	1874
Salt	10,286,210	137,181,400	1886	—	—	—	1,956,318	15,888,224	1919
Coal	92,227,211	3,161,516,065	1785	—	—	—	49,549,650	1,468,112,250	1785
Natural gas	14,457,075	340,219,023	1892	—	—	—	—	—	—
Petroleum, crude	303,561,100	1,402,016,285	1886	—	—	—	—	—	—

	New Brunswick			Quebec			Ontario		
	1955	Accumulative	Since	1955	Accumulative	Since	1955	Accumulative	Since
	$	$		$	$		$	$	
Copper	18,622	27,841	1917	74,400,117	538,378,933	1886	106,967,164	1,168,270,636	1886
Gold	—	—	—	39,893,725	727,518,794	1877	87,214,494	2,421,157,661	1887
Iron ore	—	962,002	1910	29,520,165	33,338,474	1954	31,421,702	190,375,243	1906
Lead	229,200	229,200	1955	1,512,181	23,087,537	1890	603,960	6,450,179	1903
Nickel	—	—	—	—	—	—	199,545,300	2,462,105,528	1899
Silver	**22,319**	22,645	1917	4,407,960	43,008,557	1887	5,260,630	322,927,142	1887
Zinc	—	—	—	28,007,880	248,472,039	1898	418,372	1,814,310	1899
Asbestos	—	—	—	88,558,239	998,195,975	1880	4,209,275	21,393,351	1917
Gypsum	225,000	16,851,512	1875	—	—	—	808,000	19,923,518	1886
Salt	—	—	—	—	—	—	6,143,792	100,594,752	1898
Coal	6,699,010	82,061,200	1887	—	—	—	—	—	—
Natural gas	136,500	9,319,365	1912	—	—	—	4,280,000	212,370,964	1892
Petroleum, crude	17,500	1,010,491	1910	—	—	—	1,710,300	43,775,049	1886

	Manitoba			Saskatchewan			Alberta		
	1955	Accumulative	Since	1955	Accumulative	Since	1955	Accumulative	Since
	$	$		$	$		$	$	
Copper	14,237,850	151,286,611	1917	24,226,875	209,327,981	1933	—	—	—
Gold	4,538,352	115,404,839	1917	2,893,111	74,760,529	1932	6,697	441,383	1897
Iron ore	—	—	—	—	—	—	—	—	—
Lead	—	601	1935	—	—	—	—	—	—
Nickel	16,888,394	20,505,490	1954	—	—	—	—	—	—
Silver	393,255	10,495,625	1917	1,078,979	17,940,008	1932	18	222	1927
Zinc	4,845,750	68,302,783	1930	13,465,725	132,123,274	1933	—	—	—
Asbestos	—	—	—	—	—	—	—	—	—
Gypsum	347,155	16,966,397	1901	—	—	—	—	—	—
Salt	461,200	6,349,696	1932	984,000	4,620,337	1921	740,900	7,574,777	1925
Coal	—	29,519	1931	4,171,399	75,873,866	1890	23,216,397	1,019,105,166	1886
Natural gas	—	2,700	1920	528,325	1,876,257	1934	9,506,250	176,568,595	1903
Petroleum, crude	9,905,000	17,495,232	1951	18,491,500	38,142,095	1945	273,094,800	1,296,173,832	1914

	British Columbia			Northwest Territories			Yukon		
	1955	Accumulative	Since	1955	Accumulative	Since	1955	Accumulative	Since
	$	$		$	$		$	$	
Copper	16,383,767	445,445,279	1894	—	26,607	1938	—	2,711,695	1906
Gold	8,854,370	514,391,309	1858	10,990,405	82,761,327	1935	2,567,895	237,298,201	1886
Iron ore	4,649,116	21,672,172	1886	—	—	—	—	—	—
Lead	44,106,000	794,622,915	1887	—	4,933	1934	3,704,430	25,652,788	1913
Nickel	—	87,724	1936	—	—	—	—	—	—
Silver	7,574,072	231,775,305	1887	101,595	1,311,266	1932	4,963,005	49,308,611	1899
Zinc	57,102,070	672,902,739	1905	—	—	—	2,563,495	11,589,364	1949
Asbestos	5,923,000	9,855,467	1952	—	—	—	—	—	—
Gypsum	410,000	7,056,603	1911	—	—	—	—	—	—
Salt	—	—	—	—	—	—	—	—	—
Coal	8,503,311	516,002,394	1836	—	—	—	87,444	1,559,285	1901
Natural gas	—	—	—	6,000	81,154	1936	—	—	—
Petroleum, crude	—	—	—	342,000	5,424,330	1932	—	—	—

[1]In this table the figures for 1955 are preliminary.

TABLE IV

Value of Mineral Production by Provinces, 1900-55

Year	Nfld.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Yukon	N.W.T.
					(millions of dollars)						
1955.....	68.4	67.1	15.7	357.0	583.9	62.0	85.1	326.0	189.5	14.7	25.6
1954.....	42.9	73.5	12.5	278.8	496.7	35.1	68.2	279.0	158.6	16.6	26.4
1953.....	33.8	67.4	11.7	251.9	465.9	25.3	48.1	248.9	158.5	14.7	10.3
1952.....	32.5	64.5	11.3	270.3	444.7	25.1	49.5	196.8	170.1	11.4	8.9
1951.....	32.4	59.7	9.5	255.5	444.7	30.0	51.0	168.1	176.3	9.8	8.3
1950.....	25.8	59.5	12.8	220.2	366.8	32.7	36.0	135.7	138.9	9.0	8.1
1945.....		32.2	4.2	91.5	216.5	14.4	22.3	51.7	64.1	1.2	0.5
1940.....	Not	33.3	3.4	86.3	261.5	17.8	11.5	35.1	74.1	4.1	2.6
1935.....		23.2	2.8	39.1	158.9	12.0	3.8	22.3	48.7	1.3	0.5
1930.....		27.0	2.4	41.2	113.5	5.5	2.4	30.4	55.0	2.5	—
1925.....	in-	17.6	1.7	24.3	88.0	2.3	1.1	25.3	64.5	1.8	—
1920.....		34.1	2.5	28.9	81.7	4.2	1.9	35.6	39.4	1.6	—
1915.....		18.1	0.9	11.6	61.1	1.3	0.5	9.9	5.1	28.7	—
1910.....	cluded	14.2	0.6	8.3	43.5	1.5	0.5	9.0	4.8	24.5	—
1905.....		11.5	0.6	4.4	18.8		See		22.4	—	—
1900.....		9.3	0.4	3.3	11.3		Note		16.7	—	—

NOTE: The combined value of the mineral production from Manitoba, Saskatchewan, and Alberta was $23.5 million in 1900, and $11.4 million in 1905.

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CHAPTER II

THE CANADIAN SHIELD MAINLAND

(J. M. Harrison)

The Canadian Shield is a great region of Precambrian rocks that constitutes the backbone of Canada and forms the bedrock for a land area of about 1,864,000 square miles. Most of this area is in the mainland of Canada, but about 196,000 square miles are in the Arctic Islands and another 93,000 square miles lie in the northern part of central United States (Table V).

TABLE V

Canadian Shield Areas

Labrador	104,000 sq. miles	
Quebec	538,000 "	
Ontario	254,000 "	
Manitoba	141,000 "	
Saskatchewan	87,000 "	
Mackenzie	233,000 "	
Keewatin	188,000 "	
Franklin, mainland	30,000 "	
Canadian mainland		1,575,000
Franklin, islands	196,000	
Canada Total		1,771,000
U.S.A.	93,000	
Total, Canadian Shield		1,864,000

The Canadian Shield forms a huge ellipse whose axis trends about north-northwest (Figure 1). This ellipse includes Baffin Island, which is part of the Shield, but there is a hole in the centre marked by Hudson Bay and by a thin cover of Palæozoic rocks off the southwestern part of the Bay. It is probable that Hudson Bay is largely underlain by Precambrian rocks or that the Precambrian is covered by only a thin coating of Palæozoic rocks.

One of the Canadian Shield's great resources is the water power potentially available for electrical energy, a feature that is especially valuable in the industrial east. Numerous streams following confined channels may be harnessed for their energy. Probably the greatest potential—but yet untapped—source is the Grand Falls and its Bowdoin Canyon on the Hamilton River in Labrador (Plate II) where at least two million horsepower can be developed. This region is under active study. Another great and spectacular potential source of hydro-electricity is Eaton Canyon on the Kaniapiskau River in New Quebec, about 50

Plate II | *Grand Falls on Hamilton River and head of Bowdoin Canyon, Labrador, Newfoundland.*

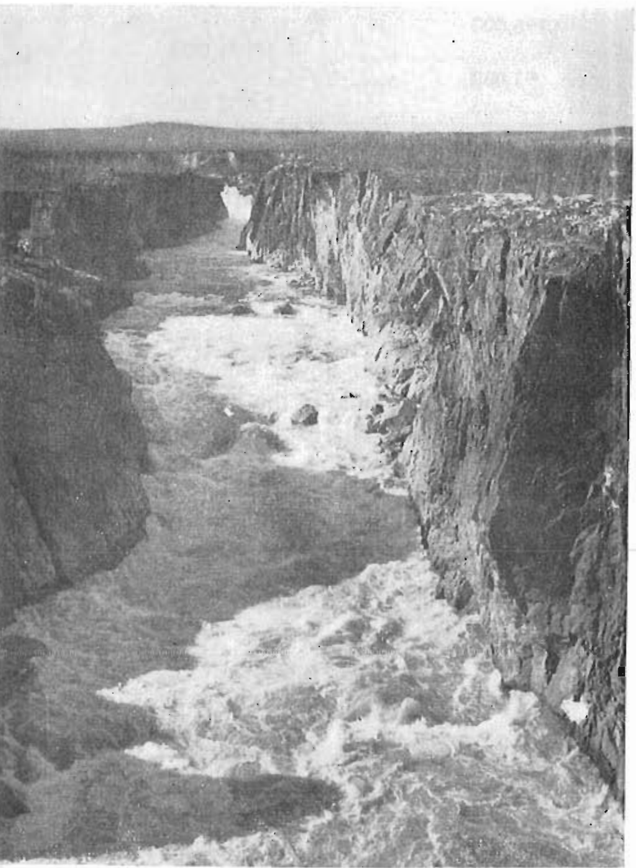


Plate III

Head of Eaton Canyon on Kaniapiskau River, Quebec.

miles northwest of Knob Lake, where at least 500,000 horsepower of electrical energy are available (Plate III).

Much of the Canadian Shield lies too far north to be farmed effectively, even if the nature of the soil were such as to permit agriculture. Here and there some of the more frost-resistant crops can be grown, but for much the larger part of the Shield area it is doubtful if agriculture ever will become important. Most of the potential soils are too sandy and gravelly to permit growth of crops, and the climate provides too short a growing season. Some exceptions occur, of which the largest area is the "clay-belt" of Ontario-Quebec. Excellent flower gardens and vegetables are grown at Yellowknife at latitude 62 degrees north, but on imported soil.

Timber in the Canadian Shield provides much income in the form of pulp and paper products, for the whole southern part of the Shield is heavily forested by coniferous trees associated with stands of mixed hardwood in the south and with birch alone in the more northerly parts. Still farther north, of course, no trees grow and the great barren lands extend as far north as land exists. In these barren regions occasional clumps of dwarf willows can be found, but mostly the growth consists of coarse sedges, mosses, lichens, and tiny shrubs.

Ever since Canada's earliest days, the northern forests and the barren lands have been a source of fur. This fur trade will probably provide an important source of income for new generations of local residents, but the proportion of wealth to be derived by furs from this northern territory will inevitably become smaller as the mineral wealth is exploited.

Topography

The topography of the Canadian Shield varies from a flat, featureless plain to wildly mountainous country. On the mainland the highest peaks are those in the Torngat Mountains (Plate IV) in the northern part of the coast of Labrador where Cirque Mountain is at an elevation of 5,500 feet a couple of miles from the sea. Most of the mountainous and more rugged terrain is near the outer edge of the Shield so that, in a crude way, the surface of the Shield is saucer-shaped. Some semi-mountainous country is known in the interior but over much of the Shield local relief is very low and the skyline monotonously even,—features that are characteristic of an ancient peneplain and that have been remarked on in hundreds of reports. Recent drilling in some interior areas of the Shield, formerly thought to be flat and featureless, has shown depths of overburden of 400 feet or more, so that at least some of the peneplained appearance is due to filling in of low spots by glacial debris.

One of the major results of the continental glaciation that covered most of the Shield was the damming and filling of previously existing drainage so that it became completely disorganized. Shallow lakes commonly spill over the lowest point of their rims into shallow but turbulent streams. Obviously this complete disorganization does not apply to lakes marked by great depths, as, for example,

Plate IV

Torngat Mountains, coast of Labrador.

Lake Superior, Michikamau Lake, the east arm of Great Slave Lake, Great Bear Lake, a lake in the New Quebec crater, and numerous other bodies of water scattered throughout the Shield. Why these great lakes should not have been filled by glacial debris is not at all clear, but it was probably due to their great pre-glacial depth, the comparatively small amount of glacial debris, and the fact that the ice cover of these lakes provided a good slip surface so that little material was dropped from the continental ice. Certain other lakes, on the other hand, show features to be expected in drift-covered topography flooded by a shallow body of water. These are especially common, for example, in the area about the height of land in the Ungava peninsula, and such lakes have been seen by everyone who has flown over the barren lands in summer. They are especially characterized by flooded or drowned ice-polygons, boulder shores, and abundant, low, muddy or bouldery islands.

The confused drainage that resulted from the glaciation also produced a myriad of lakes, a feature that characterizes much of the Canadian Shield (Plate V). This abundance of lakes made possible relative ease of travel by canoes and permitted such men as Robert Bell, A. P. Low, and J. B. Tyrrell to carry out their outstanding early explorations. In more recent times, they permitted the opening up of the north by float-equipped aircraft and, still more recently, these lakes were used to map large areas geologically on reconnaissance scale with the aid of float-equipped helicopters. However, the canoe and the float-equipped airplanes are likely to remain the prospectors' most suitable means of travel for many years to come.

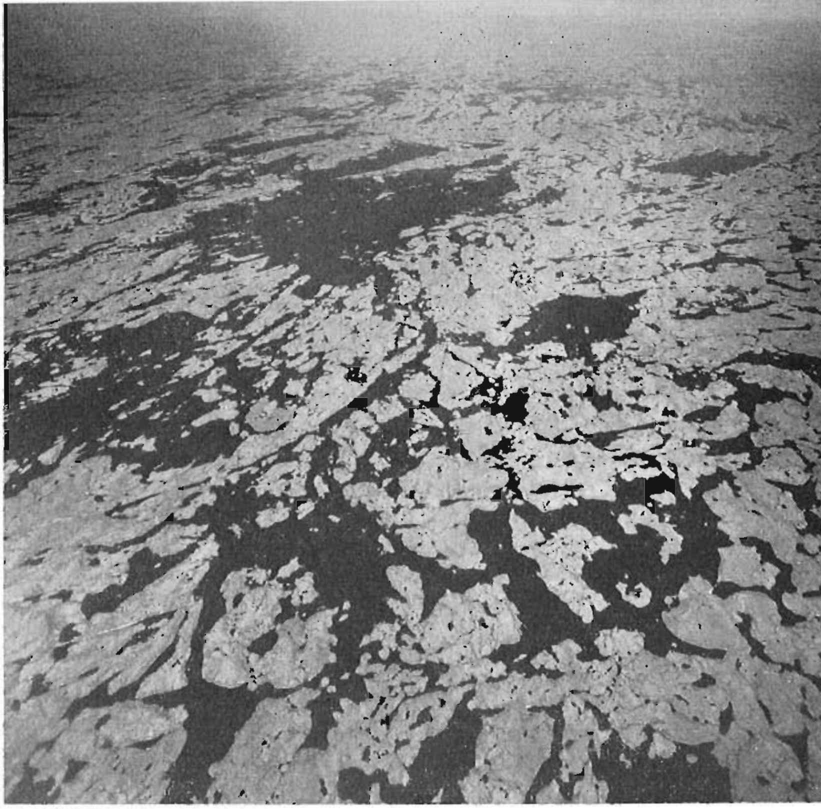


Plate V

Abundant lakes of the Canadian Shield.

History of Exploration

Geological exploration of the Canadian Shield began with the founder of the Geological Survey of Canada, Sir William Logan, who reported on the Grenville gneisses as a result of his survey of the Ottawa River in 1845: the next year, assisted by Alexander Murray, he examined the north shore of Lake Superior and in 1847 Murray mapped the north shore of Lake Huron. For many years Geological Survey work was largely exploration, and the officers were expected to collect data on flora and fauna and make topographic maps as well as to study the geology. Many men outstanding in the history of the Survey made remarkable exploratory traverses across parts of the Shield. They include A. R. C. Selwyn, G. M. Dawson, William McInnes, McIntosh Bell, and many others, but none exceeded in length, hardship and value the journeys of Robert Bell, J. B. Tyrrell, and A. P. Low in the last quarter of the 1800s. Robert Bell made many of the first surveys between Lake Superior and James Bay and between Lake Winnipeg and Hudson Bay, and was the first to report on iron-bearing rocks of the Nastapoka Islands off the east coast of Hudson Bay. A. P. Low is most noted for his explorations in the Ungava (Labrador) peninsula in the 1890s and until about 1940 almost the only available maps of much of the peninsula were those he made. In 1893 and 1894 he travelled 2,960 miles by canoe, 1,000 miles by steamer, 1,000 miles on foot and 500 miles by dog team, a total of 5,460 miles, and it was on this survey that he discovered the great belt of iron-bearing rocks from which production of high-grade iron ore is being won in the Knob Lake district. Besides this two-year project, when he wintered in the field, he spent single seasons mapping elsewhere on the peninsula and spent one season making a more detailed study of the iron-formation on Nastapoka Islands.

J. B. Tyrrell, who joined the Survey in 1881 and only in 1955 relinquished his position as president of a mining company, made some outstanding explorations in what is now northern Saskatchewan and Manitoba, and the eastern Northwest Territories. In 1893 and 1894 he made two epic trips, each of which involved walking back to Winnipeg from Churchill in the winter. The total distance travelled beyond the railways in those two years was 6,100 miles, most of it by canoe and on foot and part of it on near-starvation rations. Shortly after the turn of the century the emphasis began to change to systematic surveys of areas and consequently the assemblage of more detailed information, and by 1930 exploration surveys were virtually ended.

The advent of the float-equipped airplane in the 1920s and its general use in the 1930s greatly speeded the accumulation of data, especially in remote parts of the Shield, because so little time is consumed in reaching the area to be investigated. The simultaneous development of air photography permitted a greater degree of accuracy, and geological mapping therefore increased in rate and quality. Nevertheless, mapping the Shield was relatively slow and costly, and by the 1950s only a small percentage was mapped on any scale. Moreover, as field parties moved farther north, where seasons free of ice are shorter, canoe travel became more and more limited. In 1952 helicopters were first used in systematic reconnaissance mapping of the barren lands and their successful employment has continued through three field seasons when about 185,000 square miles of the Northwest Territories was mapped at a cost per square mile equivalent to, or less than, that of conventional methods and which made results available at least a generation earlier than would otherwise have been possible. A helicopter operation in wooded country east of James Bay is planned for 1957, and, if successful, the use of helicopters will enable the Geological Survey to supply geological maps of the whole of the Shield in the relatively near future. Besides regional mapping, geophysical and geochemical services enable the geologist to plan his work more efficiently and to interpret his work more precisely but, so far, no substitute has been found for the painstaking assemblage of field data that characterizes detailed mapping. It is probable that detailed studies of the Shield will continue for many generations.

Geology

Great strides have been made in mapping the Canadian Shield in the last decade, but even so the amount covered by systematic mapping on any detailed scale remains comparatively small. Obviously it is impossible to correlate rocks of one region with those of another because Precambrian rocks lack the diagnostic fossils so necessary for correlation. In recent years numerous determinations of absolute age have been made on minerals from dykes, sills, and granitic bodies in the Canadian Shield. These, it is hoped, will provide a sound basis on which to correlate between areas and perhaps eventually to establish a stratigraphic timetable similar to that applied to younger fossiliferous strata.

The application of rock and time terms to Precambrian strata has become much confused. At present new hypotheses are being propounded and others are being renovated, so that standardization of nomenclature is nearly non-existent and it is practically impossible to obtain any general acceptance for the meaning or usage of particular terms. The discussion that follows is an attempt to clarify the nomenclature to be used in describing various stratigraphic successions. The conclusions reached are believed to represent the opinion of most students of the Precambrian on the Geological Survey of Canada even though the statements are no doubt coloured by the writer's thoughts and experience.

General Problems of Precambrian Correlation

Many problems in Precambrian terminology stem from the wholesale transference of names from the type locality to areas far removed and for which there was no possibility of direct correlation. Thus, "Keewatin" was transferred from extreme western Ontario to the Lake Timiskaming region of Ontario and Quebec; "Timiskaming" was applied to rocks at Red Lake, as well as at Lake Timiskaming; "Huronian" was taken hundreds of miles from the north shore of Lake Huron; and so on. Unfortunately, a connotation of absolute time became associated with the names, and rocks in western Quebec were correlated with rocks in western Ontario in the belief that they were deposited at about the same time. Several geologists have pointed out the folly of this procedure and, in recent years, more and more geologists have urged that specific names be abandoned. However, local names are a common and necessary tool for descriptive and stratigraphic geology and they have been used with success in the Precambrian of Canada everywhere west of the Manitoba-Ontario boundary and in Ungava peninsula. Naturally, correlative tables have been suggested for various areas within these regions, but mainly to compare stratigraphic successions exposed in the various areas.

Except for Ontario and western Quebec it has been common to confine a name to rock units only so far as the units can be traced by outcrop. Thus, although the names are abundant and varied, the ideas have been kept somewhat clearer than would otherwise have been possible. The only terms that are used throughout the Shield are Archæan and Proterozoic, terms that are used in the sense of eras, as was rather explicitly defined by a committee of the Royal Society of Canada in 1934. These two units of rocks are commonly separated by a great unconformity—the ep-Archæan interval of A. C. Lawson and the pre-Huronian palæoplain of M. E. Wilson. Nevertheless, to many geologists the terms Archæan and Proterozoic probably signify "relatively early" and "relatively late" Precambrian of particular areas of regions.

In recent years J. E. Gill and J. T. Wilson have emphasized the probability that Precambrian time was marked by many orogenic cycles and that so-called Archæan rocks in one area may actually be younger than Proterozoic strata in another. Perhaps so, but from radioactive dates available at the end of 1955, the oldest Proterozoic rocks are all younger than rocks mapped elsewhere as Archæan. Many Proterozoic successions are older than 1,000 million years, a figure that somehow came to be considered as the beginning of Proterozoic time, and the fact that uraniferous veins cut Proterozoic strata and are about 1,900 million years old has been taken to mean that the strata and veins are Archæan in age. It would probably be more nearly correct to say that Proterozoic time began more than 1,900 million years ago.

Most of the minerals for which age determinations are available come from pegmatites or veins and presumably, therefore, these dates represent the end phases of orogenies or intrusive cycles that affect the rocks. If deposition, deformation, and intrusion follow one another fairly closely, then the date of orogeny gives a fair approximation of the date of sedimentation. Minerals from Stark Lake give an age of about 1,850 million years for pegmatites that are overlain by Great Slave rocks, and an age of about 1,700 million years for pegmatites believed to be younger than Great Slave. If the ages and interpretations are nearly correct, then Great Slave rocks are younger than 1,850 and older than 1,700 million years. If the same conditions apply to the Athabasca sandstone, then this succession probably is nearly 2,000 million years old, because radioactive minerals indicate an age of nearly 1,900 million years for veins that cut the rock. However the veins occur in folded "Athabasca" rocks on the north shore of the lake and W. E. Hale has recently reported that the flat-lying sandstone overlies the more indurated and deformed "Athabasca" rocks with angular discordance. It is possible, therefore, that the folded "Athabasca" rocks north of the lake are much older than the flat-lying rocks to the south and, if so, these lower units should receive a new name.

J. B. Tyrrell correlated the upper Athabasca rocks with the Dubawnt sandstone about 150 miles to the northeast, but the Dubawnt must be much younger than the 1,900 million years indicated by radioactive ages for the lower "Athabasca", as indicated by the arguments that follow. Uranium-bearing minerals in veins that cut the Snare-Echo Bay rocks at Great Bear Lake give an age of about 1,400 million years, or about 400 million less than similar veins in Athabasca rocks. As pointed out by K. E. Eade, the Snare-Echo Bay groups trend northeast and the trend is crossed and cut off by the rocks of the Coppermine River-Bathurst Inlet belt, so presumably the rocks along the Arctic coast are still younger. Because the trends are at large angles it seems reasonable to expect that the rocks of the Arctic belt are considerably younger than those of Snare-Echo Bay. From Bathurst Inlet a great fault that cuts the Arctic belt of rocks extends south-southeast into the region occupied by the Dubawnt sandstone. There is no suggestion of this fault in the Dubawnt area and, moreover, the valley that marks this fault locally contains flat-lying outcrops of rock exactly similar to the Dubawnt sandstone that covers the fault trace farther south. On this basis, the Dubawnt rocks should be among the youngest Precambrian groups in the northwest and very much younger than the folded "Athabasca" rocks. If they are to be correlated with the undeformed Athabasca, then the latter must also be very much younger than the folded units.

It has been argued by some geologists that to call two or more widely separated areas of rocks either Archæan or Proterozoic is to imply equivalence in age. To do so, however, no more implies equivalence in age than does the term Palæozoic when applied to Cambrian and Permian rocks. In fact, even less so, for we have already seen that Proterozoic time, as used here, extends through a much longer era than does the Palæozoic.

Some years ago J. E. Gill pointed out that so-called Proterozoic rocks differed from Archæan rocks in having an abundance of clean sandstone and quartzite, and of limy rocks. He suggested that this difference is significant and the writer is inclined to agree. Perhaps certain conditions of atmosphere, sea water, and orogeny were necessary for the deposition of these rocks and, concomitantly, the evolution of life. Even though we lack enough radioactive datings to be sure, it is a most unusual circumstance that dates all pegmatites and veins from Proterozoic successions as younger than the Archæan. It is reasonable to expect that within a comparatively few years, and assuming that our concepts of radioactive decay do not change, we should be able to assign an absolute age to the beginning of Proterozoic time.

Archæan and Proterozoic rocks have been subdivided into units used roughly in the sense of systems and series of younger rocks. Obviously, the smaller the unit the more fruitless it is to correlate with rocks of another area, and one of the unfortunate aspects of Precambrian studies has been the wholesale transfer of names from one area to another on the basis of lithologic similarities and wishful thinking. This procedure has led to much confusion in the central part of the Canadian Shield where the names were standardized throughout all Ontario and, for the most part, in western Quebec, and led to the table of formations that was shown in the previous edition of this volume as the "standard" for the Precambrian. This ideal concept is shown in Table VI. The rocks of this table are nowhere exposed in succession in any one area so that it is a combination of stratigraphic successions from various parts of the Canadian Shield in Ontario.

Table VI

"Classic" Table of the Precambrian

Era	Period-System	Epoch-Series		Age—millions of years
Proterozoic	Keweenawan	Osler, Sibley etc.	Late Proterozoic	500 to 2,000
	Huronian	Animikie		
		Cobalt	Early Proterozoic	
		Bruce		
Archæan	Timiskaming			2,000 to 4,800
	Keewatin			

In the foregoing table certain units have been omitted, such as the Grenville, because not even the classicists could agree as to their relative position. The

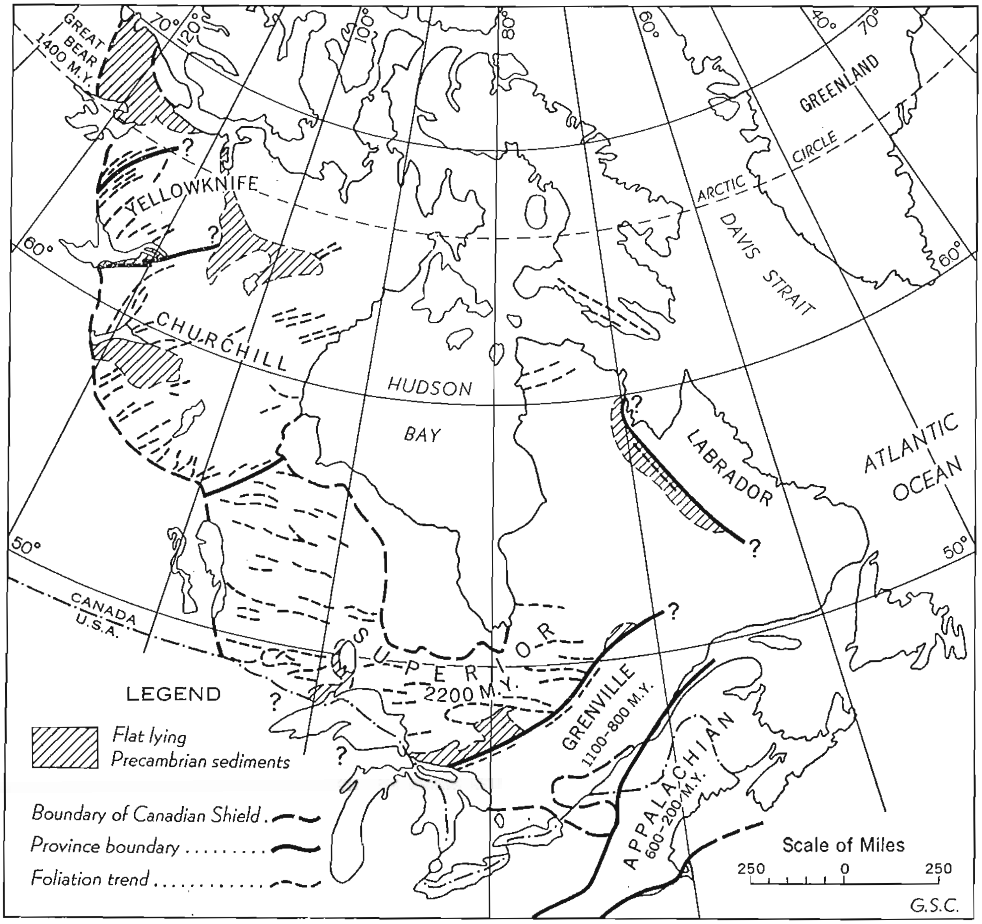


FIGURE 2. Geological provinces of the Canadian Shield. Age determinations considered to show the period of orogenic activity are shown in millions of years. (After J. T. Wilson.)

estimated time that has been assigned to the Archæan and Proterozoic eras is simply a crude guess based on rates of radioactive decay and on estimates of the age of the earth. No rocks have so far been found whose ages approach the 4.8 billion years that is currently fashionable to assign to the age of the earth. Finally, although this table leaves much to be desired, it is probably the one generally familiar and, therefore, provides a useful framework for the discussion to follow.

Lately, the concept of provincial units for the Canadian Shield has been gaining in popularity and the idea has much merit. An example of such a breakdown is shown in Figure 2. It would be much less futile to correlate rocks within structural and genetic provinces than to attempt correlations between such units. Such divisions will, of course, be modified as more knowledge is gained and eventually the increased knowledge may permit Shield-wide correlations.

Plate VI — *Pillow structure in lava of the Yellowknife group, southeast of Gordon Lake, N.W.T. Shapes indicate that top of flow faces towards upper left-hand corner.*

Archæan

For many years geologists working in Ontario and adjacent parts of Quebec separated the Archæan rocks into two major divisions, the older Keewatin and the younger Timiskaming.

Keewatin

The term Keewatin was first applied in 1885 by A. C. Lawson to lavas in the Rainy Lake and Lake of the Woods areas of Ontario. This original Keewatin succession consists of a great thickness of rather highly altered basic to intermediate lavas with some interbedded sedimentary material. The name "Keewatin" was soon applied to nearly all similar lavas throughout northern Ontario and northwestern Quebec that were believed to be the oldest strata of the particular region being mapped. As mapping progressed more and more successions of "Keewatin" lavas were found to be interbedded with sedimentary rocks. Presumably, the term now means these oldest rocks that consist mainly of basic to intermediate volcanic rocks with local accumulations of sedimentary material. Because the term was applied to the basal rocks in such mining camps as Noranda, Timmins, and Kirkland Lake, the rocks in these camps have come to be considered typical of the Keewatin.

These supposedly Keewatin rocks of the central part of the Shield contain some rhyolites and trachytes which locally, as near Noranda, occur in considerable volume. Although the lavas are commonly altered to aggregates of secondary minerals such as chlorite, epidote, sericite, and oligoclase, primary structures such as pillows (Plate VI), flow lines, amygdules, and grain, are still clear so that tops of flows can be determined.

Relatively small bodies of sedimentary rocks are interbedded with some of the flows. Many of these are ash rocks that range from fine tuff to coarse agglomerate, and thin bedding indicates that they were probably deposited in water. These bodies have rarely been traced more than a few miles along strike and, therefore, differ from the ash falls of the fossiliferous eras.

Bedded chert or fine quartz is a common associate of Keewatin lavas and, where it contains appreciable quantities of iron oxide, sulphide, or carbonate, is termed iron-formation. Most of these bands are only a few inches thick but here and there they attain thicknesses of hundreds of feet and are being intensively prospected as potential sources of iron ore.

In addition to these special sediments, more normal varieties are also found associated with the Keewatin volcanic rocks. These are assemblages of conglomerate, greywacke, and slate, and they form bands several thousands of feet wide. Some of these are interbedded with the lavas, so they must be part of the Keewatin. However, in some places they are so abundant that several geologists have divided the Keewatin into several groups and some have abandoned the term altogether.

One of the features of the Keewatin assemblages is their great thickness. M. E. Wilson gives an average of 25,000 feet in the Noranda area, and similar thicknesses are reported from many other areas.

To the west of the Ontario-Quebec region, sedimentary rocks become more abundant in the basement assemblages. In Rainy Lake district the Couchiching, a thick series of sedimentary rocks, appears to underlie the Keewatin, although some authorities consider that it is interbedded with the Keewatin. In southern Manitoba the Rice Lake series consists of a central band of lavas both overlain and underlain conformably by thick bands of sedimentary material. Farther north, the basal Amisk, Wasekwan, and Oxford House groups all contain considerable proportions of sedimentary rocks. At Lake Athabasca the Tazin group consists mainly of sedimentary rocks and metamorphic derivatives, but A. M. Christie and others consider they may actually be Proterozoic rather than Archæan. In western Northwest Territories the sedimentary members of the basal groups greatly exceed in amount the volcanic material. These groups have been variously named the Point Lake-Wilson Island, and Yellowknife groups, and in all these successions greywacke and slate are the predominant rocks.

The Shield east of Hudson and James Bays is very imperfectly known, but there seem to be no, or very few, remnants of the basal volcanic and sedimentary assemblages except, perhaps, as parts of the highly granitized terrain.

Timiskaming

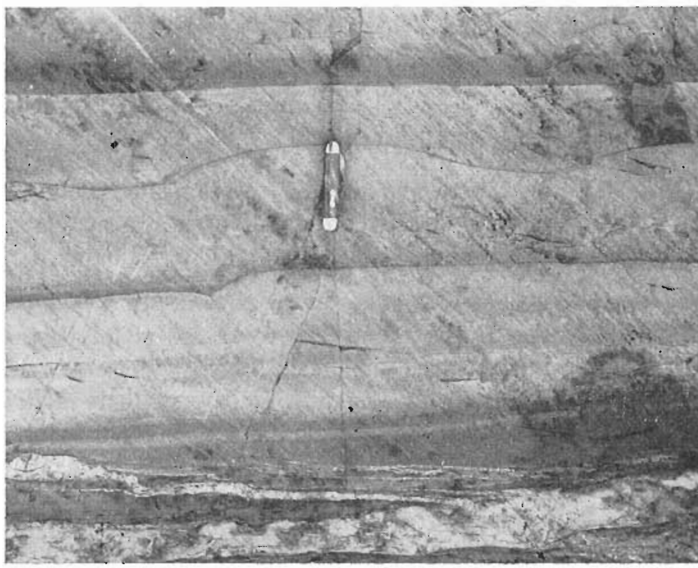
Timiskaming is a term that has commonly been applied to the younger, predominantly sedimentary rocks of the Archæan succession. They were named by W. G. Miller at Lake Timiskaming in 1911, where the group contains conglomerates characterized by pebbles of iron-formation, supposed to have been derived from iron-formation in the Keewatin, and by pebbles of granitic material.

It was, therefore, assumed that the two series were separated by an unconformity. As with "Keewatin", the term "Timiskaming" was adopted across most of Ontario and in western Quebec. Some of the successions were shown to overlie the Keewatin with structural unconformity and this feature became an inherent part of the definition. In most places granitic pebbles in the Timiskaming conglomerates provide the only evidence for a pre-Timiskaming granite, which is commonly termed the "Laurentian", but many authors infer that such an intrusion is post-Keewatin.

The successions classified as Timiskaming commonly consist mainly of greywacke and slate with a conglomerate at or near the base, but they include also some arkose, quartzite, and, locally, some limy rocks. As pointed out several years ago by Pettijohn, the Archæan successions are characteristic of geosynclinal facies

Plate VII

Graded bedding and scour in Timiskaming greywacke showing tops facing towards bottom of picture.



and the sedimentary units are marked by graded bedding (Plate VII), scour or channelling, and small-scale crossbedding. In places they are interbedded with considerable thicknesses of volcanic rocks and the total thicknesses of Timiskaming strata commonly reach several thousands of feet.

The largest belt of Timiskaming rocks is that extending eastward through Kirkland Lake, Ontario, to Val d'Or, Quebec, nearly 150 miles. Other smaller bodies of such rocks have been called Timiskaming near Cobalt, Matachewan, Timmins, Opeepeesway Lake, and Red Lake in Ontario. However, local names have been used more generally than for analogous rocks of presumed Keewatin age and, in central Ontario, the Dore series of Michipicoten and the Windigokan series east of Lake Nipigon are equated with this group. West of the lake many bodies of similar rock have been described, among which are the sedimentary rocks of Lake Savant and the Seine series of Rainy Lake.

West of the Manitoba-Ontario boundary, local names have been used exclusively to designate the younger sedimentary units. These include the San Antonio formation in southeastern Manitoba, and the Missi, Sickle, Island Lake, and Oxford Lake groups of central Manitoba and adjacent parts of Saskatchewan. Some authors have suggested that these units, especially the Missi, might more properly be designated as part of the Proterozoic. This, of course, is a possibility, but until such time as positive evidence to the contrary is available it seems more reasonable to classify these groups as Archæan. In the Northwest Territories, however, no units have been correlated with the Timiskaming, and none can be unless some of the sedimentary units in the basement successions should be so considered.

Except in a few small areas, no rocks in Quebec away from the Kirkland Lake-Val d'Or belt have been considered equivalent to Timiskaming. The exceptions are the Broadback and Opemisca groups near Chibougamau and north of there, but in the whole of Ungava peninsula no rocks are known that can be considered equivalent to the Timiskaming.

Miscellaneous Archæan

Here and there throughout the Shield are groups of rocks that do not fit in with the usual concept of Keewatin or Timiskaming, a feature, no doubt, to be expected for rocks of an era that probably lasted 2,000 million years or more.

The Pontiac group of rocks in western Quebec lies unconformably beneath the Timiskaming. The rocks are mainly sedimentary but have been converted to mica, chlorite, and talc schists with some remnants of quartzite. They are not in contact with Keewatin rocks, and their relative ages are not known. However, if Keewatin, or equivalent rocks, contain sedimentary assemblages then the Pontiac sediments probably should be considered as part of the Keewatin.

The Kisseynew gneisses of northern Manitoba and Saskatchewan have commonly been assigned to the Archæan, although the possibility of their Proterozoic age has been acknowledged. The assemblage is very highly altered and closely resembles the Grenville rocks of southeastern Ontario and southwestern Quebec except that crystalline limestone is not so abundant. It seems to the author that these rocks are more likely to be Proterozoic than Archæan and they will be discussed with Grenville rocks.

So far as our limited knowledge is concerned, most of the Ungava peninsula is underlain by granitic gneisses with remnants of sedimentary and volcanic strata preserved locally but highly metamorphosed. In fact, granitic gneisses such as these form the bedrock of much of the Shield and only in a few places, especially in the Northwest Territories and in the Grenville terrain, has it been possible to indicate areas of granitic rocks that formed during Proterozoic time. In Ungava isolated patches and belts of Proterozoic strata overlie the granitic gneisses unconformably and the gneisses are, therefore, classed as Archæan. In Manitoba and adjacent parts of Ontario and Saskatchewan no Proterozoic rocks are known and the granitic rocks are classified as Archæan with an acknowledgment that some may be Proterozoic. Even in the Northwest Territories and in northwestern Saskatchewan, where some Proterozoic granites have been distinguished, most granitic terrains are assumed to be Archæan.

Post-Timiskaming

The Archæan era, as commonly considered, was closed by a period of mountain building and granitic intrusion. It seems probable that the orogeny that closed the Archæan in one area may have occurred at a different time from the orogeny of another area, but an orogeny is the cardinal feature of the end of Archæan time in any given area. In central Canada this upheaval has been called the Algoman, but names do not seem to have been generally applied elsewhere in the Shield. The classic concept made this time into the "ep-Archæan interval" of Lawson or the "pre-Huronian palæoplain" of M. E. Wilson the time when the post-Timiskaming mountains were built and eroded. It is much more probable that several mountain chains were built and eroded at different times and each, at that place, marked the end of the Archæan. However, it is here assumed, lacking evidence to the contrary, that all Archæan rocks had formed before Proterozoic deposition commenced.

Proterozoic

In many areas underlain by Precambrian rocks two assemblages are separated by a profound unconformity, the Proterozoic being the younger, less altered, and commonly less deformed. These Proterozoic rocks occur in isolated patches or belts throughout the Canadian Shield and a crude sort of correlation between them has been attempted or implied. However, it was realized that such correlations, based on lithology and structural relations, are improbable at best, especially as Proterozoic time lasted so long.

The Proterozoic era, (era of "first life"), is the one during which life is supposed to have begun and developed. Of the nine great groups into which all animal forms are divided, eight were already represented at the beginning of the Cambrian period; the only one missing was the group of the vertebrates. So great an evolution implies that life had already existed for an immense length of time and many writers have supposed that it must extend back into the Archæan era, which they would term the Archæozoic, or time of ancient life.

Where large areas of Proterozoic rocks have been mapped it has usually been found that these rocks can be separated into two or more units on the basis of unconformable relations. The older of these groups is the Huronian of Table VI and the younger is the Keweenawan. However, the Huronian itself is broken by unconformities and, if Marsden's interpretation of Precambrian iron ranges of the United States can be equated in Canada, then an unconformity within the Huronian may be more important than that separating the Huronian and Keweenawan. On compilation maps of the Geological Survey of Canada these two units are commonly shown as early and late Proterozoic although in many areas the distinction depends on lithology. The earlier units are more indurated and may be rather highly metamorphosed, commonly contain a moderate to large amount of volcanic material, and are folded. The later units, on the other hand, usually dip at low angles, consist mainly of sandstone and arkose but may contain sheets of vesicular lava, and are only rarely metamorphosed to a high degree. Proterozoic rocks that have been mountain-built are shown in Figure 3.

Two other, perhaps important, features characterize the early successions of Proterozoic rocks: they contain large amounts of limestone and dolomite, and they contain graphitic sedimentary rocks. It seems that these rocks hold the first evidence of abundant life on the earth, with the possible exception of the Grenville series which is discussed separately, and perhaps such distinction could be used to separate Proterozoic from Archæan, as suggested earlier.

Early Proterozoic

The rocks north of Lake Huron are the type for the Huronian, as named by Logan and Murray in 1863. The Huronian was subsequently divided into the Bruce and Cobalt series by W. H. Collins in 1914, and the two series comprise the early Proterozoic of the belt extending easterly from Sault Ste. Marie across the Quebec boundary. The 1934 Committee on Stratigraphic Nomenclature defined

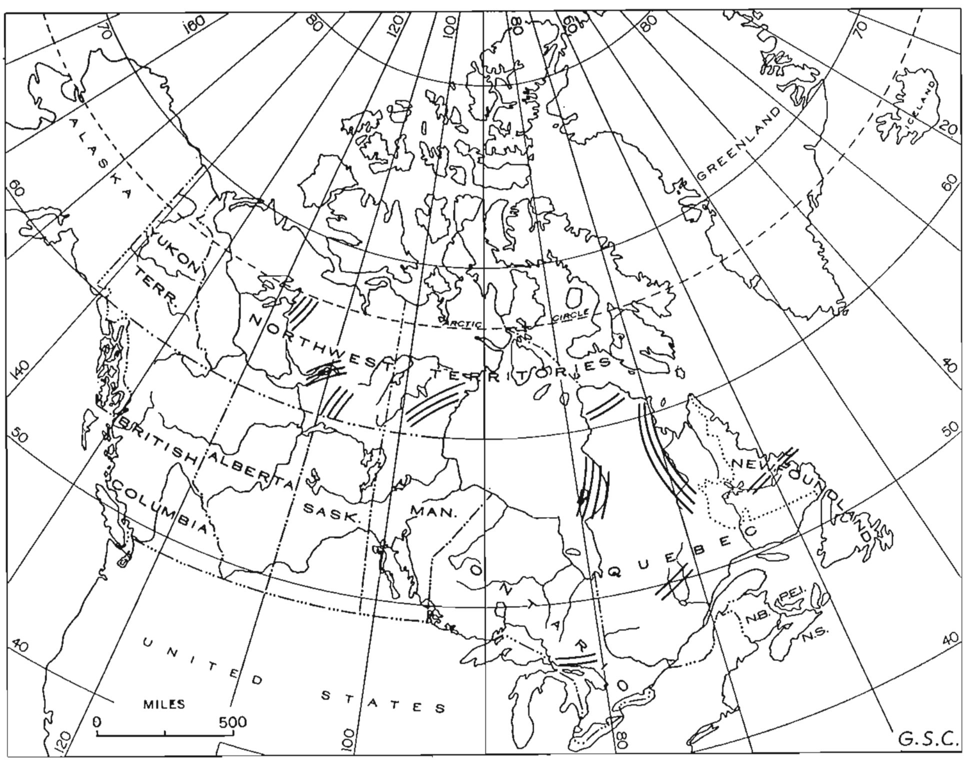


FIGURE 3. Proterozoic rocks that have been mountain-built.

the Proterozoic era as commencing with the Bruce series, or its equivalents, and the end of early Proterozoic time is assumed to have concluded with the deposition of the Cobalt series, or the end of the Huronian as defined by Logan and Murray, and by Collins.

Rocks that have been classified as Bruce series in Canada are confined to a narrow belt along the north shore of Lake Huron although they may extend westward along the south shore of Lake Superior in Michigan and Wisconsin. Recent detailed work in the eastern part of this belt by J. E. Thomson has shown that so-called Bruce rocks in Baldwin township are interbedded with so-called Keewatin rocks but are mostly younger, and do not lie on them with great unconformity. He pointed out that this evidence substantiates those geologists who considered that the so-called Bruce in the Sudbury area is actually Timiskaming in relation to the Keewatin, in its content and in its similarity to other belts of Timiskaming rocks.

In the Blind River area, a few miles west of Baldwin township, detailed geological studies have been made in conjunction with the uranium ores and there Collins' succession has been found to be good. Perhaps, then, the Blind River area should be considered the reference for Bruce rocks. Here the Mississagi quartzite was said by Collins to be about 3,000 feet thick and to lie unconformably on pre-Huronian schists. It is overlain by the Bruce conglomerate, which varies in thickness from 20 to 200 feet in the Blind River area and, in succession upwards, by the Bruce limestone (200 feet), Espanola formation of silt and limestone (300 to 400 feet), and Serpent quartzite (about 1,000 feet). All these are rocks considered to be characteristic of the "stable platform", and the total thickness of about 4,000 feet or more indicates stable conditions for a great length of time.

In the Blind River area there appears to be some evidence to indicate that part of the Bruce series was eroded prior to deposition of the Cobalt, but there is little, if any, discordance between the two so that folding could not have affected the Bruce before Cobalt rocks were deposited. The names applied here to the younger strata were imported from the Cobalt district where large areas are underlain by similar rocks.

The Cobalt series consists of the Gowganda formation at the base, overlain by the Lorrain formation. The Gowganda has a maximum thickness of about 3,500 feet; it consists, at the base, of a thick boulder conglomerate, which in places has the aspect of a lithified boulder clay, and in others resembles closely the material of eskers or kames. Other beds of conglomerate are found throughout the formation. The basal conglomerate is followed by an unstratified greywacke, strongly resembling a till, and this in turn by a thinly laminated, varved greywacke much like the varved clays of post-glacial lakes. In places it contains numerous boulders than can have been dropped only by floating ice. The whole assemblage is commonly conceded to have been the product of an ice age. The Lorrain is a series of quartzites, 7,000 feet or more thick, that overlies the Gowganda formation and in places overlaps it to lie on the Archæan basement. The lower part of the

Lorrain is rather arkosic, but the upper is a very pure quartzite, in places containing more than 99 per cent silica. Crossbedding and ripple-marks are common throughout. Thin streaks and disseminated particles of specularite occur here and there, and in one place a lean iron-formation forms a bed 75 feet or more thick. Banded cherty quartzite 200 to 700 feet thick, and a second white quartzite formation some 2,000 feet thick, overlie the Lorrain. Lavas have not been reported in the Cobalt series except in Leonard township, Ontario, where a rhyolite is described as part of the Gowganda formation.

In the Blind River area the Gowganda formation is similar to that in the Cobalt region, but the Lorrain formation is only a few scores of feet thick and the overlying formations are missing.

Except near the Murray fault just north of Lake Huron, the Bruce and Cobalt rocks are only gently flexed, forming broad open folds and rarely dipping steeper than 20 degrees. They were intruded by great sills and dykes of gabbro that are commonly termed the Nipissing diabase and were probably also intruded by granite. Evidence from south of Lake Superior indicates that intense folding and igneous intrusion took place at the end of Middle Huronian time.

A body of rocks classed as possibly equivalent to the Middle Huronian is found at Lake Chibougamau, Quebec. These rocks have been termed the Chibougamau series, and consist of some small remnants capping higher hills and of one downfaulted block. They include mainly conglomerate and arkose, and the maximum present thickness is about 3,400 feet. The beds are not greatly folded, but are much broken by faulting and are tilted in places so as to have high dips, though the average is low. They rest with great angular unconformity on older volcanic and sedimentary rocks.

At Sudbury the Whitewater series is a synclinal mass some 32 miles long and 10 miles wide lying wholly within the ellipse of the Sudbury irruptive. At the base the rocks comprise a very thick succession of volcanic breccia and tuff, which J. E. Thomson considers to be formed from *nuées ardentes* (glowing avalanches). They are overlain by the Onwatin black slate, a formation estimated at about 3,700 feet thick. It is, however, exposed in few places and appears to be identical with bands of slate contained within the Chelmsford formation. The Chelmsford quartzite, several hundred feet thick, exhibits crossbedding and other features that suggest deposition on tidal flats. These rocks have commonly been considered to represent the latest of Precambrian rocks, but J. E. Thomson and associates have recently made detailed studies that provide strong evidence for revision. They consider that the rocks within the basin are the same as those outside it, which are considered to be early Proterozoic, and the rocks within the basin are certainly much more indurated and deformed than late Proterozoic rocks elsewhere in the Shield.

In the Steep Rock Lake area a group of rocks was named the Steep Rock series by H. L. Smyth in 1891. This succession is now known to lie unconformably on granitic intrusions and the limestone beds contain "algal structures". This group, which includes also volcanic and clastic rocks as well as the iron ore of Steep Rock Lake, should probably be considered of early Proterozoic age.

West from Steep Rock Lake no rocks have been classed as Proterozoic until the Athabasca district is reached, a distance of several hundred miles. The Athabasca rocks underlie a large area south of Lake Athabasca and D. A. W. Blake has suggested that the folded rocks associated with the uranium deposits north of the lake, and which lie unconformably above the Tazin group, are part of the same succession. The Athabasca series has commonly been referred to the late Proterozoic, but age determinations on uranium-bearing veins that cut the folded rocks show an age of 1,900 million years or more. These rocks should, therefore, be classified as early Proterozoic in age. However, W. E. Hale found evidence for an unconformity within the Athabasca rocks, and suggested that the undeformed rocks south of the lake are much younger than those to the north. North of the lake the succession includes some basic lava flows, but south of the lake the unit is mainly sandstone with local accumulations of limy material. The sandstone north of Lake Athabasca is cut by granitic rocks and by veins that carry uranium minerals, but the sandstone south of the lake is not known to be cut by granite. It dips very gently and beds show ripple-marks, mud-cracks, crossbedding, and rain-drop impressions. All these indicate deposition in very shallow waters. The total thickness is probably not more than a few hundred feet.

To the north, in the Northwest Territories, local names have been used throughout and no attempt has been made to correlate the rocks with the Cobalt series. Since Map 1045A was compiled, much new information on the central and eastern regions has been obtained and Figure 4 shows the distribution of Proterozoic rocks as known at the end of 1955.

In the Northwest Territories the distinction between early and late Proterozoic age is based mainly on the degree of deformation, the lower rocks being those more highly deformed. On this basis, and on the reasoning presented earlier, the lower Proterozoic rocks are presumed to include the Great Slave, Nonacho, Snare, Echo Bay, Cameron Bay, and Hurwitz groups, and may include some others.

The Great Slave and Nonacho groups occur in roughly parallel belts separated by a few miles of Archæan rocks, and may be part of the same depositional cycle. The Great Slave group occurs along the east arm of Great Slave Lake and consists of basal, arenaceous beds about 3,000 feet thick followed by 1,000 feet of shale, slate, limestone, volcanic rocks, and iron-formation which are overlain by "algal" limestone and dolomite about 1,500 feet thick. These have been termed the lower part of the Great Slave group. The upper part comprises about 1,000 feet of dolomite and limestone overlain by sandy shale and sandstone, and may be separated from the lower part by an erosional disconformity although more recent mapping suggests that the apparent disconformity is due to facies changes in the rocks. All the rocks of the upper part display features characteristic of deposition in shoal waters and the limestones have algal structures.

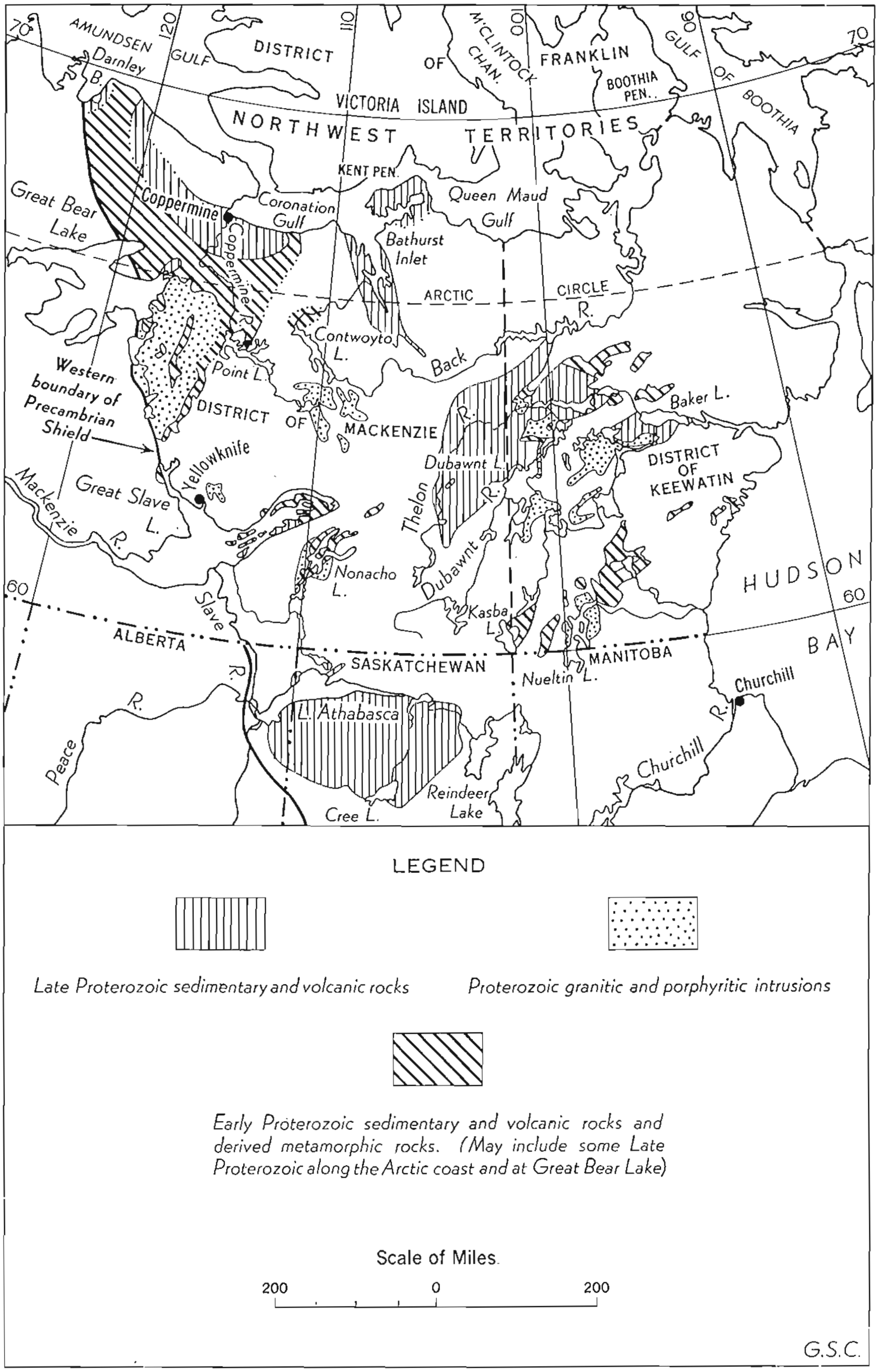


FIGURE 4. Proterozoic rocks of the mainland, Northwest Territories.

The Nonacho group, though roughly parallel to rocks of the Great Slave group, extends southerly nearly to Lake Athabasca where the group is represented by conglomerate and arkose. Farther north, near Nonacho Lake, the rocks are thicker and more diversified. A coarse conglomerate at the base is several hundred feet thick, locally as much as 2,000 feet. This is overlain by slate and greywacke, with lenses of crossbedded and ripple-marked arkose; and these in turn are succeeded by buff, yellow, and white arkoses and quartzites carrying isolated pebbles and lenses of conglomerate. These beds are crossbedded and ripple-marked; argillaceous interbeds have mud-cracks, and intraformational conglomerate or breccia is common. The strata lie in open, gently plunging folds with axes striking northeast. Dips on the limbs average 45 to 60 degrees, though they are steeper in places. The formation is intruded by late Precambrian granite and is locally metamorphosed.

Sedimentary and volcanic rocks of the Snare group form several elongated basins in an area extending north from the north arm of Great Slave Lake nearly to Great Bear Lake and have lately been traced almost directly into Echo Bay rocks of Great Bear Lake. These two groups are correlated here, but it has been customary to consider Snare rocks equivalent to the lower part of the Great Slave group to which they show strong lithological similarities. The basal strata are coarse arkoses and quartzites with some lenses of conglomerate and local thin flows of andesite or dacite. These are followed by argillite and greywacke, thin limestone, and dolomite characterized by algal structures. The rocks strike north-northwest on open folds and commonly dip less than 45 degrees.

The Echo Bay group, which is presumably correlative with the Snare, consists of about 6,000 to 9,000 feet of pyroclastic rock, chert, lava, some argillite, and minor limestone. Beds commonly dip at 45 degrees, but may be more steeply inclined.

The Cameron Bay formations contain pebbles of Echo Bay rocks but apparently are conformable with the underlying Echo Bay. Thus, they may be only slightly younger. On the other hand, Cameron Bay conglomerates contain pebbles of granite that resemble intrusions in Echo Bay formations, and the interval of time between may be great. If so, the Cameron Bay may be of late Proterozoic age. This is further suggested by the fact that the rocks are rather loosely consolidated; they consist of conglomerates, arenaceous rocks, and andesitic and trachytic lavas.

Rocks considered to be early Proterozoic have recently been mapped in the district of Keewatin. Their distribution is shown on Figure 4. These rocks, called the Hurwitz group, are characterized especially by great ridges of white quartzite that can be followed for many miles. The group includes, besides the basal quartzite, intermittent accumulations of greywacke, shale, and limestone that apparently formed in small basins. These rocks have been folded, intruded by granitic bodies, and mineralized.

In the Ungava peninsula several groups of rocks are shown on Map 1045A as undivided Proterozoic. They are all rather sharply folded and much faulted and, as such, should be considered early Proterozoic. However, no attempt is made to correlate them with other Proterozoic rocks, or with each other.

The Kaniapiskau group of Proterozoic rocks, lying in a belt colloquially known as the Labrador trough, extends for about 600 miles through central Ungava in widths varying from 10 to 60 miles. At the north end the rocks appear to plunge southward and the belt terminates in a syncline, but at the south it is not known what the relations are. There is some evidence that much of the south end is faulted off and also a suggestion that the extreme southwest part may extend far enough to connect with the Mistassini series. In the thickest part of the group, at Knob Lake, the group can be divided into two, a western succession including slate, quartzite, dolomite, and cherty iron-formation very similar to Lake Superior examples, and an eastern succession consisting mainly of basic to intermediate volcanic rocks and bands of sedimentary rocks. Probably these two successions were deposited essentially at the same time, the western succession being deposited in a shallow basin of restricted circulation while the volcanic material was accumulating in a deep, geosynclinal trough. The eastern succession is some miles thick, but the western is not more than a few thousand feet. Both north and south of Knob Lake the two units are intermingled and the distinction is far from clear cut. The eastern margin of the trough is marked in places by heavily sheared rocks, presumably marking a great fault, but there is some evidence to suggest that granitized gneisses east of the fault may be altered Kaniapiskau rocks. The Kaniapiskau succession is highly folded and faulted, intruded by many bodies of basic rocks and, in one place, apparently by granite. In places the Kaniapiskau rocks appear to be overlain with great unconformity by gently dipping sandstone or quartzite. These may represent upper Proterozoic strata, for they do not seem to have been folded. The Kaniapiskau rocks are being intensively prospected for base metal sulphide deposits as well as for iron ore. Galena from these deposits is probably nearly 2,000 million years old, certainly early Proterozoic.

North of the Kaniapiskau belt a narrow band of rocks, known as the Povungnituk range extends westward from Wakeham Bay on Hudson Strait to Cape Smith on Hudson Bay. These rocks are much like the Kaniapiskau rocks except that they contain more red beds, but no iron-formation has yet been reported although boulders of it were found by the writer in 1953. Rocks similar to these Povungnituk members have been found on the Ottawa Islands in Hudson Bay.

The Seal Lake group of rocks forms a broad belt extending nearly from the Labrador coast inland to Michikamau Lake. They consist of clastic sedimentary rocks, andesitic and basaltic lavas and pyroclastic rocks, and some limy rocks. They have been folded, intruded by basic and acid rocks, and mineralized. On the south they are in fault contact with the Archæan (?) rocks and it has been suggested that this fault marks the eastward extension of the Huron-Mistassini lineament. To the north the Seal Lake rocks lie with great unconformity on gneisses. These rocks have been intensely prospected for their copper, some of which occurs in native form. The general assemblage and the way in which the copper occurs are similar to the late Proterozoic rocks of the Keweenaw Peninsula and of the Coppermine River area and these rocks may be of late Proterozoic age also.

The Ramah and the Mugford rocks of the coast of Labrador consist of interbedded volcanic rocks and argillites, with lesser quartzite and limy beds. The Ramah is predominantly sedimentary, probably 4,000 feet thick, and is complexly faulted and folded; the Mugford group is mainly volcanic, dips gently, and is about 3,000 feet thick. A. M. Christie pointed out their similarity to the Kaniapiskau rocks and tentatively correlated the three.

Grenville Series. Grenville rocks are considered here because it is doubtful if they can be considered any younger than early Proterozoic, although they could be much older. Remarks made on lithology and internal structures apply with equal force to the belt of Kisseynew gneisses that straddles the Manitoba-Saskatchewan boundary north of Flin Flon.

Grenville is a term applied to a complex of more or less granitized sedimentary gneisses associated with large amounts of crystalline limestone and with a little lava. They appear to be separated from other Shield rocks to the north by a zone of faulting, although some geologists consider the contact to be gradational. By no means has all of the contact been studied. These sheared zones occur along a moderately straight line that has been termed the Huron-Mistassini lineament and which extends northeast from Lake Huron an unknown distance beyond Lake Mistassini, perhaps to the Labrador coast. If this zone marks a major fault, as many geologists believe, it is one of the remarkable structures of North America. Evidence here and there along it, where faulting has been found, indicates the south side has been thrust up.

Various hypotheses concerning the age of the Grenville rocks have been put forward from time to time, but for many years the general consensus was that they were Archæan. Later it was suggested by Collins and Quirke that Grenville rocks were the granitized equivalents of Huronian strata. On this basis, the Grenville was considered to be a facies of the Huronian and, therefore, of Proterozoic age. With the postulation of a fault between the two groups, the relationship became much more obscure. Lately, J. T. Wilson has suggested that the mountains of the Grenville may have supplied the sediment for the Huronian succession north of Lake Huron and Sudbury. At any rate, many age determinations made on minerals from pegmatites that cut the Grenville show that the intrusions range in age from 800 to 1,100 million years. If these pegmatites represent the end phases of the orogeny that deformed the Grenville and the sedimentary rocks they intrude are the early phases of the orogenic cycle, then the dates give an approximate age for the Grenville rocks. On the other hand, they are similar in original composition and character to the Proterozoic rocks of the western Cordillera. These rocks, although Precambrian, were not extensively folded and intruded until late in Mesozoic time. If a similar relation existed with respect to Grenville rocks, the Grenville could be much older than the age of the pegmatites.

The Grenville rocks, which extend from Lake Huron for a still undetermined distance along the north shore of the St. Lawrence River, were originally composed of sandstone, arkose, shale, limestone, and minor lava flows. However, these rocks have been so metamorphosed and granitized that they are now schists and gneisses of high metamorphic rank. Naturally, too, in rocks containing so much easily deformed limestone, the structures are extraordinarily complex and it is only possible in a few places to work out structural relations.

North of Anticosti Island on the north shore of the Gulf of St. Lawrence some quartzite, schist, and crystalline limestone within the extension of the Grenville rocks, have been shown on Map 1045A as lower Proterozoic. Perhaps it would have been more in keeping with the classification if these rocks had been considered equivalent to Grenville which, on this map, are shown as a special unit of the Archæan.

In southern Ontario, particularly in Hastings county, a second series makes its appearance. This, known as the Hastings series, apparently overlies the Grenville with erosional unconformity, but with little structural discordance. The series consists chiefly of grey, blue weathering limestone interstratified with argillite, except near the base where beds of conglomerate, interstratified with argillite, buff weathering dolomite, greywacke, and mica schist occur. The conglomerate contains well-rounded pebbles and boulders of both the igneous and sedimentary members of the Grenville series. Both series appear to be folded to about the same degree, and there is no noticeable discordance in dip.

The Grenville and Hastings rocks are intruded by gabbro, anorthosite, pyroxene diorite, and pyroxene syenite, most of which contain a pink to pale green, monoclinic pyroxene as their most abundant ferromagnesian constituent. Later than these are dykes, sills, and batholiths of granite and syenite, and their gneissic equivalents.

Late Proterozoic

The Animikie, or Upper Huronian rocks, are considered to form the lower part of the upper Proterozoic in the "classic" concept of Precambrian succession. Their type succession is in the Port Arthur district where they were named by Sterry Hunt in 1873. These rocks are not in contact with Cobalt rocks, so the relative positions are questionable, but, as a type, the Animikie merit description. They extend from a point about 25 miles northwest of Port Arthur to cross the International Boundary some 65 miles west-southwest of it. The rocks consist of a basal conglomerate, 4 feet or less in thickness, followed by cherty iron-formation, up to 500 feet thick. The iron-formation consists essentially of grey and red banded and oolitic chert, or some variety of fine-grained or amorphous silica, with which are intimately associated one or more of the iron-bearing minerals greenalite (ferrous silicate), siderite, ferruginous dolomite, magnetite, and hematite. Interbedded with the ferruginous cherts are a few small flows of basic lava, and some shaly members. The iron-formation is characterized by many structures resembling inverted bowls or thimbles, which have recently been shown to be of organic origin.

The iron-formation ranges in its iron content from 5 to 40 per cent, and may average about 25 per cent. It is overlain by a formation of slate and greywacke, 1,300 feet or more thick, part of which may represent volcanic ash or dust. A few thin beds of limestone are locally present.

The main characteristic of the Animikie is the presence of abundant cherty iron-formation. As a result, Precambrian units containing such rocks have been correlated with Animikie regardless of other relationships. The main exceptions are in the Northwest Territories where the iron-bearing formations are considered to be early Proterozoic, and the main belt of Proterozoic rocks in Ungava which contains vast amounts of iron-formation and was described as early Proterozoic. The rocks in the central part of the Shield that have been shown on the map as correlative with the Animikie are the Nastapoka series of Belcher Islands and Richmond Gulf, and the Mistassini series.

On Richmond Gulf and the Belcher Islands the formations include: thick beds of limestone and ferruginous carbonate characterized by numerous "algal structures"; thick flows of basaltic lava; sandstone, shale, and slate; and 400 to 500 feet of iron-formation similar in every way to that of Lake Superior. On Belcher Islands the total exposed thickness is more than 8,000 feet; on the mainland, considerably less. The formations have been thrown into fairly gentle folds with north-trending axes though in places on the flanks of folds dips are steep. Granite intrudes the rocks of the Richmond group on the shores of Richmond Gulf.

On the other side of the Ungava Peninsula at Lake Melville the Double Mer sandstone lies virtually undisturbed on Archæan gneisses. The sandstone is friable, and probably is not more than a few hundred feet thick.

In the Lake Mistassini basin the supposedly upper Proterozoic rocks may be divided lithologically into two formations: the lower, some 600 feet of dolomitic limestone characterized by numerous "algal structures"; the upper, an iron-formation 100 to 200 feet thick consisting of ferruginous chert, dark slaty shale, and jaspilite. The beds have comparatively low dips, except on the southeast where they are faulted against the older rocks.

Surficial rocks considered of Keweenawan age are found on the Canadian part of the Shield only on the north shore of Lake Superior. East of Port Arthur the Sibley series is found overlying the Animikie sediments with slight unconformity. The series also overlaps the Animikie to lie directly on the Archæan basement for about 100 miles north of Lake Superior, extending north and somewhat west of Lake Nipigon almost as far as the north end of that lake. The rocks are mainly mudstone, with some sandstone and a little chert and limestone. In places the mudstone and sandstone have a calcareous cement. Many are red or purple, and are ripple-marked or exhibit textures indicating mud flowage. West of Lake Nipigon some beds of dolomite are considered to belong to the Sibley series.

The Osler series directly overlies the Sibley with erosional unconformity. It consists at the base of a few feet of conglomerate and sandstone, overlain by a great thickness of lavas and interbedded fragmental rocks. The similarity of these rocks to the Middle Keweenawan of the south shore of Lake Superior is rather pronounced, and the two are commonly correlated. These strata are found only on the shore and islands of Lake Superior around Black Bay and Nipigon Bay, and also on Michipicoten Island.

At the east end of Lake Superior about 40 miles north of Sault Ste. Marie, there is a mass some 18 miles long, extending 4 or 5 miles back from the lake, of red and white sandstone and conglomerate with amygdaloidal basic flows. These dip westward at low angles and are generally considered to be of Keweenawan age.

In the Northwest Territories the Bathurst group of rocks includes the Epworth dolomite, up to 1,800 feet thick and characterized by algal structures, the Kanuyak formation, only 100 feet or so of conglomerate and ash rock, and the Goulburn quartzite, perhaps 4,000 feet thick and containing beds of conglomerate that carry pebbles of rocks similar to those of the Epworth and Kanuyak formations. These strata are apparently overlain, essentially conformably, by the Coppermine River series. These rocks, which are gently flexed, consist of about 13,000 to 30,000 feet of basalt with thin interbeds of conglomerate, succeeded by 15,000 feet of shale, sandstone and minor flows. This belt of combined Bathurst and Coppermine River strata truncates the trend of the Echo Bay rocks, so is presumably considerably younger.

In the central part of the Northwest Territories large areas are underlain by a gently dipping series of varicoloured sandstones and calcareous sandstones. These are termed the Dubawnt group and were previously considered to be part of the Athabasca sandstone. It is now known that the two outcrop areas are not continuous and are, therefore, not given the same name. The Dubawnt group is cut by dykes of massive gabbro (diabase), but otherwise is virtually unaffected by later activities of the earth's crust.

Elsewhere in the Northwest Territories smaller areas are underlain by rocks of presumed late Proterozoic age. The Et-then group of conglomerate and feldspathic sandstone outcrops on islands in the east arm of Great Slave Lake. These rocks are some thousands of feet thick and lie unconformably above rocks of the Great Slave group and the granitic rocks that intrude the Great Slave. The Hornby Bay group, on the east side of Great Bear Lake consists of loosely consolidated conglomerate and varicoloured quartzites that appear to be separated from the Cameron Bay group by an angular unconformity. The relative extent of these two groups is unknown and the Proterozoic rocks to the northwest of the bay are shown on the map as undivided Proterozoic.

End of Precambrian Time. Palæozoic rocks that lie on rocks of the Canadian Shield are almost everywhere Ordovician or younger, a feature that has led many authors to state that a tremendous time interval is represented by this unconformity. Nowhere does the latest Precambrian time appear to have been one of orogeny. Some of the youngest Proterozoic rocks, such as the Dubawnt, Et-then, and Double Mer, are only slightly folded or warped, and are intruded by only a few basic dykes. It is possible that these latest units were deposited in continental basins while

Palæozoic seas were encroaching on the Precambrian continent and, if so, are actually Palæozoic in age.

Post-Precambrian History

Much of the Canadian Shield must have been peneplaned by the end of Precambrian time and the process must have continued through the early part of the Palæozoic. Probably most, if not all, of the present Shield area had little relief so that comparatively slight downward movements would result in flooding of wide areas by the sea, and an equally slight upward movement would cause correspondingly widespread withdrawals. Throughout Palæozoic time such advances and retreats were probably common, but their mark, with few exceptions, has been left only on the margins of the Shield where the Precambrian surface dips at a gentle angle beneath the younger rocks. Another widespread flooding occurred in Cretaceous time but this seems to have been the last. We can infer that, throughout much of post-Precambrian time, the Shield had a protective covering of younger strata. Inliers of Palæozoic rocks have been found in Manitoba, in Ontario, in the central Northwest Territories, and in Ungava, and at least some of these have been preserved in downfaulted blocks. Their occurrence indicates a widespread cover of limestone and their presence, at least in some instances, shows that faulting occurred in the "stable" Shield long after Precambrian time.

It is probable that much of the Shield area was above sea-level during the early part of the Mesozoic era, but Cretaceous time was marked by a great transgression of the sea that probably covered much of the Shield. In a few places Cretaceous sedimentary rocks extend across the Palæozoic rocks to lie directly on the Precambrian. The Cretaceous west of Lake Winnipeg rises abruptly above the Palæozoic rocks as the Manitoba escarpment. Its maximum thickness there is about 1,400 feet but some has presumably been removed by erosion, because well borings back from its edge show that the Cretaceous is more than 2,000 feet thick. The rocks dip southwest with a gentle slope in the upper beds of 5 or 6 feet to the mile. It seems altogether likely, therefore, that they must once have overlapped far on the Precambrian.

Presumably the land remained stable following the post-Cretaceous uplift and it is believed by many that the even skylines of the Shield represent the Tertiary peneplain that followed this uplift. Late in Tertiary time renewed activity along ancient faults such as the Logan, Ottawa Valley, Saguenay, and Lake Melville, resulted in uplift and renewed erosion. Following this came the great continental glacial period with its advances and retreats of enormous thicknesses of ice. The elastic rebound that followed retreat of the ice is still continuing and the lakes and streams of the Shield are not yet adjusted to the new conditions; hence the highly disorganized character of the Shield drainage.

Economic Geology

The mineral resources of the Canadian Shield are numerous, varied, and abundant. Gold traditionally has been the metal with the greatest dollar value, but in recent years it has been exceeded in value by both nickel and copper. The value of all mineral production from the Canadian Shield in 1955 was estimated to be nearly $800 million compared with about $285 million in 1939. Nickel was in the lead with an output in 1955 valued at $216 million, the value of copper being $210 million, and of gold, $145 million. In addition to these metals, the Canadian Shield produces important quantities of pitchblende products, zinc, iron ore, silver, and platinum. The Cobalt camp has been one of the great silver producers in the world, and some mines are still operating although mining is primarily for cobalt. Production of iron ore is increasing rapidly, now that the Steep Rock Lake and Knob Lake deposits are in production, and it may be that the value of iron ore produced from the Canadian Shield will soon exceed the value of gold, especially as substantial tonnages of iron ore are being produced from pyrite. The value of pitchblende products must also increase enormously now that large mines in the Blind River district in Ontario and the Lake Athabasca district in Saskatchewan are operating, and that production is being obtained from the Bancroft area in Ontario and is to commence in 1957 from relatively high-grade deposits in the Marian River district, Northwest Territories.

In addition to the metallic minerals, asbestos is being mined in large quantities from the Shield, and deposits of other non-metallic minerals have been or are being exploited. Deposits of coal and oil are lacking because, of course, animal and plant life were not abundant in Precambrian time. Nevertheless, deposits of carbon-rich material have been found in the Proterozoic rocks of central Ungava and the material has been used in camp stoves to maintain fires overnight.

Most of the known deposits of metallic minerals occur in "islands" of volcanic and sedimentary rocks that are scattered through the predominantly granitic rocks of the Shield and it is these islands that have received most attention from exploration and prospecting organizations. However, minerals commonly found in pegmatites are being produced at localities far removed from such islands, and no doubt others will be discovered. The islands, particularly if they are large, may contain more than one mining camp, each with its own peculiar geological and structural characteristics. Most of the more accessible islands have been prospected with some degree of thoroughness by conventional methods, so it is safe to assume that most of the easily discovered deposits of minerals are now known. Consequently, the discovery of new mines will require increasing use of specialized and expensive prospecting tools, such as the airborne magnetometer, electromagnetic gear, and other devices that will no doubt be developed. Exploration costs must, therefore, increase.

Gold

Gold has been found practically throughout the length and breadth of the Canadian Shield, although workable deposits have been confined to particular areas. Besides the deposits that are mined solely or mainly for their gold, other ores are important sources of the metal—for example, the nickel-copper ores of Sudbury, the copper ores of Noranda, and the copper-zinc body of Flin Flon.

All gold orebodies are of the vein or lode type; placers are entirely lacking on the Shield. In many, the gold occurs in veins or stringers of quartz that cut the wall-rock, but in others the gold is disseminated in brittle rocks adjacent to faults or in rocks crumpled in tight folds.

All the veins are of the deep zone type, but experimental work in the last decade has suggested that there may be limits to the depths over which gold may be deposited in veins of this type. However, it is probable that the maximum depth to which mining will be possible will be conditioned by the physical characteristics of deep mining rather than by the bottoming of the gold deposit due to physical and chemical conditions at the time of deposition.

Gold was first discovered in the Shield in southeastern Ontario in 1866, and continued prospecting revealed veins in Peterborough, Hastings, Addington, and Frontenac counties. These veins occur in the rocks of the Grenville complex, commonly in the more granitic facies. The Deloro deposit in Hastings county contained so much arsenopyrite that it was mined for arsenic as well as gold and the plant was the forerunner of Deloro Smelting and Refining Company's plant now operating. Most of these deposits were rather small and of low to medium grade, and have not been mined since the early years of the present century. Attempts were made to operate some of them again between 1935 and 1940, but with indifferent success.

The next discoveries in the Canadian Shield followed the completion of the Canadian Pacific Railway in 1886. These deposits were found scattered through western Ontario between Port Arthur and the Manitoba boundary, and were most abundant near Lake of the Woods. The field produced more than $2 million in gold, mainly between 1897 and 1903, although some of the properties have been operated intermittently since that time. None of the mining was carried on below a depth of 600 feet.

In 1903-04 the great silver discoveries at Cobalt caused an influx of hundreds of prospectors into northern Ontario. As the Cobalt field was taken up these men spread over the surrounding country in search for new deposits. The result was the discovery in 1909 of the Porcupine field and in 1911-12 of the Kirkland Lake field. The yield from these two fields made Ontario the leading gold-producing province and eventually brought Canada into second place as a world gold producer.

For about 20 years the great mines of the Porcupine and Kirkland Lake districts were almost the only gold producers of the Shield. Some gold was obtained from other properties in Ontario and from the Central Manitoba mine, and minor amounts were also won from a number of properties that were worked for short periods or at minor intervals. With the onset of the great depression of the early '30s, however, the price of commodities dropped and the price of gold, expressed in terms of currency, rose. The gold mines thus benefited doubly—their costs decreased and their income increased. These changes stimulated gold mining enormously. Deposits that previously were too low in grade to be of economic interest became highly valuable; existing mines had large volumes of low-grade material added to their ore reserves. New mines sprang up on the Shield like mushrooms and from only 15 or 16 mines in profitable operation in 1929, the number rose to 106 in 1942. All the mines in western Quebec, and in the Thunder Bay and Patricia districts in Ontario and about 25 properties in the old established Porcupine-Kirkland Lake area were developed during this period.

Twenty-seven of the 106 gold mines operating in the Shield in 1942 were in western Quebec, 65 in Ontario, 5 in Manitoba, 1 in Saskatchewan, and 8 in the Northwest Territories. By 1955 the situation had changed greatly. In that year only 54 gold mines were operating in the Canadian Shield: 16 in western Quebec, 32 in Ontario, 3 in Manitoba, and 3 in the Northwest Territories. Much of this decline in gold producers and gold production was due to the constant price of gold since the end of World War II compared with the increasing operating costs. Eighteen of the mines operating in 1942 and 17 of those operating in 1955 treated 1,000 tons a day or more. Most of the others produced from 500 to 1,000 tons a day and several produced from 100 to 500 tons a day.

The principal features of some of the more important gold camps of the Shield are outlined briefly in the following pages.

Western Quebec

The easternmost group of mines lies in Dubuisson, Bourlamaque, Senneville, Pascalis, and Louvicourt townships, where a mass of granodiorite approximately 14 miles long from east to west with a maximum width of 6½ miles, intrudes Keewatin lavas. The Sullivan Consolidated, Lamaque, Sigma, and Bevcourt mines, as well as several past producers, lie either within the granodiorite itself, in small satellitic bodies of it, or in the lavas close to its margins (Figure 5). The vein materials are mainly quartz and tourmaline, mineralized with pyrite, some chalcopyrite, and native gold. The veins fill fractures, which are generally faults, and the

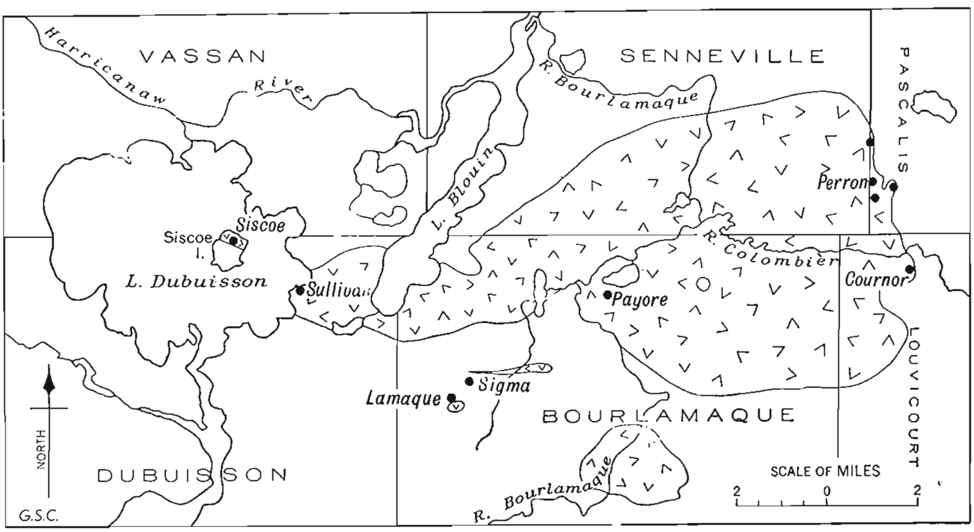


FIGURE 5. Gold deposits in relation to Bourlamaque granodiorite. (V-pattern)

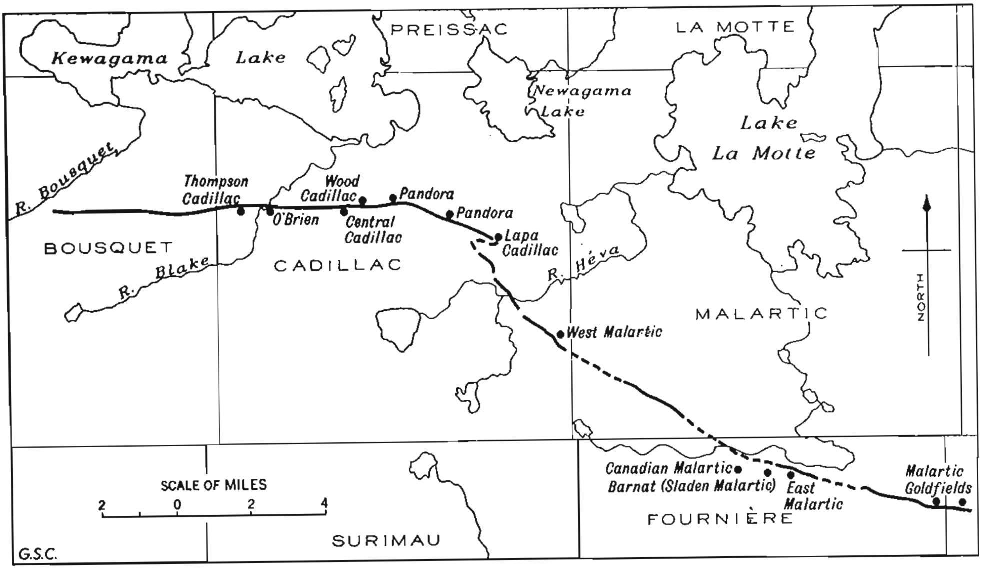


FIGURE 6. The "Cadillac break" (heavy line) and related mines.

tension cracks associated with them; in places the walls are replaced by mixtures of albite, ankerite, and quartz, with more or less pyrite and tourmaline.

To the west of this group of mines, two other groups are closely associated with a great fault known as the "Cadillac break" (Figure 6). Along the east part of this break, Canadian Malartic, Sladen Malartic, Barnat, East Malartic, and Malartic Goldfields are grouped together because they display certain similarities. Unlike the mines of the western part of the break, their ores contain neither arsenopyrite nor tourmaline and rarely any pyrrhotite. Native gold, instead of being coarse and spectacular, is generally so finely divided as to be invisible to the unaided eye. Pyrite is the principal sulphide and is accompanied by small amounts of galena, sphalerite, and chalcopyrite, with at least two tellurides, sylvanite and petzite. The deposits are typically low grade and adapted to fairly large-scale mining operations. The bullion from the ores is very high in silver, some of it carrying approximately half as much silver by weight as gold. The ores of the Canadian Malartic and Sladen Malartic are silicified and mineralized greywacke; those of the East Malartic and Malartic Goldfields are in steeply dipping sheets of rocks locally known as "diorite". These are mineralized and cut by many small veins, so that large parts of them constitute ore.

The second group of mines associated with the Cadillac break lies a few miles to the west in Cadillac township (Figure 6). The O'Brien mine has been the principal producer; others are the Thompson Cadillac, Central Cadillac, Lapa Cadillac, Wood Cadillac, and Pandora. The orebodies of this group are quartz veins mostly less than 4 feet wide, though, in the O'Brien, widths up to 15 feet were encountered. The productive veins are generally flanked by bands of altered rock 1 foot to 10 feet wide; these carry gold and materially increase the mineable widths. The quartz of the veins is commonly dark grey or bluish grey, and it carries in places spectacular shoots of coarse gold. The chief other metallic mineral is arsenopyrite, with lesser amounts of pyrite and pyrrhotite; small amounts of albite and tourmaline are usually present. The bullion from these mines carries relatively little silver, averaging roughly about one part by weight of silver to ten parts of gold.

The orebodies associated with the Cadillac break are not found in the break itself, which is a wide band of contorted mica-chlorite schist, but in subsidiary fractures in nearby hard or brittle rocks that fracture rather than shear. Of all the mines along the Cadillac break, only the Barnat, Canadian Malartic, East Malartic, Malartic Goldfields, and O'Brien were operated in 1955.

Space does not permit the description of several other, more isolated gold mines in western Quebec, the Belleterre Quebec, Beattie, Donalda, Elder, Senator Rouyn, Powell Rouyn, and Stadacona, or the numerous producers of other years.

The chief gold producer of western Quebec, however, is Noranda Mines Limited, at Noranda, its principal product being copper, and the gold a valuable by-product. At this property, Keewatin acid lavas and tuffs have been bent and shattered by intense drag-folding, and then replaced by pyrite, pyrrhotite, and chalcopyrite. The copper ores thus formed carry gold, up to 0.25 ounce a ton in places. Other parts of the country rock were silicified, and much of this silicified material, which is used as a flux in the smelting operations, carries gold up to 0.25 ounce a ton. More than 5,800,000 ounces of gold were produced from this mine from 1927, when smelting began, to the end of 1955.

Ontario

Larder Lake. At Larder Lake a shear zone about 600 feet wide trends westerly and dips steeply north; it is believed to be an extension of the Cadillac break. The orebodies of the Kerr Addison mine, which is now Canada's largest producer of gold, are all contained within this shear zone, part of which is characterized by brecciated carbonate cemented by quartz veins and stringers. Some acid intrusions that occur within the carbonate zone are also fractured. South of the carbonate zone, Keewatin basic flows occur in the sheared zone, and of the eleven known orebodies, seven are in the carbonate zone and four in the flows. Gold is intimately associated with pyrite and late quartz. From May 1938, when the mine began production at 500 tons a day, to the end of September 1955, when about 4,500 tons a day were being milled, the mine produced 3,486,000 ounces of gold.

Kirkland Lake. Kirkland Lake area comprises a group of seven large mines, the Macassa, Kirkland Minerals (formerly Kirkland Lake), Teck-Hughes, Lake Shore, Wright-Hargreaves, Sylvanite, and Toburn (Figure 7). All are in Teck township. The Lake Shore, Teck-Hughes, and Wright-Hargreaves have been the largest producers; the Toburn is mined out and the Teck-Hughes now is operating on a salvage basis. Total production from these mines to the end of 1955 amounted to $620 million.

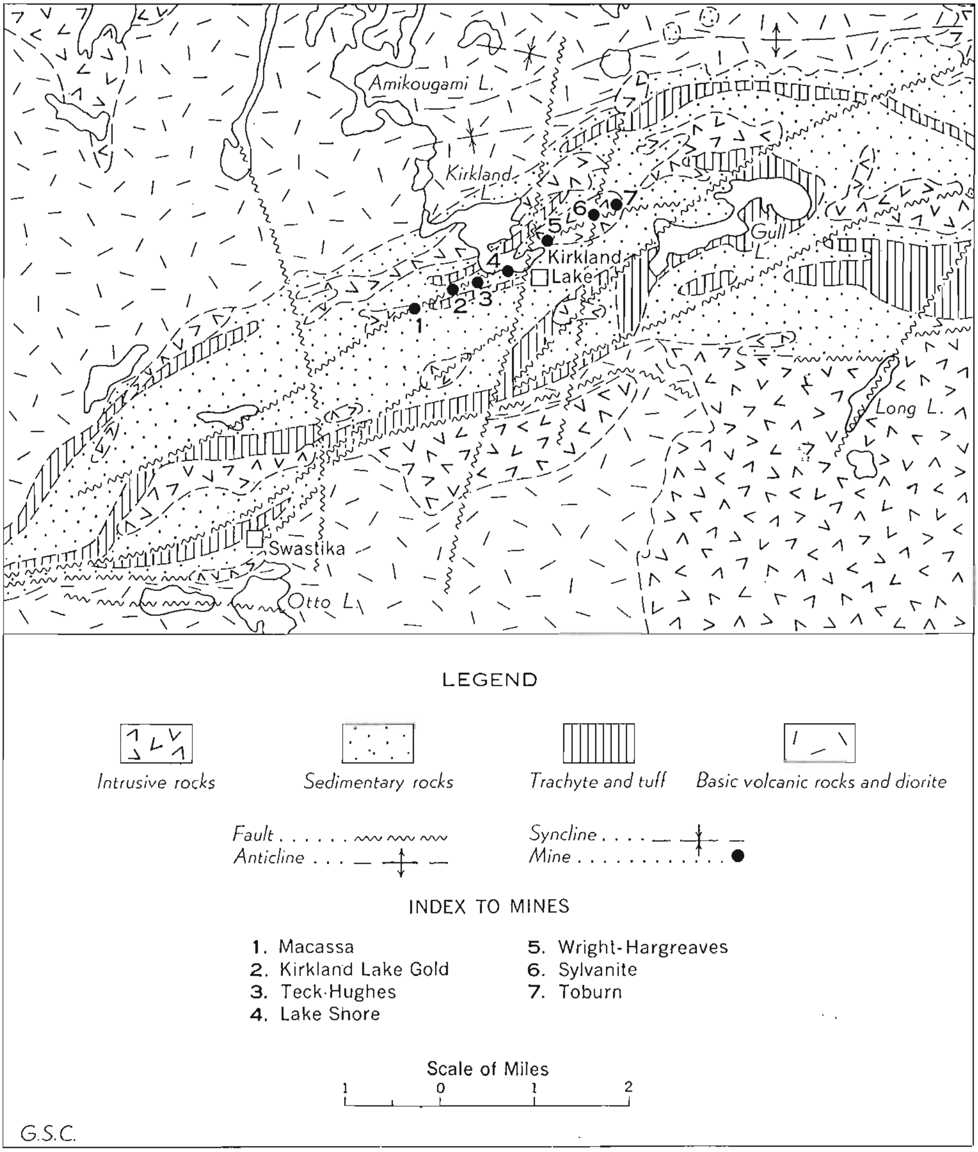


FIGURE 7. Generalized geological map of Kirkland Lake area. (After J. E. Thomson.)

These properties occur in steeply dipping conglomerate, greywacke, and tuff of the Timiskaming group that have been intruded by an elongated composite stock of syenitic composition. A syenite porphyry differentiate forms a large mass on the Wright-Hargreaves property and extends almost to the Lake Shore boundary from where long fingers project into the Lake Shore and Teck-Hughes properties.

All the properties occur along a main thrust fault that strikes about north 60 degrees east and dips about 85 degrees south, and along which the south side has been thrust up a maximum of about 2,000 feet. At the west end of the camp where displacement has been greatest the vein-fracture pattern is closely related to the main break, but at the east end where displacement is least the vein-fracture system is weaker and shows the influence of an earlier pattern, probably produced from the intrusion and/or cooling of the intrusive stock.

Hydrothermal solutions, introduced into the shattered and fissured zone, resulted in repeated quartz veining as movement recurred. Ore may occur in any of the rocks along the main ore zone but most comes from veins within or along contacts of the intrusions where the faulting induced shattering rather than shearing. Although quartz is locally abundant, the total quantity of quartz is small when tonnage of ore mined is considered. Gold and gold tellurides are the principal constituents of value. Altaite is the most abundant telluride, but calaverite, petzite, coloradoite, tetradymite, joseite, and melonite are also present.

Porcupine District. The Porcupine gold field, discovered in 1909, lies in Tisdale, Deloro, and Whitney townships. The principal producers are the Hollinger, McIntyre, and Dome Mines, all of which began milling operations in 1912. Numerous other properties were worked for varying periods. The largest of these was the Vipond mine which operated from 1911 to 1918 and from 1923 to 1936. After the increase in the price of gold in 1934 made it profitable to mine lower grade ores, however, 15 new mines were opened and have produced important amounts of gold. These are: the Aunor, Broulan Reef, Buffalo Ankerite, Coniaurum, Delnite, De Santis, Faymar, Hallnor, Hoyle, Hugh-Pam Porcupine, Moneta, Naybob, Pamour, Paymaster Consolidated and Preston East Dome (Figure 8). To the end of 1955 the Porcupine camp had produced more than $1,200 million in gold.

The Keewatin rocks of the Porcupine district appear to consist of three groups (Figure 8) consisting of altered basic volcanic rocks, some rhyolite and acid pyroclastic rocks, and banded iron-formation. According to Dunbar the youngest group, called the Hoyle, appears to have been laid down on the older after a period of erosion. The Timiskaming conglomerate, slate, and greywacke lie unconformably on the Keewatin and some geologists consider the Hoyle to be part of the Timiskaming. All are folded into steeply inclined attitudes and the lavas are intruded by bodies of grey quartz-feldspar porphyry, and are cut by numerous faults.

The Hollinger, McIntyre, and Coniaurum mines lie on a single sheared belt striking north 60 to 70 degrees east, with an almost vertical dip. The sheared zone in Keewatin lavas is about 1,600 feet wide on the Hollinger-McIntyre boundary, and narrows to about 500 feet on the Coniaurum. The veins on these properties lie within this zone and cut across it at a small angle. Their average strike is about north 50 degrees east; most of them dip steeply north. Where the veins run out of the sheared zone they feather and die out. It is common to find a "vein", the

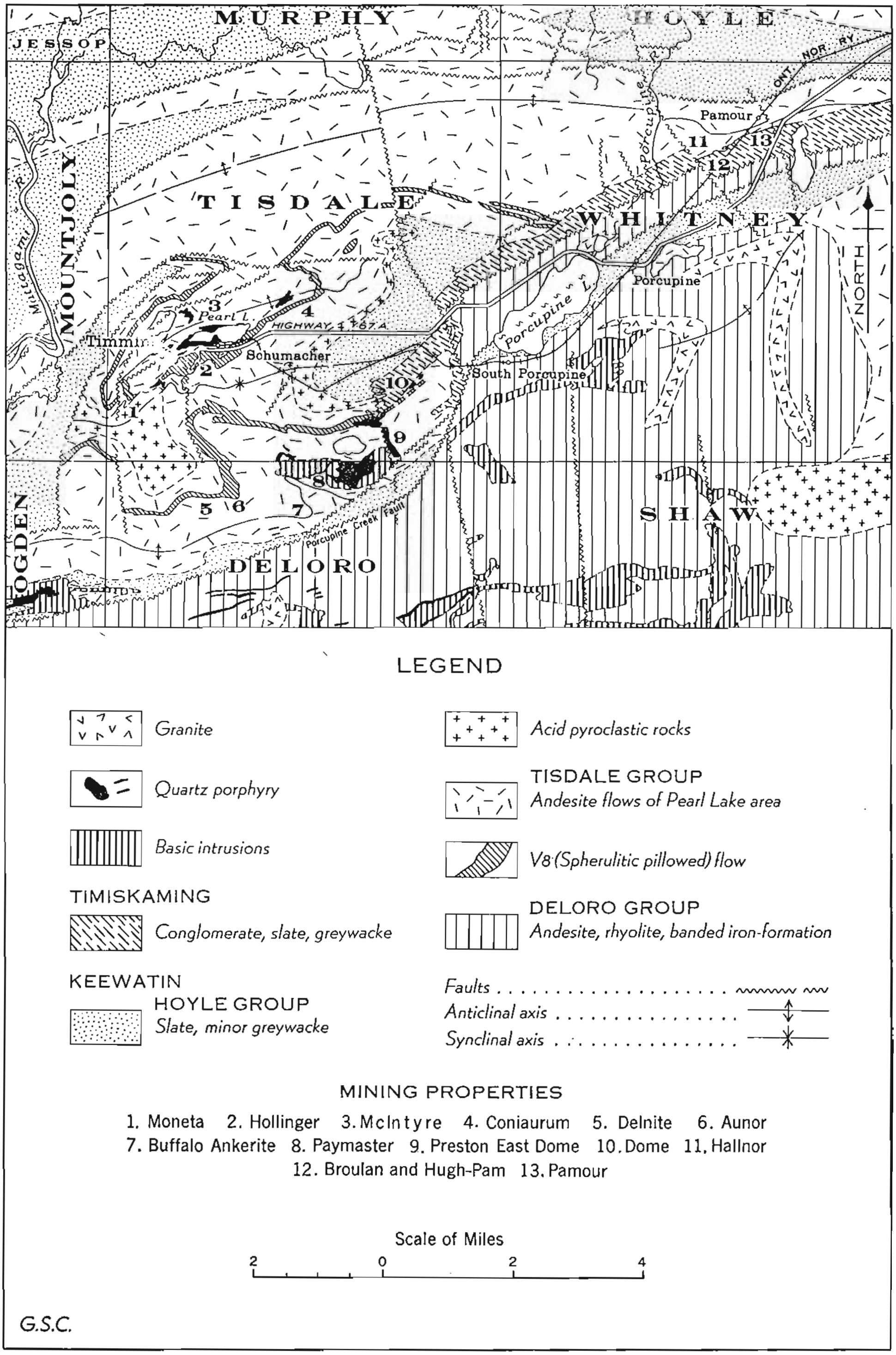


FIGURE 8. Geological map of Porcupine area. (Modified after W. R. Dunbar.)

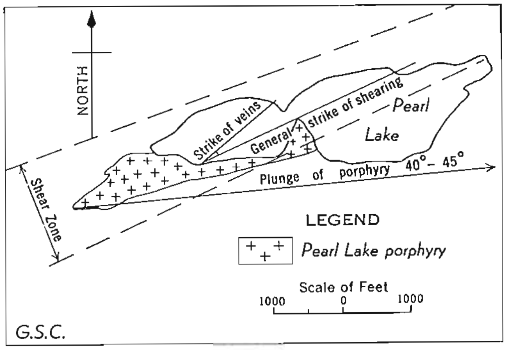


FIGURE 9.

Sketch showing structural factors of McIntyre geology. (After H. V. Skavlem.)

general strike of which cuts the schistosity at a small angle, composed of a succession of lenses of quartz separated by schist, each lens lying parallel to the schistosity and the next lens offset to the left *en échelon.*

Several porphyry masses intrude the lavas on the Hollinger and McIntyre properties, and are sheared where they fall within the schistose belt. The principal mass, the Pearl Lake porphyry, lies in the centre of the zone of shearing and vein formation. The outcrop is canoe-shaped, and underground work has shown that the western "prow" of the canoe plunges eastward at about 40 to 45 degrees along a line striking north 85 degrees east (Figure 9). The porphyry dips south and is practically parallel with the regional structure.

On the Hollinger the main ore zone, comprising a hundred or more productive veins, extends on the surface some 3,500 feet southwest of the end of the Pearl Lake porphyry and rakes east-northeast at about the same angle as the porphyry. Where the veins run into the porphyry, it has been commonly found that gold content drops off rapidly and becomes non-commercial, though the porphyry is becoming more important as host for ore with increasing depth (Figure 10).

On the McIntyre property northeast of the Hollinger only one vein of importance and a few of subordinate value outcrop north of the Pearl Lake porphyry mass. Owing, however, to the southward dip of the porphyry and its eastward plunge, other members of the Hollinger vein system appear at depth on McIntyre ground beneath the porphyry mass. Development of the McIntyre mine has been based on the hypothesis that with increasing depth more and more of such veins would be found. Time has proved the truth of this geological inference, so that the McIntyre has become progressively more valuable as exploration at depth continued (Figure 11).

The ore in the Hollinger and McIntyre mines consists of quartz and mineralized schist. The quartz is accompanied by ankerite and small amounts of albite, tourmaline, and scheelite. The metallic minerals are arsenopyrite, pyrite, pyrrhotite, sphalerite, chalcopyrite, galena, tellurides, and native gold. The schist near the veins is much altered by addition of silica, carbonate, potash, and auriferous pyrite. The orebodies, composed of quartz and auriferous schist, range in width from 1

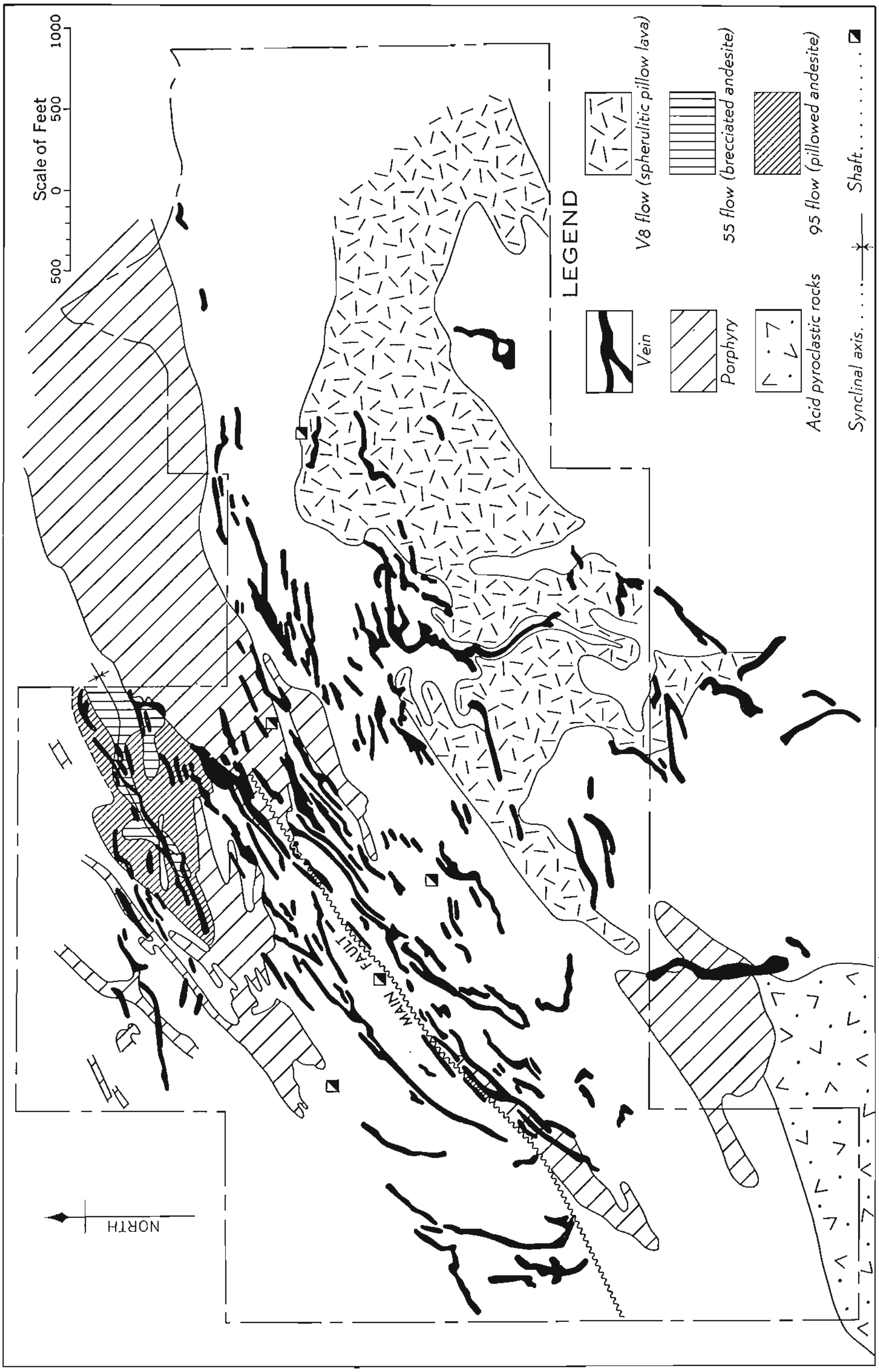


FIGURE 10. Plan of 425-foot level showing relation of Hollinger veins to geological structure. (After W. A. Jones.)

foot to 75 feet, with an average of about 10 feet. The amount of auriferous schist mined is considerably greater than the amount of quartz. Some of the ore is highly spectacular, with gold in coarse plates and cords traversing the quartz and binding it together. Total production from these two mines to the end of 1955 was $717,038,000.

The Dome mine was so called because the original stakings were on large dome-shaped outcrops of quartz. The mine lies near the extreme south edge of the basin of Hoyle (Timiskaming?) sedimentary rocks, which has a general synclinal structure, plunging northeast. At the south edge of the main syncline a deep, narrow, synclinal trough of the sedimentary rocks is infolded or infaulted into the Keewatin greenstones, and it was within this syncline that the original orebodies of the Dome lay. These were great lenses of ore, up to 600 feet in length and with widths ranging from 15 to 150 feet. The depth of some was as great as 800 feet, that of others less than 100 feet. More than thirty such bodies were found. They consisted of quartz and mineralized schist, but with the quartz very subordinate in amount, about 15 per cent.

These ores were completely worked out about the year 1928, and mining has since been carried on in the greenstones to the north of the infold of sedimentary rocks. The lavas there are a succession of flows that strike north 75 degrees east, dip about 70 degrees north, and face north. They range from 60 to 300 feet in width. These flows have been fractured along vertical east-west zones that average about 30 feet in width but may attain 100 feet or even more (Figure 12). Where these fracture zones cut brittle rocks, such as dacite or andesite, they give rise to important orebodies; but where they pass into softer rocks that shear rather than fracture, no orebodies are formed. Altogether, about 30 per cent of the volume of the fracture zones is quartz in the form of complex veins. The quartz veins carry pyrite, pyrrhotite, and native gold, and are normally selvaged with ankerite. The rock between the veins is altered and carbonated, and carries about 3 per cent of the same sulphides.

Another type of orebody is found in tuff beds lying between lava flows. These beds were apparently cut and altered by an old set of barren veins made up of quartz, tourmaline, and ankerite. Later movements fractured this material and permitted the entry of gold-bearing quartz, mineralized with a little pyrite and pyrrhotite.

A few miles northeast of Timmins the Hallnor, Broulan, and Pamour mines lie on or close to the north contact of the Timiskaming syncline with the underlying volcanic rocks. Differential movements between strata of different competency caused fracturing of the harder beds and permitted the entry of gold-bearing solutions, forming large bodies of low-grade ore. The mineral associations are the same as in other parts of the Porcupine field.

Several other mines in the Porcupine area have produced large amounts of gold, but space limitations preclude individual descriptions. Preston East Dome is unusual because a large body of porphyry has been much broken by fault

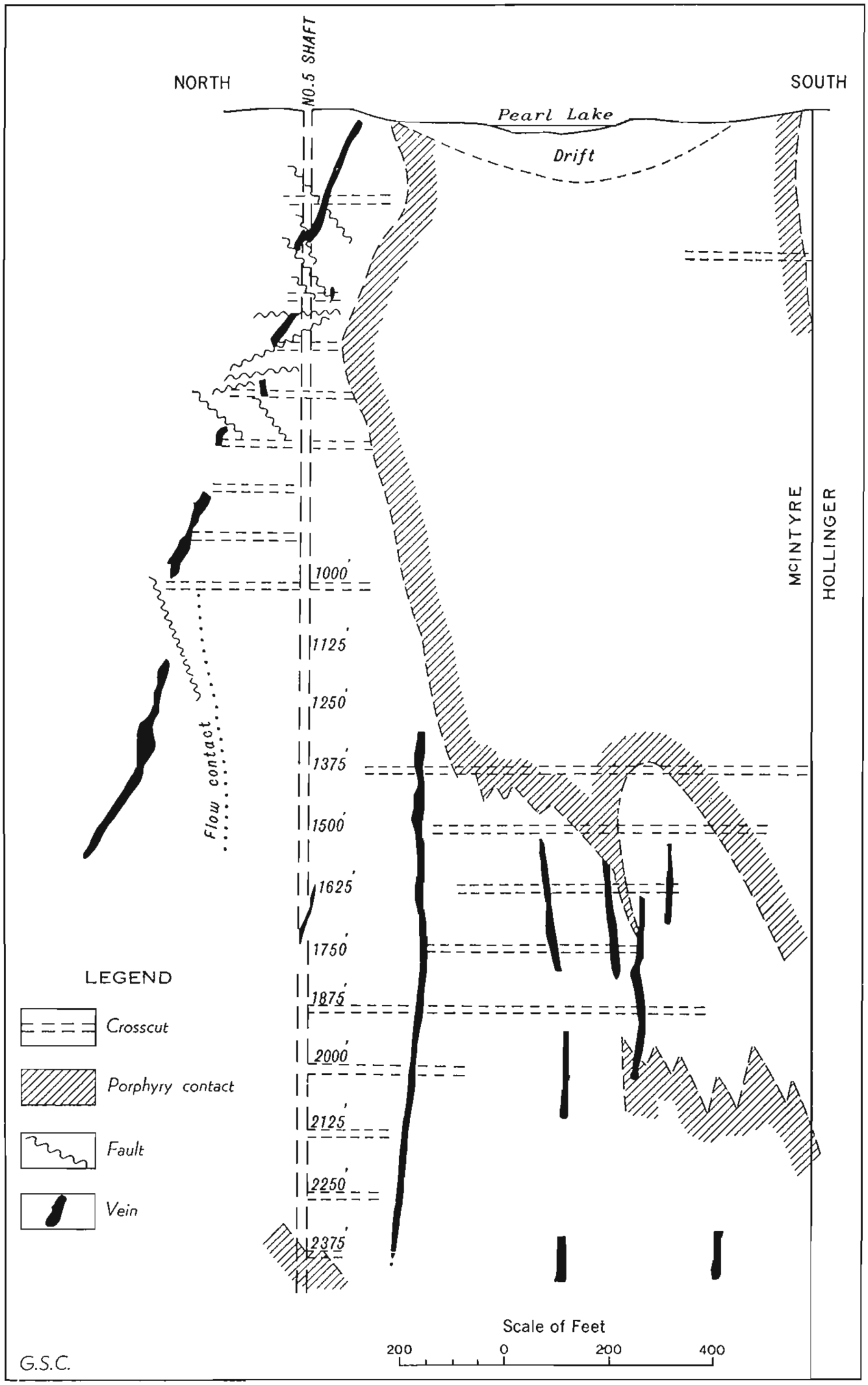


FIGURE 11. Composite section of McIntyre mine, showing veins beneath the Pearl Lake porphyry. (After A. G. Burrows.)

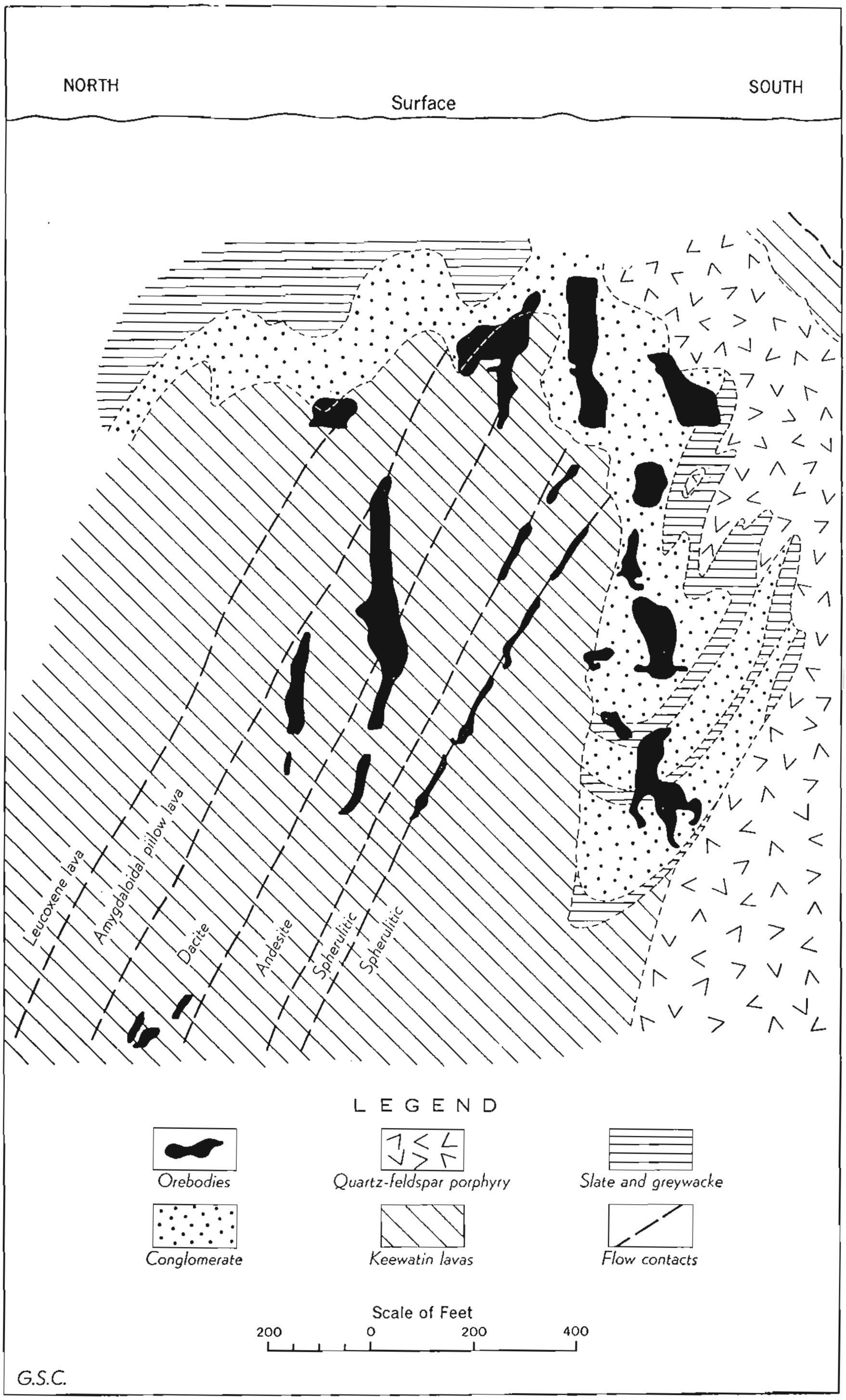


FIGURE 12. Cross-section of Dome mine, showing orebodies formerly found in syncline of Timiskaming rocks and now exhausted (right), and (left) orebodies in vertical fracture zones in lavas and in tuff beds between flows. (Courtesy of Dome Mines.)

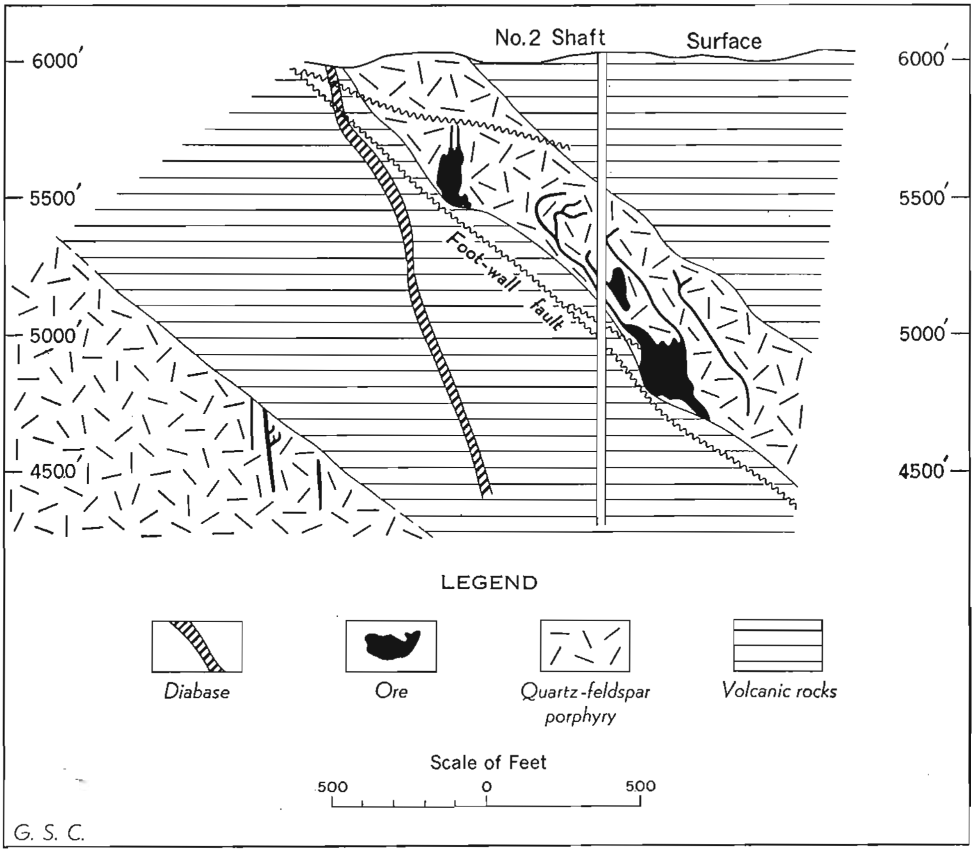


FIGURE 13. Geological cross-section facing north 36 degrees west, Preston East Dome mine. (After J. E. Hawley and R. C. Hart.)

movements, and ore-bearing solutions entering these fissures have altered and mineralized the porphyry to form large bodies of replacement ore, especially where foot-wall folds affect the underside of the porphyry (Figure 13).

Other mines in the region are the Young-Davidson of the Matachewan area, and the Ross mine of the Ramore area. The grade of ore mined from the Young-Davidson was very low, the average for 1951 to 1954 inclusive being about $2.80 per ton. Production ceased at the end of 1955 owing to depletion of the ore.

Michipicoten-Goudreau District. Gold was discovered in the Michipicoten district in 1897 and since then sporadic attempts have been made to mine the deposits. Most of them are rather narrow quartz veins carrying tourmaline, pyrrhotite, albite, and spectacular splashes and pockets of native gold. All are now closed, but the Renabie mine at the north end of the district came into production in 1947 and to the end of 1955 had produced about $10,300,000 in gold. The Renabie is unusual because its orebodies occur in fractures in granitic rocks some distance from the nearest greenstone.

Thunder Bay District. Within a belt of lavas and sediments extending from Lake Nipigon eastward for about 60 miles, eleven mines were opened in the 1934-39 period. These are: Bankfield Consolidated, Hard Rock, Jellico, Leitch, Little Long Lac, MacLeod-Cockshutt, Magnet Consolidated, Northern Empire, Sand River, Sturgeon River, and Tombill (Figure 14, localities 21-23). All but the Leitch and MacLeod-Cockshutt have since closed. This group of mines exhibits a rather wide variety of types. In some of them, such as Leitch, Sand River, and Sturgeon River, the orebodies are simple quartz veins, usually less than 4 feet wide, filling somewhat irregular fissures. The principal constituent of value is native gold; other minerals are scanty in amount.

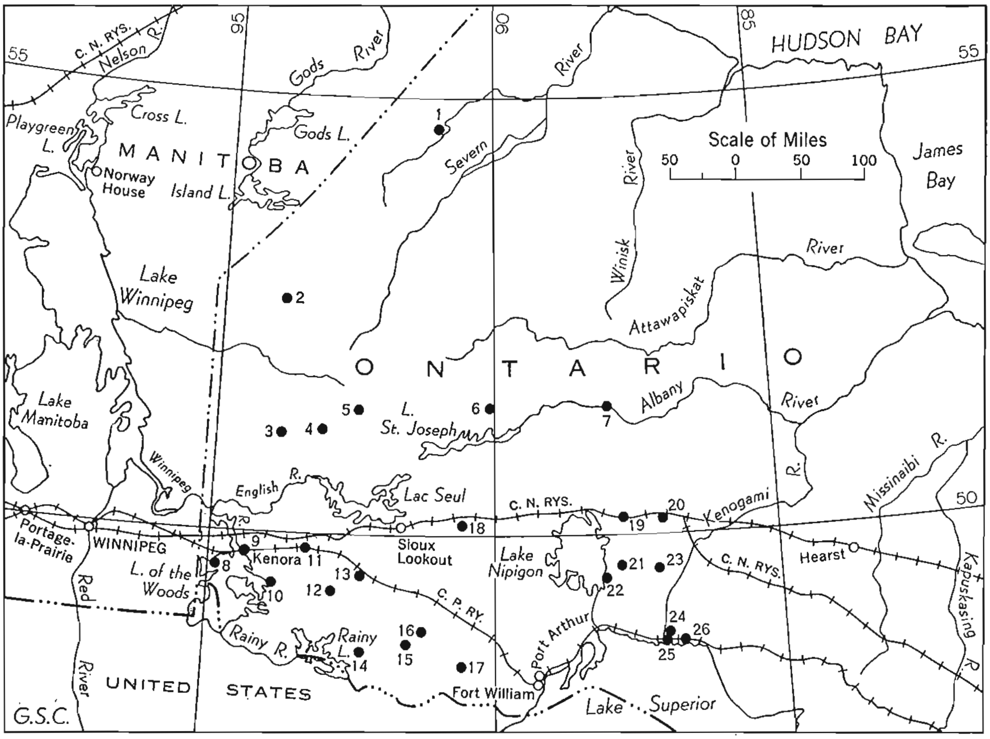


FIGURE 14. Index map of Lake of the Woods, Patricia, and Thunder Bay districts, western Ontario, showing principal known occurrences of gold. 1, Sachigo; 2, Favourable Lake; 3, Red Lake (Gold Eagle, Hasaga, Howey, *Madsen Red Lake, McKenzie Red Lake, Starratt Olson, New Dickenson, Cochenour Willans, Campbell Red Lake,* Red Lake Gold Shore); 4, Woman Lake (Hudson Patricia, J.M. Consolidated, Uchi); 5, Argosy (now Jason); 6, Pickle Lake (Central Patricia, *Pickle Crow*); 7, Fort Hope; 8, Mikado, Duport; 9, Sultana; 10, Regina; 11, Eagle Lake; 12, Manitou Lake; 13, Sakoose; 14, Mine Centre; 15, Harold Lake; 16, Hammond Reef; 17, Moss mine; 18, Sturgeon Lake (St. Anthony); 19, Tashota; 20, Kowkash; 21, Sturgeon River; 22, *Leitch,* Sand River, Northern Empire; 23, Bankfield, Hard Rock, Jellicoe, Little Long Lac, *MacLeod-Cockshutt,* Magnet, Tombill; 24, Duck Lake; 25, Schreiber; 26, Empress. Only those in italics were producing in 1955.

On the Little Long Lac property, arkose beds 1,500 to 2,000 feet thick are folded into an anticline, along the crest of which a number of shear zones strike east. Quartz injected into these has converted them into lodes that are uniform in width and continuous over remarkably long distances. The quartz carries a large amount of native gold and small amounts of arsenopyrite, pyrite, bournonite, stibnite, and tetrahedrite.

At the MacLeod-Cockshutt mine, about 2 miles southeast of Little Long Lac, the earlier discoveries were in iron-formation, parts of which were fractured and the fractures filled with quartz and auriferous pyrite. Mining operations have proved that beneath these is a mass of feldspar porphyry, the upper surface of which contains a deep westward-plunging trough or roof pendant of greywacke. Both the sedimentary rocks and, to a less extent, the porphyry along the contact are replaced by coarse pyrite, arsenopyrite, and a little native gold. This ore has an average grade of about 0.15 ounce a ton.

Patricia District. In the Patricia district twenty mines have produced gold. Of these the Howey came into production in 1930, but none of the others began milling before 1934. The ores of these mines are for the most part fairly rich. The controlling factor in their development was not the rise in the price of gold, but the growth of air transportation. In 1955 only seven of them were still operating (Figure 14, localities 3 and 6). As in so many places elsewhere in the Shield, the orebodies have been localized mainly where bodies of hard or brittle rock occur. Under the stresses of folding or faulting such bodies tend to shatter or fracture rather than shear, thus permitting the entry of ore-bearing solutions. The following descriptions of three of the principal mines illustrate this.

At Campbell Red Lake mine, which started production in 1949, the orebodies occur in two parallel zones of silicified sheared rock that cut across the regional trend of the enclosing Keewatin lavas at a low angle. The ore occurs in quartz veins that average 3 feet in width and consists of pyrite with less pyrrhotite and arsenopyrite, and minor chalcopyrite and sphalerite accompanied by coarse native gold.

The Central Patricia and Pickle Crow mines are adjoining properties on a band of iron-formation that strikes northeast. The iron-formation, an interbanded mixture of cherty silica and iron oxide or carbonate, has been folded into an overturned syncline that pitches northeast. At Pickle Crow the main orebody has been the Howell vein, a fracture that crosses the band of iron-formation at a small angle. The vein minerals are pyrrhotite and arsenopyrite, smaller amounts of pyrite and chalcopyrite, and native gold. The carbonate and chlorite of the adjacent iron-formation is partly replaced by auriferous pyrrhotite. The vein is bent into a series of drag-folds that yield very rich ore, and the iron-formation next the vein is much fractured and replaced by sulphides to give mineable widths of 8 to 18 feet. Where the vein runs out of the iron-formation into the surrounding greenstone, which fractured less readily, it narrows to about 3 feet and the wall-rock ceases to be ore.

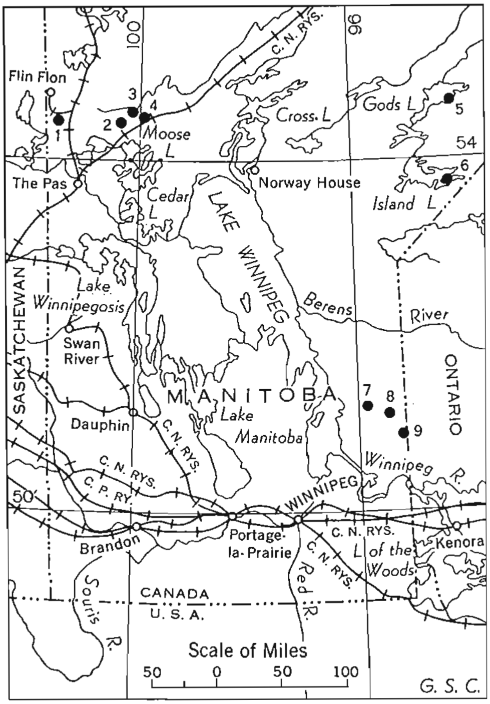


FIGURE 15. Index map of Manitoba showing principal known occurrences of gold. 1, Gurney; 2, Reed Lake; 3, Nor-Acme; 4, Laguna; 5, Gods Lake; 6, Island Lake; 7, San Antonio, Forty-four, Ogama-Rockland; 8, Central Manitoba; 9, Diana, Gunnar, Beresford Lake.

Manitoba and Saskatchewan

Although prospecting for gold began in about 1910, few properties have made profitable mines. At the end of 1955 only three were in production, the San Antonio, Forty-Four, and Nor-Acme (Figure 15).

The San Antonio mine, on the north shore of Rice Lake, is in a diabase sill, 200 to 500 feet thick, which strikes southeast and dips about 45 degrees northeast. Two complementary sets of fissures cut the sill. One trends nearly parallel with the walls of the sill and dips vertically; the other strikes northeasterly, at a large angle to the walls, and dips 60 degrees northwest. They narrow and die out as they approach the edges of the diabase body; only rarely do they extend into the surrounding schist. They are filled with quartz, patches of iron carbonate, and some albite and chlorite; the quartz is mineralized with fine pyrite, native gold, and a little chalcopyrite. The wall-rock is somewhat altered, but contains insignificant amounts of gold. In places, however, it is cut by so many small veins that the whole mass can be mined. The average tenor is about 0.3 ounce a ton. The rake and dip of the ore zone carries it northeast onto the ground of the Forty-Four mine. The latter came into production on January 1, 1955, the ore being mined through the San Antonio shaft and treated in the San Antonio mill.

The Nor-Acme deposit occurs at the crest of a northeasterly plunging anticline where a fault intersects the contact between basic pyroclastic rocks on the hanging-wall and acid lavas and sedimentary rocks on the foot-wall. The ore is a silicified, brecciated rock mineralized with arsenopyrite, pyrite, pyrrhotite, and fine gold. The gold is associated mainly with arsenopyrite and the grade averages about 0.17 ounce a ton.

Most of the gold of Manitoba and the adjacent part of Saskatchewan has come, however, not from the gold mines proper but from copper ores of the Mandy, Flin Flon, Cuprus, and Sherritt Gordon mines (Figure 30). Since the smelting of ore from these mines began in 1931 the recovery of gold has been more than double that obtained from the gold mines.

No gold mines are operating in Saskatchewan. At Goldfields, on the north shore of Lake Athabasca, sill-like bodies of coarse, reddish granite have been greatly fractured and injected by quartz to form stockworks of small veinlets. The quartz is sparsely mineralized with coarse auriferous pyrite, a few grains of chalcopyrite and sphalerite, and native gold. At the Box mine (Figure 16), the Consolidated Mining and Smelting Company of Canada Limited attempted mining one of these bodies on a large scale, but the average grade proved very low, less than 0.05 ounce a ton. Milling, which began in 1939, ended in August 1942. Some production of gold was also won from small properties in Saskatchewan near Flin Flon.

Northwest Territories

Most of the deposits of the Northwest Territories are in the Yellowknife district, northeast of the north arm of Great Slave Lake, where the volcanic and sedimentary rocks of the Yellowknife group are intruded by great bodies of granite, and are more or less metamorphosed near the contacts to knotty schist and hornfels. The rocks stand on edge in closely spaced isoclinal folds and have been displaced by two sets of great faults, one striking north 20 degrees west, the other practically at right angles to this. Rupture on a smaller scale is also common along the axes of the tight folds.

Gold-bearing veins are found in the lavas and the sedimentary rocks. Those in the sedimentary rocks are mainly bedded veins, saddle reefs, and veins intro-

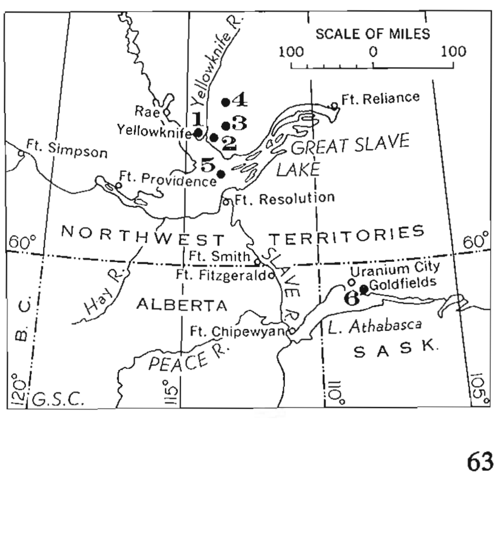


FIGURE 16. Index map of part of Northwest Territories and Saskatchewan, showing principal known occurrences of gold. 1, Giant Yellowknife, Con-Rycon, and Negus; 2, Ptarmigan; 3, Thompson-Lundmark; 4, Consolidated Discovery; 5, Outpost Islands; 6, Box.

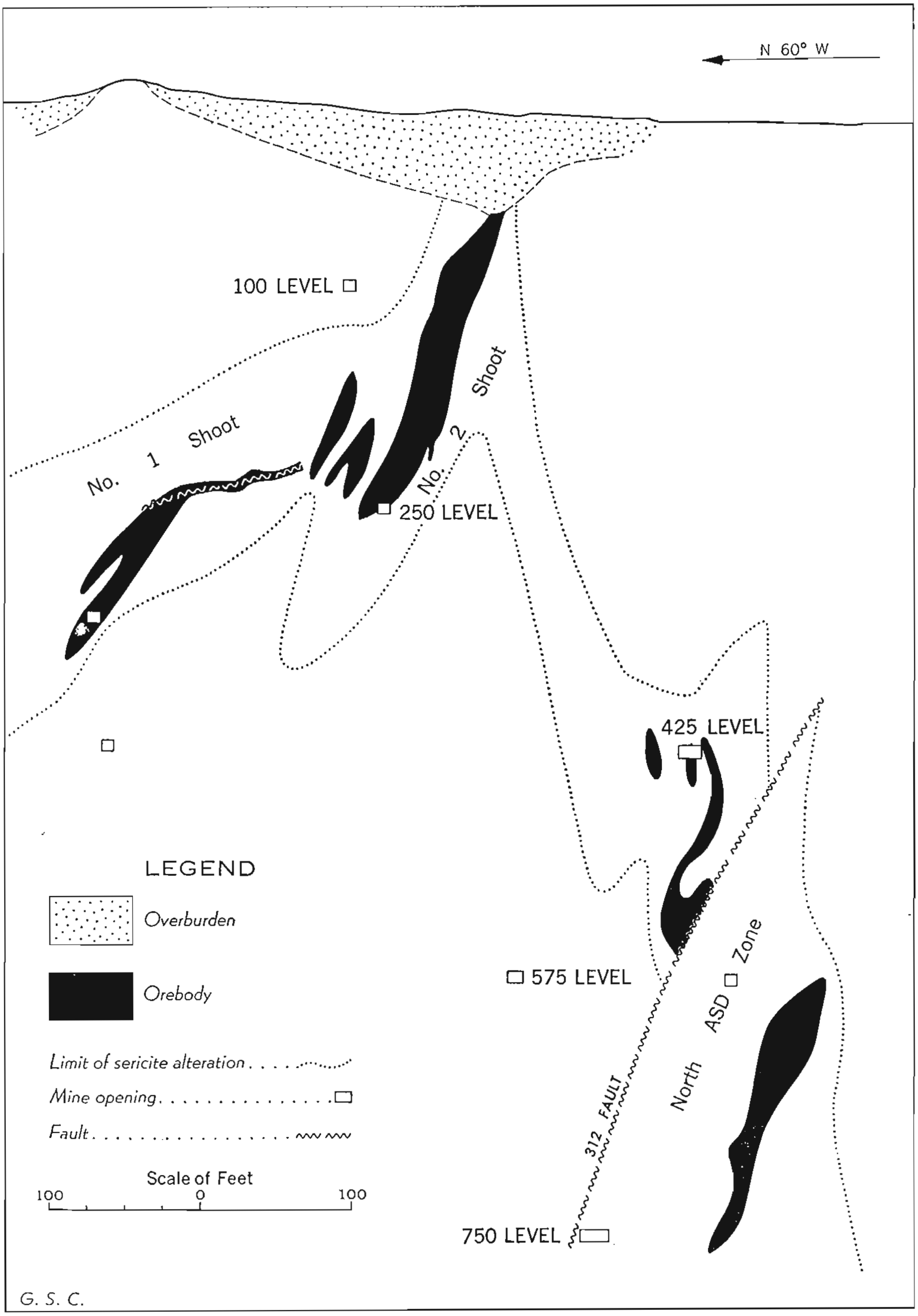


FIGURE 17. Structure-section 800 feet north of B shaft, Giant Yellowknife mine. (After C. E. G. Brown and A. S. Dadson.)

duced along the fractured axes of the folds. Two small mines, the Ptarmigan and Thompson-Lundmark (Figure 16), commenced milling in the last half of 1941, but wartime conditions compelled both to close, in 1942 and 1943, respectively. However, the Consolidated Discovery mine came into production in December, 1949 on a high-grade deposit formed in a drag-folded quartz vein in slightly metamorphosed but highly contorted greywacke. The orebody occurs near the crest of the drag-fold, which plunges steeply north and whose limbs dip steeply west. The orebody is 100 feet or more long and averages 4 to 7 feet wide.

The ores in the lavas are of two types. Those first discovered lie in small shear zones that parallel the large faults striking north 20 degrees west. The veins are lenticular bodies of quartz averaging about 5 feet wide, though attaining in places 15 feet or more. The quartz, moderately mineralized with pyrite, is much cracked, and the cracks are filled with a great variety of minerals, including various sulpharsenides, sulphantimonides, and tellurides in small amount. The gold, which is mostly free, tends to be most abundant in the relatively pure quartz. The veins are vuggy in places, suggesting that they were developed after the main movements had been completed.

The Con-Rycon and Negus mines were developed on veins of this type. The first came into production in September 1938, the second in February 1939. The ore milled by each had an average tenor of nearly an ounce a ton. These properties were closed in 1943 and 1944, respectively, but the Con-Rycon resumed operations in 1946.

The Giant Yellowknife orebodies are of a different type. They are in chloritic zones, up to 200 feet wide, formed along what are believed to be early thrust faults that now have fold-like attitudes. The orebodies may occupy any part of the sheared zone, but occur particularly near the crests of the apparent folds (Figure 17). They are accompanied by sericitic and carbonate alteration and by 30 to 90 per cent quartz. A complex assemblage of metallic minerals includes abundant, barren, fine-grained pyrite, lesser arsenopyrite, some sphalerite, chalcopyrite, and several sulphantimonides and sulpharsenides. Gold, either alone in quartz, or associated with the sphalerite or the complex sulphides, averages about three-quarters of an ounce a ton.

Silver

In 1955 mines within the Canadian Shield produced about 9 million ounces of silver. Most of this output was a by-product from the mining of other metals, whereas in 1924, by contrast, all but 7.1 per cent of the 10,699,684 ounces of silver mined from the Shield came from ores worked mainly for their silver. At that time, of course, the great Cobalt silver camp was not worked out.

Besides the Cobalt camp and its subsidiary districts, which together stretch 75 miles westerly from Lake Timiskaming, a second district around Port Arthur has produced some silver; also silver is recovered from the Eldorado pitchblende deposits at Great Bear Lake.

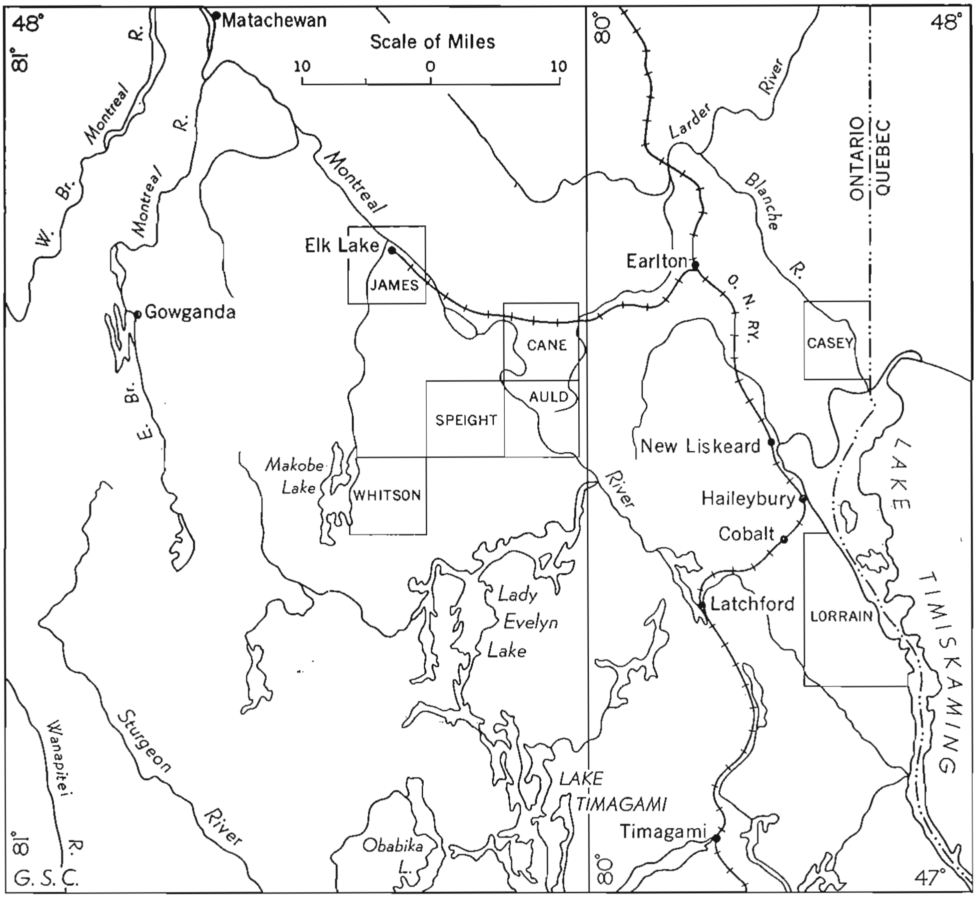


FIGURE 18. Index map showing positions of chief silver-bearing areas in the Cobalt region, Ontario.

Ontario

Cobalt and Subsidiary Districts. Silver was discovered at Cobalt in 1903 and shipments commenced in 1904. Up to the end of 1937 the Cobalt camp alone yielded 383,635,561 ounces of silver, the Gowganda camp 24,647,496 ounces, the South Lorrain camp 22,867,295 ounces, and the outlying camps of Casey township, James township, Maple Mountain, Speight, and Whitson townships, 2,831,367 ounces, a grand total of 433,981,719 ounces (Figure 18). In addition to the silver, the mines yielded in the same period 80 tons of bismuth, 931 tons of copper, 355 tons of lead, 6,230 tons of nickel, 16,328 tons of cobalt, and 72,189 tons of arsenic. Since 1937, and particularly since the beginning of the war, the mines have been operated mainly for their cobalt content, although important amounts of silver are also being produced. In the last decade some new but small mines have been discovered and have become producers.

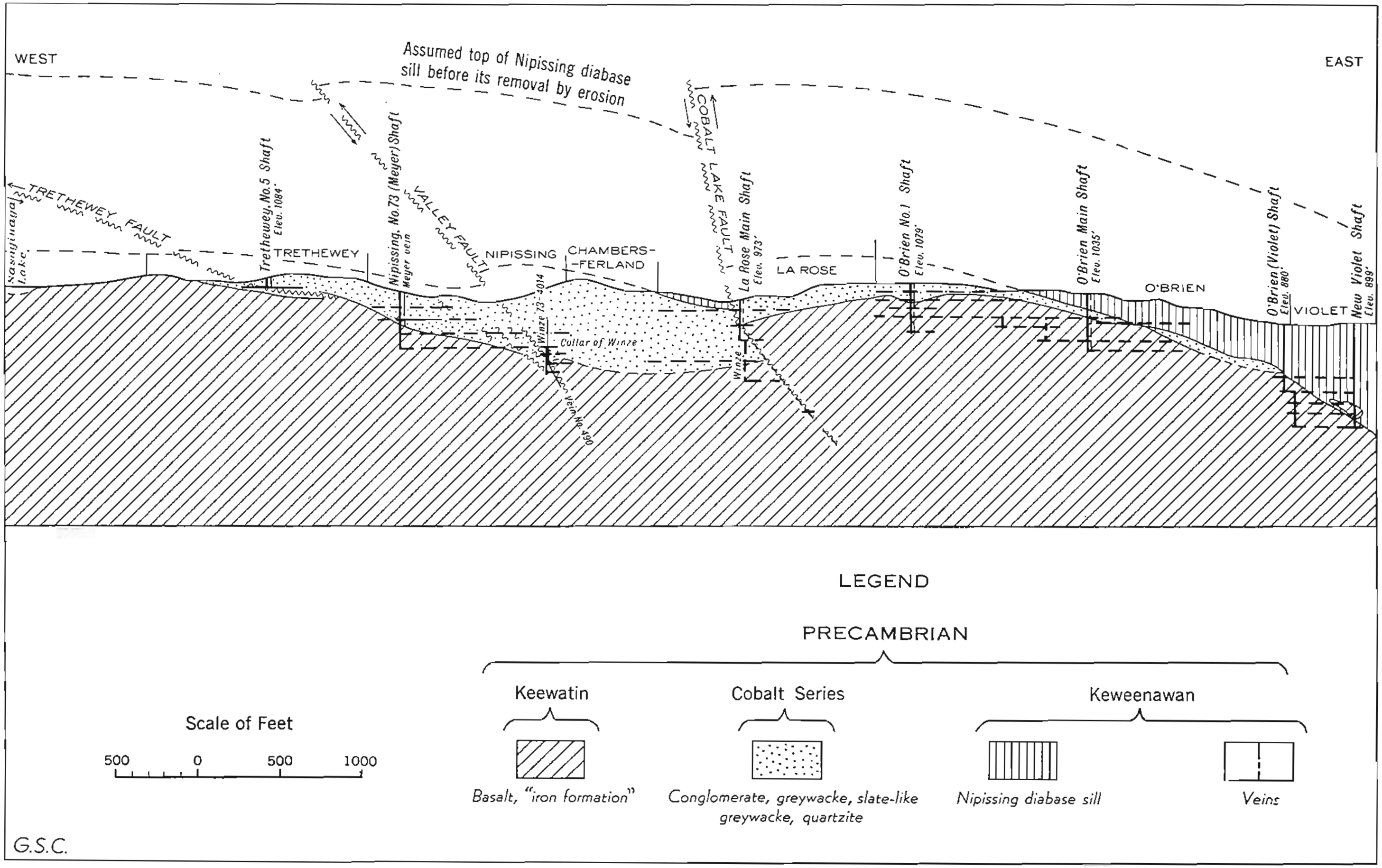


FIGURE 19. Vertical section through north part of Cobalt camp, Ontario. (After C. W. Knight.)

Most of the productive mines at Cobalt were grouped within an area of about 6 square miles. The rocks are gently dipping strata of the Cobalt series laid down on an irregular erosion surface of steeply folded Keewatin lava, tuff, and iron-formation. A sill of Nipissing diabase about 1,000 feet thick intrudes these along a warped plane that passed in part through the Cobalt series, in part through the Keewatin rocks. In general the sill dips gently east, and erosion has now removed parts of it so that the western part of the field is now largely occupied by Keewatin and Cobalt strata that lie below the sill, whereas the eastern part is underlain by the sill itself, together with some areas of Keewatin or Cobalt rocks that overlie the sill.

The silver ores may have emanated from the diabase sill; at any rate no ores have been found where the diabase sill is absent, and all the ores were found within a few hundred feet of the contact, either above or below, or within the diabase itself. A curious feature is that the Keewatin rocks, for some reason, seem to have been essential to ore formation. No important quantity of pay-ore has been found where the Keewatin is absent. Nevertheless, veins did not commonly extend into the Keewatin much below the base of the Cobalt series, and when they did the silver disappeared.

In general, silver was found in three positions. About 80 per cent of it was found in the Cobalt series within 100 to 200 feet of the Keewatin contact (Figure 19); the remainder occurred along the upper or lower contact of the sill, mostly within 200 or 300 feet of either margin. Few veins were found near the middle of the sill. Pre-ore faults played their part, mainly acting as dams or barriers that confined deposition to certain areas. In south Lorrain, however, much of the ore came from the Woods fault or branches of it. In fact, faults are now believed to have been responsible for localizing most of the ore in the camp.

The high-grade veins were mostly narrow, from an inch to a foot in width, though in rare instances, and for relatively short lengths, widths attained several feet. The veins had all directions of strike and usually vertical dips. Some were followed for several thousand feet, but most of them were much shorter. Besides the high-grade veins, in places the wall-rocks were broken by innumerable tiny cracks into which the vein-forming solutions penetrated and deposited silver. Considerable widths of rock were thereby converted into a low-grade ore, locally termed mill-rock.

The high-grade veins contained a great variety of minerals, of which the chief were calcite, smaltite, niccolite, and native silver. Pyrargyrite, proustite, argentite, millerite, chalcopyrite, sphalerite, galena, and many others were also present. The silver occurred in films, flakes, wires, and flattened masses, and was usually accompanied by argentite and native bismuth. Typical high-grade ore averaged about 10 per cent silver, 9 per cent cobalt, 6 per cent nickel, and 39 per cent arsenic, but some contained much more silver, up to 7,000 ounces a ton.

In South Lorrain township a diabase sill forms an irregular, elongated dome a few miles long, whose central part has been completely removed by erosion. The productive veins occurred in the sill and in overlying Keewatin rocks within a small area, about 100 acres, on the western edge of the dome. The main vein occurs in the Woods fault, a reverse fault with a displacement on the dip of about 30 feet. The Woods vein, unlike the narrow fissures of the Cobalt area, is a fractured zone that attained widths of 5 to 10 feet. The vein material did not extend from wall to wall, but formed a number of stringers that ramified through the shattered country rock. Also, unlike anything to be seen at Cobalt, the more strongly fractured parts of the Woods fault displayed intense weathering, due to pre-glacial downward circulation of ground water, to a depth of at least 560 feet. As a result, secondary enrichment occurred below the zone of oxidation and immensely rich bonanza masses of native silver, argentite, and ruby silver were formed. Below the altered zones the usual Cobalt-type minerals were found.

In the Gowganda area, about 55 miles northwest of Cobalt, the diabase sill is probably not more than about 500 feet thick. More than one sill may be present. As at Cobalt, the diabase is injected into Keewatin rocks and gently dipping beds of the Cobalt series. Most of the veins yet found lie at the upper contact of the sill in the diabase itself, though one important vein was in Cobalt conglomerate, and a few in Keewatin greenstone, just above the sill.

At Gowganda the diabase displays a series of differentiation products that progress to an aplite carrying little feldspar but much calcite and some chalcopyrite. Some aplite veins carried irregularly distributed masses of calcite accompanied by native silver, smaltite, and niccolite. These features suggest that the silver veins themselves may be the result of differentiation of the diabase.

Considerable silver was obtained from Casey township, 15 miles northeast of Cobalt. The usual calcite veins occurred in Cobalt rocks and were formed apparently at horizons not far below the base of a diabase sill completely removed by erosion.

Silver-bearing veins of similar types have also been found near Bay Lake, 10 miles west of Cobalt; in Auld, Cane, Speight, Whitson, and James townships northwest of Cobalt; and south of Larder Lake. The total production, however, has not been large.

Port Arthur District. In Port Arthur district Archæan rocks are overlain by gently dipping Animikie sedimentary rocks, which have been invaded by sills and dykes of diabase. The assemblage has been faulted, and the fissures thus formed are filled with calcite, barite, and quartz, mineralized in places with chalcopyrite, pyrite, argentiferous sphalerite, argentiferous galena, native silver, argentite, and a great variety of other minerals. The proportions of the different minerals vary widely, and the veins themselves range in width from a few inches to 20 feet.

Most of the silver from this area was obtained from Silver Islet, an island less than 80 feet in diameter lying off Thunder Cape. The deposit was discovered in 1868 and was worked for 16 years, in which time silver valued at about $3,250,000 was produced. Silver at that time was worth about $1.30 an ounce. The rocks are Animikie shales, almost flat lying and cut by diabase dykes that strike northeast and dip steeply southeast. These are cut by faults that strike northwest and have been healed by vein materials. The Silver Islet fault strikes north 35 degrees west and dips 70 to 80 degrees northeast. It has given the Silver Islet dyke a left-hand horizontal displacement of about 80 feet. The Silver Islet dyke is 350 feet wide at the surface, and decreases to 250 feet at a depth of 560 feet, which width is maintained to the 1,100-foot level. Ore was found only where the fault crossed the dyke; in the surrounding shales the vein feathered out.

Numerous other discoveries were made throughout the region between the International Boundary and Nipigon Bay. The more important were in two groups, one at Rabbit Mountain and the other at Silver Mountain, about 18 and 30 miles, respectively, west-southwest of Fort William. Since 1892 nearly all of these mines have lain idle, though from time to time a re-examination or some further development has resulted in a little additional production. Total production to the end of 1913 was valued at about $1,500,000.

Northwest Territories

In 1930 native silver was discovered at the east end of Great Bear Lake, and the richness of some of the early finds caused many to hope that a new Cobalt had been found. However, continued exploration did not substantiate the earlier expectations, and now it does not appear likely that production will be great.

Both the composition of the ores and their history of deposition are complex and all that can be said is that a complex of Proterozoic rocks, both igneous and sedimentary, was cut by faults along which repeated movements took place. After each movement the fractures were healed by deposition of a variety of minerals, both metallic and non-metallic, so that the ores are now a mineralogist's paradise. Pitchblende and silver, both native and in various compounds, were among the last minerals deposited. In some places the silver minerals were distinctly later than the pitchblende, and may form bodies from which pitchblende is absent; in others the silver and pitchblende seem to be contemporaneous, and are found together. The ores are valuable mainly, however, not for their silver content but for the radium and uranium present in the pitchblende.

Nickel

Ontario

Sudbury District. Nickel occurs in several places in the Canadian Shield, but by far the greater part of the production of the metal is derived from the Sudbury nickel-copper ores. These deposits were first noticed in 1856, but were disregarded until the completion of the Canadian Pacific Railway in 1885 made transportation possible. During the first few years the ores were exploited for their copper content alone; not until 1887 was the presence of nickel determined.

In 1955 these mines furnished approximately 65 per cent of the world production of the metal. From the start of production in 1889 to the end of 1955 they have supplied about 3,700,000 tons of nickel, together with a roughly equivalent amount of copper and important amounts of gold, silver, platinum, palladium and other metals of the platinum group.

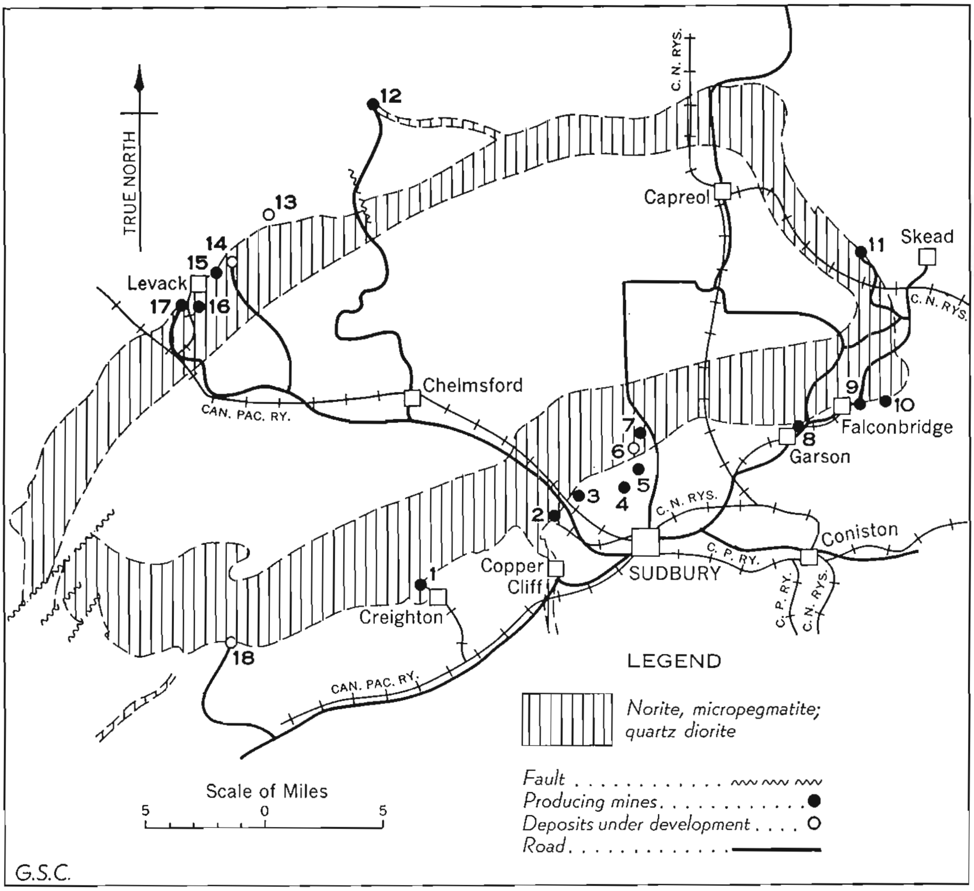


FIGURE 20. Sudbury nickel district, Ontario. (After Mines Branch.) 1, Creighton; 2, Murray; 3, McKim; 4, Frood; 5, Stobie; 6, Blezard; 7, Mount Nickel; 8, Garson; 9, Falconbridge; 10, East Falconbridge; 11, East Rim; 12, Nickel Offsets; 13, Longvac; 14, Fecunis Lake; 15, Levack; 16, Boundary; 17, Hardy; 18, Crean Hill.

The Sudbury ore deposits (Figure 20) are closely associated with a body of norite and micropegmatite that outcrops as an oval ring 37 by 17 miles in diameter, and 1 mile to 3.6 miles broad. The outer part of the ring is norite, and the inner, micropegmatite, with a fairly rapid gradational change from one to the other. Inside the oval ring of norite-micropegmatite, the Whitewater series of volcanic agglomerate, tuff, and sedimentary rocks is complexly faulted and folded. Wide dykes of olivine diabase cut indiscriminately through norite, Whitewater series, and other rocks, and small bodies of granite invade the norite in places.

The apparently open synclinal structure of the Whitewater series, the annular shape of the norite-micropegmatite mass, and the symmetrical disposition of these acid and basic phases combined to suggest that the igneous mass is a thick sheet intruded along the contact of the Whitewater series with older rocks. However,

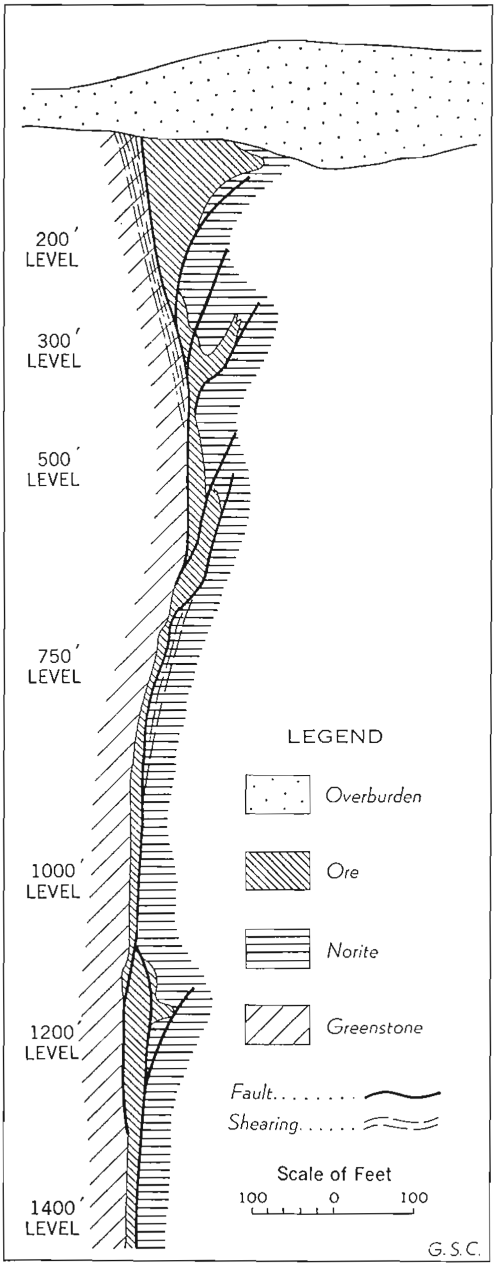


FIGURE 21. Geological cross-section, Falconbridge mine (looking west). (After D. R. Lochead.)

studies by the Ontario Department of Mines have produced evidence that the Whitewater series may actually be part of the presumed older rocks outside the ring and special investigations by J. Howell Williams have produced further evidence suggesting that the irruptive is actually a ring dyke and, therefore, a composite intrusion. Although this interpretation is being challenged, it provides an explanation for the dips of the intrusion, which vary from about 35 degrees inward to steeply outward.

The orebodies lie either along or close to the outer margin of the norite and are called "marginal deposits", or they form dyke-like or irregular bodies in the older rocks and are known as "offset deposits". The ore minerals are chiefly pyrrhotite and chalcopyrite, the former predominating. Nickel is mainly, if not solely, contained in the mineral pentlandite, and platinum in the mineral sperrylite. The sulphides apparently replaced the matrix of breccia so that the ore consists of rock fragments cemented by the sulphides and partly replaced by them. The fragments vary in size from bodies several hundred feet in length to minute grains, and may constitute up to 60 per cent of an orebody.

Up to a few years ago it was generally considered that these ores originated by settling from the presumed sheet-like mass of norite-micropegmatite, but if the intrusion is a ring dyke, then such an origin for the ores is obviously precluded. The ore is almost everywhere associated with a so-called quartz diorite that is considered to be a phase of the norite. The orebodies occur where intensely brecciated rock, formed by intense faulting, has subsequently been mineralized; the great Frood orebody is localized along an intensely brecciated zone of quartz diorite. The pipe-like orebodies near Copper Cliff, of which No. 2 mine is an example, occurred where a zone of brecciation cuts across the quartz diorite. Some Creighton ore occurs at the contact between granite and quartz diorite.

The Falconbridge deposit is a continuous and well defined sheet of sulphides trending roughly east and standing almost vertically, with a steep average dip to the south, away from the basin. The mine is about a mile long, workings extend down 4,025 feet, and drills have intersected ore some 5,600 feet below surface (Figure 21). The ore zone averages about 15 feet in width, but locally exceeds 100 feet. It is apparently a mineralized fault and it has been found that, where post-basin faults are lacking on the contact in the Falconbridge area, there are no ore zones.

The relatively late age of some of the ores is indicated by a discovery at the Garson mine, where a body of ore some 40 feet in width is reported to cut directly across a dyke of olivine diabase, the youngest Precambrian rock of the region. Elsewhere, sulphides are reported to cut the latest granitic rocks.

The tenor of the ore is variable. Some years ago the mine average was about 3.5 per cent nickel and 2 per cent copper. Of late years, however, the grade has gradually fallen, until in 1955 the average tenor was about 2 per cent nickel and slightly less than that amount of copper. This is due to the inclusion with the higher grade ores of large amounts of low-grade material, particularly from the

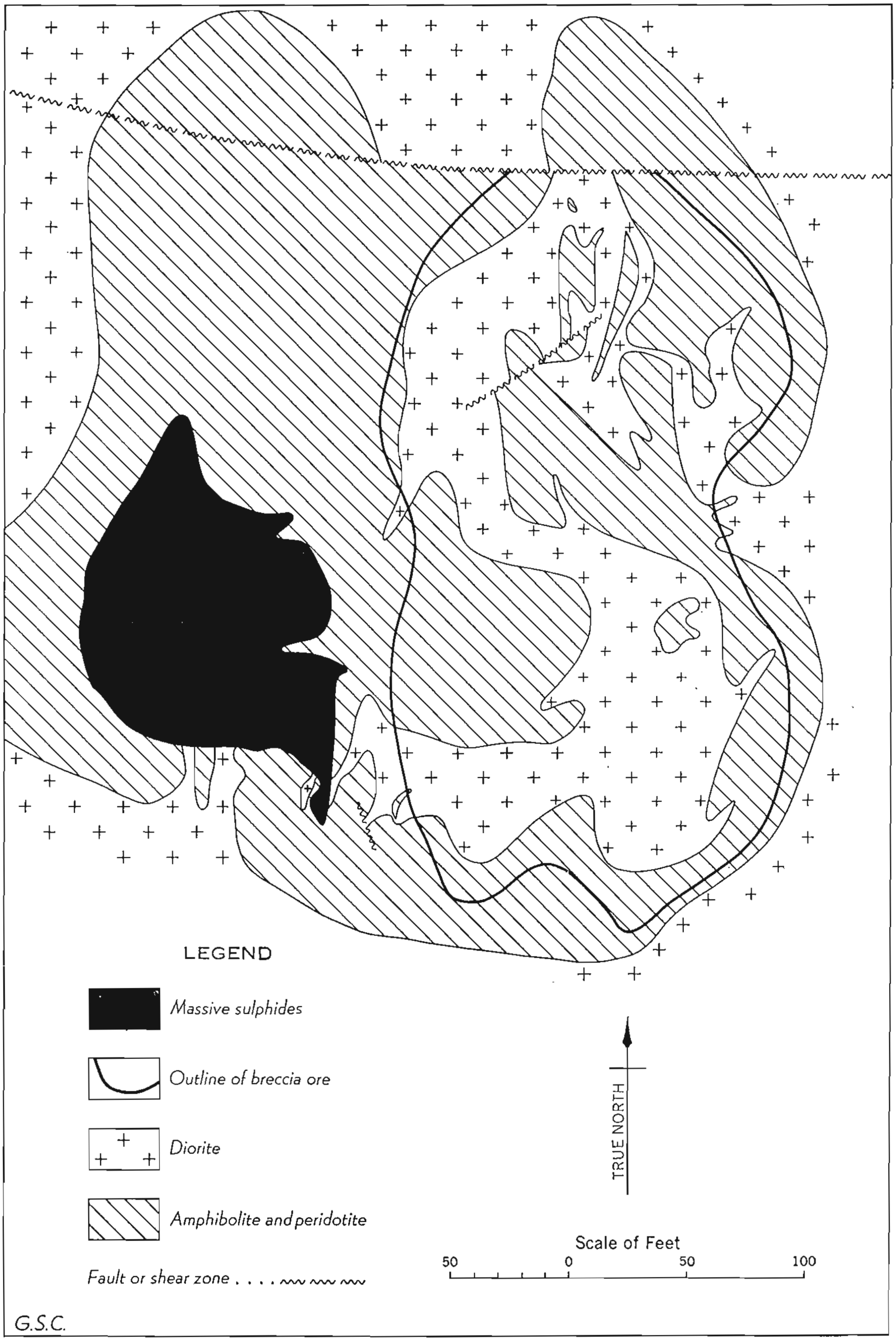


FIGURE 22. Plan of 575-foot level, "EL" orebody, Lynn Lake, Manitoba. (After G. D. Ruttan.)

open pit at the Frood mine. The price of nickel has been high and the demand strong, so that the Sudbury basin has been the scene of intense exploration. As a result, several new mines have come into production since 1950 and more are expected to be in production by 1958. These include East Falconbridge, McKim, Hardy, Mount Nickel, Fecunis, Boundary, and Longvack, all under control of Falconbridge Nickel Mines; and Nickel Rim and Nickel Offsets. Some nickel has been produced from other mines in the basin area, including Crean Hill being re-examined by International Nickel Company, and the Blezard Mine.

Other Deposits. Some nickel was also produced from the Alexo mine, northwest of Timmins, where nickel ore occurred at the edge of a body of serpentine that intrudes Keewatin lavas. The ore was chiefly pyrrhotite, carrying small amounts of pentlandite, chalcopyrite, and pyrite. Massive ore varied in width from a few inches to 20 feet; disseminated ore, from 3 to 20 feet. The massive ore carried 6 to 8 per cent nickel and less than 1 per cent copper. In the years 1912-19, inclusive, 51,279 tons of ore were mined and shipped to the Mond Nickel Company's smelter at Sudbury. No figures are available for the nickel recovered.

Several deposits have been found elsewhere in Ontario, some recently and others many years ago, but none have become important producers. The Trebor deposit in the Timagami area is reported to contain 4,780,000 tons of low-grade, complex nickel-copper material in peridotite. Some production was won prior to 1937, but the operation was not economic. Low-grade deposits of nickel have recently been reported in association with high-grade copper deposits at Lake Timagami. About 50 miles west of Port Arthur, south of Shebandowan Lake, Keewatin lavas are intruded by granite, and 50 or 60 feet from the contact a zone of sulphides from 1 foot to 35 feet wide has been traced by pits and trenches for more than a mile. The ore is mainly pyrite, with some chalcopyrite and pyrrhotite. Values up to 7 per cent in nickel are reported, but these are rare. Some showings have been discovered in the Kenora district and are being intensively prospected. They are associated with gabbro and peridotite.

Manitoba

Sherritt Gordon's Lynn Lake nickel-copper property, about 110 miles north of its old Sherridon copper mine, came into production late in 1953. Ore reserves of about 13,820,000 tons, calculated at December 31, 1955, occur in seven orebodies that have been found in two basic plugs. Ore occurs as massive sulphides, disseminated sulphides, or stockworks of sulphide stringers where faulting has fractured the intrusions. The sulphides are pyrrhotite, pentlandite, chalcopyrite, and pyrite. Cobalt, zinc, and gold occur in minor amounts. The orebodies are cut by post-mineral faults.

The "EL" mine is on the richest orebody, which occurs within an inner core of a basic plug (Figure 22). Massive sulphides lie adjacent to but separate from mineralized amphibolite and diorite. Alteration of the basic rock varies from extreme to negligible. The six other orebodies occur in one basic plug that is about 12,000 feet long and 5,000 feet wide, and they occur where the basic rock has

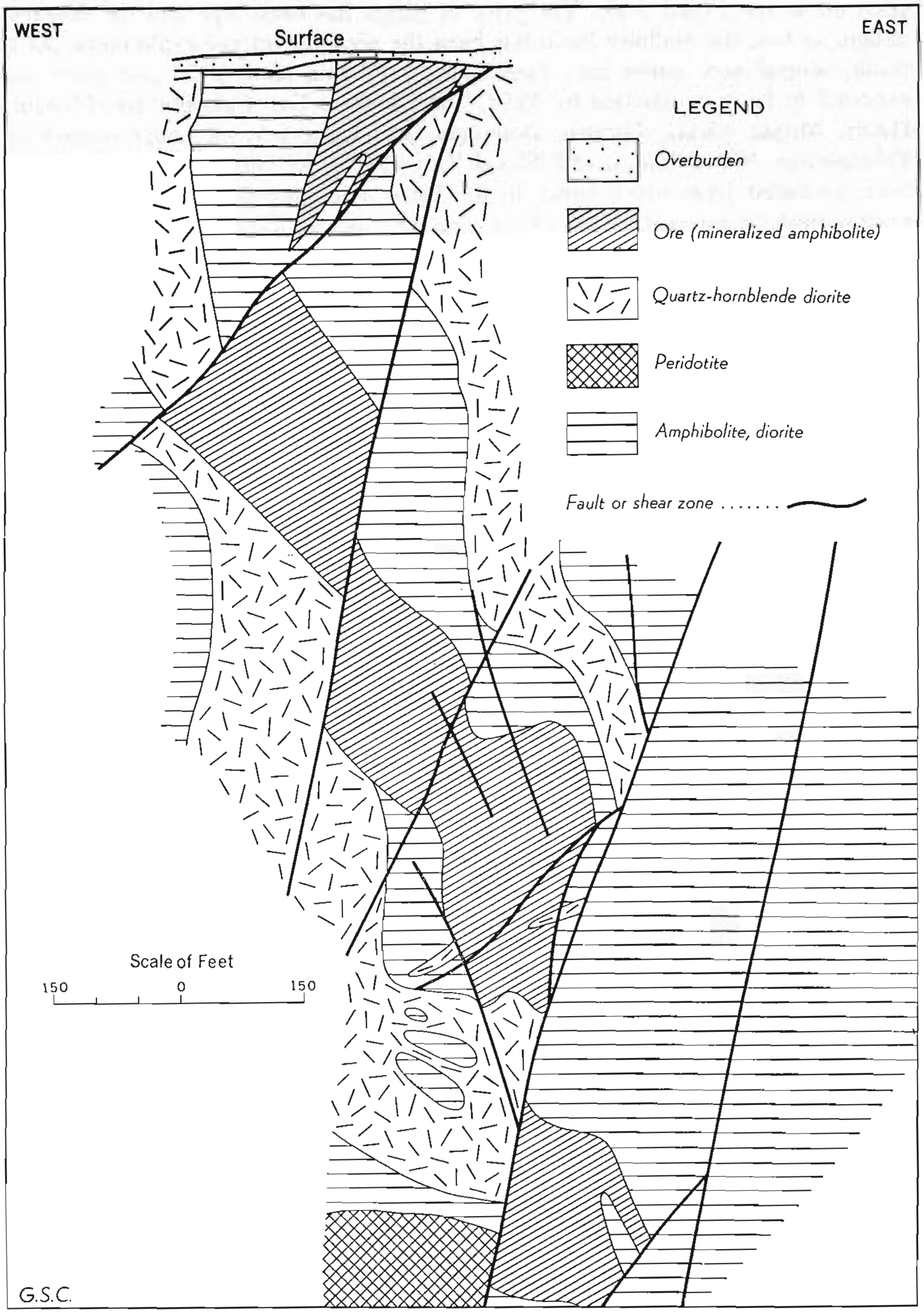


FIGURE 23. West-east vertical section, "A" orebody, Lynn Lake, Manitoba. (After G. D. Ruttan.)

been most brecciated by pre-ore faults. The ore itself appears to be displaced by these west-dipping thrust faults (Figure 23) but actually the amount of post-ore movement on these faults is minor.

Besides explorations for nickel in the region about Lynn Lake, large areas of Manitoba have been examined. The International Nickel Company of Canada Limited announced late in 1956 its intention to proceed with the development of its Mystery-Moak Lake deposits about 400 air miles north of Winnipeg which contain enormous tonnages of material. This will involve an expenditure of $175 million and will bring into production two new nickel mines by 1960 with an anticipated combined output of 8,000 tons of ore a day. Low-grade nickel has been reported from the Knee Lake area, east of Mystery Lake. In southeastern Manitoba, small deposits containing more than 1 per cent nickel have been known for many years at Maskwa and Bird Rivers and they are again being actively explored.

Saskatchewan

At Birch Lake, near the Saskatchewan-Manitoba boundary, lenses of massive sulphides occur in a zone of schist mineralized by chalcopyrite and nickeliferous pyrrhotite. At Dinty Lake, about 24 miles northeast of Goldfields, a fairly large body of sulphides carries nearly 1 per cent of nickel. The ore is intersected by thick dykes of granitic rock dipping at about 45 degrees.

Northwest Territories

On the north shore of Rankin Inlet, west coast of Hudson Bay, a sill of pyroxenite, largely serpentinized, is 200 to 300 feet thick, strikes east, and dips 50 degrees south. At a point where the base of the sill bulges outward a lens of ore about 250 feet long displays some 8 feet of massive and 18 feet of disseminated sulphides. The ore is pyrrhotite with a little chalcopyrite. An extensive program of diamond drilling in 1952 disclosed 435,000 tons averaging 3.3 per cent nickel and 0.8 per cent copper. Shaft sinking and drifting were undertaken in 1953 and 1954. Production from the property is scheduled to commence in 1957.

Several years ago, Canadian Nickel Company made a discovery of nickel at Ferguson Lake, about 150 miles west of Rankin Inlet. An exploration concession was obtained and much drilling was done.

Copper

Until 1927 almost the only copper producers in the Canadian Shield were the nickel-copper mines of the Sudbury area, which have already been described. However, during the years 1917-20 the Mandy mine, Manitoba, shipped some 25,000 tons of copper ore averaging nearly 20 per cent copper. The ore was teamed 50 miles, carried by barge another 50 miles to The Pas, and then sent 1,200 miles to the Trail Smelter, British Columbia. In 1927 Noranda Mines Limited in Quebec began to produce copper, and other mines in its vicinity have since added to the production of the district. In 1930, mining began at the Flin Flon mine in Manitoba and Saskatchewan; in 1931 the Sherritt Gordon mine, Sherridon, Manitoba, began shipping concentrates to the Flin Flon smelter. Both the Quebec and Manitoba-Saskatchewan districts continue to yield large amounts of the metal. Although the Sherritt Gordon mine is worked out, new mines are coming into production in the Flin Flon area.

Ontario

In 1955 the copper production of the Sudbury district was about 146,400 tons, compared with about 154,000 tons in 1942. The total production of Ontario from 1886, when Sudbury came into production, until the end of 1955 was about 3,636,000 tons. The only other copper producers in Ontario in that period were

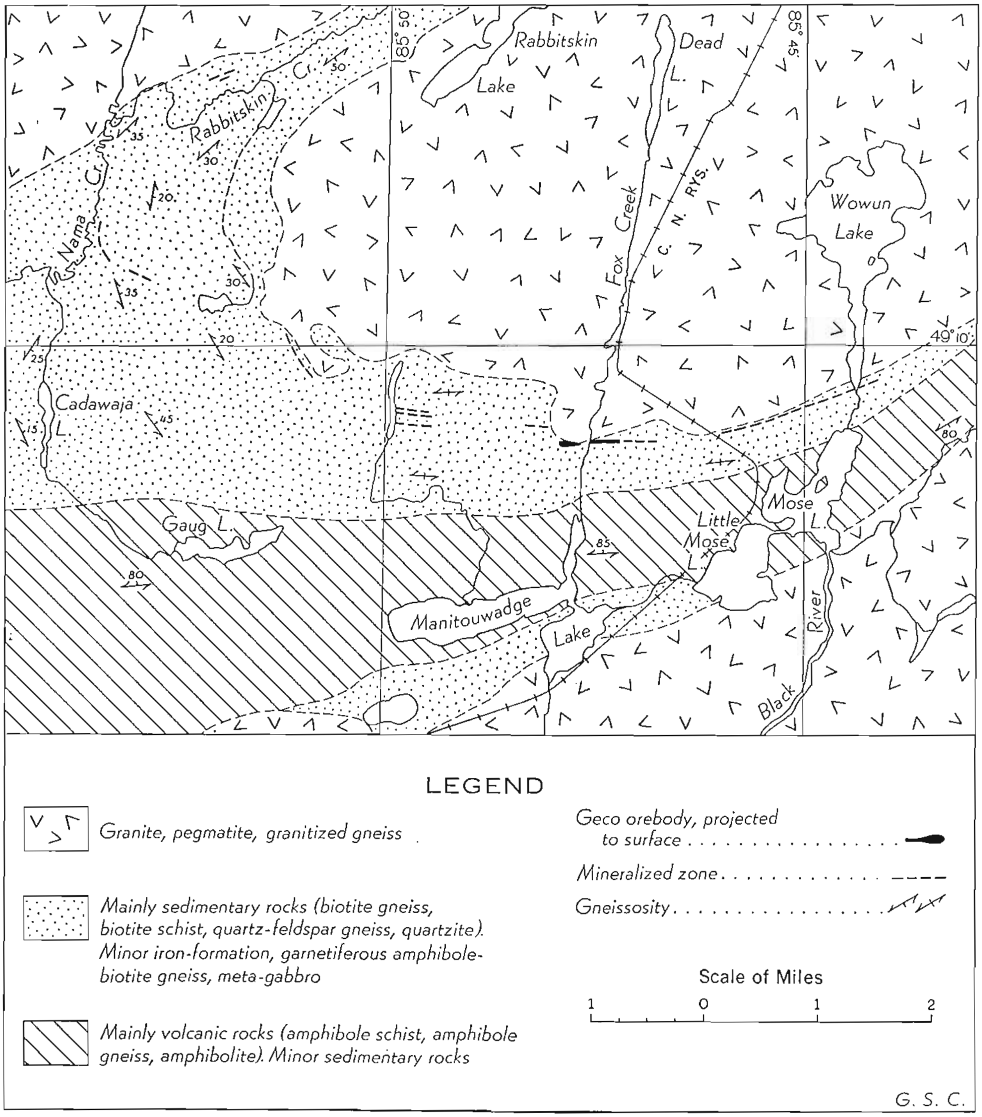


FIGURE 24. Map of Manitouwadge Lake area, Ontario. (Generalized after E. G. Pye.)

Bruce Mines about 40 miles east of Sault Ste. Marie, and two or three smaller properties. In all, these probably did not yield more than 10,000 tons of metal, so that the Sudbury production alone was more than 3,500,000 tons.

At Bruce Mines copper mining in North America began in 1846 and mining continued there, with interruptions, until 1921. Veins that traverse diabase sills in Huronian sedimentary rocks consist of quartz and chalcopyrite with minor amounts of calcite and barite. They vary from mere stringers to veins 50 feet wide. A main vein has been traced 2,000 feet and may extend for at least 8,000 feet; in the more productive parts it averaged 5 feet in width, and was worked to a depth of 450 feet. The deposit was first worked from 1846 to 1876, then, except for a short period of operations in 1908-09, it lay idle until purchased by the Mond Nickel Company, which shipped the ore to Coniston as a flux. Mining was carried on by Mond from 1915 to 1921, in which time approximately 160,000 tons of ore were shipped. No figures for the copper recovery are given, but the maximum tenor of the ore appears to have been about 3½ per cent copper.

A number of other copper deposits have been found in Ontario, and attempts have been made to mine some of them, with production of small amounts of the metal, but until the discoveries in 1953 in the Manitouwadge Lake area, Thunder Bay district, all proved too small or too low-grade for profitable operation.

The Geco zone in the Manitouwadge Lake area is being developed for commercial production in 1957 (Figure 24). The deposits are sulphide replacements in a wide zone of sericite schist at the contact between granitic rocks and hornblende-biotite gneisses. In general the ore consists of a massive core of pyrrhotite and sphalerite enclosed by disseminated chalcopyrite, pyrite, pyrrhotite, and minor sphalerite in quartz-sericite schist. The Geco orebody, some 2,700 feet long and as much as 220 feet thick, has been faulted into three segments separated by a few score feet, the easternmost section being separated from the central by diabase dykes as well. Other zones with similar minerals are known but all are shorter, narrower, and lower in grade than the Geco.

In 1955 production of copper began from high-grade zones of chalcopyrite in islands in Lake Timagami. Timagami Mining Company Limited reports that 50,000 tons of ore averaging 20 per cent copper are indicated, as well as 575,000 tons averaging 3 per cent copper. The orebodies occur in a faulted band of altered rhyolite, some beneath the lake, and were found by geophysical methods. It is reported that a mill with a capacity of 2,000 tons a day is to be built to replace a smaller unit now operating.

Quebec

Noranda mine, in Rouyn township, Quebec, blew in its smelter in 1927 and is one of the great copper mines of Canada. In addition to Noranda, the Quemont, Waite-Amulet, Aldermac (idle for years), Normetal, and East Sullivan have produced considerable amounts of copper (Figure 25). Copper from this group of mines to the end of 1955 amounted to about 1,475,000 tons of which more than half came from Noranda's Horne mine. Important amounts of gold,

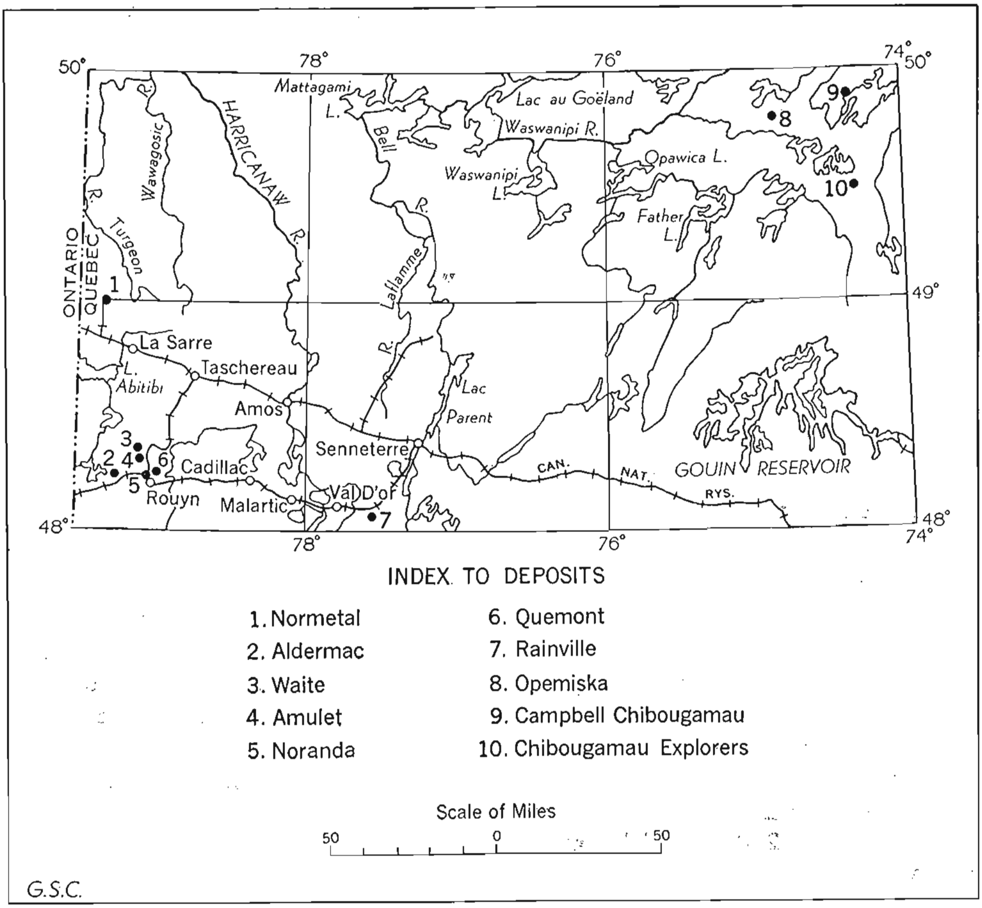


FIGURE 25. Index map showing principal copper deposits in western Quebec.

silver, and zinc have been produced as well. Recently three mines have come into production in the Chibougamau area, some 250 miles east-northeast of Noranda, where an important copper camp appears to be in the making (Figure 25).

Noranda District. All the ores of the Noranda district are of the same general type. They are massive sulphides, mixtures of pyrite, pyrrhotite, and chalcopyrite in varying proportions; in the Quemont, Waite-Amulet, and Normetal ores there are also important amounts of sphalerite. The ores have formed by replacement, usually of rhyolitic agglomerate and tuff, or of rhyolite lava shattered by folding or fault movements. One of the Amulet orebodies, however, has replaced a shattered zone in andesite. At their edges the massive ores usually grade rather rapidly, first into rock thickly spotted with sulphides, and then into rock with little or no sulphide. Much of this low-grade material is mined, however, because its highly siliceous composition makes it valuable as a flux in smelting the heavier sulphides. All the orebodies are associated with faults, which may have served as channels

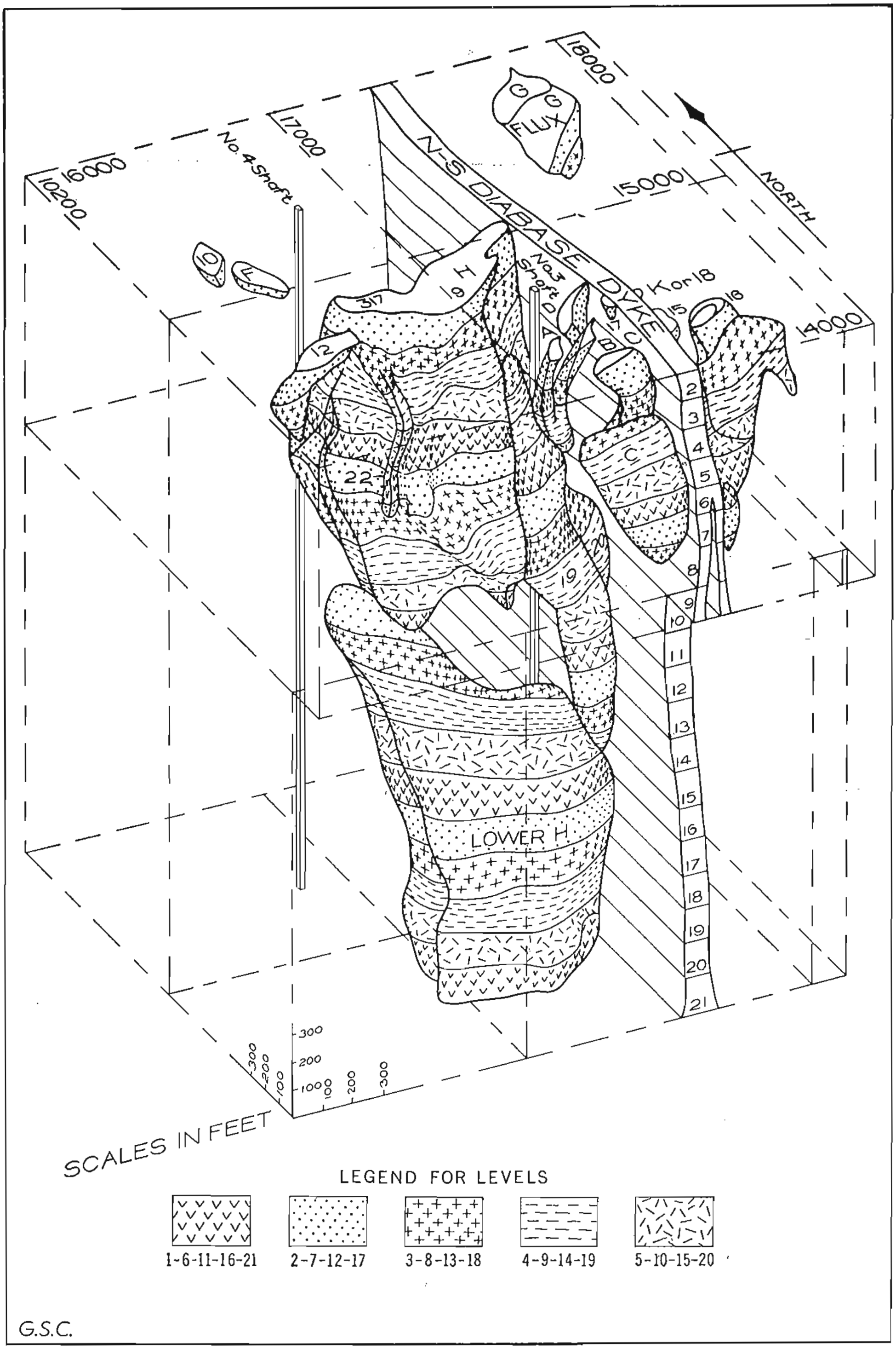


FIGURE 26. Isometric projection of orebodies at Noranda Mines. (After Peter Price.)

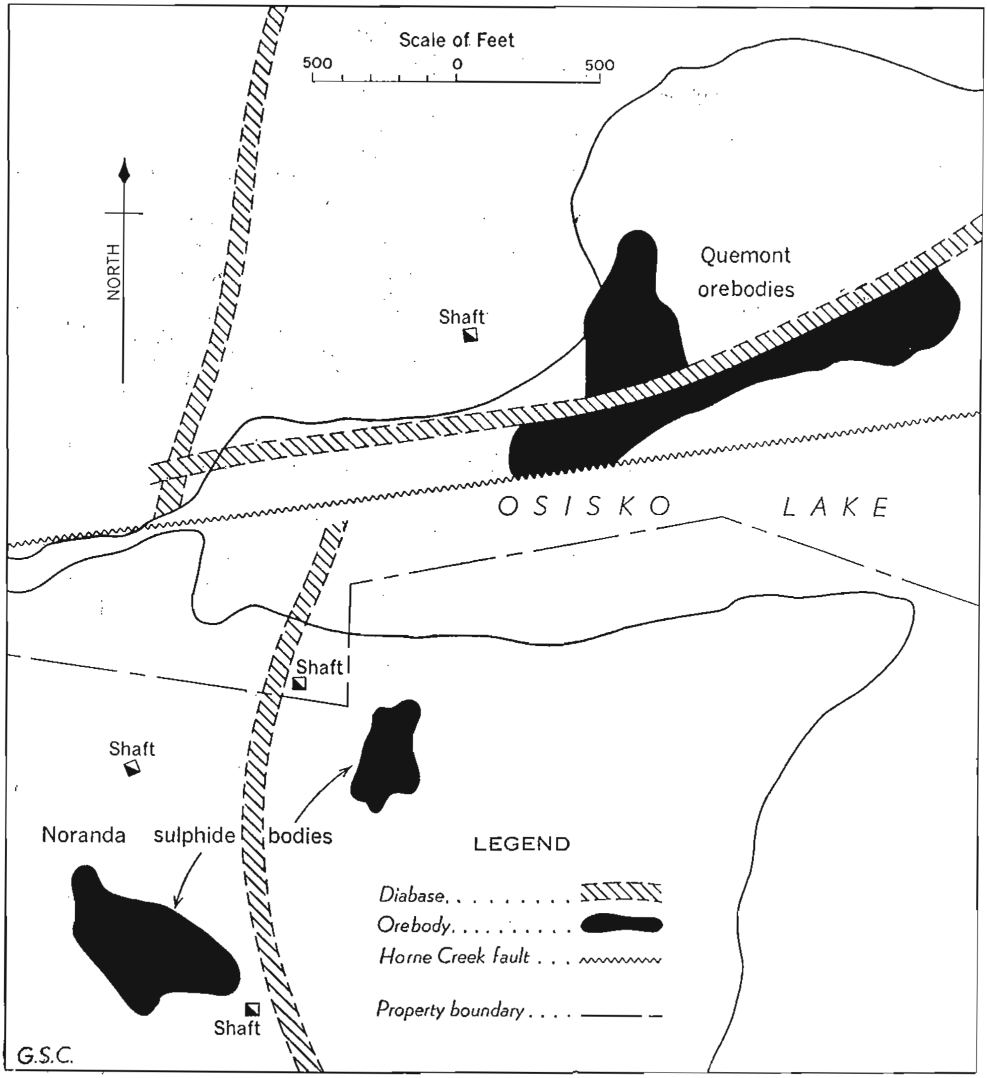


FIGURE 27. Relations of the Noranda and Quemont orebodies to the Horne Creek fault. (After A. G. Ballachey.)

enabling the ore-bearing solutions to rise into the permeable horizons where replacement could take place.

The Noranda orebodies are relatively short, thick masses with long axes dipping steeply or vertically (Figure 26). The Aldermac bodies, low in copper content, have much the same shape. The Waite and Amulet orebodies, which replace certain flow horizons over the top of a broad anticline, are pancake-shaped masses with low dips. The Normetal mass is a sheet-like body with an 80-degree dip, apparently developed along a zone of shearing in the rhyolites.

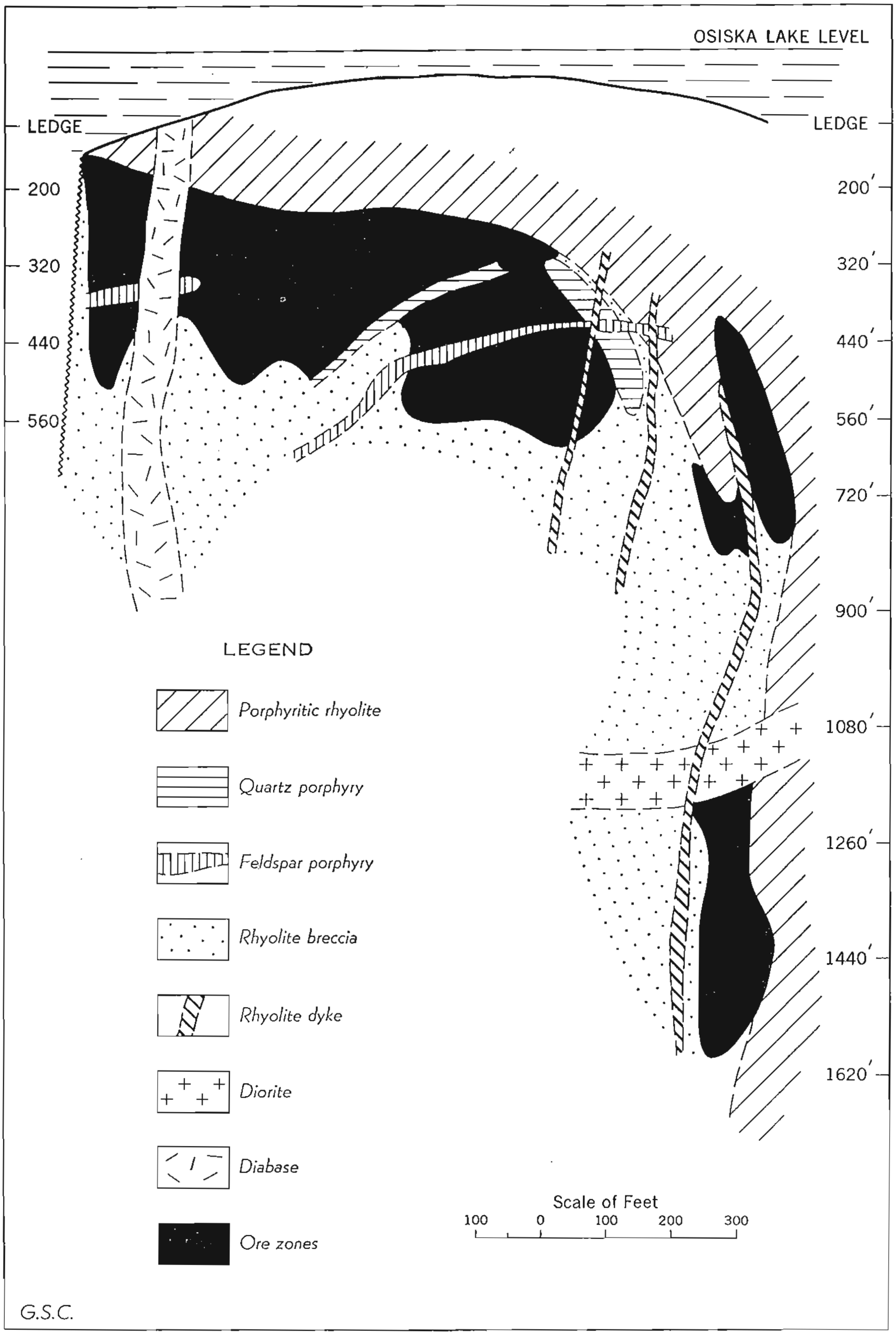


FIGURE 28. Generalized section through Quemont orebodies, looking West. (After A. G. Ballachey.)

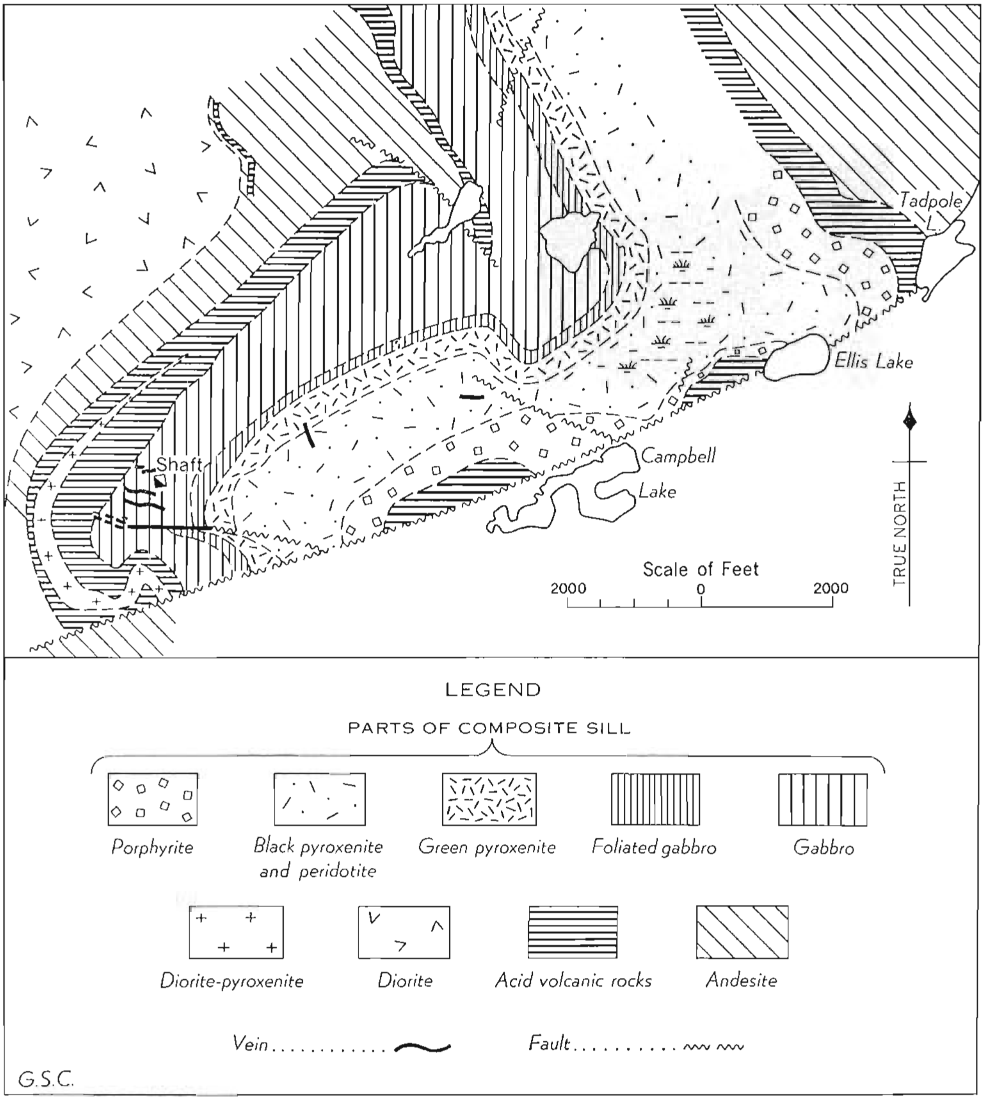


FIGURE 29. Geological plan of Opemiska Copper Mines. (After D. R. Derry and J. C. Folinsbee.)

The Quemont orebodies, which were discovered in 1945 and came into production in 1949, are also among the largest. Reserves at the end of 1955 were estimated to be 8,440,000 tons, and total production up to that time was 70,300 tons of copper, 85,200 tons of zinc, and more than 600,000 ounces of gold. Three main orebodies occur in a rhyolite breccia beneath a capping of porphyritic rhyolite folded into a dome with flanks dipping north, east, and west. The south side of the dome is truncated by the Horne Creek fault, on the other side of which is Noranda's Horne mine (Figure 27). The deposits are sulphide replacements of the breccia beneath the capping of porphyritic rhyolite where flexures of the contact were suitable for disposition of ore (Figure 28). From top to bottom of the orebodies the ore is commonly massive sulphides, chloritized breccia with disseminated sulphides, and shattered breccia with sulphide stringers.

Chibougamau Area. At Chibougamau the copper-gold ore occurs in basic rocks that intrude Keewatin volcanic rocks. The Opemiska copper mine began producing in 1954, the Campbell Chibougamau in 1955, and Chibougamau Explorers early in 1956.

The Opemiska mine is producing from veins along faults near the nose of a syncline that plunges southeast. The faults trend nearly parallel to the south-dipping axial plane, but they dip north at high angles (Figure 29). A sharp drag-fold on the south limb, near the nose of the main fold, does not appear to bear any specific structural relation to the main folding but the veins occur on the nose of this drag-fold. The ore is enclosed in gabbro and is chiefly in veins, although replacement of fracture zones does occur and some disseminated sulphides extend into the walls of the veins. The ore consists of mixtures of chalcopyrite, pyrite, magnetite, lesser pyrrhotite, small amounts of galena and sphalerite, and small but significant quantities of gold and silver. Molybdenite is a common accessory.

The Campbell Chibougamau orebodies occur in anorthositic rocks near Lake Chibougamau. The orebody being mined is a sulphide replacement deposit within a shear zone that strikes about west and dips south at angles from 55 degrees at the surface to near vertical at lower levels. Porphyry dykes have been intruded essentially parallel to the ore zone. The main sulphides are pyrrhotite, chalcopyrite, pyrite, and sphalerite. The shear zone varies from 100 to 600 feet wide and the ore varies from 12 to 80 feet wide, averaging about 40 feet. It has so far been developed for 600 feet along strike, but its total length is not yet known. Ore reserves before production were estimated at about 2 million tons grading about 3 per cent copper and about 0.08 ounce of gold a ton.

The deposit being mined by Chibougamau Explorers also occurs in a sheared zone in a basic intrusion but the mineralized zone is apparently smaller than the Campbell. Ore reserves before production were estimated at about 550,000 tons averaging 0.3 ounce of gold a ton and 0.93 per cent copper.

Manitoba-Saskatchewan

Four mines near the Manitoba-Saskatchewan boundary have produced considerable quantities of copper. These are the Flin Flon, Mandy, and Cuprus, controlled or owned by Hudson Bay Mining and Smelting Company, and the Sherritt Gordon mine at Sherridon about 40 miles northeast of Flin Flon. The Mandy, Cuprus, and Sherritt Gordon mines are now worked out, but from the end of 1930, when the Flin Flon smelter was blown in, these mines contributed large amounts to the total of about 953,000 tons of copper produced by this group. In addition to those named, the Schist Lake mine, Manitoba, came into production in 1955; the North Star mine, Manitoba, and the Birch Lake and Coronation mines in Saskatchewan were being prepared for production (Figure 30); and two promising prospects rich in copper are known near Snow Lake.

The Flin Flon deposits, which form much the largest mine, lie in a strong drag-fold that plunges southeast, across an offset in the interprovincial boundary, into Saskatchewan. The orebodies follow a sheared quartz porphyry at the contact between competent basaltic and andesitic lavas above, and more easily sheared pyroclastic and flow breccias beneath. The ore, a replacement of the sheared rocks, is mainly localized along or near the northeast limb of the anticlinal part of the main drag-fold, and ends against its crest (Figure 31). The ore zone is up to 400 feet wide, and has been followed for 6,500 feet down the plunge. The country rock near the orebodies has been extensively altered, some parts being highly silicified,

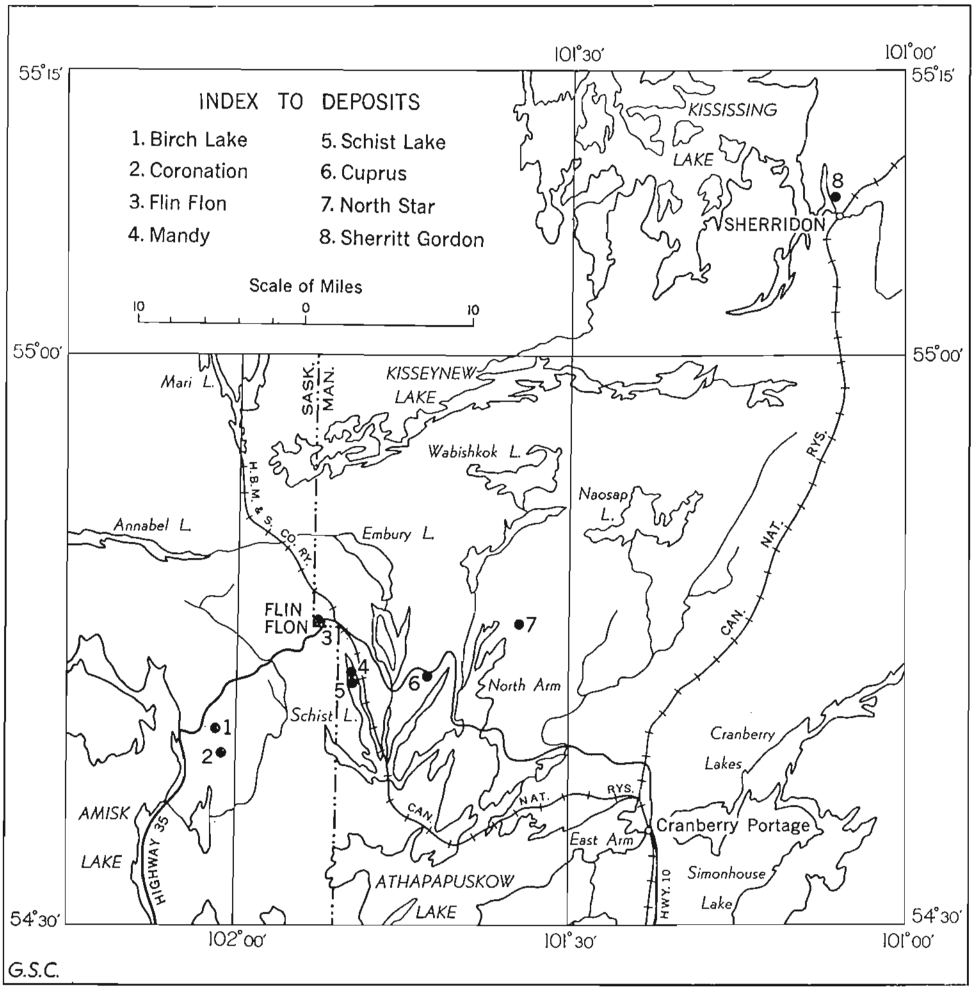


FIGURE 30. Index map showing principal copper deposits in western Manitoba and eastern Saskatchewan.

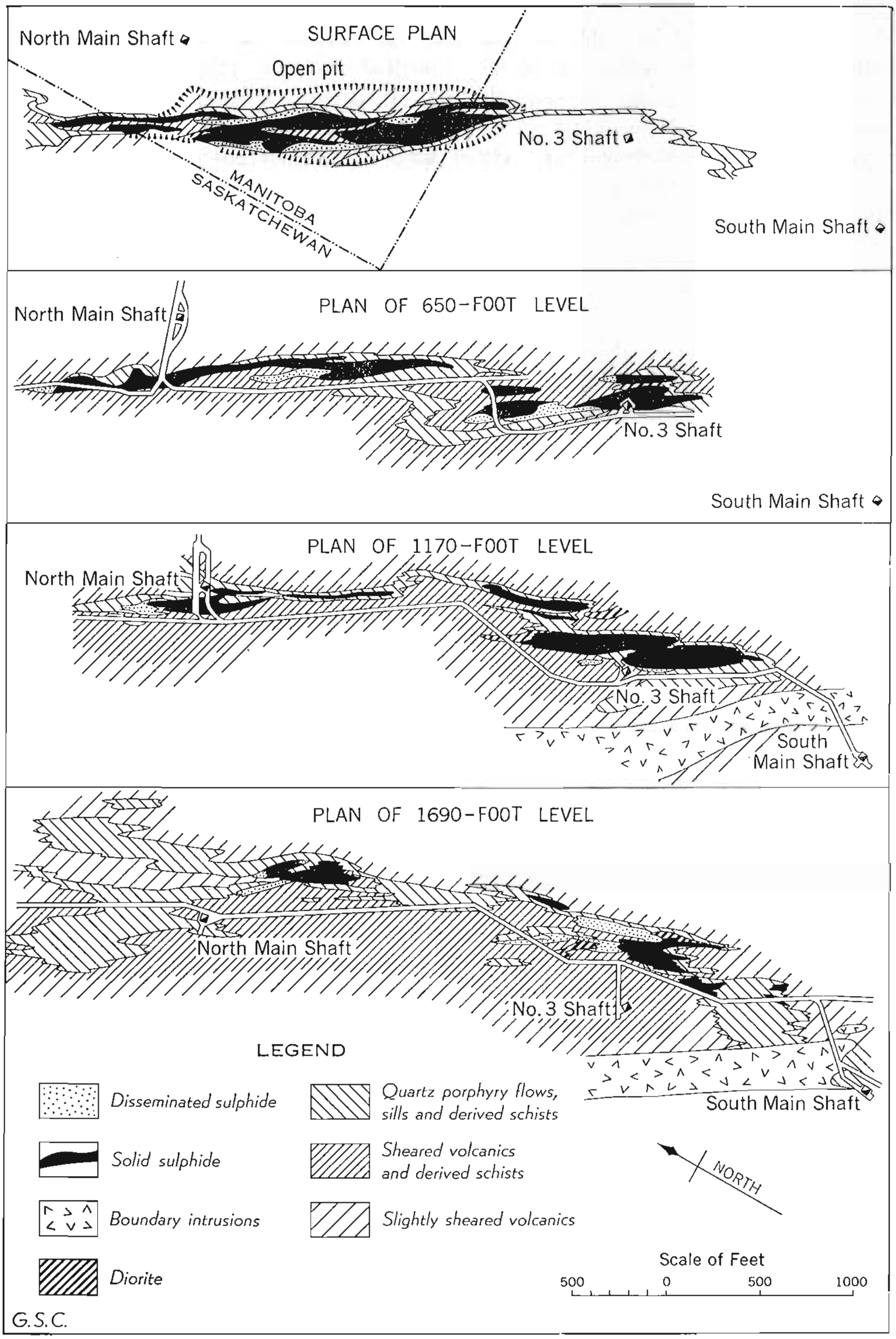


FIGURE 31. Flin Flon Mine, surface and underground geology. (After the staff, Hudson Bay Mining and Smelting Company, Ltd.)

other parts converted into chlorite and talc. The chlorite and talc in places are spotted with sulphides sufficiently to be a low-grade ore. The principal orebodies, however, are solid masses of sulphides, mainly pyrite with minor amounts of chalcopyrite and sphalerite. Pyrrhotite is present, but is not a major constituent as in the Quebec and Sudbury ores. Other minerals include galena, tetrahedrite, arsenopyrite, and magnetite. Since 1935, cadmium, selenium, and tellurium have been recovered from the ore.

Ore reserves as of January 1, 1956, mainly on the Flin Flon mine but also including Schist Lake, North Star, Birch Lake, and Coronation properties, were given as 16,680,000 tons averaging 3.16 per cent copper, 3.6 per cent zinc, 0.068 ounce of gold and 0.96 ounce of silver a ton. All of these outlying orebodies have essentially the same mineralogy as the Flin Flon mine but are smaller and tend to be richer.

The Cuprus mine, about 13 miles southeast of Flin Flon, was operated from 1948 to 1954. It consisted of several small but rather high-grade lenses averaging about 3.5 per cent copper and 6.5 per cent zinc.

The Mandy mine was a base metal producer from 1917 to 1920 and again in 1943 and 1944. Altogether some 137,700 tons of ore were mined. The ore was similar to that at Flin Flon, but higher in grade, averaging about 7.3 per cent copper, 12.9 per cent zinc, 0.09 ounce gold, and 1.8 ounces silver a ton. Mine workings extend to the 1,025-foot level. Most of the ore was obtained from a lens that extended from the surface to a depth of 230 feet, but some was found at horizons down to 825 feet. The ore lenses were in schistose andesite breccia; they followed the strike of the formation, and plunged steeply south.

Production at the Sherritt Gordon mine at Sherridon commenced in 1931, but the mine was inactive from 1932-37. The mine yielded nearly 15,000 tons of copper annually during the war, but was worked out by 1951. During its life, it produced 133,122 tons of copper, about 74,500 tons of zinc, 101,026 ounces gold and 3,218,324 ounces of silver. The ore apparently replaced a pegmatite sill that followed the contact between a gneiss and quartzite. The pyrrhotite-chalcopyrite-sphalerite ore formed two long, shallow lenses separated by a gap of 3,600 feet. The gap is on a cross-anticline and it is presumed that the two lenses were originally one body, the ore in the gap having been removed by erosion. The northwestern lens has a vertical extent of 500 to 800 feet; the southeastern, about 250 feet. The combined length of both lenses, including the 3,600-foot gap, is nearly 16,000 feet. Substantial quantities of copper are being produced from the company's Lynn Lake nickel operation which began late in 1953.

Northwest Territories

The few tons of copper produced from this region have been derived from complex gold ores which have already been described, or from the Eldorado uranium mine at Great Bear Lake. However, several occurrences of copper are known in the area about the east arm of Great Slave Lake and in the Coppermine River area.

Lead and Zinc

A large part of the zinc produced from the Shield has come from the copper-zinc mines of Quebec and Manitoba. These are the Waite, Amulet, Normetal, East Sullivan, and Quemont group of Quebec, and the Flin Flon, Mandy, Cuprus, and Sherritt Gordon mines of Manitoba and Saskatchewan. The Mandy, Cuprus, and Sherritt Gordon mines are worked out; the rest together produced about 110,000 tons of zinc in 1954.

Quebec

At the Golden Manitou property in Bourlamaque township a strong fault, which strikes a little north of east, cuts a body of rhyolite, converting a band of it into sericite schist. The ores are replacements of this schist, mainly on the north side of the fault. The main body is 800 feet or more long and ranges from 15 to 65 feet wide. The ore consists of various proportions of medium-grained pyrite and sphalerite, and contains remnants of unreplaced schist. It carries from 7 to 11 per cent of zinc, together with small amounts of lead, gold, and silver. By the end of 1955 the mine, which came into production in 1942, had yielded about 192,400 tons of zinc and about 12,300 tons of lead.

The Barvue mine in Barraute township was discovered in September 1950, and came into production in November 1952 at a rate of 3,000 tons a day, the rate in 1956 being 5,300 tons a day. The company completed its changeover from open-pit to underground mining in October 1956, the scheduled milling rate for underground production being 3,000 tons a day. Up to the end of 1955 the mine had produced about 107,000 tons zinc, about 2 million ounces silver, as well as 34 tons of lead on a trial basis. Ore reserves at the end of 1955 were given as 5,200,000 tons to the 500-foot level, and averaging 3.6 per cent zinc and 1.3 ounces of silver a ton. The ore occurs as a replacement in sheared rhyolite breccia that may mark a fault subsidiary to a main northeasterly fault zone. The schistosity strikes southeast and dips northeast at 70 degrees. The ore consists of pyrite, pyrrhotite, sphalerite, and galena in a zone about 1,250 feet long and more than 100 feet wide.

Considerable zinc and some lead were obtained from the Tetreault mine, about 45 miles west of Quebec City. Masses of sphalerite and galena were found along the foot-wall side of a band of altered Grenville limestone. They varied from less than a foot to more than 50 feet wide and consisted (a) mainly of sphalerite with minor amounts of other sulphides, or (b) of a fine-grained intimate mixture of sphalerite, galena, pyrrhotite, pyrite, and minor amounts of chalcopyrite. The average run-of-mine ore contained about 9 per cent zinc, 3 per cent lead, 0.1 per cent copper, 0.09 ounce gold, and 8.3 ounces of silver a ton. Mining was carried on, with some interruptions, from 1912 to 1929, and again from 1934 to 1937. Total production in those years was about 60,000 tons of zinc and 20,000 tons of lead. During the war period, 1942-44, an additional 6,399 tons of zinc and 1,672 tons of lead were obtained. The deposit was re-opened in 1948, and to the end of 1954 had produced about 117,000 tons of zinc, 39,000 tons of lead, several million ounces of silver, and several thousand ounces of gold. In 1953 United Montauban Mines came into production on the north end of the zone but operations ceased after only 5 months' production.

The New Calumet mine is on Calumet Island in Ottawa River about 60 miles above Ottawa. The orebody is in a sheet-like mass of biotite-hornblende gneiss that strikes a little west of north and dips 35 to 40 degrees east. It ranges in thickness from a few tens of feet to about 300 feet, and is considered to be a bed of altered impure limestone. The principal ore minerals are sphalerite with some galena; these are accompanied by small amounts of chalcopyrite, native gold, and silver compounds. Part of the ore is massive or nearly massive sulphide; other parts consist of sulphides disseminated through the gangue of rock minerals, mainly altered feldspar and pyroxene. A less common type, rich in gold, is a dark-coloured calcite-tremolite rock carrying crystals of auriferous galena, and veined by stringers of calcite and coarser galena, also auriferous. Although the property was discovered in 1893 and sporadic attempts were made at intervals to mine it, there was no important production until 1943. To the end of 1955 it had yielded over 132,000 tons of zinc, 36,000 tons of lead, and 6,120,000 ounces of silver.

Ontario

About 25,000 tons of lead have been produced from the Kingdon mine, which operated from 1914 to 1932. The mine is on Chats Island in the Ottawa River near Galetta village, 40 miles west of Ottawa. A fault fissure, striking north 65 degrees west through limestone and other rocks of the Grenville series, was filled with galena and calcite and with minor amounts of other minerals. The vein had an average width of 5 feet, and was followed for more than 2,700 feet along the strike and to a depth of more than 1,300 feet.

Towards the west end of the Sudbury basin strong faults cut the Whitewater series with an east-northeast strike (*see* Figure 20). Bodies of lead-zinc ore have been found in these faults, and the Errington mine was operated by the Treadwell Yukon Company from 1928 to 1932. Several orebodies were found, one with a length of more than 550 feet and an average width of 12 feet. The ore is massive pyrite, partly replaced by sphalerite carrying galena, chalcopyrite, and pyrrhotite. The metal contents of the ore appear to have averaged about 6 per cent zinc, 1 per cent lead, and the same of copper, with a little gold and silver.

About 20 miles north-northwest of the last locality, the Lake Geneva Mining Company operated a small property. Work bean in 1928, was suspended in 1930, resumed in 1941, and was suspended again in 1944. The deposit is a vein that strikes northwest and at the surface dips about 45 degrees southwest, following in a general way the strike and dip of the ancient volcanic and sedimentary rocks. Its width ranges from a few inches to 7 feet, averaging about 4½ feet. The ore is mainly fine-grained sphalerite, carrying a good deal of siliceous gangue and a little galena, chalcopyrite, and pyrrhotite. The metal content of the ore runs from 9 to 13 per cent zinc and 3 to 6 per cent lead. Official figures on production are not available, but comparatively small amounts of lead and zinc were produced.

The Jardun mine, about 20 miles northeast of Sault Ste. Marie, was first mined at intervals between 1878 and 1904 but records are not available. It finally came into continuing production in 1954 and in that year it produced about 1,300 tons of lead, 550 tons of zinc, as well as 23,000 ounces of silver. The ore occurs as sphalerite, galena, pyrite, and chalcopyrite, in a band of greenstone schist bounded by granite. In 1956 ore reserves were 304,000 tons averaging 3.14 per cent lead, 3.52 per cent zinc, and 1.65 ounces of silver a ton.

Manitoba

Early in 1956 a zinc deposit had been discovered by drilling beneath the waters of Chisel Lake, near Snow Lake. Early reports indicate the possibility of a major zinc deposit in an easterly trending shear zone. Although most sulphide deposits in this region are noted for their copper rather than zinc, the Chisel Lake deposit is reported to contain no copper.

Platinum Group Metals

The metals of the platinum group include platinum, palladium, iridium, osmium, rhodium, and ruthenium. The first three are utilized in considerable quantities, but uses of the others are as yet small.

These metals are produced only from the Sudbury ores. Platinum and some rhodium occur in the mineral sperrylite, a platinum diarsenide that is sparsely scattered through the sulphides. The source of the palladium and other metals is unknown, but it is suspected that they occur in some undiscovered compound of copper, as there is much more of platinum and palladium in the copper-rich parts of the ore than in the nickel-rich parts. The average content of the metals of this group in the ore is about 0.08 ounce a ton. In 1929, the last year for which separate records are reported, the yield was 12,474 ounces platinum, 12,231 ounces palladium, 3,037 ounces rhodium, 1,376 ounces ruthenium, 497 ounces iridium, and no osmium. These figures give some idea of the relative proportions in which the various metals occur. From 1920 to 1955 inclusive the Sudbury ores yielded about 3,622,000 ounces of platinum, and about 3,536,000 ounces of other platinum metals.

Cadmium

Cadmium is obtained as a by-product from the copper-zinc mines of the Flin Flon district in Manitoba and Saskatchewan. In 1955 about 95 tons were produced compared with 66 tons in 1945.

Selenium and Tellurium

Selenium and tellurium are not mined for themselves, but are recovered as by-products in the electrolytic refining of blister copper. They are thus produced from the nickel-copper ores of Sudbury, and from the copper ores of Quebec and Manitoba. Production of selenium from these sources in 1955 totalled about 215 tons; of tellurium about 3 tons. Total production from these mines to the end of 1955 was about 3,930 tons of selenium and about 144 tons of tellurium. The use of selenium has increased greatly in the last few years.

Cobalt

Much of the cobalt produced from the Shield is obtained from the old silver mines at Cobalt, Ontario. Moreover, most of the Canadian output is obtained as by-products from nickel-copper mines of the Sudbury basin, Ontario and from the base metal operations at Lynn Lake, Manitoba. In 1955 about 1,500 tons of the metal were produced, compared with about 55 tons in 1945. When the Cobalt camp was in full operation large amounts of the metal were obtained and much was discarded. For many years only salvage operations were carried on by persons leasing the old mines or picking old dumps. Total value of all ore thus produced in 1942, including the silver, was only $750,000 compared with over $6 million for cobalt alone in 1955. This increase is largely the result of the action of the Federal Government in 1951 in raising the price of cobalt contained in cobalt ores and concentrates to stimulate production and to increase the incentive for operators to search for, mine, and recover cobalt in the Cobalt-Gowganda area. This premium price plan was terminated in December, 1956. The principal shippers from the area in 1956 were Cobalt Consolidated Mining Corporation, Silver Miller Mines Limited and Silver Crater Mines Limited.

Sulphur

The principal sources of sulphur on the Shield are from pyrite, and from gases from International Nickel's smelter at Copper Cliff, Ontario. In 1953 some 290,000 tons of pyrite were produced as a by-product of the copper mines of Quebec and late in 1954 a plant for treatment of pyrite was put in operation by Noranda Mines. Total production of sulphur from the Shield in 1955 had a value of more than $3 million.

Several pyrite deposits were mined on the Shield, especially during World War I. Many are known now, but their development must await the time when prices and costs will make it profitable to mine them. All are deposits of essentially massive pyrite.

Arsenic

Arsenic in the form of the mineral arsenopyrite is commonly associated with silver-cobalt ores and all of Canada's production of refined white arsenic originates from this source. In western Quebec Beattie-Duquesne Mines, Limited was recovering crude white arsenic from the treatment of its gold ores prior to discontinuance of its gold mining operations in July 1956. O'Brien Gold Mines, Limited recovers the material as a by-product at its gold property in Cadillac township, Quebec.

Canadian production of refined white arsenic in 1955 was 325 tons.

Iron

Iron mining on the Canadian Shield commenced at a very early date. The first furnace was erected at Furnace Falls (Lyndhurst), Leeds county, Ontario, in 1800, and others were built in the next 20 years in Hastings county and other places. Bad roads and difficulties in procuring the charcoal that was used as fuel hampered these efforts and made most of them unprofitable, and when the St.

Lawrence canals, completed about 1848, permitted cheap foreign iron to be brought in most of them ceased operations.

Iron mining continued sporadically until 1939 when the Helen mine of Algoma Ore Properties Limited in the Michipicoten area, Ontario, began continuous production. Since then the company has brought other sections of its deposits in the area into production. Steep Rock Iron Mines at Steep Rock Lake, Ontario, Iron Ore Company of Canada's operation in New Quebec and Labrador and the Marmoraton deposit at Marmora, Ontario, are in steady production and other deposits are being explored or developed towards production. The deposits at Knob Lake and those at Steep Rock Lake are of direct-shipping ore; ore from all the others must be concentrated before it can be marketed.

The deposits in the Shield have been variously classified, but the present classification is simply a comparative one. The Lake Superior type is exemplified by Knob Lake; Steep Rock by the Steep Rock mine; the Michipicoten by the Helen and Victoria mines; the magnetite-skarn, or contact metamorphic (pyrometasomatic) by the Marmora, Ontario, and Bristol, Quebec, deposits; and the magnetite-ilmenite by deposits at Allard Lake on the north shore of the St. Lawrence River, which are described as titanium deposits.

Lake Superior Type

In terms of tonnage produced, the Knob Lake deposits are the most important, and this production is the result of one of the most spectacular developments in Canada's history. The deposits are in the Ungava wilderness, some 320 miles north of Sept Isles, Quebec, on the St. Lawrence River. Prospecting for iron there began in 1936 and as more and more deposits of high-grade iron ore were discovered, the intensity of geological mapping, prospecting and drilling were increased. By the autumn of 1950, some 420 million tons of high-grade ore had been indicated by drilling, a tonnage that was considered large enough to justify the huge capital expense necessary to get the iron ore to market. Iron Ore Company of Canada was established and by 1954 a railroad of 360 miles had been built; a docking site, collecting yards, loading facilities, and repair depots had been prepared at Sept Isles, marshalling yards and terminal facilities had been built at the Knob Lake end, and the nearby new town of Schefferville was established. In July, 1954 the first ore was shipped from Sept Isles, and during the shipping season of 1955 more than 7 million tons left the port. Production for 1956 was planned at 12 million tons, which is expected to be the minimum rate in succeeding years.

Forty or more deposits of high-grade ore are known in the area and in addition there are several occurrences whose dimensions are unknown. All the orebodies occur in the Ruth and Sokoman formations of the Kaniapiskau group. These formations are iron-bearing units similar in all respects to the iron-formations of the Lake Superior district of the United States. The Ruth formation is a ferruginous, black, highly carbonaceous slate with interbeds of greenish grey chert. It passes stratigraphically upwards to the Sokoman formation through a zone where the slate and a magnetite-rich silicate member are interbedded. This banded silicate member is the basal member of the Sokoman and typically passes upwards

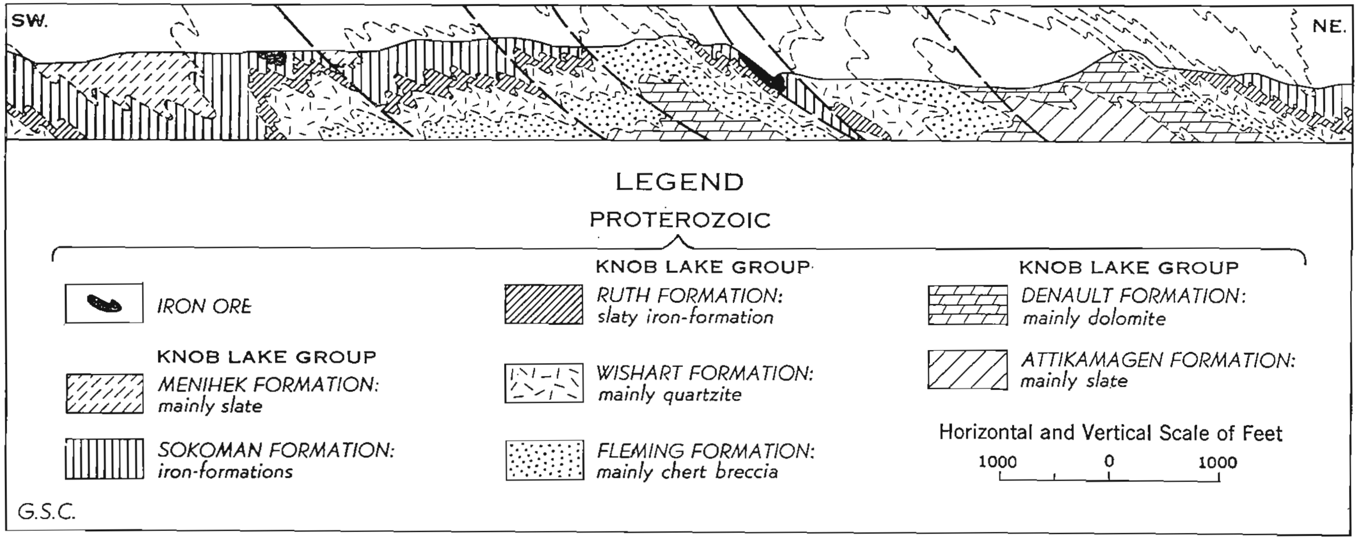


FIGURE 32. Generalized structure-section at Knob Lake, Quebec.

to a thin-banded jasper, to banded grey chert, to thick-banded jasper, to greenish chert and carbonate, and finally to slaty iron-formation. Except for the greenish chert, all these members contain interbeds rich in iron oxides. The greenish chert, or lean chert, is poor in iron and, locally, contains no iron oxide. In other places iron carbonate is common and forms yellow-weathering blebs or bands. Company geologists commonly separate the Sokoman into 3 or 4 units for ease of reference: the lowest silicate member; the metallic member, which includes banded and massive jasper and grey or white chert; the lean cherts; and the magnetic slates. They have found that, on enrichment, the Ruth slate produces a red earthy iron ore, the banded silicate produces a yellow ore and the metallic iron-formation produces a blue or reddish blue ore.

Structures are complex and appear to be the result of thrusting from the northeast. The formations trend northwest and dip northeast, except at the crests of folds and in a few other localities where special conditions seem to have prevailed. The typical structure is an overturned anticline that has been shoved forward and up along a thrust fault (Figure 32). Ore occurs in the hanging-wall part of such a fault, but at least some of the orebodies are in normal faults immediately over the thrust. Some faulting is post-ore, for slickensided ore has been found, and it may be that the ore has been preserved in down-faulted zones. However, all orebodies are shallow and most bottom within 300 to 350 feet from surface, although a drill in one orebody was stopped in ore at more than 550 feet. Company geologists have pointed out that the ore commonly bottoms at the same distance beneath the surface no matter what is the elevation of the surface of the particular orebody; that the ore is porous and appears to have the specific gravity to be expected if it were produced from iron-formation by removal of the silica; that formations enclosing the ore are deeply weathered; that the ore is in structural troughs open to the surface; and that specific evidence of hydrothermal activity is lacking. For these reasons, they suggest that the ore was probably produced by weathering at some time in the past when tropical conditions prevailed.

Since the start of mining it has been found that crevices more than 300 feet deep in the ore existed in late Mesozoic or early Tertiary time, for a narrow band of debris in one orebody consists of blocks of decomposed iron-formation, quartzite, chert breccia, ore, and plant remains of late Cretaceous or Tertiary age. Hence, at least some of the ore must have been formed by that time. This feature also shows that weathering did affect the rocks to depths at which the orebodies commonly bottom. On the other hand, certain features are difficult to explain by weathering. These include replacement of such rocks as quartzite and chert breccia by iron oxide near orebodies; the presence of specularite in the ore; cementing of breccia by iron oxides; occurrence of veins of iron oxide; and alteration of Ruth slate, a formation rich in alumina, to iron ore by separation of iron from the alumina. It seems that the same sort of argument will persist about these deposits as about the similar deposits in Minnesota and Michigan.

Both north and south of Knob Lake in rocks of the Kaniapiskau group there are huge bodies of lower grade material that are relatively easy to concentrate to merchantable grade. Some of the better known of these are at Wabush Lake, Labrador; Mount Wright, New Quebec; and various bodies near Leaf and Payne Bays on the west side of Ungava Bay. These appear to be metamorphosed iron-formation equivalent to the Sokoman of the Knob Lake area. Those near Wabush Lake average about 35 to 40 per cent iron, which is about 5 to 10 per cent higher than the others. The Wabush Lake deposits also are a little coarser grained so may be more easily concentrated. There can be no doubt that all these deposits will be important sources of iron in years to come.

Similar iron-formations are found in the district running southwest from Port Arthur to the United States boundary, in the Belcher and Nastapoka Islands of Hudson Bay, and in the region near Lakes Mistassini and Albanel in Quebec. None of these has so far been found to contain merchantable ore, but recent explorations of the Belcher Islands and of the Lake Albanel area have disclosed promise of concentrating ore.

Steep Rock Type

At Steep Rock Lake a vast body of high-grade iron ore was found, by drilling, to underlie much of the lake. In order to get at the ore, part of the lake was diverted from its normal drainage, dammed off from the rest of the lake, and then pumped out—a remarkable feat of engineering. Production began in 1944, and in 1955 about 2¼ million tons were shipped. In 1954 operators began to dewater the southeast arm of the lake so that the presumed continuation of the Steep Rock orebody can be mined. Originally, it was believed that each of the different ore zones represented different orebodies, but A. W. Jolliffe has recently presented convincing evidence that all are faulted segments of the same ore zone (Figure 33). If so, this is one of the great orebodies of the world for it is several miles long and varies in width from 100 to 300 feet. The ore is of very good grade except that it contains about 10 per cent of water. It is low in silica, phosphorus, and sulphur.

All the orebodies strike about northwest and dip steeply southwest. The foot-wall, or north side, is the Steeprock limestone, which has been variously ascribed to metasomatic replacement of some pre-existing rock or to sedimentary origin[1]. The latest data strongly favour sedimentary origin, and the "algal structures" in it, to organic origin. Above the limestone lies the ore zone. It consists of a foot-wall of manganiferous 'paint' rock a few feet thick that rests on an irregular surface of the limestone. This irregular surface, as pointed out by Jolliffe, strongly resembles a tipped karst surface, and he suggested that the 'paint' rock is at least partly due to residual accumulation as the limestone was weathered away. Above this 'paint' rock is the ore, which consists mainly of goethite in angular fragments. Here and there it is cemented by hematite, or has been converted to it, and the hematite and goethite are locally cut by veins of pyrite, a paragenesis that is exactly the reverse of what would be expected if the goethite were of hydrothermal origin. Jolliffe suggested that the original goethite was locally transformed to hematite by hydrothermal action associated with the pyrite. The goethite is associated with a weathered surface and contains pisolitic structures exactly

[1]J. W. Gruner has recently suggested that the limestone was formed by deposition from hot springs.

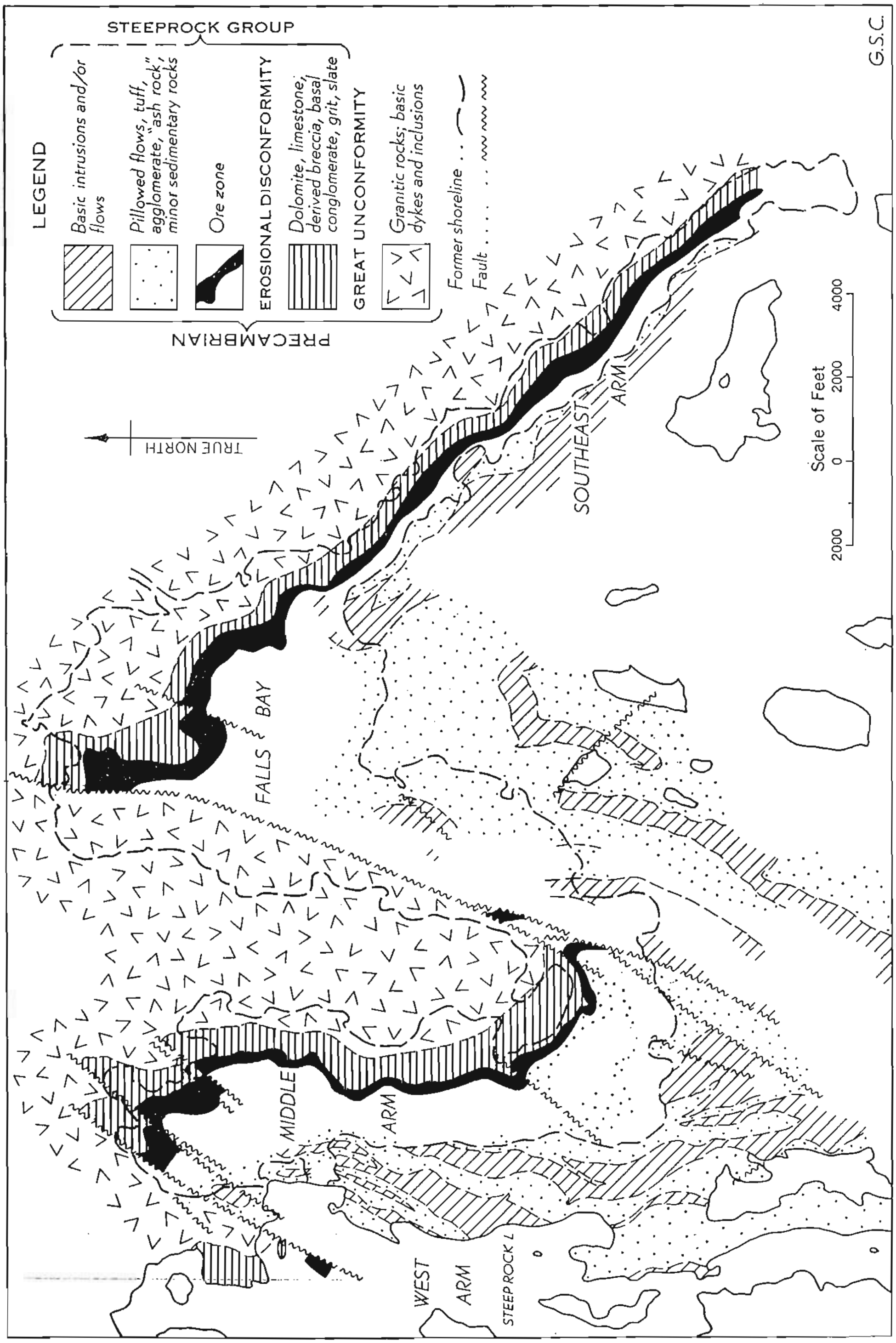


FIGURE 33. Geological map of Steep Rock Lake area. (Generalized after A. W. Jolliffe.)

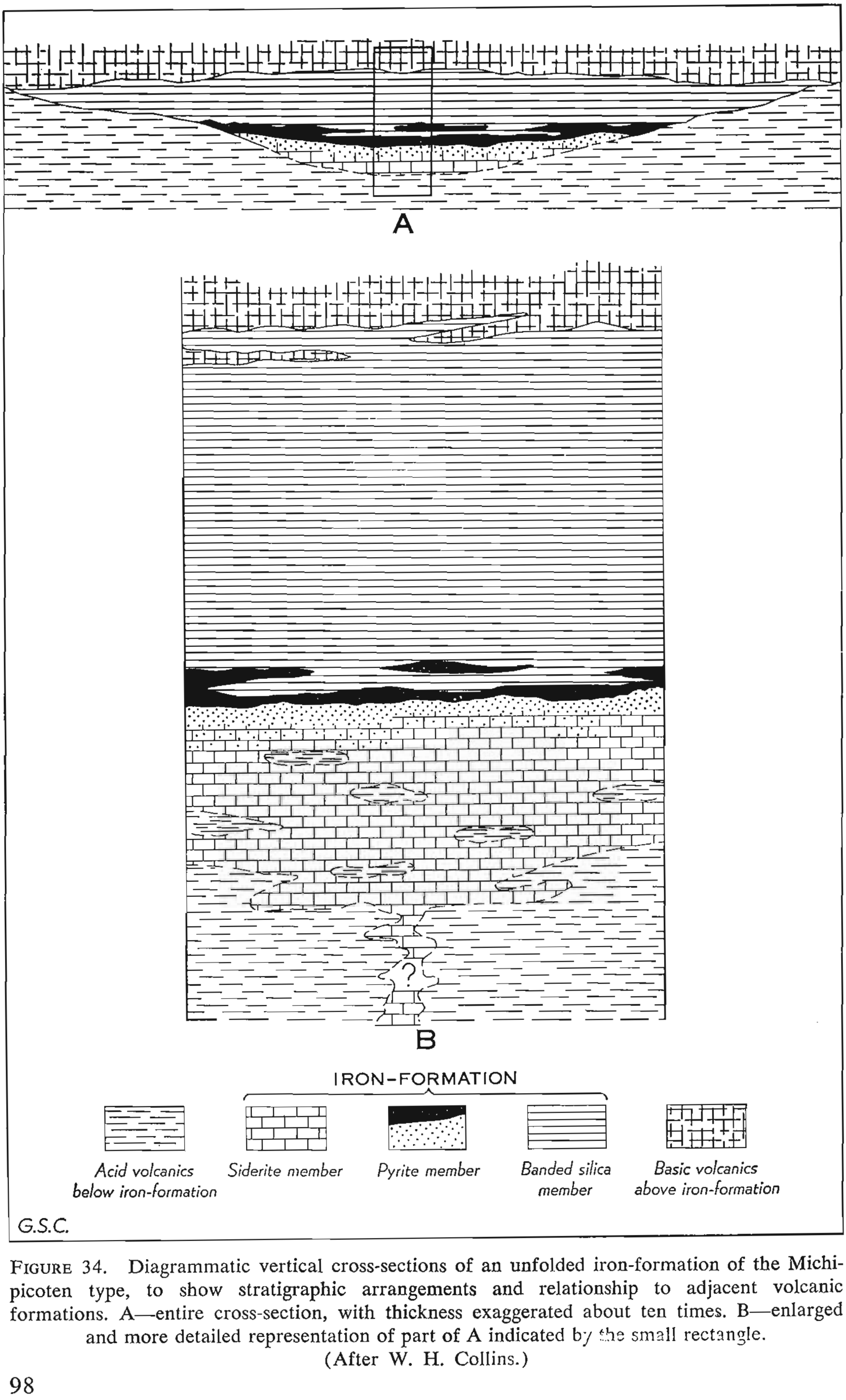


FIGURE 34. Diagrammatic vertical cross-sections of an unfolded iron-formation of the Michipicoten type, to show stratigraphic arrangements and relationship to adjacent volcanic formations. A—entire cross-section, with thickness exaggerated about ten times. B—enlarged and more detailed representation of part of A indicated by the small rectangle.
(After W. H. Collins.)

analogous to those in bauxite deposits so that it is reasonable to postulate a sedimentary origin for the deposit. It may be a huge laterite, perhaps reworked by shallow waters. It was buried beneath a cover of "ash rock" that is most easily accounted for as an explosive volcanic breccia perhaps *nuées ardentes,* or glowing avalanches.

Most of those who examined the area in days before openings were made in the ore were of the opinion that the ore was due to replacement of the carbonate rocks and, perhaps, of the ash rock. One of the features difficult to explain by the sedimentary hypothesis is the occurrence of solid lenses of ore in the "ash rock", well away from the main body. No doubt the origin of this ore will remain a subject of controversy for many years, but the sedimentary or lateritic origin seems to be the most logical from the data so far obtained.

Michipicoten Type

This type is, of course, exemplified by the ores of the Michipicoten district where W. H. Collins established a classic concept for the deposits. He summarized the stratigraphy as (1) a basic lava constitutes the cover of the iron-formation, or its hanging-wall where the dip is high; (2) in sharp contact beneath this lava is a banded silica member of the iron-formation; (3) in sharp, partly alternating contact below the banded silica is a pyrite member; (4) the pyrite member grades downward into a carbonate member, commonly siderite, although other carbonates are also present; (5) the carbonate member, in turn, passes gradationally downward into an acid volcanic formation that constitutes the foot-wall of the iron-formation (Figure 34). Most of the smaller deposit lack one or more of the members, but most of the larger deposits show the sequence indicated.

The carbonate member is either directly, or by conversion into secondary ores, the source of all the iron ore deposits of the Michipicoten district. It attains a maximum thickness of 240 feet at the Helen mine, and in other places ranges in thickness down to nothing. Even in the same iron range there are wide variations in thickness within short distances. Collins considered the evidence clear that the carbonate member had been formed by replacement of the underlying lavas, but detailed studies have led W. L. Young to conclude that the carbonate is of sedimentary origin. According to Collins' hypothesis, deposits like those at the Helen mine originated through the action of volcanic steam and vapours on newly extruded lavas. These agents, where poured out on the surface, deposited the banded silica and iron oxide that constitutes the ordinary iron-formation; but in places the rock beneath was replaced by pyrite and iron carbonate. According to Young, however, the iron carbonate is a primary deposit of sedimentary origin. It appears to be comparable to the large bodies of sedimentary siderite locally found in the Kaniapiskau rocks of central Ungava.

At the Helen mine (Figure 35) the carbonate member extends from the west end of Boyer Lake eastward for slightly more than a mile, in which distance the thickness ranges from 50 to 240 feet. At the east end of Boyer Lake it was oxidized from the surface downward to form a pocket of brown iron ore 700 feet

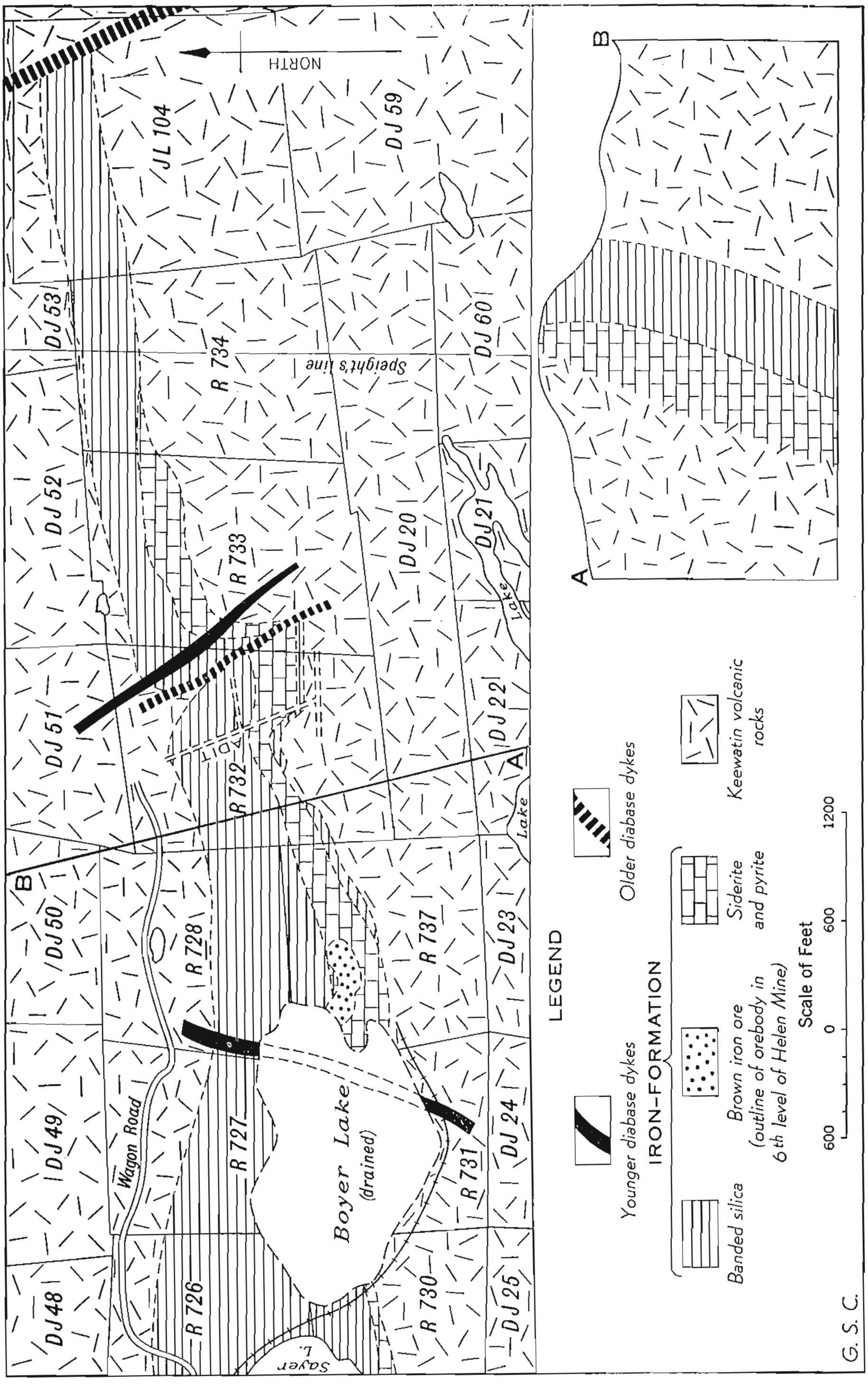


FIGURE 35. Plan and vertical cross-section of main part of Helen iron range. (After W. H. Collins.)

long by 200 feet wide and 650 feet deep. This constituted the old Helen mine, which was worked from 1899 to 1918, and from which 2,780,236 tons of high-grade iron ore were extracted. The property then lay idle until 1939, when mining was resumed on the immense remaining tonnage of carbonate ore. This ore, which contains considerable pyrite, is roasted to get rid of the sulphur and carbon dioxide, and the product is shipped mostly to lower lake ports.

The Magpie mine, about 13 miles due north of the Helen, was developed on a similar carbonate band and about 1,500,000 tons of carbonate were mined between 1910 and 1921.

The Josephine mine was about 8 miles northeast of the Helen. There the cherty silica member had been brecciated and cemented by hematite to form an orebody about 3,200 feet long and varying from 5 to 135 feet thick. Towards the more intensely brecciated south part of the cherty lenses, some high-grade pockets of pure hematite were found, but a few years ago the roof of the mine caved in and allowed the mud and water of Parks Lake to fill the workings. It seems possible that the hematite there is of hydrothermal origin although, as usual, opinions vary depending on the weight individuals assign to particular aspects of the relationships.

Magnetite-Skarn

This type of deposit, commonly referred to as pyrometasomatic, is common in Shield areas of southeastern Ontario and southwestern Quebec. Most of them contain enough titanium to render them valueless, but several were worked in the past. E. R. Rose concluded that most, if not all of them, were derived from basic intrusive rocks and that the closer the deposit is to the source rock, the higher the percentage of titanium. Some of the deposits are contained within the basic intrusion and should probably be classed as magmatic segregations, but a few are far enough from such a source to be free of titanium. The Marmoraton deposit is one of these; the old Bristol mine is being prepared for production; and some consideration has been given to the reopening of the Calabogie property. All require concentration of the iron ore. Deposits richer in titanium and more directly associated with the basic intrusions are not being seriously considered as potential sources of iron ore unless the iron might be obtained as a by-product from the production of titanium.

The deposit at Marmora was discovered beneath about 125 feet of early Palæozoic limestone in 1950 when an aeromagnetic anomaly was drilled by Bethlehem Mines Corporation. The deposit is in the Grenville series of Precambrian rocks unconformably beneath the limestone, and less than a mile south of the village of Marmora in Hastings county, Ontario. Mining began in 1955 after removing about 20 million tons of the overlying limestone. The orebody is about 2,400 feet long, a maximum of 400 feet wide, and dips steeply southwest. It averages about 37 per cent iron and less than 1 per cent titanium. The ore is fine-grained magnetite that impregnates meta-gabbro, amphibolite, and a dark green pyroxene-epidote-garnet skarn, or tactite. Crystalline limestone forms the foot-wall of this assemblage, and granitic rocks, the hanging-wall. The deposit seems to be a metasomatic replacement of skarn and of amphibolite facies of sedimentary and igneous rocks.

The old Bristol mine, which was operated many years ago, is in Pontiac county, Quebec, about 35 miles north of Ottawa. It has been intensively drilled and production is planned for 1957 or 1958. Magnetite is the chief ore mineral, and occurs in foliated amphibolitic rocks at and near their contacts with interbanded, impure crystalline dolomitic limestone of the Grenville series. Magnetite has been altered to martite (hematite pseudomorphous after magnetite) for a depth of at least 260 feet. Minor sulphides are present in the ore zone, which has been traced for a length of about 2,500 feet and has a width of about 500 feet. The zone is parallel to the foliation in the rocks and dips about 60 degrees northeast.

The Calabogie deposit has been known since 1883 but has only recently been explored by deep drilling. The ore mineral is magnetite in a zone about 3,000 feet long and, at most, 270 feet thick. The iron ore replaces skarn and amphibolites at and near the brecciated contacts of intercalated crystalline limestone and metamorphic pyroxenite bands.

Miscellaneous Iron Ores

Many small bodies of hematite or limonite have been mined in the district between Ottawa and Georgian Bay. Some proved to be shallow masses formed by the oxidation of underlying bodies of pyrite; others were found in fissures and cavities and many were deposited there after leaching from beds of Palæozoic rocks that once overlay them.

Noranda Mines Limited is treating some of the barren pyrite found associated with its copper ore, and International Nickel Company is recovering iron ore from its nickel-bearing pyrrhotite concentrate. When all units are completed the plant will have an output of about one million tons a year.

At various places, metamorphic iron-formation, presumably associated with Keewatin rocks, has been proven to contain large reserves and to be potential sources of iron. Such deposits are those of Iron Bay Mines Limited, 30 miles south of Red Lake, Ontario, and a property in Boston township in the Kirkland Lake area, Ontario, now under option to Jalore Mining Company, Limited.

Titanium

Ilmenite, a titanite of iron, is the principal titanium mineral in the Shield. It occurs as magmatic segregations in anorthosites of southern Quebec, which are found here and there from the lower Ottawa River to the North Atlantic coast. The most important deposits known are those of Quebec Iron and Titanium Corporation at Allard Lake, near Havre St. Pierre, which contain about 150 million tons of ore averaging about 35 per cent titanium oxide and 40 per cent iron. The company's metallurgical plant at Sorel, Quebec, treated 311,230 tons of ore in 1955 to produce 108,300 tons of pig iron and 145,300 tons of titanium slag.

Ilmenite has also been mined for many years on a small scale near St. Urban about 9 miles north of Baie St. Paul on the north shore of the St. Lawrence River below Quebec City. At this locality ilmenite forms a number of bodies in massive anorthosite and they are elongated parallel to an indistinct gneissoid structure in it. The walls of the ilmenite bodies are sharply defined. The ore is massive, carries some feldspathic matter, and at one occurrence contains streaks and rude bands so rich in rutile, the oxide of titanium, that the ore could be mined for the rutile alone. Ilmenite carries about 30 per cent of titanium, rutile about 60 per cent.

Manganese

Very little manganese has been produced as such in Canada. The deposits of iron ore near Knob Lake, Quebec, described under iron, contain pods of ore that assay 10 per cent or more manganese.

Molybdenum

Molybdenum, which is used principally in the making of steels, occurs mainly as the sulphide molybdenite, which occurs in many places on the Shield.

In the southwest corner of Lacorne township, Quebec, and the adjoining corner of Malartic township, deposits of molybdenite have been known for many years and have been worked intermittently since May, 1943. These are the only deposits now in commercial operation, the sole Canadian producer being Molybdenite Corporation of Canada, Limited. From 1943 to the end of 1955, production was about 3,500 tons of molybdenite. The deposits occur where a biotite schist of sedimentary origin was invaded by thin sills of granite and then by pegmatitic quartz veins carrying molybdenite. The assemblage as a whole strikes northeast and dips northwest at about 60 degrees, though some veins dip southeast. Most of the veins average 3 to 4 feet in width and the ore, as mined, averages slightly more than 0.5 per cent molybdenite.

In 1942 a promising find was made in Preissac township, Quebec. The Indian Molybdenum mine came into production in 1943 on a zone between two faults in a granite body. The fault block, about 40 feet thick, dips about 45 degrees northeast and, from the hanging-wall fault, gently dipping quartz veins extend across the granite to coalesce with the foot-wall fault. Molybdenite occurs in fresh quartz and on slip surfaces in the quartz. Average grade is about 0.45 per cent molybdenite. but mining ceased in May 1944.

In Renfrew county, Ontario, bodies apparently of contact-metamorphic origin were mined for molybdenite during the war of 1914-18 and to a lesser extent during the last war. Such were the Zenith mine near Renfrew, the Hunt and other mines in Mount St. Patrick area 20 miles southwest of Renfrew, and the Spain mine about 30 miles southwest of Renfrew. Bodies of granite, syenite, or pegmatite, intrusive into the Grenville series, have metamorphosed crystalline limestone along contacts to pyroxenite heavily mineralized with pyrite, pyrrhotite, and more or less molybdenite. These bands of ore ranged from a foot or two in width to 30 feet. Rich pockets of molybdenite were found in them, but on the whole the grade was low and operations were unprofitable.

A similar occurrence near Montcerf, 15 miles north of Maniwaki, Quebec, was mined to some extent during the last war. At the contact with granite, Grenville limestone is converted into a mixture of pyroxene, mica, calcite, and feldspar, and across a width of about 5 feet this material is mineralized with some pyrite, pyrrhotite, and molybdenite. Parts of the deposit, it was estimated, ran 1.25 to 1.50 per cent molybdenite, but the general average was much lower.

Much molybdenite was produced from the Moss mine near Quyon, Quebec. The mine was operated from 1916 to 1919 and produced 382½ tons of molybdenite from 61,206 tons of rock mined. From 1919 to 1926 it was worked intermittently, then closed until 1940. The deposits occur in a mass of fine-grained, pink syenite carrying numerous inclusions of an older, coarser syenite. The syenite body is about 2 miles long from east to west by 1 mile wide. The principal deposits lie at the northeastern exposure of this body. At their edges, the pink quartz syenite passes by a gradual transition into the mineralized zones, which differ from the ordinary syenite merely in their grey to green colour and in the presence of finely disseminated molybdenite, pyrite, fluorite, and magnetite. Within the principal mineralized zone are scattered lenticular masses of high-grade ore consisting of molybdenite, feldspar, quartz, fluorite, pyrite, and magnetite. The first mass of this high-grade ore to be mined proved to be approximately 200 feet long, 50 feet wide, and 75 to 125 feet deep. The general tenor of the ore appears to have been 0.5 to 0.75 per cent molybdenite, though richer parts ran 2 per cent or better. The general mineralized zone in which this mass lay was about 500 feet long, 60 feet wide, and at least 250 feet deep. The origin of these deposits is uncertain. Some geologists believe that they are magmatic segregations or replacements. Others have advanced the suggestion that they are roof pendants of the older Grenville series, completely recrystallized and mineralized—a suggestion for which their manner of pinching out at no great depth seems to offer some support.

Tungsten

The principal ore of tungsten on the Shield is scheelite, the calcium tungstate. It is found chiefly in gold ores and also in quartz veins in the Yellowknife-Beaulieu area of the Northwest Territories. No deposit worth mining for tungsten alone has yet been found, but to fill war requirements Canadian gold mines went to considerable expense to separate and save the relatively small amounts occurring in their ores. Hollinger Consolidated Gold Mines Limited, at whose property in the Porcupine area, Ontario, perhaps the largest bodies of scheelite were found, erected a mill which treated 135 tons of ore daily. Ore from the other mines in the Porcupine district was shipped to this mill.

Some tungsten was obtained in the past from a deposit on Outpost Islands, Great Slave Lake. The ore is a gold-copper-tungsten-tin complex, and difficulty was encountered in producing a satisfactory tungsten concentrate. The tungsten mineral there is mainly ferberite, a tungstate of iron, and the ore is said to run about 1 per cent tungsten.

Chromite

No chromite is being produced from the Shield. In the years 1934-37 a few thousand tons were mined from a deposit near Obonga Lake, Thunder Bay district of Ontario, just northwest of Lake Nipigon. There a mass of "serpentine rock" composed of serpentine, carbonates, talc, and chlorite in varying proportions underlies an area about 3¾ miles long and three-quarter mile wide. Masses of disseminated chromite were found in several places, particularly towards the eastern end of the mass, carrying on an average from 3 to 10 per cent chromic oxide. Attempts made to concentrate this material proved, however, that the best concentrate carried only about 43 per cent Cr_2O_3, and had a chrome-iron ratio of about 1 to 1. As good commercial concentrates carry 45 to 50 per cent of chromic oxide and have a chrome-iron ratio of nearly 3 to 1, the product did not prove satisfactory and mining operations were suspended.

Much interest was aroused by the discovery in 1942 of large low-grade chromite deposits north of Bird (Oiseau) River, southeastern Manitoba. The deposits have received intermittent attention but there has been no commercial production. A great sill-like mass of gabbro intruded into Precambrian rocks has been differentiated, presumably by gravity, into products ranging from augitite at the base to feldspathic quartz diorite at the top. Somewhat below the middle of the sill a band of the rock, paralleling the strike and dip, is filled with small grains of chromite. The chromiferous material is banded in alternate narrow bands of high- and low-grade ore. The main zone averages 7 feet in width, and has been traced for several miles. The run-of-mine ore is said to average between 16 to 20 per cent Cr_2O_3, but the best chrome-iron ratio is about 1.2 to 1.

Pitchblende

Prior to 1955 no figures were released on the value of pitchblende products. Production that year was valued at $26,032,000. The chief products being uranium oxides and salts, the others being radium salts, silver and cobalt. The annual value will increase greatly within the next few years as a result of the mines that have come or are coming into production in the Lake Athabasca area in Saskatchewan, and in the Blind River and Bancroft areas in Ontario.

Northwest Territories

In the spring of 1930 pitchblende was discovered at LaBine Point, at the east end of Great Bear Lake. This discovery became the Eldorado mine and for Canada was the forerunner to the so-called atomic age.

The rocks at the mine belong to the Echo Bay group of Proterozoic age and comprise thinly banded cherty sedimentary material, bedded tuff, and coarser fragmental rocks, with a little limestone. They strike north and are folded into a synclinal-like structure that appears to plunge north. A flow or sill of feldspar porphyry 100 feet or more thick is interbanded with them. Three faults strike east-northeast across this structure; the northernmost dips vertically, the others about 55 degrees north. The ores are found in shatter zones of these faults. In the

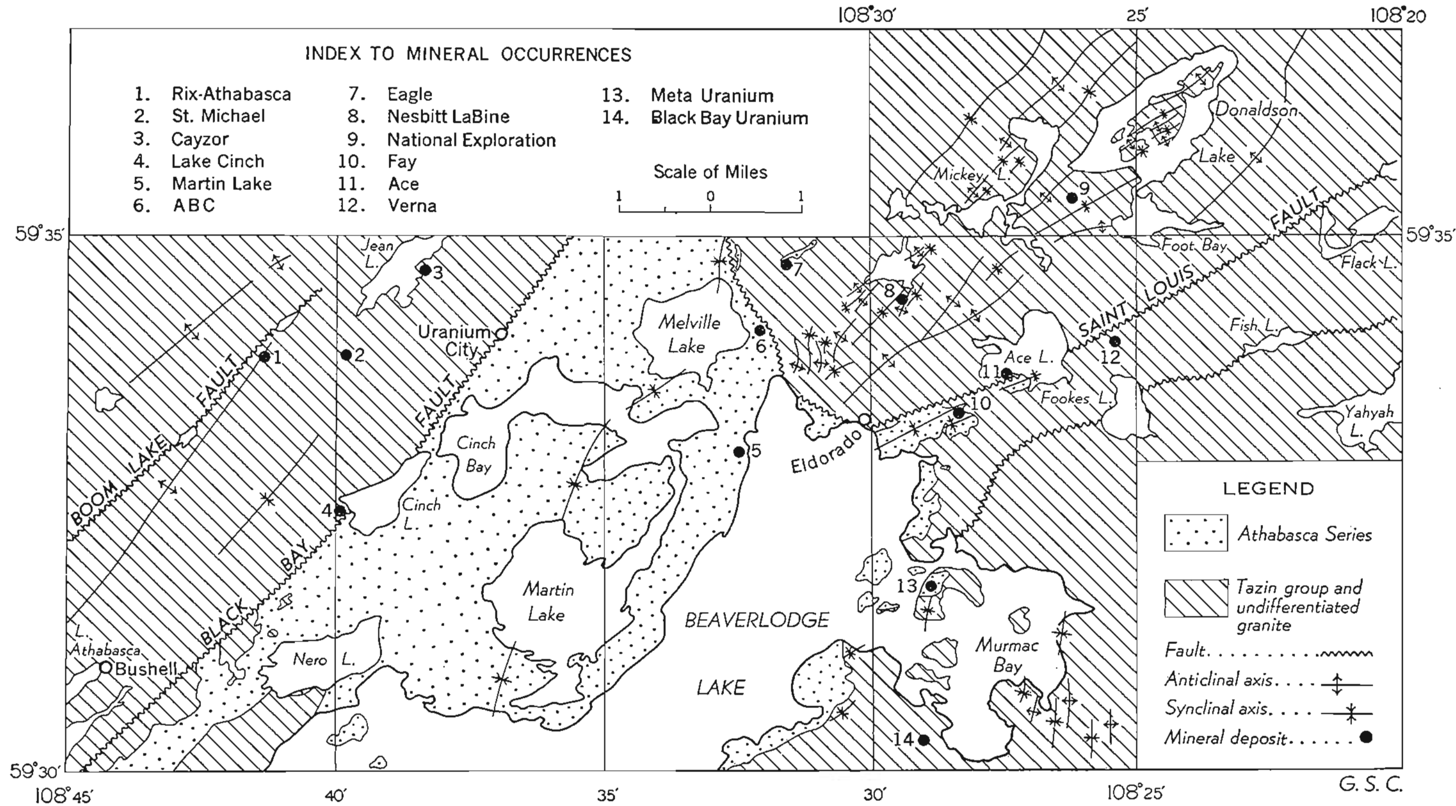


FIGURE 36. Generalized geology of Beaverlodge Lake area, Saskatchewan. (After L. P. Tremblay.)

two northernmost faults the ore is found only in the sedimentary rocks, apparently because the faults were not strong enough to shatter the porphyry extensively; but in the southern, which has a shatter zone up to 30 feet wide, ore is found in the porphyry as well. Due to this peculiarity, the ore in the two northern faults bottoms on the porphyry syncline, some 800 feet below the surface.

Ore is by no means uniformly distributed throughout the shatter zones, but occurs in shoots separated by barren sections. Pitchblende is the main constituent of value, but is only one of a remarkable variety of minerals. At least thirty-four metallic minerals and five non-metallic gangue minerals have been identified. These were deposited in recurrent waves of mineralization, separated by periods of renewed fracturing. The first minerals deposited were pitchblende and quartz, followed successively by: cobalt and nickel minerals with more quartz; lead, zinc, and copper sulphides with dolomite; ferruginous rhodochrosite, copper and silver sulphides, and native silver. The country rocks near orebodies are converted into fine-grained, hard, red alteration products, consisting of quartz and feldspar reddened with finely disseminated hematite. A similar but much less intense alteration is fairly general throughout the district.

Promising discoveries have been made in the Marian River area 50 to 100 miles north of Yellowknife where relatively high-grade deposits have been disclosed in giant quartz veins. Production by Rayrock Mines Limited is scheduled to commence in 1957.

Saskatchewan

In the Beaverlodge area, north of Lake Athabasca, sedimentary and granitized rocks of the Tazin group underlie most of the region and are traversed by red granite and pegmatite. Locally this assemblage is overlain unconformably by relatively fresh clastic sedimentary and volcanic rocks of the Athabasca series. Uranium deposits are in rocks of both groups, but the major known deposits are in those of the Tazin assemblage (Figure 36).

Some structures in the area affect Tazin rocks only, others affect Athabasca rocks as well. The early folds are more intense and the late folds are reflected in the northeasterly trending structures of Tazin rocks by minor cross-folds. Early faults are characterized by zones of brecciation whereas the late faults are clear-cut fractures. Because the early structures are generally more continuous and larger, they contain most of the producing mines of the area. It appears also that rocks rich in mafic minerals had a favourable effect on localizing ore in the Beaverlodge area.

The Ace-Fay mine of Eldorado Mining and Refining Limited entered production in April 1953. This and the company's Verna deposits occur in banded quartz-feldspar and epidote-chlorite rocks in and near the foot-wall of the St. Louis fault. The fault trends somewhat north of east and dips about 50 degrees south, making a small angle with the trend of the formations. The formations north of the fault are on the southeast limb of an anticline; those to the south of the fault are near the trough of a syncline that plunges southwesterly. In addition, the

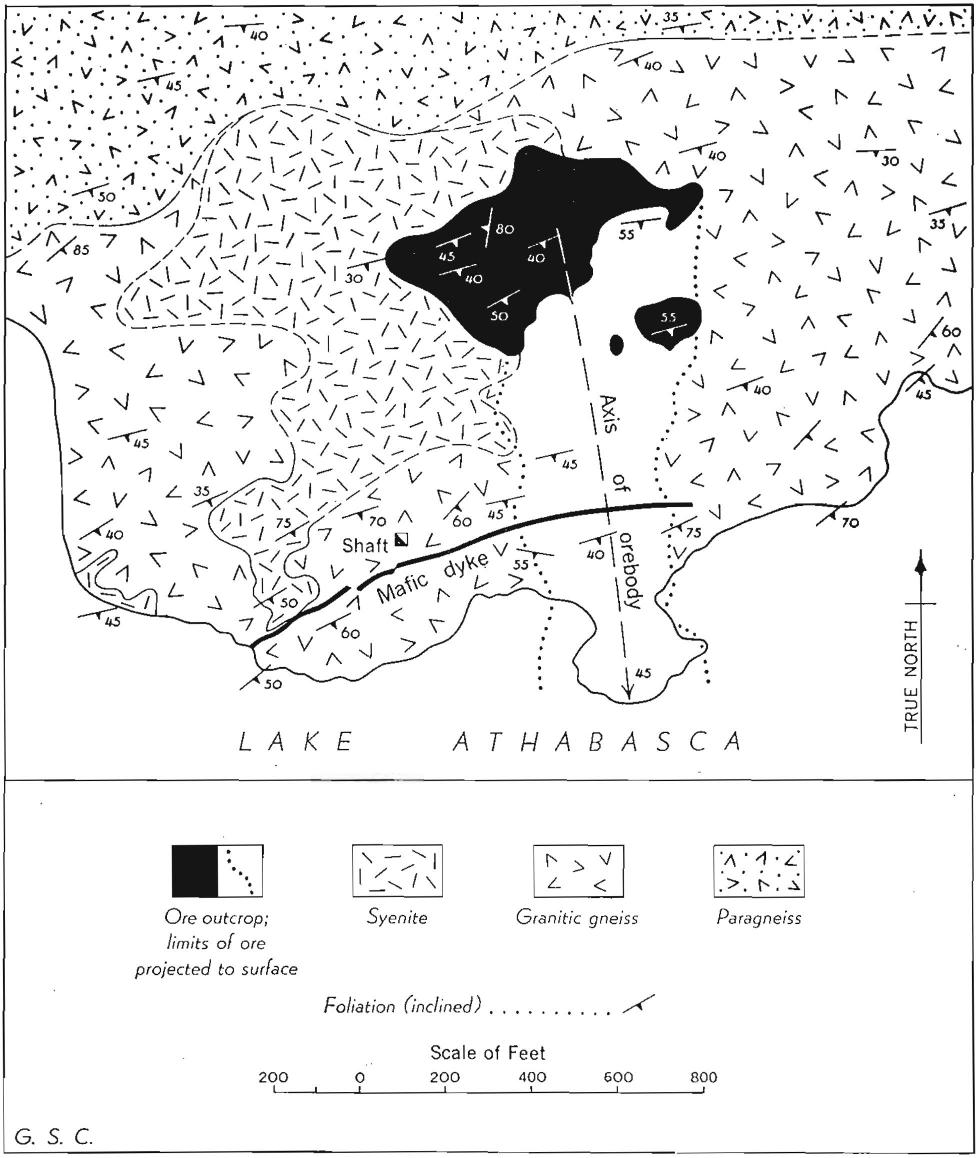


FIGURE 37. Gunnar "A" orebody, Lake Athabasca, Saskatchewan. (After A. W. Jolliffe.)

formations have been drag-folded and partly brecciated along the fault. Pitchblende occurs in brecciated granitized material and as calcitic veins filling narrow fractures parallel to or at a low angle to the St. Louis fault. There appears to be a relation between faulting, brecciation, and drag-folding.

The Gunnar mine, which came into production in 1955, is on the Crackingstone Peninsula of Lake Athabasca, about 12 miles south of Beaverlodge Lake.

The main zone is a well defined, pipe-shaped body of carbonatized albite syenite that contains disseminated pitchblende and uranophane (Figure 37). The pipe lies within and near the foot-wall of a sill-like mass of albite granite gneiss that is bounded by meta-sedimentary rocks of acid composition. Probably the syenite and granite are metasomatized equivalents of sedimentary rocks also. The rocks are brecciated and hematitized in places, and are most affected in that part of the syenite that constitutes the orebody. No reason is yet known for this intense brecciation, but it may be due to the position, shape, and size of the syenite mass in relation to faults.

The ore occupies the northeast corner of the triangular-shaped mass of syenite that measures about 1,200 feet on each side. The ore shoot extends down from the surface for more than 1,400 feet along a plunge of 45 degrees to the south. Ore reserves are estimated at more than 3 million tons to that depth. Pitchblende is accompanied by hematite, pyrite, chalcopyrite, and galena. Uranophane, the principal supergene mineral, is associated with barite and persists at least to a depth of 1,000 feet. Uniform grade of ore from the surface down suggests that primary pitchblende was altered to uranophane by circulating artesian waters but with little or no migration of uranium. Conflicting lead-uranium age determinations make it fruitless to speculate on the source of the pitchblende.

In addition to the Gunnar and the Ace-Fay mines, several other properties have produced some pitchblende and plans are being laid for more regular and greater production from them and for new production from others. These include the Consolidated Nicholson, Lorado, Nesbitt LaBine, Lake Cinch, and Rix-Athabasca.

Ontario

Blind River Area. Huge tonnages of uranium ore have been disclosed in the Blind River area since 1953. Production was started at the Pronto Mine in August 1955. Algom Uranium Mines Limited operates the Quirke Lake mine which was brought into production in 1956 and the Nordic Lake mine which is scheduled for production in 1957. Consolidated Denison is also expected to commence production in 1957. These developments will make the Blind River area one of the largest uranium camps in the world, if not the largest.

The area is part of the type area for the Bruce series of Proterozoic rocks. It lies unconformably on the Archæan basement and is overlain by the Cobalt series, although it is by no means certain that the Cobalt is unconformably above the Bruce. The Huronian rocks have been folded into a rough Z-shape, the northern part of the structure being the Quirke Lake syncline plunging west at about 5 degrees (Figure 38). The southern part of the structure is presumably anticlinal but is much more irregular.

All the orebodies are contained in quartz-pebble conglomerate in the lower part of the Mississagi formation, the basal formation of the Bruce series. Knowledge of the stratigraphy and structure thus permits accurate location of drill-holes to intersect the favourable conglomerate bed. Not all the conglomerate is mineable

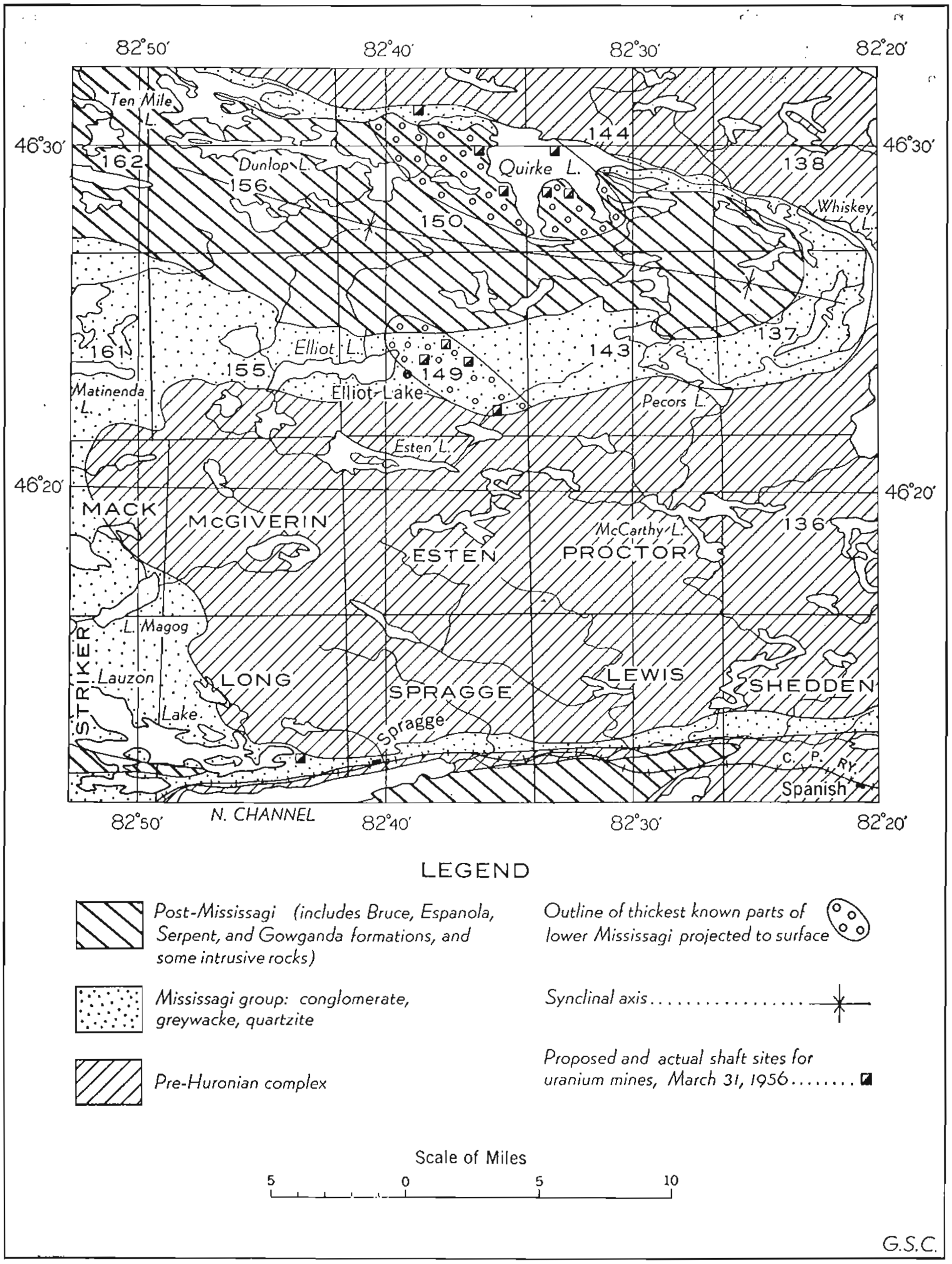


FIGURE 38. Sketch of Blind River-Quirke Lake uranium area. (After W. H. Collins and S. M. Roscoe.)

because of thinness of the beds or low-grade or both. The mineable bodies appear to lie in pronounced depressions on the pre-Huronian surface. The thickest beds of conglomerate occur in the lowest parts of the depressions, and are underlain by green schists in contrast to pre-Huronian granitic rocks that underlie the thin parts of the conglomerate. Thus it appears that the depressions were caused by differential erosion. However, the main ore-bearing conglomerate is not at the base of the Mississagi, and at the Quirke and Nordic mines, at least, in addition to a continuous bed of ore grade, there are other conglomerate beds above and below, all in the Mississagi.

The ore minerals, named in order of abundance, are brannerite, pitchblende, uraninite, and monazite. They are associated with detrital minerals of the conglomerate, and with several sulphides. Pyrite is the most abundant of these and there are minor quantities of pyrrhotite, galena, chalcopyrite, sphalerite, molybdenite, marcasite, and cobaltite. Gold is erratically distributed. At present, the origin of the ores is debatable. Geologists favouring a sedimentary origin emphasize the remarkably uniform distribution of uranium in the conglomerate, isolation of individual grains of radioactive minerals, and the known occurrence of detrital brannerite. The hydrothermal hypothesis is supported by the abundance of crystalline sulphides, high ratio of uranium to thorium, and by the ratio of iron to titanium.

Bancroft Region. Deposits carrying uranium in the Bancroft region of Grenville rocks have been known for many years, but because many are small and irregular in shape and grade, there was no important mining for uranium until recently. By late 1955 and early 1956 the Bicroft and Faraday properties, respectively, had proved enough ore to permit special contracts to be negotiated for the sale of concentrates. The properties are about 5 miles apart and only a few miles from Bancroft (Figure 39).

At Bicroft, uraninite and uranothorite occur in a series of lenticular pegmatites in a northerly trending zone of metamorphic gneisses. The pegmatitic bodies vary from a few feet to 400 feet long and are as much as 80 feet wide. The uranium minerals have a tendency to be concentrated near the walls. At Faraday the main pegmatites have been found in amphibolite and other meta-sedimentary rocks, and the principal dyke so far explored extends at least 3,000 feet on surface. The pegmatite is relatively low in uranium minerals except where it contains lenses of material rich in pyroxene and magnetite.

Miscellaneous Deposits

Radioactive mineral occurrences have been reported from scores of localities in the Grenville sub-province of Ontario and Quebec. Most of these are in pegmatites, but a few are in skarn and in calcite-fluorite veins. Several radioactive occurrences were discovered in the belt of Proterozoic rocks near Seal Lake, Labrador, in 1955, and several occurrences were reported from the Northwest Territories north of Lake Athabasca and south of Great Slave Lake. In recent years many deposits have been found along the west edge of the Shield from Great

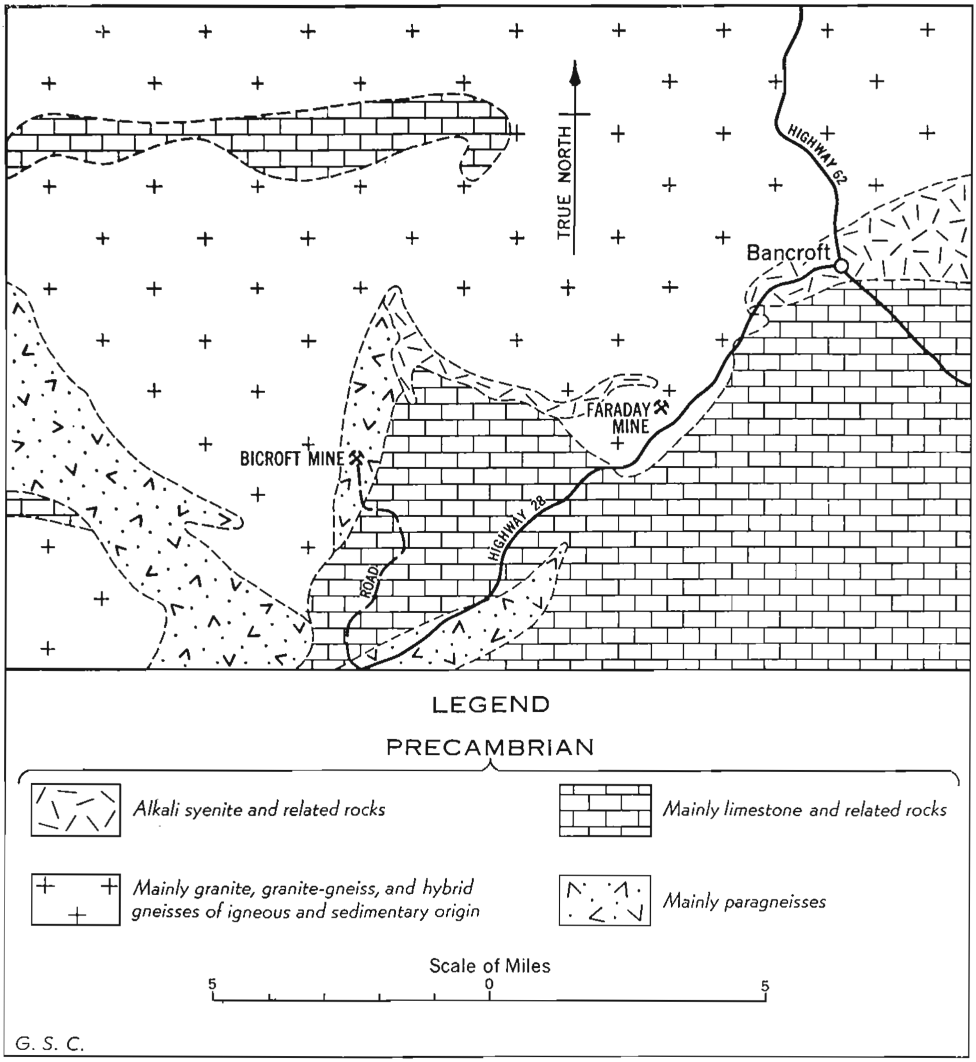


FIGURE 39. Map showing generalized geology of part of Bancroft region, Ontario. (After A. H. Lang.)

Slave Lake to Great Bear Lake. No doubt other areas of potential importance will be disclosed as prospecting continues.

Lithium

Amblygonite, spodumene, and lepidolite are the chief lithium minerals of commerce and, when reasonably pure, usually contain, respectively, about 8, 6, and 4 per cent of lithium oxide.

Except for a few hundred tons, mainly of spodumene, that were shipped in 1937 from southeastern Manitoba, production began with shipments from Quebec

Lithium Corporation's property in the Preissac-Lacorne district, Abitibi county, Quebec, in 1955. Ore reserves were estimated at 15 million tons averaging 1.2 per cent lithia. The spodumene occurs in a group of parallel pegmatite dykes, the largest of which is more than 10,000 feet long, and which are remarkably constant in grade and texture.

Numerous granitic pegmatites and quartz veins are associated genetically and spatially with the Preissac-Lacorne batholith. The pegmatites are marginal to and outside the batholith, and three regional zones of pegmatites and quartz veins have been outlined: (1) pegmatites of the inner zone containing beryl but no lithium minerals, (2) a central zone containing all of the pegmatites carrying spodumene, and (3) an outer zone of quartz veins that carry molybdenite. Emplacement of all appears to have been controlled by fracture systems related to the batholith.

The spodumene pegmatites are zoned. Zones, when ideally developed, are shells concentric about an innermost core and are marked by differences in mineral content or texture, or both. Even where not complete, the zones commonly reflect the shape or structure of the pegmatite. Although the pegmatites at Lacorne are zoned, some of them can be mined without regard to the zones because the spodumene-bearing zones greatly exceed the barren zones in bulk. The spodumene occurs as laths, plates, prismatic crystals, and needles that may be white, buff, or green. These are as much as 18 inches long, but most of them are less than 4 inches; many are oriented perpendicular to the walls of the pegmatite.

Many pegmatites are known in southeastern Manitoba but those containing lithium minerals are found only in meta-volcanic rocks, or in granitic bodies close to the margins. All the lithium-rich pegmatites that have been examined have internal structure due to replacement of pre-existing pegmatite. Montebrasite and spodumene occur in zones or lenticular pods, whereas the lithia micas occur as replacement bodies or fracture fillings. Spodumene is the most abundant lithium mineral and large tonnages appear to be present in some dykes.

Several spodumene pegmatites occur in quartz diorite near Herb Lake, Manitoba. One of these is at least 900 feet long, an average of 18 feet wide, and contains about 13 per cent spodumene in crystals up to 18 inches long.

In the Yellowknife-Beaulieu area of the Northwest Territories, many pegmatites are associated with bodies of biotite-muscovite granite and intrude metamorphosed rocks of the Yellowknife group. The lithium-bearing pegmatites are commonly zoned and the lithium occurs near the core. Amblygonite is present in some but spodumene, in crystals over 4 inches long, is the most common mineral. Columbite-tantalite and beryl are common accessory minerals in the wall zones of the pegmatites. Lithium minerals are unevenly distributed but the richest zones probably contain 20 to 30 per cent spodumene.

Beryllium

Beryl, at present the only commercial source of beryllium, is a silicate of aluminium and beryllium carrying 4 to 4½ per cent of the latter. The mineral occurs in pegmatite dykes, and most of the world production has been as a by-product from the mining of such dykes for feldspar, mica, and other products.

No commercial production of beryl has yet been made in Canada. In Lyndoch township, Renfrew county, Ontario, a pegmatite dyke about 45 feet wide has been quarried experimentally and some 50 tons of beryl are said to have been recovered. From this figure it has been estimated that the average beryl content is about 0.25 per cent, or 5 pounds a ton.

Pegmatite dykes carrying beryl are fairly numerous in southeastern Manitoba in the general district of Pointe du Bois on Winnipeg River, and some of these carry considerable amounts of beryl. A little beryl has been found in the Preissac-Lacorne area where pegmatites are being mined for lithium. However, beryl and lithium minerals do not occur in quantity in the same dyke, so it is unlikely much beryl will be obtained as a by-product of the lithium mines. In the Yellowknife-Beaulieu area of the Northwest Territories dykes of pegmatite are numerous and some have been found to carry beryl in promising quantities.

Tantalum and Niobium

Only a few pounds of tantalum or niobium (columbium) concentrates have been produced from Canadian occurrences and have resulted from development or experimental work. In 1943 several pegmatite dykes carrying these elements were found east of Yellowknife and more recently, potentially productive deposits were found in complexes of carbonate and alkaline rocks near Manitou Islands, Lake Nipissing, Ontario, and at Oka, Quebec.

At Lake Nipissing three deposits of niobium are known on the property of Beaucage Mines, Limited. The deposits occur in a complex of concentric bands of alkaline silicate and calcite rocks cut by lamprophyric dykes and all overlain, in places, by Ordovician strata. The Newman deposit, the most important of the three, is a mineralized zone at least 1,100 feet long and as much as 300 feet wide, containing disseminated uranium pyrochlore associated with acmite, soda hornblende, biotite, apatite, pyrite, and magnetite. The deposit lies in a band of potash-feldspar and calcite rocks, and apparently cuts across these rocks along a zone of intense fracturing where late solutions from an alkaline magma deposited the uranium pyrochlore. It is reported that diamond drilling indicated 5,431,000 tons averaging 0.53 per cent niobium oxide and 0.039 per cent uranium oxide. High-grade lenses within the mineralized zone are being outlined by underground exploration on the 400-foot level. A 50-ton pilot mill was placed in operation in 1956.

The niobium deposits in the Oka complex of carbonate and alkaline rocks, about 20 miles west of Montreal, Quebec, are potential sources of a large tonnage. Medium- to coarse-grained carbonate rocks are intruded by alkaline silicate rocks, and hybrid rocks have been formed. Owing to sparse exposures, the internal structure of the complex is not yet understood. Pyrochlore, the most important niobium mineral, is in metasomatized calcite rocks at or near contacts with the intrusions. Of the other niobium-bearing minerals, betafite occurs in biotitized rocks of the alkaline intrusions, niobium perovskite is in altered hybrid rocks that contain zeolites and vesuvianite, and niocalite, a newly discovered calcium niobium silicate, is found in calcitic rock. Large tonnages of rock carrying 0.30 per cent or more niobium oxide and some medium- to high-grade material occur as lenses. The lenses range from 50 feet long and 10 feet thick to 1,700 feet long and more than 200 feet thick. Some cut across different rock types and contain two or three niobium minerals. Although these deposits are in an area of Grenville rocks, they may be much younger, possibly the same age as the Monteregian intrusions which are Devonian or younger. This is suggested by the presence of fragments of Palæozoic-like limestone in one of the deposits and by a very recent age of some minerals based on rate of decay of radioactive isotopes.

Columbite and tapiolite occur in the Ross Lake district, Northwest Territories, in satellitic granitic pegmatites that show a zonal arrangement about the parent granite body. Pegmatites containing columbite or tapiolite, or both, occur in a zone between 9,000 and 11,000 feet from the parent granite body. Columbite occurs as an accessory mineral close to the walls of some of the dykes and tapiolite is found in small muscovite bodies replacing pegmatites. Beryl and spodumene also occur in some of the pegmatite dykes in the district.

Tin

No tin ores have been found in the Shield although the oxide, cassiterite, has been identified in many of the pegmatite dykes mentioned in the last section, and in others in southeastern Manitoba.

Magnesium

Defence requirements and the transportation industry have created a tremendous demand for magnesium metal, particularly for use in aircraft. Accordingly, in 1942, the plant of Dominion Magnesium was brought into production near Renfrew, Ontario. It utilizes dolomite beds of the Grenville series quarried nearby. The dolomite is calcined to magnesium by the ferrosilicon process.

Deposits of brucite occur near Wakefield, Quebec, also in Grenville limestone. The brucitic limestone is surrounded by masses of hastingsite syenite. Analyses of the brucite-bearing rocks indicate that magnesium and calcium oxides are present in about the same proportions as in pure dolomite, suggesting that thermal metamorphism of dolomite may have been responsible for producing these rocks. Some of the material mined is shipped to Arvida, Quebec, where The Aluminum Company of Canada, Limited, converts it to magnesium chloride and thence to magnesium metal, but most of it is processed at Wakefield for the recovery of magnesia.

Dolomitic magnesite is mined from Grenville rocks at Kilmar, in Argenteuil county, Quebec. The product is calcined and used as a basic refractory. In 1955 total output of brucite and dolomitic magnesite was about 1,800 tons.

Asbestos

The Munro mine of Canadian Johns-Manville near Matheson, Ontario, came into production in July, 1950, and ushered in the first commercial production of chrysotile asbestos from the Shield. The deposit is in a differentiated sill of mafic rock that intrudes Keewatin volcanic rocks. The body is cut by several northerly trending faults that effect right-handed displacement varying from a few feet to hundreds of feet. The sill has been traced for more than 3 miles along a strike of north 65 degrees west. It varies from 900 to 1,000 feet thick and dips essentially vertically. From north to south the sill consists of 350 feet of gabbro that grades sharply to coarse-grained pyroxenite, which in turn passes abruptly to serpentinized dunite and peridotite. The ultramafic zone is about 500 feet thick in the main ore zone at the surface, but is enveloped in a sheath of talc-carbonate rock that thickens with depth. Veins of asbestos are contained in the core of the ultramafic sill or in adjacent serpentinized peridotite and are associated with a medium to light green, granular serpentine. Altogether, four different areas of commercial quality asbestos were known before production commenced. Fibre is up to one inch long and most is rather harsh, though flexible. Cross-fibre occurs as one-fibre veins and two-fibre veins, most of which are parallel with the trend of the sill but which are crossed by veins normal to this direction. The result is a rectangular pattern of veins, more pronounced in some areas of ore than in others. Statistics of production are not given for separate mines, but Ontario produced about 25,000 tons of asbestos in 1955.

Small bodies of serpentine are common in the Grenville series, particularly north and east of Ottawa. Opinions differ as to whether these represent intrusions of peridotite or have been formed by metamorphic processes from the crystalline limestones. They carry veins of asbestos in many places, and the fibre is of high quality, low in iron and usually entirely free from magnetite. Attempts have been made from time to time to mine the deposits, but they have invariably been found too small to be commercial.

Elsewhere in the Shield, small deposits of chrysotile asbestos are known but none has proved profitable although several have yielded small quantities of asbestos, especially in northern Ontario along the so-called Abitibi serpentine belt. An unusual deposit in Bannockburn township, Ontario, occurs in a shattered zone of rhyolite at its contact with a highly serpentinized body of peridotite. Veinlets of asbestos formed in the fractured rock. A minor amount was produced.

About 3 miles east of Actinolite village, Hastings county, Ontario, large bodies of actinolite were mined, with interruptions, from 1883 to 1927. The mineral in some places appears to be in basalt or other greenstone altered by the intrusion of granite-gneiss. Other parts of the belt carry considerable dolomite or ferruginous carbonate, and thus suggest the possibility that the rock is an altered crystalline limestone.

Several showings of crocidolite, the blue, sodic and ferruginous asbestos, have been found near Knob Lake, New Quebec. They occur in areas where the normal iron-formation has been somewhat more highly metamorphosed than is usual for the district, and also where the iron-formation is complexly folded. The showings have caused a vigorous program of exploration and development, but none of commercial value was known to the end of 1955.

Apatite

Apatite, the tri-calcium phosphate, has been mined in considerable quantity for manufacture of superphosphate fertilizer. About the beginning of the century, however, competition from cheap foreign supplies closed most of the mines, and the little produced was a by-product of mica mining and was used mainly for the manufacture of phosphorus. Production in 1941, about 2,500 tons, was the largest for many years; none has been produced since 1951 when the output was 6 tons.

Almost all the apatite came from Quebec, north of Ottawa, or from Ontario, north and northeast of Kingston. It is found in irregular, pockety masses in pyroxene formed by alteration of crystalline limestones of the Grenville series.

Mica

All the mica produced from the Shield at present is amber mica or phlogopite, and comes from the same areas and the same types of deposits described for apatite. Output from some of these bodies in the past, such as the Lacey mine northwest of Kingston, was large. Production of phlogopite from the Shield in 1955 was about 570 tons. Most of the phlogopite comes from mines in Quebec and all of the muscovite of the Shield came from Ontario. All the muscovite deposits occur in pegmatites, apparently where they are especially coarse grained as at Eau Claire, near Mattawa, Ontario, and near Buckingham, Quebec.

Feldspar

Feldspar is also mined from pegmatite dykes, and from the same general areas as apatite and mica. Many deposits are known in the Shield from western Quebec west through Ontario to Georgian Bay, and in the Sudbury district. Most of the Canadian production comes from the Gatineau and Buckingham areas of Quebec. Many deposits are of large size. Thus the Derry mine, about 9 miles north of Buckingham, Quebec, is on a dyke 150 feet wide with an exposed length of 350 feet. A 50-foot strip along the west wall of this dyke is clean spar with only a little quartz, tourmaline, and pyrite. The Richardson mine, 25 miles north of Kingston, Ontario, is on a steeply inclined dyke 150 feet wide. For a length of 400 feet the dyke consists mainly of deep red microcline flanking a central mass of quartz.

Production of feldspar has fallen greatly since 1948 when nearly 55,000 tons were produced. In 1955 about 18,000 tons were produced in Quebec, about 1,000 tons in Ontario. Most of the feldspar is used by glass, pottery, and enamel manufacturers.

Nepheline Syenite

A string of nepheline syenite bodies extends from Sebastopol township in Renfrew county, Ontario, westerly almost to the southwest corner of Haliburton county. A small, but important mass also occurs in Methuen and Burleigh townships, Peterborough county. These bodies are developed close to contacts between granite and crystalline limestones, and have been regarded as differentiates of the granite. However, detailed studies, undertaken in connection with the mining, strongly indicate that they are due to the granitization of calcareous Grenville sedimentary rocks. The nepheline-rich parts are essentially parallel with the enclosing gneisses, show banding (bedding?) parallel with and continuous with that of the gneisses, and grade into the gneisses.

The Canadian output to the end of 1955 came from deposits of American Nepheline Limited in the Peterborough area, Ontario; the output for 1955 being 146,068 tons. In this area a body of syenite forms a pear-shaped mass about 5 miles long with a maximum width of 1½ miles. Nepheline ore is known in four parts of the mass for a total reserve of about 5 million tons. The mineral is mined mainly for use in the glass and ceramic trades as a substitute for feldspar because this nepheline rock averages 24 per cent alumina compared with 17 to 20 per cent for feldspar.

Another company, International Minerals and Chemical Corporation (Canada) Limited, with deposits of nepheline in the Peterborough area, came into production in 1956.

Corundum

Corundum occurs as a constituent of the nepheline syenite group of rocks described in the preceding section. The corundum occurs chiefly as a component of reddish alkali syenites, and of pegmatitic facies of these syenites occurring in dykes up to 18 feet wide. The corundum-bearing phases are found and have been exploited chiefly in Raglan and Carlow townships, Ontario. In places corundum forms as much as 10 per cent of the rock mass, though the average content of the rock milled was between 5 and 6 per cent.

Mining of corundum began about 1900, and production reached a maximum in 1906. Between 1900 and 1921, 19,524 tons of the mineral were shipped. No commercial shipments have been made since 1946 when treatment of old tailings at the Craigmont property, Renfrew county, Ontario, was completed. During the two years of operation about 2,600 tons of concentrate were shipped to the United States.

Silica

Considerable quantities of silica are mined from the Canadian Shield. Much the greater part is not from Precambrian rocks, but is impure, siliceous sand and gravel used as flux for the smelters at Sudbury and Flin Flon. In addition, these smelters commonly buy low-grade siliceous copper or gold ores where these are conveniently available, using them primarily as flux with the metal content as a valuable by-product. Thus the Mond Nickel Company at Sudbury for years mined the siliceous copper ores at Bruce Mines; Noranda Mine Limited utilized the siliceous gold ores of Powell-Rouyn Gold Mines.

Many of the pegmatite dykes mined for feldspar contain segregated masses of almost pure quartz, and though much of this has been discarded as waste, some has been sold to smelters or manufacturers of ferrosilicon.

The upper third of the Lorrain formation, the upper part of the Cobalt series, is a very pure quartzite, and has a wide distribution throughout northern Ontario. It is mined near Sault Ste. Marie for the manufacture of silica brick, and near Killarney, Ontario, for the manufacture of ferrosilicon. Over 1,500,000 tons of quartz were mined in Ontario in 1955.

Talc

All the talc produced from the Shield has been from deposits near Madoc, Ontario. The only important producers have been the adjacent Conley and Henderson mines, operated since 1937 by Canada Talc Industries Limited. This deposit was discovered in 1900, but for some years was operated only 2 months in the year and shipped its products to the United States. In 1907, however, a grinding mill was erected, and operation has since been almost continuous. Well over 500,000 tons were produced to the end of 1955. The body is a very high-grade, white, foliated talc forming a nearly vertical tabular mass 25 to 75 feet wide and at least 1,100 feet long. It lies between beds of dolomitic limestone, into which it grades sharply at the edges. Within the talc body can be seen traces of bedding planes of the original dolomitic limestone from which the talc is derived. It is probable that the action of solutions from a nearby granite led to the formation of the talc, and that an intermediate stage in the alteration was the conversion of the limestone to tremolite.

Other properties in the neighbourhood have produced some talc from time to time, but this in general has been of a lower grade.

Barite

No barite is mined from the Canadian Shield but there are a number of important occurrences. It occurs in veins of Palæozoic age, but cutting Precambrian rocks, in southeastern Ontario and southwestern Quebec. In northern Ontario veins of Precambrian age also carry barite, some in widths as much as 15 feet. In the Port Arthur district barite is an important constituent of some of the silver-bearing veins in the Proterozoic rocks.

Celestite

Celestite, like barite, occurs in eastern Ontario and adjacent parts of Quebec in veins of Palæozoic age, though many of these veins are found in Precambrian rocks. Much of it was thrown on the waste dumps in the mining of the veins for fluorite near Madoc, Ontario. A deposit in Bagot township, Renfrew county, Ontario, was mined to a small extent in 1920-21, and an attempt to re-open it was made in 1941. The celestite contains much barite, however, and on that account was not usable.

Fluorite

Fluorite is the most valuable constituent of the group of veins mentioned in the two preceding sections. These veins, of Palæozoic age, are all found in eastern Ontario and adjacent parts of Quebec close to the Palæozoic-Precambrian boundary and in rocks of both groups. The principal minerals are fluorite, barite, and calcite, with smaller amounts of celestite and minor quantities of quartz, chalcopyrite, pyrite, and other minerals. The proportions of the principal minerals vary widely from one vein to another, and even in different parts of the same vein. Those that carry fluorite in commercial quantities are found near Madoc, Ontario, and to a smaller extent in Cardiff township, Haliburton county, Ontario.

The veins near Madoc occur in two groups, the Moira Lake and the Lee-Miller. Those of the Moira Lake group centre around a northwesterly trending fault fissure that has been traced more than 5 miles. Most of them lie in this fault fissure, but some are in parallel subsidiary fractures. The Lee-Miller group lies a mile or two west of the Moira Lake group, and forms a string of deposits trending northwest, but somewhat more northerly than the Moira Lake group. Their linear arrangement suggests that they lie on a fault line.

The vein materials are concentrated along the fractures in lenses from a few feet to 200 feet long, and from 2 to 17 feet wide. The fluorite is partly massive and partly in crystals in numerous vuggy openings.

Production from these veins has been mainly a wartime effort. From 1906 to 1920 nearly 20,000 tons of fluorite were mined, but from 1920 to 1940 there was little or no production. In 1940-42 some of the old mines were re-opened with the assistance of the Federal Government, and from 1940-45, inclusive, 38,671 tons of fluorspar were recovered. A few hundred tons of fluorite have been shipped annually in recent years from veins in the Madoc area.

Graphite

Flakes of graphite form a common constituent of the crystalline limestones of the Grenville series. In places these rocks have been acted on by silica-bearing solutions, presumably derived from granites or other intrusions, and are converted to a varying extent to silicate minerals such as feldspar, diopside, scapolite, and mica. In places these silicated bodies also carry important amounts of graphite and some pyrite and quartz. These minerals appear to have been among the last to form, as they cut through and seemingly replace the silicates. In addition to this relationship, there appears also to have been a structural control, because the graphite bodies are much wider and richer at the crests of sharp folds than farther out along the limbs.

The most important graphite deposit was the Black Donald mine, about 25 miles southwest of Renfrew, Ontario. This body was discovered about 1889, and was in operation, with some interruptions, from 1895 to 1954. The deposit is a bed-like mass 10 to 30 feet thick that has been sharply folded into an asymmetric syncline plunging northeast at an angle of about 20 degrees. Available data seem to suggest that, at the northeast end of the workings, the north limb of the syncline rolls over into an anticline. The grade of the ore was unusually high. Much of the ore mined in the earlier days was 70 to 85 per cent graphite, and it has been estimated that the body as a whole averaged 55 to 65 per cent, although the last two years of salvage operation produced only about 15 per cent graphite. In the ten years from 1944 to 1953 about 23,000 tons of graphite were produced.

Elsewhere in the Grenville series other deposits of graphite have been discovered, but none has provided commercial production, except during war years.

Garnet

Garnetiferous schists and gneisses are strikingly developed in various parts of the Shield, especially in the Grenville-Hastings area of eastern Ontario and adjoining parts of Quebec. Very little garnet is mined however: in 1942 only 17 tons were mined, all from the River Valley property of the Canada Garnet Company about 40 miles northwest of North Bay; in 1944 only 3 tons were mined. The Canada Garnet Company also carries on intermittent operations near Labelle, Quebec. The reason for the small production is that Canadian garnet does not meet the rather exacting specifications demanded for industrial use.

Kyanite

Kyanite is a metamorphic mineral and is fairly common as an accessory in highly metamorphosed gneisses in many parts of Canada. Extensive occurrences were found in the Mattawa district, Ontario, in 1951. Shortly after, occurrences were reported near Sudbury, in Labrador, and in the Northwest Territories. At Mattawa it occurs as a prominent mineral in beds of kyanite gneiss that are interbanded with other Grenville gneisses. Selected areas contain 15 per cent or more of kyanite.

Kaolin

Kaolin is found near St. Remi, Labelle county, Quebec, about 70 miles northwest of Montreal. A north-trending ridge about half a mile wide is composed of nearly vertical beds of Grenville quartzite and garnet gneiss striking north-northwest. The eastern side of the ridge is massive and unbroken, but the west side, throughout a zone approximately 1,000 feet wide, is almost everywhere shattered to a friable condition by faulting. The shattered zone has been traced at least 7,000 feet.

Within this zone are vein-like masses of kaolin ranging in width from a few feet to more than 100 feet. The kaolin bodies contain fragments and disseminated grains of quartzite, amounting roughly to two-thirds of the whole mass. Excellent evidence shows that the kaolin formed by replacement of the shattered quartzite presumably through the agency of ascending hot liquids or vapours. The average kaolin content of the whole shattered zone has been estimated to be about 11 per cent.

Nearly 25,000 tons of this material were mined in 1942, but none has been mined since 1946. A by-product is washed silica sand suitable for glass making.

Several other occurrences of kaolin have been discovered in Quebec. One, near Point Comfort on Thirty-one-mile Lake, carries high-grade china clay. Other deposits, as yet little explored, are near Brebeuf on Lake Labelle, and near Chateau Richer. None of these, however, is of sufficient size and uniformity to warrant development.

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CHAPTER III

THE APPALACHIAN REGION

(L. J. Weeks)

The Appalachian region of Canada comprises Nova Scotia, New Brunswick, Prince Edward Island, the Island of Newfoundland, and that part of the Province of Quebec that lies southeast of the Logan fault, which extends from Lake Champlain northeastward in a gently curving arc to Quebec City and from there down the St. Lawrence River and Gulf.

Physical Features

The Appalachian region of Canada belongs to a larger unit usually referred to as the Appalachian Mountain System which stretches from Alabama in the southwest to Newfoundland in the northeast, a distance of some 2,000 miles. This larger region, marked throughout by Palæozoic deformation, is divisible into a number of physiographic provinces, each showing characteristic surface features. The Appalachian region, or province, of Canada is the northeast continuation of the New England physiographic province, which includes the Green Mountains of Vermont, with elevations up to 4,393 feet (Mount Mansfield), the White Mountains of New Hampshire and Maine culminating in Mount Washington, 6,293 feet high, and the Highlands of Maine.

In Canada, the Appalachian region as a whole is a gently southeastwardly sloping upland dissected by valleys and broken by broader lowland areas developed on belts of weak rocks. Much of the area is bounded by sea-coast which is, for the most part, irregular in outline and penetrated by many deep embayments.

The Appalachian province of Canada is divided into a large number of physiographic units shown in Figure 40 (in pocket) and described below.

Newfoundland

The surface of Newfoundland expresses itself in three highland, three upland, and four lowland areas. The highland areas are known as the Newfoundland Highlands. Two of these are roughly parallel and join each other near Corner Brook. The western of these two parallel belts comprises the Long Range Mountains in the north and the Serpentine Range to the south of Corner Brook. The other part extends from Port aux Basques to Partridge Point and Cape St. Martin, between White Bay and Notre Dame Bay. This highland area includes the Long Range extending northeast from Port aux Basques, the Topsail Hills southeast of Grand Lake, and the Dunamagon Highlands between White Bay and Notre Dame Bay. To the east of the Long Range and separated from it by a narrow valley of soft Carboniferous rocks, lie the Anguille Mountains, the third of the highland areas. The highland areas are as a rule rugged and vary in elevation from 600 to 700 feet to around 2,000 feet with occasional higher peaks. The western edges of many of these highland areas are precipitous, particularly where the Long Range joins the St. Georges Lowland northeast of Port aux Basques. There the boundary between the two physiographic subdivisions is a fault known as the Long Range fault. In a similar manner, the Serpentine Range descends abruptly to the sea. North of Corner Brook, however, the Long Range mountains descend less abruptly on their west side to the Belle Isle coastal belt, an upland area not appreciably lower than the highland. Where stream erosion has occurred, the highland areas are rugged and present steep slopes. In areas where such erosion did not take place, however, the highland surfaces present a gently rolling terrain, which is in effect the surface of an old peneplain believed to have been developed in Cretaceous time and which now slopes gently towards the southeast.

The upland areas, of which there are three, lie at lower elevations than the highland areas, commonly between 600 and 1,000 feet, and either formed through being underlain by soft rocks, as in the upland areas of the west coast, or represent those parts of the peneplain which lie at a lower elevation because of the south-easterly slope of the old surface. The Belle Isle Coastal Belt and the Port au Port Uplands are formed on softer rocks that lie in juxtaposition with the harder elements of the Newfoundland Highlands. The Atlantic Uplands of Newfoundland lie to the east of the highland areas and owe their lower elevations to the south-easterly slope of the old peneplained surface; the rocks underlying them are in most respects as competent as those underlying the highlands. Where stream erosion has occurred, the uplands may be just as rugged and rocky as the highland. Where not so eroded, upland areas present the same rolling terrain that is found on the tops of the highlands.

All the lowland areas of Newfoundland are on rocks which are softer than those of adjacent highland or upland areas. Two of these areas, the St. Georges Lowland and the Grand Lake Lowland, are underlain by soft Carboniferous sedimentary rocks. In these areas elevations seldom exceed about 200 feet. The Central Lowland of Newfoundland, extending southwest from Notre Dame Bay, and the Bay d'Espoir Lowland, extending northeast from Bay d'Espoir, are both underlain by mainly sedimentary rock of middle Palæozoic age, in which few intrusive rocks are found. Where these intrusive rocks do occur they usually cause an eminence which, except for its small size, could be classed as an upland or even a highland. The Central Lowland of Newfoundland varies in elevation up to 500 feet in the vicinity of Red Indian Lake, its most inland extension, but is sharply marked from the surrounding uplands in which intrusive rocks are common. The surface of the land in these lowland areas is gently rolling and largely covered with overburden. The few good farmlands in Newfoundland are mainly located on the lowland areas.

Plate VIII — The flat-topped upland surface of northern Cape Breton Island.

Nova Scotia

The surface of Nova Scotia is expressed in three highlands, three uplands, and three principal and a number of smaller lowlands. As in Newfoundland, the uplands to the southeast are believed to be parts of the same peneplain shown on the highlands in the north of the province.

The highlands include the following: the Cobequid Mountains, extending parallel to Cobequid Bay from Cape Chignecto east to the vicinity of Pictou; the Antigonish Highlands, extending south and west from Cape George; and the Cape Breton Highlands, which include most of the northwestern side of Cape Breton Island and small parts on the southeast side of Bras d'Or Lake. The Cobequid Mountains have a flat, rolling surface, are about 10 miles wide, and reach elevations of about 900 feet. The Antigonish Highlands, being smaller, are more dissected than the Cobequid Mountains, but have the same type of surface and reach about the same elevations. The Cape Breton Highlands are dissected by streams in places but, where free of such erosion, present an almost plateau surface at elevations of 1,300 to 1,500 feet (Plate VIII).

The uplands of Nova Scotia include North Mountain and the Atlantic Uplands of Nova Scotia. North Mountain is a narrow, flat-topped belt, averaging about 550 feet high, that extends along the southeast side of the Bay of Fundy from Cape Blomidon in Minas Basin and southwest for 120 miles to Brier Island. The Atlantic Uplands of Nova Scotia lie along the entire coast from Cape Sable to Louisburg, some 350 miles, and are divided by a small lowland belt on the south side of Bras d'Or Lake into two areas, that on the mainland of Nova Scotia, and that on Cape Breton Island. The surface of this upland reflects the supposedly Cretaceous peneplain and slopes to the southeast from elevations of about 600 feet to sea-level along the Atlantic shore.

The principal lowland areas are: the Cumberland Lowland, lying on the north and east sides of the Cobequid Mountains and extending north to Northumberland Strait; the Minas Lowland, surrounding Minas Basin and Cobequid Bay on all sides; and the Annapolis Valley, which lies between North Mountain and the Atlantic Uplands of Nova Scotia. Smaller lowlands lie in various parts of Cape Breton Island and are formed by the infolding of softer Carboniferous rocks within the harder, more resistant rock of the highlands and uplands.

New Brunswick and Prince Edward Island

New Brunswick falls naturally into one highland, one upland, and one lowland. The highland, called the New Brunswick Highland, is U-shaped, with the west arm covering much of the central part of the province, the curved part occupying the southern part, and the east arm bordering the Bay of Fundy. The southern part of the U is crossed by the Saint John River which divides the highland into three parts, the Mirimachi Highlands northeast of the river, the St. Croix Highlands west of the river, and the Caledonian Highlands east of the river. Inasmuch as the flat surfaces of the highland area represent the supposedly Cretaceous peneplain, the northwest parts are higher than those bordering the Bay of Fundy; for example, the Mirimachi Highlands reach elevations greater than 2,000 feet and the St. Croix and Caledonian Highlands are only about 1,000 feet high.

An upland area, known as the Chaleur Uplands, lies north and west of the New Brunswick Highlands, extends into Gaspé, and is a continuation of the New England Uplands of Maine. The boundary between the New Brunswick Highlands and the Chaleur Uplands is not well defined and the latter are termed upland solely because they are considerably lower than the Notre Dame Mountains of Quebec, which lie to the north.

The New Brunswick Lowland is an area almost enclosed by the U-shaped New Brunswick Highlands. This lowland together with the Prince Edward Island Lowland and the Magdalen Islands comprise a single physiographic unit.

The New Brunswick Highlands are underlain by volcanic, sedimentary, and much igneous rock. Igneous rocks are scarce in the Chaleur Uplands, and this accounts for the lower elevations. The lowland areas are underlain by soft, Carboniferous rocks, through which, particularly in the Magdalen Islands, small bodies of intrusive rocks cause prominent eminences.

Appalachian Quebec

As mentioned before, the Chaleur Uplands are bounded on the north by the Notre Dame Mountains, and these extend from near Thetford Mines to Gaspé Bay, a distance of some 400 miles. The eastern part of the Notre Dame Mountains is commonly known as the Shickshock Mountains, which reach elevations in excess of 4,000 feet. The mountain tops present a flat surface (Plates IX and X) and are part of the general peneplain believed to have been formed in Cretaceous time and which now slopes from the Notre Dame Mountains southeasterly to the Atlantic.

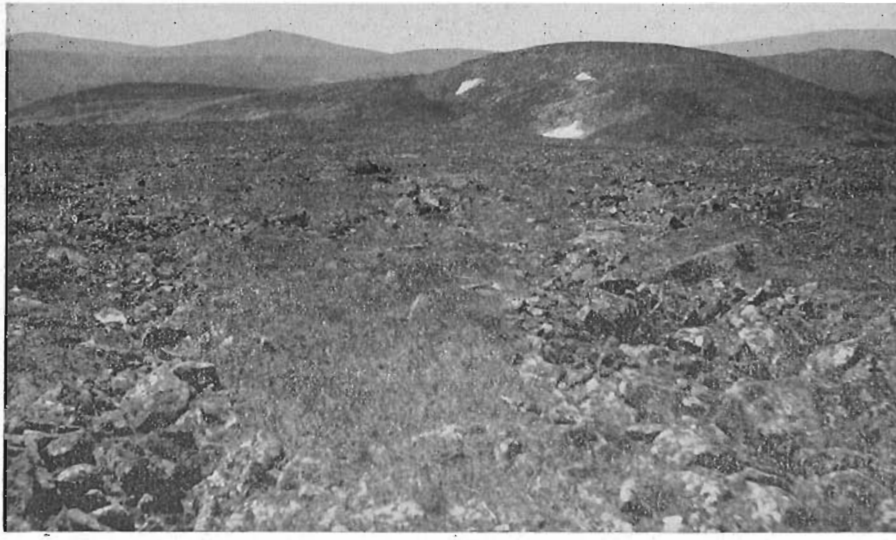


Plate IX

The summit of Tabletop Mountain, central Gaspé, Quebec, showing old peneplain exposed in the Shickshock Mountains.

In the southwestern part of Appalachian Quebec are two other highland areas separated by an upland. The western of these, the Sutton Mountains, is a continuation of the Green Mountains of Vermont, which extend some 40 miles into Canada and have there an elevation of 3,175 feet at their highest point. Some 40 miles east of the Sutton Mountains, the Megantic Hills lie astride the International border and are part of the larger White Mountain subdivision of the New England States. The Sutton Mountains and the Megantic Hills are highest in the south and blend with the Eastern Quebec Uplands to the northeast. This upland area, which has an elevation of 900 to 1,000 feet between the Sutton Mountains and the

Plate X

Uplifted peneplain, Gaspé Peninsula, from south of Restigouche River.

Megantic Hills, decreases gradually in elevation to the northwest and can be considered to be terminated at the Logan fault.

Geological Investigations

The first geological work to be carried out under government auspices in the Island of Newfoundland was performed by J. B. Jukes, M.A., of St. John's College, Cambridge, during the years 1839-40. Jukes' work was a preliminary reconnaissance, chiefly around the coast, and served to call attention to the coal resources of the west coast. In 1864 Alexander Murray began his geological investigations on the island, at first under the direction of Sir William Logan, his former chief on the Geological Survey of Canada. This work instituted the first serious attempt at a systematic and detailed geological survey of the country. In 1869 Murray engaged as his assistant James P. Howley and together they examined much of the country until 1883 from which date Howley continued the work independently until 1909. The first geological map of the island was issued by Howley in 1905, but much of the interior remained unexamined geologically and the map was highly generalized. Between 1926 and 1930, the position of government geologist of Newfoundland was held by H. S. Baker, B.Sc., former government geologist of the Falkland Islands, who, in addition to examining numerous mineral prospects on the island, made detailed studies of the St. Georges coalfield and Precambrian rocks of the Avalon Peninsula.

After a lapse of several years the Geological Survey of Newfoundland was reinstituted by the Commission of Government in 1933, with A. K. Snelgrove as government geologist and supervisor. Snelgrove was succeeded by C. K. Howse who directed the Geological Survey of Newfoundland until confederation with Canada in 1949. This was a period of considerable activity and as many as ten parties were working in different parts of the island each season. Maps produced during this time bear such names as G. R. Heyl, J. R. Cooper, G. H. Espenshade, F. C. Foley, A. O. Hayes, H. Johnson, F. Betz, A. de P. Watson, H. J. Maclean, R. E. van Alstine, E. R. Rose, and T. N. Walthier. In 1949, after confederation with Canada, the Geological Survey of Canada commenced a program of mapping on the island, on scales of 1 mile to 1 inch and of 4 miles to 1 inch. Maps published by the Geological Survey include such authors as A. M. Christie, D. M. Baird, E. R. Rose, J. Kalliokoski, J. J. Hayes, R. D. Hutchinson, W. D. McCartney, D. A. Bradley, and J. R. Cooper.

Geological investigation began in Nova Scotia as early as 1827 when Frances Alger, a mineralogist from Massachusetts, studied the iron ores of Annapolis county and made notes on various mineral and rock occurrences of the Bay of Fundy region. Alger continued work in association with Charles T. Jackson, who later became State Geologist of Maine, New Hampshire, and Rhode Island, and in 1829 the two published an account of their more extended explorations, accompanied by a geological map of the province. The first Nova Scotian to undertake serious geological research was Abraham Gesner, a physician from Parrsboro, who became increasingly interested in rocks and minerals, and in 1836 he published a book on the geology and mineralogy of the province. Two years later he was appointed Provincial Geologist of the neighbouring province of New Brunswick. In 1845 J. W. (later Sir William) Dawson published the first of his many works on the geology of his native province. Dawson, who from 1855 to 1895 was principal and professor of natural history at McGill University, is best known for his *Acadian Geology* which was published in four editions. Another important pioneer geologist was the Reverend David Honeyman who first published in 1859.

Since confederation in 1867 the Geological Survey of Canada has carried out investigations in Nova Scotia. Of the earlier Survey workers the best known names are those of Hugh Fletcher and E. R. Faribault. The former is best known for his work on Cape Breton Island and in the Carboniferous areas of the Nova Scotian mainland. Faribault devoted himself almost entirely to the study of the Gold-bearing (Meguma) series. Later detailed studies of local areas were made by W. A. Bell, M. Y. Williams, F. H. McLearn, G. W. H. Norman, J. T. Wilson, L. J. Weeks, and others. In particular, Bell's studies of the Carboniferous of Nova Scotia have furnished a new conception of the complicated history of that period. Much information has also been contributed by provincial and other workers. The physiographic history of the province has been interpreted by R. A. Daly and J. W. Goldthwait.

Geological investigation began in New Brunswick with the appointment of Gesner as Provincial Geologist. His five annual reports, 1839 to 1843, cover much of the province. In 1844 Gesner returned to his native province and the task of carrying on geological investigation in New Brunswick fell to James Robb who in 1849 was appointed first professor of chemistry and natural history in King's College, Fredericton. His successor, L. W. Bailey, ably continued the work from 1863 to 1904. About 1860 two residents of Saint John, George F. Matthew and C. F. Hartt, became interested in the geology of that city, particularly in the beds known as the Fern Ledges. Hartt later carried out geological explorations in Brazil and became the head of the Geological Commission of that country. Matthew continued to make the study of New Brunswick geology his chief life interest and for years was associated with Bailey in geological investigation and mapping. He published numerous accounts of his findings.

After confederation in 1867 the Geological Survey of Canada commenced systematic mapping in the province. For years Bailey and Matthew were employed by the Survey during the summer months, and other work was carried out by permanent members of the Survey staff, such as R. W. Ells and Wm. McInnes. The bedrock geology of the entire province was mapped on a scale of 1 inch to 4 miles, and much of the surface geology was covered on the same scale by Robert Chalmers. More recent systematic mapping of the province, on the scale of 1 inch to 1 mile, has resulted in the detailed investigation of many key areas. Among those responsible for this work may be mentioned G. A. Young, W. J. Wright, W. S. Dyer, A. O. Hayes, G. W. H. Norman, J. S. Stewart, F. J. Alcock, G. S. MacKenzie, J. E. Muller, R. Skinner, and F. D. Anderson. Other important items of research include John M. Clarke's work on the early Devonian faunas of Dalhousie; Marie C. Stopes' report on the flora of the Little River group, and B. F. Howell's account of the Cambrian of Saint John.

In 1827 Dr. J. T. Bigsby published a paper on the rocks in the vicinity of Quebec and Point Levis, but actual geological mapping in the province of Quebec began with the work of William E. Logan who in 1842 was appointed to undertake a geological survey of Canada. At that time Canada consisted of only two provinces, Lower Canada and Upper Canada, now Quebec and Ontario, respectively. Logan was born at Montreal, but was educated in Scotland and later became keenly interested in geology during work that he carried out in connection with coal and copper mining in Wales. It was with great enthusiasm, therefore, that he returned to his native country where a virgin field for geological research awaited him. The organization he founded and which he directed for twenty-six years has continued to the present and has been responsible for the greater part of the geological exploration and mapping carried out in Canada.

Logan's first chosen field of operations was Gaspé Peninsula. In 1843 he mapped a part of its coast and, in the following year, continued this work and, in addition, made a section across the peninsula. Under him and his successor, Alfred R. C. Selwyn, the task of working out the succession and complicated structure of the entire Appalachian belt of the province made great progress. The finding of copper ore, asbestos, and chromite in southern Quebec, and later of zinc- and lead-bearing veins in central Gaspé gave an impetus to detailed studies. The work of J. A. Dresser, B. R. MacKay, H. C. Cooke, T. H. Clark, and others in south-eastern Quebec, and that of F. J. Alcock in Gaspé Peninsula, for the Geological Survey of Canada, together with the investigations of I. W. Jones and H. W. McGerrigle of the Department of Mines of the province of Quebec, have done much to increase the information available concerning this belt. Outside workers also made important contributions; the studies of John M. Clarke on the early Devonian strata of eastern Gaspé and those of Charles Schuchert and S. A. Northrup on the Silurian rocks of Port Daniel and Black Cape deserve special mention.

Geology

The Appalachian region of Canada is underlain chiefly by Palæozoic rocks, although both older and younger formations are present. The region underwent extensive deformation twice during the Palæozoic. The first, the Taconic orogeny, took place at the close of the Ordovician, and the second, the Acadian orogeny, in Devonian time; both of these disturbances developed structures that in the main trend northeasterly. The great Appalachian revolution at the close of the Palæozoic, which folded and faulted the strata to the south thereby producing the Appalachian Mountains, had only local effects in this northern region, and these effects are most strongly shown in Newfoundland and eastern Nova Scotia. The generalized table (Table VII, in pocket) shows the geological succession in various parts of the Appalachian region.

Archæan (?)

The Appalachian region contains several groups of rocks whose ages are known definitely to be Precambrian. Such are the crystalline rocks of the Long Range Mountains and gneisses of the peninsula between White and Notre Dame Bays in Newfoundland, the George River group of Nova Scotia, and the Green Head group of New Brunswick. These rocks are separated from the lowermost Palæozoic strata by a considerable period of time, during which many other groups of rocks were deposited, and are generally considered to be Archæan in age.

Inasmuch, however, as there are no rocks of known Archæan age with which to compare these formations, and as no geophysical dating has been completed for any of them, the possibility must exist that they are Proterozoic. Granitic intrusions cut these rocks in many places, and some of these bodies may also be of Archæan age but others have been dated by geophysical means and found to be Palæozoic.

White Bay, Fleur de Lys, and Mings Bight Groups

These names have been applied in different localities to what is essentially a single group of schist, limestone, marble, gneiss, and quartzite on the peninsula between White and Notre Dame Bays in Newfoundland. The Fleur de Lys group (also called Rattling Brook) has been subdivided into six formational units which cannot, however, be traced into adjacent areas and need not be listed here. These rocks are highly metamorphosed and are separated by a great unconformity from overlying, much less metamorphosed, Ordovician rocks. As these rocks are believed to have been under erosion in Cambrian time, their Precambrian age is undisputed; their Archæan age is assumed, because they are unlike any part of great thicknesses of Proterozoic rocks that immediately precede the Cambrian elsewhere in Newfoundland.

Long Range Mountains

Forming the core of the Long Range Mountains from Bay of Islands to the northern tip of the Island of Newfoundland, is a group of gneiss, schist, marble, slate, and amphibolite which is similar in most respects to the crystalline rocks of the White Bay-Notre Dame Bay peninsula. These rocks are separated by a great unconformity from overlying conglomerate of the Lower Cambrian Labrador group and their Precambrian age is established. They are considered to be Archæan for the same reasons as are those rocks in the White Bay-Notre Dame Bay peninsula.

Forming the rugged front and flat tops of the Long Range from a point east of Corner Brook southwest to Port aux Basques, are rocks that are similar in many respects to those just described, but lacking, so far as is known, in calcareous beds. These are not overlain by Cambrian or Ordovician rocks and their age is not established, but the possibility of their being Archæan must not be overlooked.

George River Group

The George River group, present in many of the upland areas of Cape Breton Island, is in part similar to the crystalline rocks of Newfoundland, but as a rule

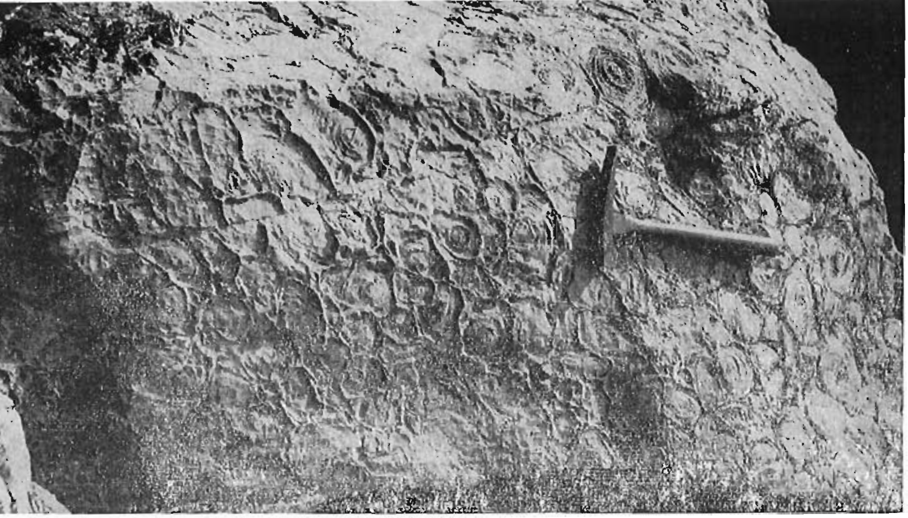


Plate XI

Archæozoon acadiense, possible primitive fossil from the Green Head group, Saint John region.

has a much larger proportion of calcareous beds. It was first named and described in the Boisdale-George River area southeast of St. Andrew Channel. The rocks comprise crystalline limestone and dolomitic limestone; quartzite and hornfelsic shale, commonly schistose; greywacke; mica schist, in places garnetiferous; dark hornblendic gneisses; and, locally, dark green volcanic types. These rocks are intruded by dykes and by deep-seated granitic masses ranging in composition from granite to diorite. Locally an intimate intermixture of the altered sedimentary and the intrusive rocks gives rise to gneisses.

The age of the George River is clearly Precambrian. Fossiliferous, Middle Cambrian, Bourinot beds overlie the George River in the Boisdale Hills, are separated from them by an unconformity of considerable magnitude, and are much less metamorphosed. They are assumed to be Archæan for the same reasons advanced for similar strata in Newfoundland.

Green Head Group

The Green Head group in southern New Brunswick takes its name from Green Head in the peninsula immediately west of Saint John where it is typically developed. It forms a belt extending from Musquash Harbour on the west to a point near Smithtown on Hammond River to the northeast, a distance of about 40 miles; small inliers, exposed in regions of younger rocks, occur as far west as Dipper Harbour and to the northeast on Clover Hill, 10 miles southwest of Sussex. The group also forms part of Grand Manan Island and of some of the smaller islands to the east.

The rocks consist of crystalline limestone and dolomite, quartzite, argillite, graphitic slate, and mica schist and gneiss. They are cut by numerous small basic dykes and by deep-seated intrusions of granite, diorite, and gabbro. The carbonate rocks vary from bluish and grey to white. In places the weathered surface shows concretionary markings, described under the name *Archæozoon acadiense,* which may represent algal growths (Plate XI).

At the Mount Pleasant Avenue entrance to Rockwood Park at Saint John, limestone beds of the Green Head group are overlain with an angular unconformity by Proterozoic volcanic rocks of the Coldbrook group. The Green Head is regarded as probably Archæan.

Proterozoic (?)

Harbour Main Group

Rocks of the Harbour Main group are present over large parts of the Avalon Peninsula in eastern Newfoundland. Similar rocks of uncertain age, but believed to be correlatives of the Harbour Main, occur extensively on the Burin Peninsula and have been observed on the west side of Bonavista Bay. The latter are known as the Love Cove group and exhibit only faulted relationships with adjacent formations.

The rocks are mainly volcanic in origin, but include some sedimentary types which are most plentiful in the middle of the group. Rhyolite, andesite, breccia, and tuff comprise the bulk of the volcanic rocks, with minor basalt, latite, and their pyroclastic equivalents. The sedimentary beds are mainly red, poorly sorted sandstone, slate, boulder to pebble conglomerate, and some green greywacke and slate.

The bottom of the Harbour Main is nowhere exposed. The group is unconformably overlain by basal beds of the Proterozoic Conception group. On the south side of Fortune Bay, near Terrenceville, rocks correlated tentatively with the Harbour Main are overthrust onto Upper Devonian conglomerates. The Precambrian age of the Harbour Main is undisputed. Whether it is Archæan or Proterozoic is at present in doubt.

Proterozoic

Rocks of known Proterozoic (Late Precambrian) age are exposed in Newfoundland, Cape Breton Island, and southwestern New Brunswick. The Meguma series of southern Nova Scotia, originally referred to the early Palæozoic and then placed in the Proterozoic, is now believed more properly to belong in the Ordovician system. The Macquereau group of southeastern Gaspé is pre-Middle Ordovician and probably Precambrian. Certain schist groups forming the cores of anticlines in the Eastern Townships of Quebec are likewise of doubtful age. In this section will be treated only those formational units known to be Proterozoic in age.

Conception and Connecting Point Groups

The Conception group occurs in three main east of north trending belts on the Avalon Peninsula of eastern Newfoundland, and are separated from one another by younger or by older rocks. The Connecting Point group, which probably is a correlative of the Conception, extends in a belt trending east of north from the head of Trinity Bay to the head of Bonavista Bay.

The Conception group, as the term is used today, includes the earlier-named, 'Conception slate' and the overlying 'Torbay slate', both of which are terms proposed by Walcott in 1899. Separation into two constituent formations can be made only in the eastern Avalon Peninsula. Here the 'Conception slate' includes fine-grained, green to greenish grey siltstone, argillite, sandstone, and slate, with some conglomerate, tuff, and agglomerate. Some of the beds display the characteristics of graded greywackes. The 'Torbay slat' includes flinty green sandstone, green, red, and reddish brown siltstone, sandstone, argillite, and slate, with some quartzite, quartzitic sandstone, and minor conglomerate. In general there is more argillaceous material in the 'Torbay slate' than in the 'Conception slate'. In the western parts of the Avalon Peninsula the Conception group is mainly grey and green beds with more greywacke than farther east.

The Connecting Point group, named for a headland in Chandler Reach of Bonavista Bay, was first described in a locality some 60 miles from known Conception beds. Since then work in the intervening territory leaves little doubt of the continuity of one unit throughout. Lithologically, the Connecting Point is much the same as the Conception and includes grey, green or black, fine-grained, sedimentary rocks, mainly shale, slate, argillite, and greywacke with minor conglomerate. These rocks, in common with the Conception, weather with a whitish kaolinic coating in strong contrast to the dark colour of the fresh rock.

The Conception and Connecting Point groups are succeeded disconformably or unconformably by late Proterozoic rocks known as the Cabot, Hodgewater, and Musgravetown groups, and are generally ascribed to the early or middle Proterozoic.

Cabot, Hodgewater, and Musgravetown Groups

Overlying the Conception and Connecting Point are three named groups of rocks that, although differing considerably in lithology, may represent a single, continuous rock unit. The term Cabot is applied to post-Conception rocks on the eastern seaboard of the Avalon Peninsula; the term Hodgewater, to beds overlying the Conception group on the west side of Conception and St. Mary's Bays; and the term Musgravetown, to strata succeeding the Connecting Point on the west side of Trinity and Bonavista Bays.

The Cabot group is subdivided into the St. John's, Signal Hill, and Blackhead formations. Rocks of the group range from black slate of the St. John's formation through medium- to fine-grained, red and green sandstone of the Signal Hill and Blackhead formations. Although these two formations are similar to each other, there are extensive beds of conglomerate only in the Signal Hill and of argillite only in the Blackhead. The conglomerate pebbles were derived from the weathering of Harbour Main and Conception rocks.

The Hodgewater group has been subdivided in the Harbour Grace and Holyrood areas into four formations, the Carbonear, Hallstown, Whiteway, and Snows Pond. The Carbonear, comprising about 3,500 feet of dark grey to black slate grading upward into grey siltstone, may probably be correlated with the St.

John's formation of the Cabot group. The Hallstown, of massive greenish grey arkose, siltstone, and slate, is probably equivalent to the lower part of the Signal Hill. The Whiteway and Snows Pond formations, of siltstone, slate, and arkose, with some greywacke, cannot be directly correlated with any part of the Cabot. The conglomerates of the Cabot are lacking in the Hodgewater and some greywacke is present in the latter that has not been observed in the Cabot.

The Musgravetown group, separated by Trinity Bay from the Hodgewater group, has not been subdivided, except that a volcanic member has been named the Bull Arm felsite. Rock types present include conglomerate, volcanic rocks that range from rhyolite to basalt with acid types predominating, and sandstone and greywacke. Upper parts of the group are strikingly similar to the Signal Hill formation. Greywackes appear to be more common than in the Hodgewater, particularly in that part of the formation above the Bull Arm felsite.

The Cabot, Hodgewater, and Musgravetown all rest on the Conception or Connecting Point, the Cabot with a disconformity, the Hodgewater with no apparent disconformity, and the Musgravetown with an angular unconformity. The Hodgewater and Musgravetown are overlain with little if any disconformity by the latest Proterozoic Random formation of white quartzite described in the following section, and all three groups, whether entirely equivalent or not, are undoubtedly Proterozoic in age and probably are late Proterozoic.

At the western end of Burin Peninsula are beds of conglomerate, sandstone, and shale, with minor limestone. They are separated from Lower Cambrian strata by white quartzites believed to be Random, and are probably equivalent to one or all of these three groups.

Random Formation

Beds of the Random formation overlie with no apparent disconformity those of the Hodgewater group, the Musgravetown group, and those rocks at the western end of the Burin Peninsula which are believed to be equivalent to them. The Random is overlain by Lower Cambrian fossiliferous beds with a slight disconformity on the eastern side of Trinity Bay, and with no apparent disconformity in those areas where it is underlain by Musgravetown rocks.

The Random is a white indurated quartzite, laced with quartz veins, and its distinctive characteristics make it invaluable as a horizon marker. It is estimated to be 250 feet thick on the east side of Trinity Bay, is about 340 feet thick on the north shore of Smith Sound, and varies between 300 and 400 feet thick at the west end of Burin Peninsula.

The Random formation has at various times been included either in the Lower Cambrian or in the uppermost Proterozoic. It is now generally believed that the latter age is the true one.

Fourchu Group

The name Fourchu is applied to a group of rocks exposed in three anticlines in Cape Breton Island; one extends along the southeast coast of the Island from

Scatari Island to the village of St. Esprit; one extends along the southeast side of Bras d'Or Lake from a point near Marion Bridge on Mira River to Sporting Mountain some 35 miles to the southwest; the third, and smallest, occurs discontinuously on the southeast side of the Boisdale Hills for a distance of about 12 miles. The Fourchu group is mainly of volcanic origin; volcanic breccia, tuff, and lavas comprise the bulk of the rocks, with minor shale and sandstone, the latter possibly a greywacke. In places, particularly on the southeast side of Bras d'Or Lake, the rocks have been altered to schist. The volcanic rocks are commonly acidic and weather white, but are dark green on fresh surfaces.

The bottom of the Fourchu is not exposed. It is succeeded conformably by the Morrison River formation which in turn underlies, with little or no disconformity, Lower Cambrian strata. The group is clearly Precambrian in age and probably is late Proterozoic.

Morrison River Formation

The Morrison River formation extends in a narrow band from a point about 8 miles north of Louisburg, in Cape Breton Island, southwest to the village of St. Esprit, a distance of about 35 miles. Small exposures also occur west of Mira River.

Three distinct members comprise the formation, the lowermost sandstone and conglomerate member invariably being many times the thickness of the other two combined. Above the coarse clastic member is a shale band that varies in thickness from 15 feet at the southwest end of the formation to an estimated 50 feet at the northeast; this is succeeded by a characteristic white quartzite, with quartz veinlets, that varies in thickness from 6 feet at the southwest to an estimated 150 feet at the northeast. The entire formation thickens to the northeast from 130 feet to about 2,200 feet.

The Morrison River lies conformably below the upper subzone of the Lower Cambrian *Olenellus* zone. It is non-fossiliferous and may represent the lower subzone of the *Olenellus* zone, or may lie just beneath the Cambrian. Both views have been put forward and the matter is discussed further in a following section dealing with correlation.

Coldbrook Group

The Coldbrook group, made up almost wholly of volcanic rocks, receives its name from Coldbrook, a settlement 3 miles northeast of Saint John, N.B. It underlies early Palæozoic strata that comprise beds ranging in age from Lower Cambrian to Lower Ordovician. In places Lower Cambrian basal conglomerate rests on the Coldbrook, and most of the boulders and pebbles of the conglomerate consist of Coldbrook rocks. The age of the Coldbrook is therefore Precambrian, and, as members of the group unconformably overlie beds of the Green Head group, the Coldbrook is regarded as Proterozoic in age.

Rocks correlated with the Coldbrook underlie most of the Caledonian Mountain belt in southeastern New Brunswick. They consist of volcanic flows, tuff, and breccia of both acid and basic composition, with some associated tuffaceous sediment, phyllite, and conglomerate. Many of the rocks are massive; others are sheared and in places schistose. The whole assemblage is cut by stock-like masses of granite and diorite and by basic dykes.

Southwest of Saint John a belt of rocks, running from Beaver Harbour northeast to Lock Alva, consists of rhyolite and basic volcanic rocks intruded by granite and by felsite dykes. This assemblage has been correlated with the Coldbrook, but may be older, possibly Green Head.

Correlation of Proterozoic Formations of Newfoundland and Nova Scotia

There are many similarities between the late Proterozoic rocks of Cape Breton and those of Newfoundland—so many, in fact, that pure coincidence may be discounted. They are lithologically much alike and were formed under similar conditions of sedimentation, but they differ in thickness.

The Morrison River is a formation of coarse clastic material, much of which was derived from the weathering of rocks similar to the Conception group, and overlies the Fourchu group of predominantly acid volcanic rocks. The upper part of the Musgravetown group in Newfoundland is likewise a succession of predominantly coarse clastic beds derived from the weathering of Conception rocks, and overlies the Bull Arm felsite, a predominantly acid volcanic sequence. At the top of the Morrison River is a white quartzite indistinguishable in many places from the Random quartzite that overlies the Musgravetown and the Hodgewater in Newfoundland.

A tentative correlation of these and other Precambrian formations of the Appalachian region is shown in Figure 41. The Coldbrook group is correlated with the Fourchu and with the Bull Arm. This succession attains its maximum thickness in the west and pinches out in the extreme east. The Random is shown as equivalent to the white quartzite member of the Morrison River, and the latter, as a whole, to the Musgravetown, Hodgewater, and Cabot, which are thicker in the east and pinch out in the extreme west.

Cambrian

Cambrian rocks are found in eastern Newfoundland, in western Newfoundland, in Cape Breton Island, in southwestern New Brunswick, in Gaspé, and in the Eastern Townships of Quebec. In Cambrian time apparently two basins of deposition, separated by a land area, covered the Appalachian region of Canada. Cambrian sediments laid down in the two basins differ in lithology, in succession of beds, and in their faunas. The beds of eastern Newfoundland, Cape Breton Island, and southwestern New Brunswick were deposited in the southeastern basin, or the Acadian geosyncline; those of western Newfoundland, Gaspé, and the Eastern Townships of Quebec were deposited in the northwestern basin, or the St. Lawrence geosyncline. The land area between them is known as the New Brunswick geanticline and its presence is verified by the unconformity of Ordovician beds on Precambrian gneiss and schist on the peninsula between White and

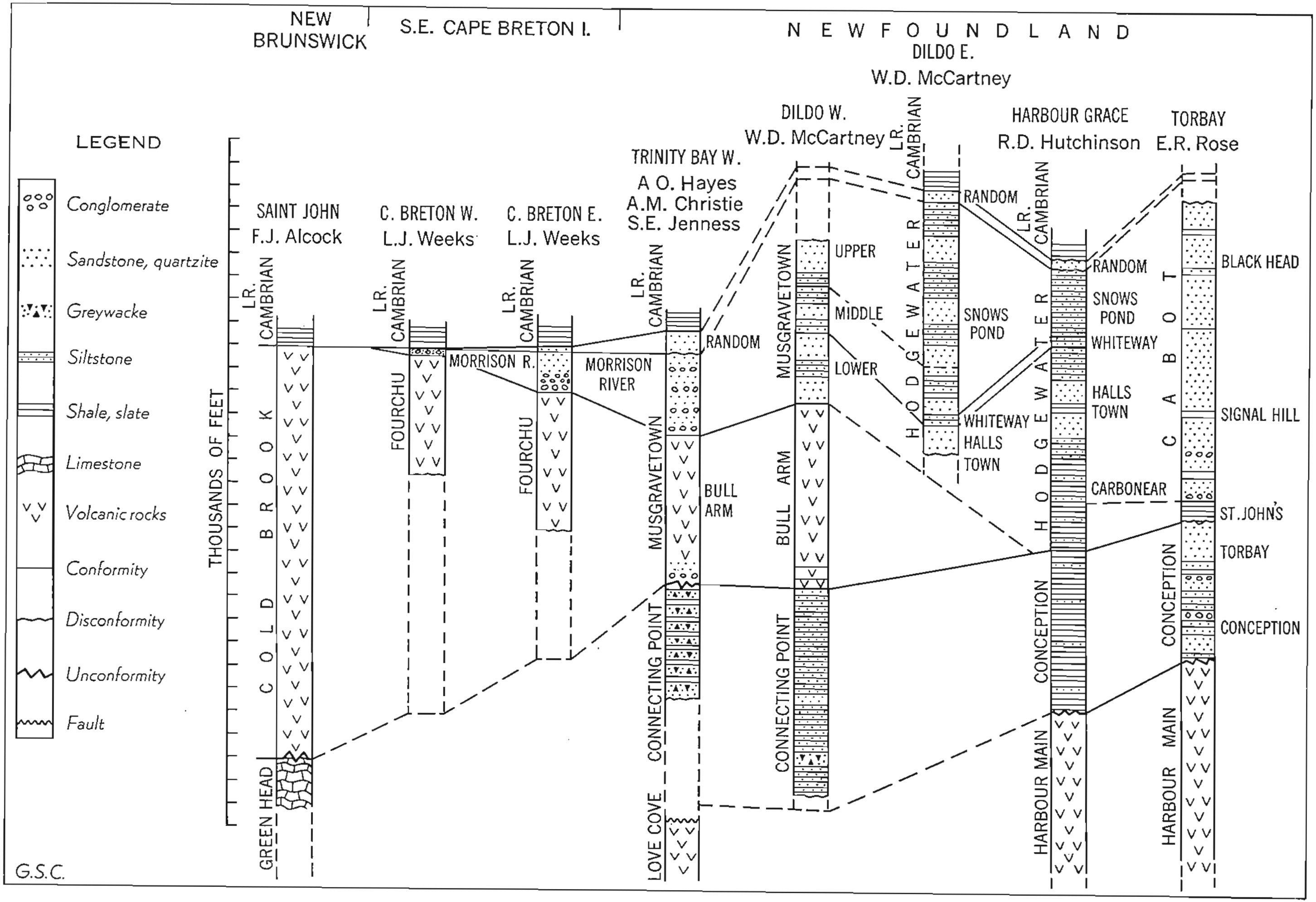


FIGURE 41. Tentative correlation of Precambrian formations in eastern Newfoundland and in the Maritime Provinces. (Groups are shown vertically on the left of each section, formations horizontally on the right. The lithology within a formation is indicated diagrammatically.)

Table VIII

Relationships of Cambrian Formations in New Brunswick, Cape Breton, and Newfoundland, and Faunal Zones of North America and Europe

	Faunal Zones of North America		West Newfoundland	North Shore of Fortune Bay	Avalon Peninsula	Cape Breton West	Cape Breton East	Saint John N.B.	Faunal Zones of Europe
UPPER CAMBRIAN	*Saukia*			Salmonier Cove	Elliot Cove	MacNeil			*Peltura*
	Ptychaspis-Prosaukia						MacNeil		*Leptoplastus*
	Conaspis							Narrows	*Parabolina*
	Elvinia							Boulders in Black Shale Brook	*Olenus*
	Aphelaspis							Agnostus Cove	*Agnostus pisiformis*
	Crepicephalus		Boulders in Cow Head breccia						
	Cedaria		Petit Jardin						
MIDDLE CAMBRIAN	Unnamed zone						Maclean Brook		*Lejopyge*; *P. forchhammeri*
	Bathyurus		March Point	Young's Cove	volcanics Manuels		Trout Brook	Hastings Cove	*Paradoxides davidis*
	Bolaspis		Treytown Pond			MacMullin		Porter Road	*Paradoxides hicksi*
	Glossopleura		Cloud Rapids		Chamberlains Brook	Bourinot		Fossil Brook	*Paradoxides bennetti*
	Albertella								
	Poliella-Plagiura								
LOWER CAMBRIAN	*Olenellus* Zone	Upper Subzone (*Olenellus* and other trilobites)	Hawke Bay; Forteau	Not certainly	Brigus		Canoe Brook; MacCodrum	Hanford Brook; Glen Falls	*Protolenus*
		Lower Subzone (*Olenellus* only)	Devils Cove; Bradore / Cloud Mountain	known	Smith Point; Bonavista		Morrison River	Ratcliff Brook	*Callavia*; *Coleoloides*

Plate XII

Syncline in Middle and Upper Cambrian slate and siltstone, east shore of Trinity Bay, Nfld.

Notre Dame Bays, Newfoundland, about half-way between the two basins. Most information on the Appalachian Cambrian comes from New Brunswick, Nova Scotia, and Newfoundland; Table VIII shows the Cambrian sections and faunal zones at key localities in those provinces.

Eastern Newfoundland

Cambrian rocks occur in both southeastern and northwestern Newfoundland, but are not known in the central part of the island (Table VII, in pocket). In southeastern Newfoundland they outcrop in numerous widely scattered areas, chiefly on the Avalon and Burin Peninsulas, and also on the north shore of Fortune Bay, the west shore of Trinity Bay, and the south shore of Bonavista Bay. They commonly occur as synclinal or down-faulted remnants (Plate XII), surrounded by large areas of Precambrian rocks, upon which they rest with more or less pronounced unconformity. The sequence is fairly complete, with Lower, Middle, and Upper Cambrian rocks all represented. They comprise a miogeosynclinal sequence of dominantly shaly rocks, with minor limestone, siltstone, sandstone, and locally, a basal conglomerate. A thin sequence of basic lavas, with associated tuffs, occurs in the Middle Cambrian around the head of Trinity Bay. The Cambrian rocks vary up to almost 3,000 feet in total thickness. They contain a succession of dominantly trilobitic faunas, which are strikingly similar to those around Saint John, N.B., in Cape Breton Island, and in the Cambrian of western Europe. On the other hand, these faunas appear to be quite unrelated to those in northwestern Newfoundland and elsewhere in the interior of North America, where the succession also is markedly different. In most outcrop areas the Cambrian beds are the youngest consolidated rocks; locally, however, they are overlain without angular discordance by Lower Ordovician (Tremadocian) beds; and on the north shore of Fortune Bay, they are overlain with angular unconformity by conglomerate of probable Devonian age.

Western Newfoundland

Cambrian rocks are known in northwestern Newfoundland at several localities on the west coast or just inland, from Port au Port Peninsula northward to the Strait of Belle Isle. They have also been reported from Canada Bay and the west shore of White Bay, on the eastern side of the northern peninsula. They rest with angular unconformity on the Precambrian. The exact sequence is not well known, but is evidently much less complete than in southeastern Newfoundland. The Lower Cambrian is fairly widespread in the area. These rocks have been recognized along the west coast as far south as Bonne Bay; they are also represented in Canada and White Bays. The Middle Cambrian has been reported only from Canada Bay and from the Port au Port Peninsula, and palæontological evidence suggests that most of the Middle Cambrian sequence is lacking. The Upper Cambrian is likewise poorly represented; early Upper Cambrian rocks occur on the Port au Port Peninsula and in Bonne Bay, but the rest of that series is apparently lacking. The Cambrian rocks vary in thickness up to about 2,500 feet and are mostly thin-bedded shale and limestone, with a basal sandstone formation. They contain a succession of trilobite faunas which are closely related to those found in Cambrian rocks in the interior of North America and around the Pacific Ocean, and which are strikingly different from the other Cambrian faunas of the Atlantic region. The Cambrian rocks are overlain, apparently disconformably but without angular discordance, by early Ordovician rocks.

Nova Scotia

In Cape Breton Island, Cambrian rocks outcrop in the opposed valleys of Indian and MacLeod Brooks in the Boisdale Hills; on the western flanks of the Coxheath Hills, north of East Bay; and in a broad belt surrounding the upper Mira River and extending southwest to the village of L'Ardoise. The succession in the first two mentioned localities differs somewhat from that in the third and both are referred to in Table VIII, as, respectively, Cape Breton west and Cape Breton east.

In Cape Breton west, the lowermost Cambrian beds, those of the Middle Cambrian Bourinot group, rest on rocks of the Precambrian George River group and consist of volcanic rocks, quartzite, shale, and minor greywacke. The Bourinot group is succeeded by the Middle Cambrian MacMullin formation of quartzite and shale with minor conglomerate, and this formation, in turn, is succeeded disconformably by the Upper Cambrian MacNeil formation of black shale and limestone.

In the Cape Breton east area, the Morrison River formation, already described, is succeeded conformably by strata of the Lower Cambrian MacCodrum and Canoe Brook formations of green shale and red to green claystone. No fossils have been found indicating the lowermost Cambrian faunal zone (Lower *Olenellus* subzone) and some doubt must exist as to whether the Morrison River formation is the uppermost Proterozoic succession, as suggested in Figure 41, or whether it is the lowermost Cambrian. East of Mira River, Canoe Brook beds are succeeded by grey and black shales of the Middle Cambrian Trout Brook formation, which in turn is succeeded by siltstone and shale of the likewise Middle Cambrian MacLean Brook formation. West of Mira River, Canoe Brook beds are succeeded by a non-fossiliferous eugeosynclinal sequence of dominantly greywacke, volcanic tuff, and conglomerate, with minor lava and sandstone, which is correlated with the Bourinot group of the Cape Breton west Cambrian area, and is considered to have been deposited in the same basin but farther removed from the borders. The Trout Brook is likewise considered to be the equivalent of the Bourinot, but farther removed from the borders of the depositional basin. Overlying these Bourinot-equivalent beds west of Mira River are strata of the Middle Cambrian Kelvin Glen group (not shown on Table VIII), of conglomerate, conglomeratic sandstone, shale, and siltstone. Rocks of this group are believed to be equivalent to the MacMullin formation in the Cape Breton west Cambrian area, and to the upper part of the Trout Brook farther east in the Cape Breton east area.

In both east and west Cambrian areas, Middle Cambrian beds are succeeded by the Upper Cambrian MacNeil formation of black shale and limestone.

Southwestern New Brunswick

At Saint John, southwestern New Brunswick, and in several small areas immediately to the northeast, are beds of a lower Palæozoic sequence which range in age from Lower Cambrian to Lower Ordovician. The succession of the Cambrian beds is shown on Table VIII. This table does not show series names, which are, however, included in the following descriptions.

The Ratcliffe Brook formation consists of sandstone and conglomerate and is as much as 200 feet thick. An interesting exposure can be seen in a rock-cut on the river road between Fredericton and Saint John about due west of the middle of Catons Island. There coarse conglomeratic beds rest on and contain large boulders of granitic rocks; the granitic basement is, therefore, Precambrian. The Glen Falls formation is a white sandstone or quartzite, locally 30 feet thick. It is succeeded by the Hanford Brook formation consisting of about 75 feet of hard grey sandstone carrying *Beyrichona,* grading upward into the *Protolenus* shale, about 10 feet thick. The *Protolenus* fauna is marine and permits correlation with Lower Cambrian strata elsewhere in the North Atlantic region, particularly in southeastern Newfoundland and northwestern Europe.

The Middle Cambrian Loch Lomond series is characterized by the presence of the trilobite genus *Paradoxides.* Its lowest formation, the Fossil Brook, has for its basal member a hard, siliceous, black limestone about 5 feet thick. This is overlain by grey shale. The succeeding Porter Road formation has two shale members, a lower one about 35 feet thick, consisting of dark, hard, heavy bedded fissile shale abundantly fossiliferous; and an upper member of thinly bedded, gritty, finely fissile, black shale from 25 to 75 feet thick. The Hastings Cove formation consists mainly of thinly bedded black shale with a few lenses and nodules of dark limestone.

The Upper Cambrian and Lower Ordovician beds are divided into two series, the Johannian and the Bretonian. The Johannian includes the Agnostus Cove formation, consisting of black and grey shale and micaceous grey sandstone with lenses and concretions of buff weathering limestone, and the Black Shale Brook formation made up of black shale and thin-bedded limestone. The basal formation of the Bretonian, the Narrows, is undoubtedly Upper Cambrian, and consists of black shale with limestone concretions and thin interbeds of sandstone. Fossils are rare, but enough are present to prove that two well-known northwestern European faunas are represented. The succeeding Navy Island formation consists mainly of thinly bedded black shale carrying *Dictyonema flabelliforme* and is Upper Cambrian or Lower Ordovician. The youngest formation of the series consists of thinly bedded, black, graptolitic shale and outcrops at the upper end of Saint John Harbour, north of Suspension Bridge. The beds contain *Tetragraptus* and *Didymograptus* and are clearly Lower Ordovician.

Quebec

In southeastern Quebec most of the Cambrian rocks are metamorphosed to a greater or lesser degree, and some are highly schistose. In Sutton Mountains the Sutton schists include rocks of Lower Cambrian age, some of probable Upper Cambrian age, and some that may possibly be Ordovician. In the Oak Hill fault slice near the Vermont border a series of Lower Cambrian strata, 3,000 to 4,000 feet thick, consists of slate, quartzite, dolomite, greywacke, and sericite schist, and rests on a basement of chlorite schist, known as the Tibbett Hill, which is probably Precambrian. Farther south in Vermont formations of Lower, Middle, and Upper Cambrian age are present. In Quebec, evidently, uplift occurred at the close of the Lower Cambrian and was followed by long continued erosion during most of Middle Cambrian time. Deposition was resumed in late Middle Cambrian and again in Upper Cambrian time. At the close of the latter epoch, or a little later, there was uplift once more in northwestern Vermont and adjacent parts of Quebec, accompanied by tilting of the strata and perhaps some folding.

Rocks of the Thetford-Beauceville region, which are presumably Cambrian, underlie strata that are considered to be Ordovician and have been described under the name Caldwell group. This group comprises a succession of nearly pure quartzite, slate, and lava. The lower, highly metamorphosed parts consist largely of crumpled, silvery, sericite schists, and are called the Bennett schists. These also include chlorite schist, phyllite, dark mica schist, and minor amounts of limestone and dolomite. The contact between the schists and the overlying quartzites is a transition zone in which bands of massive pure quartzite alternate with layers of fissile schist. The lava members are fine grained, dark green, basaltic types, commonly showing pillow structure. They lie for the most part either at or near the top of the quartzite. Associated with them are tuff, flow breccia, and agglomerate. Northeast of Thetford the quartzites and volcanic rocks are overlain conformably by a rather thick zone of grey and green slate, all part of the Caldwell group.

At Levis, opposite Quebec City, conglomerates of Lower Ordovician age contain boulders in which Lower Cambrian fossils are found. The Lower Cambrian fauna *Botsfordia, Austinvillia,* and *Bonnia,* has been found in the upper part of a 2,000-foot black shale sequence at Chaudiere Falls. These black shales, the Charny formation, were formerly regarded as part of the "Sillery" formation, as described in the section on the Lower Ordovician. Middle and Upper Cambrian strata appear to be absent in this area and the Charny formation is overlain by the Ville Guay conglomerate, which represents the initial sedimentation of Canadian age. Similar stratigraphic relationships appear to exist along the St. Lawrence Valley and into Vermont.

In Gaspé Peninsula some beds of hard grey limestone, separated by layers of ribboned shaly limestone, outcrop for about a mile on Murphy Creek, about 6 miles northwest of Percé. The strata are known as the Murphy Creek formation and have yielded a late Cambrian fauna including a graptolite, a sponge, a linguloid brachiopod, and some twenty species of trilobites, many of which are small forms.

Cambrian or Earlier

Mention has already been made of the Caldwell group whose Cambrian age is not firmly established. Other rocks occur, principally the Macquereau group, regarding whose age there is only negative evidence.

The Macquereau group extends along the Chaleur Bay coast of Gaspé Peninsula for 15 miles in the Newport-Chandler region. It consists of sedimentary and volcanic rocks. The former include arkosic quartzite, slate, red and green shales, quartzose argillite, and quartzite conglomerate containing pebbles of quartz, granite, granite-gneiss, greenstone, and schist. Locally, beds of carbonate rock are also present. The volcanic members are subordinate and consist of dense, dark green to black varieties. The beds are intruded, on the upper waters of North Port Daniel River, by masses of serpentinized peridotite which locally show a border zone of amphibolite. Dykes of granite cut the Macquereau strata, the serpentine, and the amphibolite. The group is overlain unconformably by strata of Middle Ordovician age and, elsewhere, by Silurian beds. In this region no intrusive rocks were found cutting either of these overlying series. The age of the Macquereau is, therefore, certainly pre-Middle Ordovician and probably Precambrian.

Ordovician

Ordovician rocks are found in Newfoundland in three main belts. In eastern Newfoundland, specifically in that part of the island southeast of an overthrust fault that extends northeasterly along the south side of Fortune Bay and has not been traced inland, such rocks are limited to the Lower Ordovician which rests on Upper Cambrian beds. They are mainly miogeosynclinal in character; that is, they are composed of normal sedimentary successions that are lacking in volcanic rocks or greywackes. In central Newfoundland, between the Fortune Bay fault and the Long Range fault which parallels St. Georges Bay and extends probably to White Bay, Ordovician rocks extend in age from the latest Lower Ordovician to late Middle Ordovician. They rest on Precambrian gneiss and schist, except in the extreme southeast where they rest on Middle and Upper Cambrian beds. They are eugeosynclinal in character, that is, they were laid down under conditions of tectonic activity in which great thicknesses of volcanic rocks were interbedded with greywackes and conglomerates. West of the Long Range fault, Lower and Middle Ordovician strata lie on Upper Cambrian successions, and, in early Middle Ordovician time, the character of the beds changed from miogeosynclinal to eugeosynclinal.

In New Brunswick rocks of Middle Ordovician age occur near Bathurst and are the host rocks of large base metal deposits. Stretching to the southwest from there is a wide belt of sedimentary rocks with, in places, associated volcanic material. Much of this complex may be of Ordovician age. In the southwestern part of the province, the Charlotte group is probably Ordovician. It is made up of two divisions, one known as the Dark Argillite, the other as the Pale Argillite. The former lies unconformably below strata of Silurian age and is composed of argillite, slate, quartzite, mica schist, gneiss, and minor amounts of volcanic rocks. It is intruded by masses of granite and gabbro. The Pale Argillite consists of argillite, sandstone, arkose, slate, and mica schist. In the St. Stephen area the beds are apparently conformable with, and grade into those of the Dark Argillite. On early maps the Pale Argillite was classed as Devonian on account of the reported finding on Cox Brook, a tributary of Magaguadavic River, of a *Lepidodendron*-like form. Later work has failed to reveal any fossils whatever in these rocks.

In Nova Scotia Ordovician rocks are known in the Pictou-Antigonish upland. They comprise metamorphosed, sedimentary, volcanic, and intrusive varieties. The Browns Mountain group, consisting of argillite, slate, and greywacke, is regarded, on the evidence of a few fossil linguloids, as of Lower Ordovician age. Locally associated with the sedimentary rocks are interbedded volcanic flows and tuffs, and cutting them is a stock of granite and dykes and stocks of rhyolite and quartz porphyry. In the Arisaig region, strata of this group are overlain by coarse conglomerate and grit of the Malignant Cove formation, which is believed to be of Middle Ordovician age. In the Pictou region purplish red arkosic conglomerate, purplish grey arkosic grit, and purplish red argillite form what is known as the Stewart Brook formation, which is probably correlative with the Malignant Cove.

In the Appalachian belt of Quebec, Lower, Middle, and Upper Ordovician strata are known, but in many places fossils are not diagnostic of epochs. In the long belt from the Vermont border to the east end of Gaspé Peninsula the deformed Ordovician strata were formerly referred to as the 'Quebec group'. This term had first been applied by Logan in 1860 to beds at Quebec City that had been thrust against and over younger strata of Middle and Upper Ordovician age. Later the term became a convenient one to include all those early rocks whose exact age was unkown.

Lower Ordovician

The oldest Lower Ordovician beds of Newfoundland, the Clarenville formation of fissile sandstone and sandy shale, are exposed in a basin extending northeasterly from Clarenville, west of Random Island, and lie in the previously mentioned eastern belt of Newfoundland. The strata rest apparently conformably on the Upper Cambrian Elliott Cove group. No consolidated rocks succeed them.

On Bell, Little Bell, and Kellys Islands in Conception Bay, the Lower Ordovician Bell Island and Wabana groups occupy a stratigraphic position above the Clarenville and the latter is assumed to lie beneath the waters of Conception Bay. The Bell Island group comprises thick formations of grey, grey-brown, brownish, and greenish sandstone, grey brown, and black shale, and micaceous sandy shale, together with beds of red oolitic hematite and ferruginous sandstone and shale. The group is about 4,000 feet thick. Rocks of the Wabana group, which overlie the Bell Island beds with a minor disconformity, contain oolitic hematite beds and other rocks much like those of the Bell Island, but black shale is more abundant and graptolites make their appearance in the fauna.

In western Newfoundland the lowermost Lower Ordovician beds are those of the Green Point 'series' of limestone, shale, and sandstone, which are found at a number of scattered localities from a point just north of Bonne Bay, south to Port au Port Peninsula. The beds are poorly exposed inasmuch as they are an incompetent succession and commonly had been involved in overthrusting. The Lower Ordovician St. Georges 'series' of limestone and dolomite is well exposed in the country between Bonne Bay and Port au Port Peninsula and has been correlated with rocks of a similar character around the northern end of the peninsula of the Long Range Mountains and as far south as Canada Bay on the east side. Beds of the St. George are not known to be in contact with those of the Green Point.

In eastern Quebec Logan divided his Quebec group at Quebec City into two formations, the 'Sillery' and the Levis. The former is the older and consists of red and green shale and lenticular masses of red and green sandstone; fossils are few, and what there are—chiefly *Phyllograptus* and other graptolites—indicate a close similarity with the fauna of the Levis. In the vicinity of Quebec City the original 'Sillery' is now divided into the Cambrian Charny and the Ordovician Lauzon formations. The Levis consists chiefly of hard grey, green, and red shale, thin-bedded hard blue and grey limestone, and thick and thin beds of limestone conglomerate. It carries an early Ordovician graptolite fauna. The pebbles in the conglomerate members include some composed of 'Sillery' rocks showing that the formation is younger than the 'Sillery'. There are also pebbles carrying Lower Cambrian fossils, others with Upper Cambrian fossils, and still others with Lower Ordovician Beekmantown fossils. The rocks have been folded, overturned, and thrust against younger Ordovician rocks to the north.

These rocks extend in a southwest direction from Levis and may continue to the Vermont border. They also continue to the northeast along the St. Lawrence River, forming a belt that may be followed to the eastern end of Gaspé Peninsula. In the Thetford-Beauceville region rocks that may correspond to them, in part at least, have been described under the name Beauceville group. In the Thetford area this group consists of black slate with a basal conglomerate and some interbedded impure quartzite or greywacke, overlying unconformably the Cambrian, Caldwell group. In the Beauceville region tuffs and flows are interbedded with the sedimentary rocks and in places the succession is so altered that it is difficult to distinguish the volcanic from the sedimentary members. Still farther southwest, near Phillipsburg in the Lake Champlain region, a thick series of fossiliferous Beekmantown strata consisting of shale and limestone overlies Upper Cambrian beds and is followed by strata of Chazy or Middle Ordovician age.

Northeast of Levis rocks consisting of red, green, grey, and black slate, quartzite, and conglomerate form a belt in places 20 miles wide. These beds have been correlated with the 'Sillery', but both younger and older strata have been included. An interesting feature in these rocks is the presence of belts of limestone conglomerate. These occur at various horizons in both the 'Sillery' and the Levis and form layers from about a foot to more than 100 feet thick. The pebbles and boulders consist of grey limestone and weigh from less than an ounce to many tons. Similar limestone conglomerates are found in Newfoundland and Vermont. They have been interpreted as the result of local slipping and breaking up of limestone along the sea bottom by earthquakes in a zone where faulting was prevalent. Another feature of the 'Sillery' is the occurrence of belts of quartzite, locally called the Kamouraska formation. These belts are lenticular, but extensive, and their thickness varies greatly.

Middle Ordovician

In Newfoundland beds of Middle Ordovician age are found only in the central and western parts of the province. The sequences in the two areas have little in common.

Surrounding Notre Dame Bay and extending southwest to within 35 miles of the south coast, north of La Poile, is a triangular belt of rocks which comprises eugeosynclinal sequences of predominantly Middle Ordovician strata. The Badger Bay and Exploits groups, described, respectively, in the western and in the central parts of Notre Dame Bay, probably each incorporate most of the stratigraphic extent of these Middle Ordovician beds, and without much doubt are correlatives of each other. Probably each of the Snooks Arm, Baie Verte, Nippers Harbour, Lush's Bight, and Cutwell groups is equivalent to a part of the Badger Bay and Exploits groups. Large areas of similar rocks around Red Indian Lake have not as yet been given formational names. These groups comprise lavas and pyroclastic rocks, greywacke, conglomerate, shale, and minor limestone. Where the lowermost members are exposed, they are seen to rest on Precambrian schist and gneiss. Fossils are rare in assemblages of this nature except in interbedded shale and limestone, or more commonly as exotic pebbles in greywacke. Fossils found in the Snooks Arm group near its basal contact with Precambrian gneisses place those particular beds at the top of the Lower Ordovician. As the age of the basal beds is nowhere else established, and as all other fossil collections establish a Middle Ordovician age, the groups are considered to extend from the top of the Lower Ordovician throughout most of the Middle Ordovician.

Volcanic rocks of the Cape St. John group, at the eastern end of the peninsula between White and Notre Dame Bays and originally believed to be Middle Ordovician, are now thought, because of their similarity to volcanic rocks in the Devonian Springdale group, to be of probable Devonian age.

The Baie d'Espoir group, which extends northeasterly some 50 miles from Bay d'Espoir to the headwaters of Terra Nova River, was formerly believed to be Precambrian in age. In 1951 early Middle Ordovician fossils were found in rocks of this group near Mount Sylvester. The beds apparently comprise a eugeosynclinal sequence of greywacke, sandstone, and argillite, metamorphosed to various degrees.

On the north side of Fortune Bay and on the Hermitage Peninsula are Middle Ordovician beds of lava, pyroclastic rock, greywacke, sandstone, shale, and conglomerate, similar in many respects to those found around Notre Dame Bay, but which are in contact with Middle and Upper Cambrian beds.

In western Newfoundland the lowermost Middle Ordovician strata, the Table Head 'series', comprise a miogeosynclinal sequence of limestone, dolomite, and some shale. Table Head beds overlie those of the St. Georges 'series' at and south of Hawke Bay on the west coast, and near Corner Brook are overlain by Middle Ordovician Humber Arm rocks. The Long Point group, exposed only on the long needle-like spur of Port au Port Peninsula, is believed to be Middle Ordovician in age, but exposures are isolated by a fault from other Ordovician beds. The rocks include calcareous sandstone and shale, and limestone.

The Middle Ordovician Humber Arm group overlies the Table Head group and shows some evidence of being an eugeosynclinal sequence. The rocks include sandstone and shale, volcanic rocks and minor greywacke, the last commonly being coarse but very thin. At the base of the Humber Arm is the unusual Cow Head breccia, a giant conglomerate that carries fragments of Lower Ordovician and Cambrian rocks which may be hundreds of feet in length. It is believed to have been deposited by a process of slumping on a steep submarine slope, and its presence at the base of the Humber Arm is considered as further evidence favouring an eugeosynclinal or tectonic manner of deposition for this group.

At Quebec City, the Quebec City formation (Figure 42) carries Trenton fossils and consists of limestone, shale, and thin belts of limestone conglomerate. The beds have been altered and cleaved; to the south beds of the older Levis formation have been thrust against them, whereas to the north they are in faulted contact with younger beds of Upper Ordovician age. Southwest of Quebec City the Beauceville (Farnham) group may be largely or wholly of Middle Ordovician age, although, as mentioned above, it is possibly Lower Ordovician in the Thetford-Beauceville region. In the Disraeli area the St. Francis group of lava and impure quartzite and greywacke is regarded, on rather meagre fossil evidence, as Middle Ordovician. In the St. Lawrence River region, in Montmagny, L'Islet, and Kamouraska counties, slaty shale, graphitic shale, limestone, sandstone, and limestone conglomerate of the Pohenagamooke formation are regarded as Middle Ordovician. To the east, in the Matane area, similar rocks have basalt flows

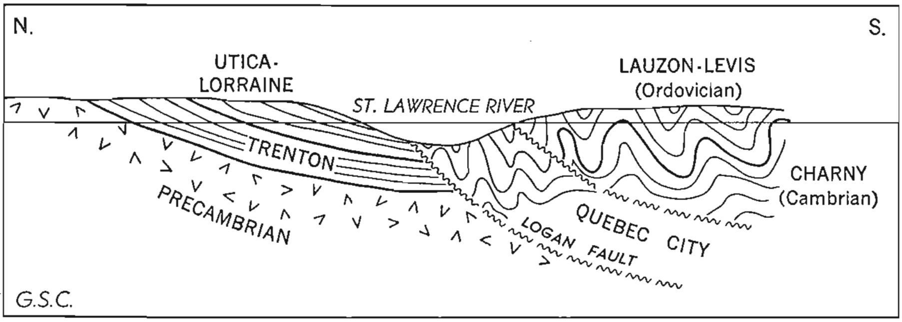


FIGURE 42. Diagrammatic section across the St. Lawrence Valley near Quebec City, looking east.

associated with them. On Lake Matapedia and in the central Shickshock Mountains, the Shickshock formation, consisting of interbedded arkose and volcanic rocks, is probably correlative with these.

In the Port Daniel area, on the Chaleur Bay side of Gaspé Peninsula, dark grey to black shales carrying late Middle Ordovician fossils, chiefly graptolites, have been described under the name Mictaw series. Associated with the shales are limestone beds and conglomerates. The beds rest on Macquereau rocks and, at one place where the contact can be observed, the basal Mictaw beds consist of coarse conglomerate made up largely of Macquereau boulders, but containing also some of quartz, granite, and reddish gneiss. The Mictaw beds are cut by basic intrusive rocks.

On the opposite side of Chaleur Bay, in the northern part of New Brunswick, black slates outcropping on the north bank of Tetagouche River have also yielded a graptolite fauna of Middle Ordovician age. Associated with them are argillite, quartzose sandstone, arkose, quartzite, and conglomerate. There are also associated igneous rocks, dark volcanic flows, and tuffaceous rocks locally altered to schists. Both the sedimentary and the volcanic members have supplied pebbles to the succeeding Silurian rocks in the region.

Upper Ordovician

Upper Ordovician rocks are not known in Newfoundland, Nova Scotia, or southern New Brunswick. In Matapedia and Restigouche Valleys, at the southwest border of Gaspé Peninsula and farther east on the north side of Chaleur Bay, are strata that locally have yielded fossils of Upper Ordovician age. The beds in Matapedia Valley consist of limestone, slate, and quartzite, and are known as the Matapedia group. The limestone is dense, dark grey, and argillaceous, is associated with argillaceous slate, and in many places beds 1 inch to 2 inches thick are separated by argillaceous partings. The argillaceous rocks everywhere show a slaty cleavage which, however, is much better developed in some types than in others. Locally they pass into phyllites with a silky lustre. Bedding planes can be recognized in most places, and the beds have been highly crumpled. Farther east similar rocks on the north side of Chaleur Bay are associated with beds of quartzite, grit, and conglomerate. Tracadigash Mountain, north of Carleton, lies on a broad belt of conglomerate and grit about 2,000 feet thick.

At Percé similar much deformed strata, consisting of thin-bedded limestone and shale with minor amounts of black shale, sandstone, and basal and intraformational conglomerates, have been described under the name White Head formation, whose beds have yielded a considerable fauna of middle or late Richmond age. On Grand River west of Percé grey limestone, shaly limestone, and shale carrying a meagre fauna of late Ordovician age have been termed the Pabos formation. Both of these formations are correlated with the Matapedia.

Ordovician or Earlier

Meguma Series

The Meguma series, also known as the Gold-bearing series, occupies the Southern Upland of Nova Scotia, extending along the Atlantic coast from Canso to Yarmouth, a distance of 275 miles. The series consists of a great thickness of conformable quartzitic greywacke and slate intruded by many large masses of granite and by dykes of diabase. Around the granite bodies, and in places for several miles from the nearest granite outcrop, the sediments are metamorphosed to gneiss and schist. The series was at first considered to be Lower Cambrian in age; then, for many years, a Proterozoic age was ascribed to it; it now appears that the age is probably Ordovician, but at present this cannot be proved. The reasons for considering the age as probably Ordovician follow.

Ordovician fossils have been found in a narrow belt of rocks south of Kentville that have been considered to be Meguma. The continuity of these rocks with known Meguma beds cannot, however, be established because of intervening granite. One reason that a Proterozoic age had been proposed for the Meguma was the supposed similarity to the Conception group in Newfoundland. The similarity is slight, but this might be accounted for by the distance between the two localities. The similarity between the Meguma and the Baie d'Espoir group of southern Newfoundland now known to be Middle Ordovician, is, however, more pronounced. Both the Meguma and the Baie d'Espoir comprise a lower part of predominantly quartzite with minor argillite, phyllite, and slate, and an upper part of predominantly argillaceous rocks with little quartzite. The remarkably complete sections of late Proterozoic rocks on Cape Breton Island, none of which resembles the Meguma, would indicate that it is not late Proterozoic. Finally, if the age were earlier Proterozoic, it would be most unusual if so thick a formation, so magnificently exposed on the mainland of Nova Scotia, did not have a remnant anywhere resting on the Archæan or earliest Proterozoic George River group in Cape Breton Island. The matter, however, cannot be considered settled.

The Meguma series is separable into two conformable divisions, a lower, known as the quartzite or Goldenville formation, and an upper, called the slate or Halifax formation. The former consists chiefly of thick-bedded, compact, greenish and bluish grey greywacke or quartzite, in the main feldspathic and micaceous and commonly containing large cubes of pyrite. Interbedded with the quartzites are

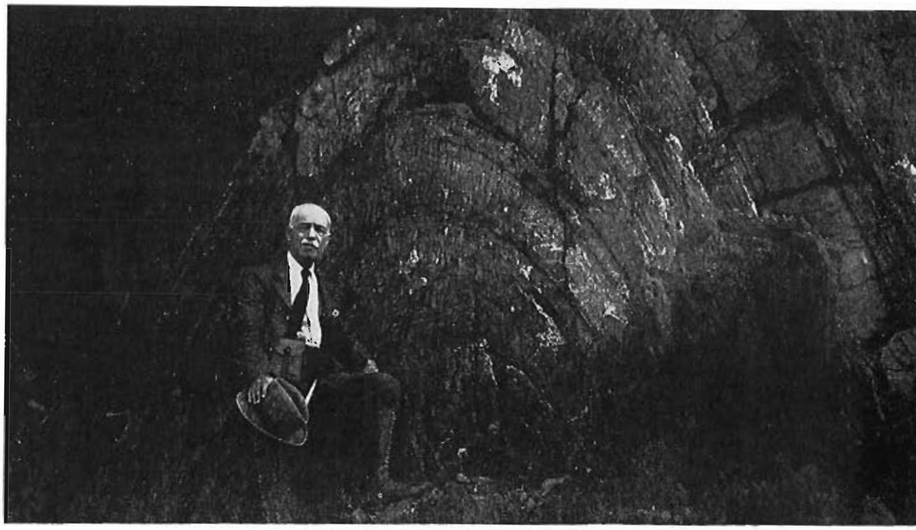


Plate XIII | *Folded slates of the Meguma series.*

layers of argillaceous, siliceous, and micaceous slates. The thickness of the Goldenville formation as measured along Liverpool Bay, Queen's county, exceeds 23,700 feet. The Halifax formation consists chiefly of argillaceous and siliceous slates, mostly dark grey to black, but passing at certain horizons into greenish and bluish grey, talcose argillites or into grey, chloritic, arenaceous beds. The black slates are commonly heavily charged with pyrite. A few beds of siliceous limestone are present near the base of the formation at certain localities east of Halifax. Near the top, are a number of beds of lava and tuff. The thickness of the formation as measured on Black River is 11,700 feet. It is in the beds of the Black River section, occurring south of Kentville and chosen by E. R. Faribault as the most complete of Halifax sections, that Ordovician fossils are found.

The Meguma series has been closely folded into anticlines and synclines whose axes trend east (Plate XIII). In addition, there are cross-folds giving rise to a series of domes. On an average the main folds are about 3 miles apart and the domes along the anticlinal axes are about 10 to 20 miles apart. The strata are traversed by local faults and by longer cross-country faults that may be traced for miles. The granite masses that cut the beds are of Devonian age. The basic dykes and sills may also be Devonian, but their relation to the granite is not definitely known. The beds contain many, mostly narrow, quartz veins, a large number of which carry gold; for this reason the strata are referred to commonly as the Gold-bearing series.

Silurian

Silurian rocks occur in Notre Dame and White Bays in Newfoundland; in Cape Breton Island, in the Antigonish highlands, and near Kentville in Nova Scotia; in north, central, and southwest New Brunswick; and at a number of scattered localities in Quebec from Gaspé to the Eastern Townships.

Newfoundland

Silurian rocks in Newfoundland are known only on the north-central part of the island. The most westerly exposures are those at White Bay; the most easterly, those at Notre Dame Bay and adjacent Sir Charles Hamilton Sound. Little is known about the interior areas where probable extensions of these rocks might occur.

In the White Bay region the Silurian is represented by the Natlins Cove formation. It is exposed as a narrow belt on the west side of the Bay and is generally marginal to an elongate granitic intrusive body. The formation is subdivided into three members: an upper sandstone member, an intermediate volcanic unit (Sops Island volcanic member), and a lower sandstone member. The two sandstone members are similar in lithology and are mainly fine-grained grey sandstone and argillaceous sandstone with some arenaceous conglomerate. A generalized Silurian fauna, *Favosites gothlandicus, F. hisingeri, Clathrodictyon vesiculosum, Heliolites* and ? *Pentamerus,* occurs in the sandstone members. Fossils originally present in the Natlins Cove formation have been largely destroyed by metamorphism. Towards the head of White Bay the formation is made up of thinly bedded grey and greenish grey quartzite with zones of grey slate, silicified limestone, and crystalline limestone, which are cut by dykes of rhyolite and pegmatite. The Sops Island volcanic member is exposed on the east side of Sops Island and in Big Spear Cove. It is composed of dark grey and grey-brown rhyolite flows, grey-green andesites with minor tuffs, and one thin bed of sandstone.

In the Notre Dame Bay area, the Silurian strata are represented by the Goldson and Pike Arm formations. These are well exposed on the northeast shore of New World Island. Similar rocks occur along South Arm and New Bay, 35 miles to the west. The Goldson formation consists of thick-bedded conglomerate containing thin lenses of bluish grey siliceous limestone. This formation is exposed in Goldson Arm and Herring Head, New World Island, and on Martin Eddy Point near the mouth of the Exploits River. The Pike Arm formation is exposed in Goldson and Pike Arms, New World Island. The formation consists of dark grey coralline argillite, black fossiliferous argillite, and barren grey and pink sandstone. The Pike Arm has a fauna of forty-two species, and the Goldson, of fourteen species. These two formations contain a community of species which have the following forms in common: *Clathrodictyon vesiculosum, Favosites gothlandicus, F. hisingeri, Heliolites interstinctus, Atrypa reticularis, Parmorthis elegantula, Rhynchotreta cuneata, Eophacops newfoundlandensis and Encrinurus anticostiensis.* Together the two formations are correlative with the Jupiter River formation of Anticosti Island, the Clemville-Anse Cascon-La Vieille units of the Chaleur Bay sequence, the Ross Brook formation of Arisaig, and the Clinton formation of New York State.

A grey crystalline limestone block containing *Strictlandinia exploitensis* has been reported from a small exposure of flow breccia on Upper Black Island in the Bay of Exploits. The block is a remnant of an otherwise unrepresented Silurian limestone.

In Sir Charles Hamilton Sound, Silurian rocks are exposed along the shores of Gander and Horwood Bays and extend inland to Burnt Lake. The rocks are also exposed on several islands in the sound including Yellow Fox Island, the Indian Islands, and the Dog Bay Islands. All these rocks are termed the Indian Island group and consist of slightly metamorphosed sedimentary rocks, largely phyllitic slate, quartzitic sandstone, calcareous sandstone with thin limestone lenses, and with some conglomerate. The slate has a pearly grey lustre and is crumpled and crenulated. It contains distorted but recognizable specimens of *Pentamerus, Favosites, Heliolites,* and *Clathrodictyon.*

Nova Scotia

The best section of Silurian strata in Nova Scotia is at Arisaig where an almost continuous exposure, about 2½ miles long, of 3,800 feet of sandstone, calcareous sandstone, and shale is known as the Arisaig series. The basal beds rest upon a flow of rhyolite, probably of late Lower Ordovician age; the series is overlain by the Knoydart formation of Lower Devonian age. The Arisaig beds are highly fossiliferous. Sections on the shore and in the stream valleys show the strata to be crumpled, faulted, and in places overturned. The main structure is a syncline broken and faulted along its axis, and complicated by minor folds and faults.

The series is made up of five formations (Table IX). The basal Beechhill, 160 to 300 feet thick, is composed of conglomerate, sandstone, and arenaceous shale. The succeeding Ross Brook formation consists of black and grey shales, 825 feet thick. The McAdam formation, 1,120 feet thick, consists largely of shale with some sandstone, and carries a bed of oolitic hematite 2 feet thick. The Moydart is made up of 380 feet of grey or bluish grey shale and sandstone, and the Stonehouse of 1,275 feet of grey and greenish grey sandstone, red shale and sandstone, and grey and greenish shale and sandstone. Deposition throughout apparently took place at the bottom of a shallow sea under varying conditions of clear and muddy water. The faunas can be correlated better with British than with American sections. Resemblances to the Chaleur Bay faunas of Quebec and northern New Brunswick and to those of Maine and southern New Brunswick are slight.

Southwest of Kentville the New Canaan formation of marine-deposited volcanic breccia, siltstone, slate, and limestone, carries Silurian fossils. The beds are underlain by the unfossiliferous Kentville formation of slate and siltstone and it, in turn, is underlain by the unfossiliferous White Rock formation of quartzite, siltstone, and slate. These three formations are apparently conformable with one another and the lowest one, the White Rock formation, is underlain with apparent conformity by Lower Ordovician beds that, as mentioned previously, are believed to be Meguma. The Lower Ordovician beds were at one time mistakenly thought to be Kentville beds and to contain *Dictyonema websteri* (Dawson) on which the Silurian age was based. This fossil is now believed to be *Dictyonema flabelliforme* (Eichwald), *sensu lato* and to indicate a Lower Ordovician age. No fossils have been found in the re-described Kentville beds.

Silurian fossils have been found in shale and sandy shale in the metamorphic complex of the Cobequid Mountains.

Table IX

Correlation of Silurian Formations

		Ontario, New York	Arisaig, N.S.	Chaleur Bay, Quebec and New Brunswick	Eastport, Maine	Great Britain
Upper Silurian	Cayugan	Manlius Akron Bertie Salina			Eastport Pembroke	
Middle Silurian	Niagaran	Guelph	ARISAIG SERIES Stonehouse	CHALEUR BAY SERIES Indian Point West Point	Edmunds	Ludlow
		Lockport	Moydart McAdam	Bouleaux Gascons La Vieille	Dennys	Wenlock
		Clinton	Ross Brook	Anse Cascon Clemville	Quoddy	
Lower Silurian	Medinan	Medina-Cataract	Beechhill			Llandovery

In southeastern Cape Breton Island beds of the Middle River group, as a result of faulting, underlie several scattered areas. The beds comprise coarse sandstone, arkosic sandstone, conglomeratic sandstone, and conglomerate, and are probably of continental or deltaic origin. The assemblage is non-fossiliferous, but is known to have been laid down after the Taconic orogeny of late Ordovician time and before the intrusion of granites that accompanied the Acadian orogeny in early or middle Devonian time. Its continental character indicates that it most probably followed the slight uplift that occurred in Silurian time and is called the Caledonian uplift; the beds are therefore believed to be of Silurian age.

Quebec

At Port Daniel and Black Cape, on the north side of Chaleur Bay, sections show probably the thickest continuous marine succession of Middle Silurian age in North America and one of the thickest known anywhere. At Black Cape the Chaleur Bay series outcrops almost continuously for about 3 miles along the coast in cliffs ranging from 50 to 80 feet high. The beds occur in regular succession as one limb of a syncline and dip, in general, about 60 degrees south. At the top of the sequence volcanic flows are interbedded with the sediments. At Port Daniel the structure is more complicated but the same faunal and lithological divisions are recognized. The series has been divided into formations shown in Table IX, and their variation in thickness is as follows:

Formation	Port Daniel	Black Cape
	Feet	Feet
Indian Point	456	....
West Point	1,714	543
Bouleaux	888	2,594
Gascons	1,890	3,835
La Vieille	405	1,155
Anse Cascon	332	300
Clemville	824	?
Total	6,509	8,427+ feet of sedimentary rocks; plus 4,626 feet of volcanic rocks; total 13,053+ feet.

The Clemville is nowhere found along the coast in either of the sections, but in the Port Daniel region it is seen inland along Little Port Daniel River and also in the vicinity of Clemville. The beds consist chiefly of shale and sandstone. At Jacquet River, in northern New Brunswick about opposite Black Cape, a coastal section shows a much greater thickness of the Clemville, at least 3,400 feet of sandstone and shale and about 500 feet of volcanic rocks. The fauna of the formation is dominantly a brachiopod assemblage. The Anse Cascon begins with conglomerate and sandstone and these grade up into shale; the shale becomes increasingly calcareous and grades upward, in turn, into hard knobby limestone of the La Vieille formation. The latter contains many fossils, particularly corals; the guide fossil is the large brachiopod *Stricklandinia gaspénsis*. The Gascons formations consist of argillaceous, fine-grained sandstone marked by many cephalopods, by gastropod trails, an abundance of worm-borrows known as *Taonurus,* and locally by the graptolite *Monograptus*. It grades without break from the La Vieille below to the Bouleaux above. The latter, consisting of greenish and reddish, muddy and arenaceous shales, and thin-bedded limestones formed largely of coral reefs and breccias, is, in its turn, transitional into the limestones of the West Point formation. These are mostly pink, thick-bedded limestones containing an abundance of *Crotalocrinus* columnals. In its upper part the formation contains four marine basalt flows interbedded with the sediments. These flows are both porphyritic and amygdaloidal, and have thicknesses of 80, 13, 540, and 3,630 feet. Above the upper thick flow is a zone of interbedded sedimentary material and layers of amygdaloidal andesite porphyry. The Indian Point formation of the Port Daniel area consists of muddy, fine-grained, deep green sandstone weathering purplish red, and interbedded with more or less local lenses of yellowish limestone. Its fauna is marked by a dominance of pelecypods.

Silurian beds also occur in the central Gaspé basin north of the Port Daniel-Black Cape area. There the beds occur along the northern margin of the basin and are also exposed along fold axes within the basin in the Mount Alexander, Saint John River, and Gastonquay-Clapperton belt. Dark grey shale, exposed on the south limb of the eastern part of the Saint John River anticline, contains a graptolite fauna which provides evidence for correlation with zones 22 and 23 of the British graptolite succession.

In the Lake Matapedia region of western Gaspé the Silurian beds are divided in ascending order into three formations, the Val Brillant, the Sayabec, and the St. Leon. The shelly fauna of these beds permits correlation with formations of the Chaleur Bay region. The Val Brillant belongs to the La Vieille, and the Sayabec apparently does also; fossils from the St. Leon suggest a correlation with the Gascons and Bouleaux. In the Lake Temiscouata region, the Mount Wissick beds have been assigned to the Middle Silurian. Still farther southwest Silurian strata are known at Knowlton Landing on Lake Memphremagog, just north of the Vermont border.

New Brunswick

In northern New Brunswick rocks of the Chaleur Bay series outcrop in several areas along the Chaleur Bay coast, as at Jacquet River, Black Point, Blacklands Point, Petit Rocher, and Belledune. The best section is at Jacquet River where formations from the Clemville to the Gascons are exposed. The section consists of a major syncline with the western limb much better exposed than the other; it is disturbed by faults and local folds and is concealed locally by flat-lying red clastic beds of Carboniferous age. The most striking feature of the section is the great thickness of the Clemville strata.

In southern New Brunswick Silurian rocks are known at a number of localities. In the St. George, Passamaquoddy Bay, and Oak Bay regions on the Bay of Fundy sedimentary rocks interbedded with great quantities of volcanic rocks, chiefly rhyolite and andesite, have been described under the name Mascarene group. At Oak Bay the base of the group is a coarse conglomerate known as the Oak Bay formation, which rests unconformably on the Dark Argillite of the Charlotte group. Other beds include shale, limestone, sandstone, and dense, hard, fine-grained argillitic quartzite locally containing ash material. The volcanic material includes flows, tuff, breccia, and associated intrusive rocks. The belt is a continuation of one extending from the Eastport area of Maine where sedimentary and volcanic rocks have been divided into a number of formations known from their fossil content to be of Middle and Upper Silurian age. Silurian strata are also known in an area to the northwest of Long Beach on Saint John River. On Kingston Peninsula, on the opposite side of Long Beach, a narrow fringe of Silurian sediments is separated by a fault from older volcanic rocks that underlie the greater part of the peninsula. Silurian strata are found farther north in the Woodstock-Edmundston district, and there they are ferruginous and manganiferous. Such beds are extensions of the manganiferous purple and red slates and banded manganiferous hematite deposits of Maine.

Silurian or Devonian

Rencontre Group

About 150 miles east of La Poile Bay, on the south coast of Newfoundland, are extensive exposures of beds of the Rencontre group of coarse clastic sedimentary rocks that were deposited under continental conditions. The group is unfossiliferous and rests with an angular unconformity on Ordovician beds. Relationships to granitic rocks are not known. The beds may be considered to be younger than the Taconic orogeny, which would make them Silurian or younger. For the present these beds may be considered to be Silurian or Devonian.

Devonian

Rocks of Lower Devonian age occur in central Newfoundland, in western Newfoundland, in Quebec, in New Brunswick, and in Nova Scotia. Sedimentation at this time was accompanied by widespread volcanism, and at the close of the epoch extensive deformation took place, known as the Acadian orogeny, which was accompanied by the intrusion of granite masses. The emplacement of granitic intrusions probably began before the orogeny commenced, at least in some places, and may have continued in other places to the close of the Devonian period, or even into early Carboniferous time. In Middle Devonian time great thicknesses of clastic sediments accumulated in Gaspé Peninsula, and in Upper Devonian time sedimentation progressed locally in the Chaleur Bay and Bay of Fundy regions.

Lower Devonian

The best Lower Devonian sections of the Appalachian region of Canada are at the eastern end of Gaspé Peninsula, Quebec, and at Dalhousie, N.B. The former, which are well exposed on the Forillon Peninsula on the northeast side of the mouth of Gaspé Bay, form a thick, orderly succession of southwesterly dipping limestones (Plate XIV) and limy shales.

Plate XIV — *Lower Devonian limestone near Shiphead, Cape Gaspé, Quebec.*

The Gaspé limestone group of Forillon Peninsula has been divided into three formations, the St. Alban, the Cape Bon Ami, and the Grande Grève. The upper formation, the Grande Grève, consists of limestone and cherty limestone; it has yielded a fauna of one hundred and fifty-five species, characteristic mainly of the Helderberg-Oriskany, but with a considerable representation of the later Onondaga of New York. The Cape Bon Ami formation, in its upper part, consists of interbedded limestone and shale, which form a massive cliff-forming unit. These beds are barren of fossils. The lower part of the formation is a grey shale containing *Monograptus*. Underlying these beds are the red, green, and grey shales and the grey fossiliferous limestones of the St. Alban formation. The base of the St. Alban formation is a limestone conglomerate which rests unconformably on the folded Ordovician shale of the Cape Rosier formation. Similar beds are exposed at Percé. There the Mont Joli formation is probably equivalent to the St. Alban, and the Murailles limestone, in its upper part at least, to the Grande Grève. In the Matapedia Valley region, at the western end of Gaspé Peninsula, Lower Devonian shale and argillaceous limestone, at least 2,200 feet thick, are called the Causapscal formation. They apparently grade up into the sandstone of the Heppel formation of Middle Devonian age. In central Gaspé, Lower Devonian shale and limestone cover wide areas. The beds are folded, faulted, locally intruded by dykes and stocks of porphyry, syenite, and diorite, and are mineralized with zinc- and lead-bearing veins and with disseminated copper-bearing minerals. In places, associated with the sedimentary beds, are thick deposits of volcanic rocks, also probably of Lower Devonian age.

To the southwest, in the Beauceville region, beds consisting of conglomerate, limestone, and shale carry fossils that, apparently, represent an Onondaga age, and have been described under the name Famine series. Between Chaudiere River and

Lake Memphremagog are a number of Devonian remnants of Helderberg age. In the Disraeli map-area near Thetford these rocks have been called the Lake Aylmer group.

Lower Devonian rocks occur near La Poile Bay in southwestern Newfoundland, where three groups of strata have been studied in some detail and consist of both sedimentary and volcanic rocks. What is believed to be the oldest, the Bay du Nord group, is predominantly slate with minor quartzite and conglomerate, and carries remains of *Drepanophycus spinaeformis*. The beds are considered to be of Lower Devonian or early Middle Devonian age. The Bay du Nord group is estimated to be between 10,000 and 15,000 feet thick and to have been laid down under continental conditions, probably lacustrine. The second of the three groups, a group of schist and gneiss, is believed to be younger than the Bay du Nord, and is separated from it by a fault. The group is non-fossiliferous and consists of: conglomerate, arkosic greywacke; metamorphic equivalents of these that include mica schist, staurolite schist, and gneiss; and minor volcanic rocks. The La Poile group believed to be the youngest of the three is, like the schist and gneiss group, unfossiliferous. The group falls into three divisions, a basal conglomerate division, a dominantly sedimentary division in which minor amounts of volcanic rocks are found, and, the largest of the three, a dominantly volcanic division which includes some sedimentary rocks. All three groups have been invaded by a succession of igneous rocks ranging in composition from peridotite to granite. The igneous rocks are believed to have been associated with the Acadian orogeny and to have been intruded during an interval lasting from early Middle Devonian time to the end of the Devonian period, or even later. The youngest of the three groups cannot, therefore, be much younger than early Middle Devonian.

In north-central Newfoundland, extending southwest from Notre Dame Bay, is an extensively exposed group of rocks known as the Springdale. The rocks were originally believed to consist only of red sandstone, siltstone, and conglomerate. Later work has indicated that the group includes great thicknesses of acid volcanic rocks similar in many respects to the Cape St. John group of the Burlington Peninsula, and to those included in the La Poile group. The Springdale is not known to carry indigenous fossils, but exogenous Middle Silurian corals have been found in Springdale conglomerates, and for some years that age was ascribed to the group. As Springdale rocks are intruded by granitic rocks associated with the Acadian orogeny of probable Middle Devonian time, and as Middle Silurian rocks were under erosion at the time of their deposition, the group is now considered to be early Devonian in age.

In western Newfoundland the Clam Bank formation, of very limited extent, occurs on the northwest side of Port au Port Peninsula. It is mainly a red clastic sequence and has yielded a meagre fauna of marine shells, including the bulbous holdfast of the crinoid genus *Scyphocrinites*. The formation is tentatively referred to the Lower Devonian.

Lower Devonian rocks, known as Dalhousie beds, cover a number of areas in northern New Brunswick. They consist of marine strata with interbedded volcanic flows and tuffs, and are associated with dykes and with volcanic necks such as that forming Sugarloaf Mountain at Campbellton. In the lower part of the succession the sedimentary material is relatively abundant, whereas, in the upper part the volcanic members predominate. The best and most readily accessible section is on the shore at Stewarts Cove at Dalhousie and belongs to the upper, dominantly volcanic, division, but includes a larger proportion of sediments than does the division as a whole. The sediments are highly fossiliferous, having yielded over ninety species, and some of the beds are crowded with shells. The succession, in descending order, is as follows:

	Thickness Feet
Pyroxene andesite (fifth and fourth flows of Stewart andesites)	40+
Intrusive andesite and breccia (Bon Ami andesites)	90
Pyroxene andesite (third, second, and first flows of Stewart andesites)	85
Gap in section	250
Upper Dalhousie beds	
16. Arenaceous limestone with barren grey shale	25
15. Hard, grey limestone	2
14. Thin-bedded shale with limestone	35
13. Ash bed	1
12. Blocky, calcareous shale	2
11. Ash beds with thin limestones and shales	30
10. Thin, grey shale	10
9. Limestone and calcareous shale	75
8. Calcareous, sandy shale	20
7. Arenaceous limestone	7
Agglomerate and andesite (with bed 6)	280
Lower Dalhousie beds	
5. Hard, grey limestone	10
4. Coarse, yellowish white tuff	12
3. Hard, grey, arenaceous shale with limestone	40
2. Grey, calcareous shale with limestone	125
1. Silicified limestone with shale	30
Basalt tuff and breccia	30
Basalt	15
Palagonite tuff	180
Calcareous shale	90

In the Nictaux-Torbrook area of Annapolis and Kings counties, N.S., are early Devonian slates and quartzites with associated ferruginous beds. Similar rocks occur farther southwest in the Bear River area.

In the northern part of the province southwest of Arisaig the Silurian strata of the Arisaig series are overlain by the Knoydart formation. This formation consists of about 1,000 feet of fine-grained, red, arenaceous slate and grey sandstone and is apparently continental in origin. The formation contains *Pteraspis whitei*, *Cephalaspis novascotica*, and *Onchus* sp., and the grey sandstone has yielded remains of fish regarded as Lower Devonian (Lower Dittonian).

In the Boisdale region of Cape Breton Island, between East Bay and St. Andrew Channel, the McAdam Lake formation of grey, freshwater arkose and conglomerate, for the most part steeply dipping, carries plant fragments indicative of a Lower or Middle Devonian age. At one place the sediments are associated with tuffs.

Lower and Middle Devonian

Much of the interior of Gaspé Peninsula is underlain by sandstone, conglomerate, and arenaceous shale varying from green and drab to red. The type locality for these rocks is on Gaspé Bay where Logan measured a section 7,036 feet thick. The beds lie above the Gaspé limestones, and Logan gave the name Gaspé sandstones to them. The lower part carries plant remains of the *Psilophyton-Drepanophycus* flora and also fish remains. Marine invertebrate fossils have been found in several localities. In the type section the beds are conformable, or nearly so, with the underlying limestones, although the change in lithology is abrupt. At places in the interior of Gaspé Peninsula beds of the lower part of the succession carry fossils, that, apparently, represent a transition from Lower to Middle Devonian. In the zinc and lead field of Berry Mountain and Brandy Brooks, the Gaspé sandstone beds, unlike the Lower Devonian limestone beds, are not cut by granitic and syenitic intrusive rocks nor are they mineralized by veins.

Middle Devonian

On the north side of Mal Baie, at the eastern end of Gaspé Peninsula, is a belt of conglomerate about 3,000 feet thick which, because of its distinctive lithology, has been separated as a unit known as the Malbaie formation. The beds are conformable with those of the underlying Gaspé sandstone, they have yielded plant fragments similar to those in the sandstone, and the age of the formation is considered, therefore, to be Middle Devonian.

A series of coarse sandstones in Matapedia Valley has been designated the Heppel formation. It overlies, with a fairly sharp boundary, Lower Devonian beds of the Causapscal formation, has a probable thickness of at least 6,500 feet, and locally has yielded a considerable fauna of Middle Devonian age. Its lithology, its relation to older rocks, and its fossils all point to a correlation with the Gaspé sandstones.

Upper Devonian

A thick succession of conglomerate, sandstone, and shale is extensively developed on the north shore of Fortune Bay, Newfoundland, and forms limited exposures on the south side of the bay, where it forms the underthrust segment of the Fortune Bay fault. Plant remains indicate that the age of the group is probably late Upper Devonian. The beds lie unconformably on Cambrian and Ordovician strata and are intruded by granitic rocks believed to have been associated with the Acadian orogeny.

On the north side of Chaleur Bay, opposite Dalhousie, a series of interesting beds of Upper Devonian age has attracted many fossil collectors because of its wealth in fish remains. The strata are best exposed along the shore between West Maguasha and Escuminac Point (Figure 43). They form a broad syncline pitching north, are underlain to the west by Gaspé sandstone, and are overlain by red

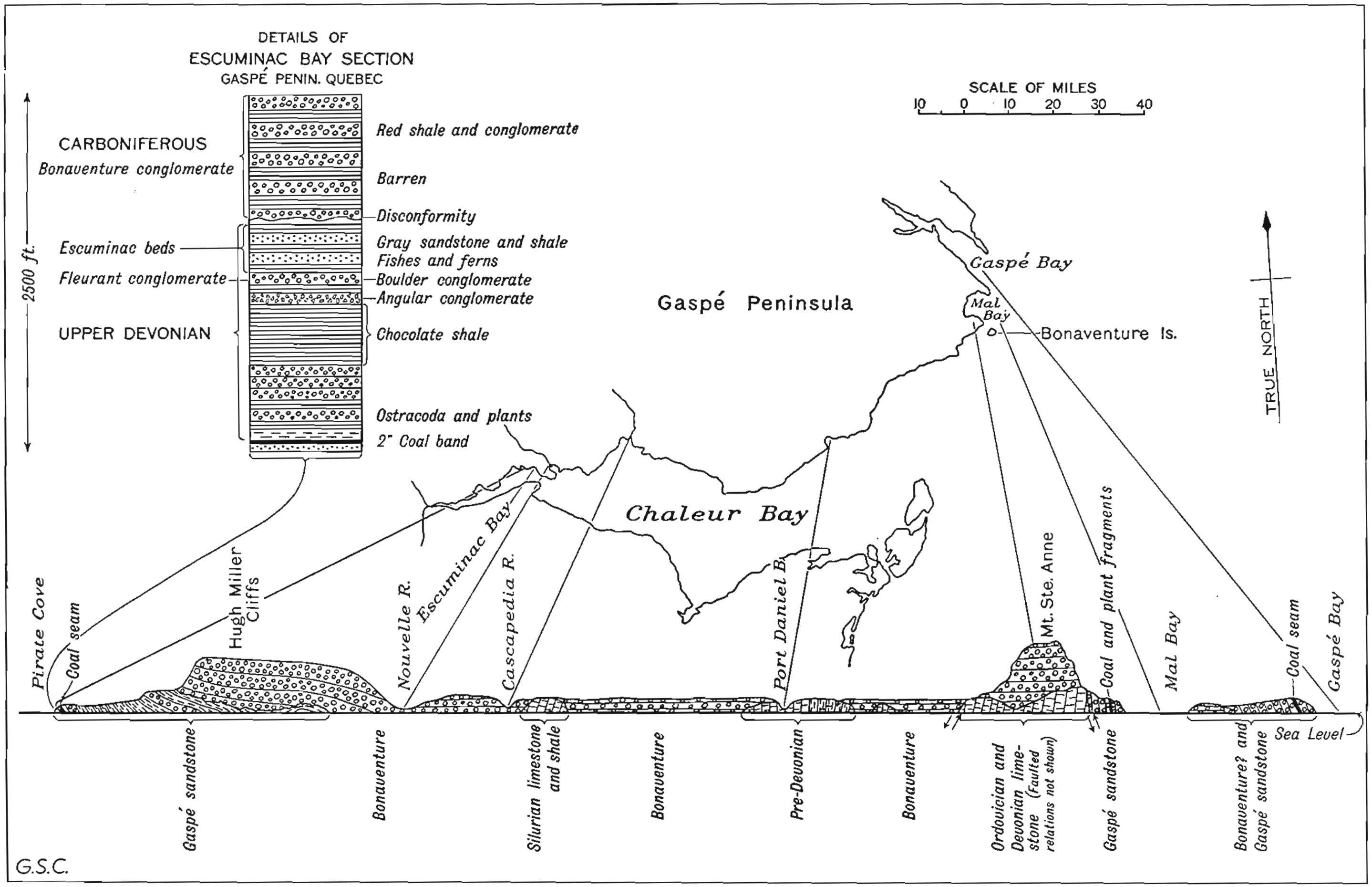


FIGURE 43. Diagrammatic section near the shore from Escuminac Bay to Gaspé Bay, Quebec. (By F. J. Alcock.)

Bonaventure conglomerate of Carboniferous age. They have been divided into three formations. The lowest, the Pirate Cove, consists at its base of about 400 feet of coarse, angular-pebble conglomerate interbedded with chocolate, green, and grey, argillaceous and sandy beds; the lower beds of this zone contain an ostracod fauna and numerous plant remains, the latter closely associated with a seam of coal 2¼ inches thick. This basal zone is overlain by 210 feet of coarse, angular-pebble conglomerate with a salmon-coloured matrix, and this in turn is succeeded by 450 feet of coffee-coloured shale with occasional green bands, and a conglomerate member up to 40 feet thick. The second, or Fleurant, formation consists of coarse, round-pebble and boulder conglomerate with a grey matrix. It has a thickness of 45 feet. The type locality is Fleurant Point, but it is also seen at Mushroom Rock and in a low cliff on the shore a third mile southeast of Englishman Creek. The upper formation, the Escuminac, consists of grey shale and shaly sandstone, culminating in a 16-foot member made up of reddish beds. This formation is 370 feet thick, and is the one that has yielded excellent fish fossils and fine plant remains. The latter include Upper Devonian ferns, some common to the Perry formation in Maine. There is a definite erosional break between the Escuminac beds and the succeeding Bonaventure conglomerate.

Beds of red sandstone and conglomerate, which are correlated with the Perry conglomerate of Maine, underlie areas on the western side of Passamaquoddy Bay in the St. Andrews region of New Brunswick near the Maine border; on the opposite side of the bay on Mascarene Peninsula; at Blacks Harbour south of St. George; and on some of the adjacent islands. The beds lie for the most part with low dips and in gentle folds. In some places they rest unconformably on Silurian rocks and in other places are in fault contact against them. The conglomerate contains boulders of the Silurian and pre-Silurian rocks and of the St. George granitic intrusions. On Hill Island two basic amygdaloidal lava flows are interbedded with the red sediments, and similar volcanic rock shows on Howard Island. Locally the beds are cut by dark dykes. Similar dykes and flows are associated with the conglomerate beds at St. Andrews. Plant remains, too poor to be identified, have been found on the northwest side of Blacks Harbour. The rocks, however, are so similar to those of the Perry formation on the Maine coast that there can be little doubt that they belong to the same series. The Perry formation in Maine has yielded an Upper Devonian flora.

Intrusive Rocks

The intrusive rocks of the Appalachian region range from ultrabasic varieties, through gabbros and diorites, to granite, the last varieties predominating. Although some of the intrusions were emplaced at times other than Devonian, all are described here because by far the bulk of these rocks were introduced during Lower, Middle, and Upper Devonian time, and were associated with the Middle Devonian, Acadian orogeny. Basal conglomerates of the Lower Cambrian Ratcliffe Brook formation on Saint John River carry granite boulders similar to that of the basement on which they rest. Similar relationships are reported between Lower Cambrian conglomerates and granites on Conception Bay, Newfoundland, but these relationships have been questioned. An age determination indicates that granitic rocks in southern New Brunswick that intrude only Precambrian beds are Devonian in age. On the other hand it is possible that much of the granitic and other intrusive rocks cutting the gneisses and schists of the Long Range Mountains in Newfoundland are Precambrian, but the actual contact with Cambrian beds has not been observed. Ultrabasic rocks, of which two or more belts are known in the Appalachian region, are generally conceded to be Ordovician, but near La Poile Bay in southwestern Newfoundland peridotite occurs as a border phase of a diorite stock cutting schists of probable Lower Devonian age. Small plugs of basalt intrude both lower and upper Mississippian rocks in Cape Breton Island and are definitely post-Devonian. In Fortune Bay, Newfoundland, some granites believed to be associated with the Acadian orogeny intrude beds of such a late Devonian age that the possibility must be admitted of the intrusive cycle having extended into Mississippian time.

That the intrusive rocks associated with the Acadian orogeny actually preceded the orogeny and continued their intrusive cycle after its close is well indicated in southwestern Newfoundland. There both known and probable Lower Devonian beds were intruded by a succession of rocks that today exhibit degrees of metamorphism ranging from gneisses to fresh massive unaltered granite. It is assumed that the first intrusions underwent more deformation than those subsequently emplaced. The unaltered granite is similar in many respects to an intrusion about 150 miles to the east that produced contact effects in late Upper Devonian beds.

There is some evidence that intrusive activity began earlier in Devonian time in Nova Scotia than in Newfoundland, and possibly did not continue so long. The MacAdam Lake formation is probably Lower Devonian in age, but could possibly be early Middle Devonian. Boulders of intrusive rocks similar to those intruding Silurian and older beds are common in its conglomerates. However, in western Nova Scotia, Lower Devonian shale and slate are intruded by the main granite batholith of southern Nova Scotia.

These Devonian intrusions are responsible for almost all the metalliferous and many of the non-metalliferous mineral deposits of the Appalachian region. All of the asbestos and chromite, and much of the talc, is found in or associated with bodies of ultrabasic rocks. The copper deposits of Notre Dame Bay, Newfoundland, are believed to be associated with intrusions of diorite, quartz diorite, or granodiorite, and the Mindamar orebodies in Cape Breton Island, with nearby intrusions of diorite. Other orebodies are believed to have been formed by emanations from nearby intrusions in general, without specifying the particular body.

Carboniferous

In Quebec rocks of Carboniferous age outcrop along the shore of Chaleur Bay and on the Magdalen Islands. In the Chaleur Bay region the beds are of red conglomerate and sandstone of the Bonaventure formation; they are fresh and, for the most part, are undisturbed. Magdalen Islands are composed of sedimentary and volcanic rocks of Mississippian age, overlain disconformably by red and grey

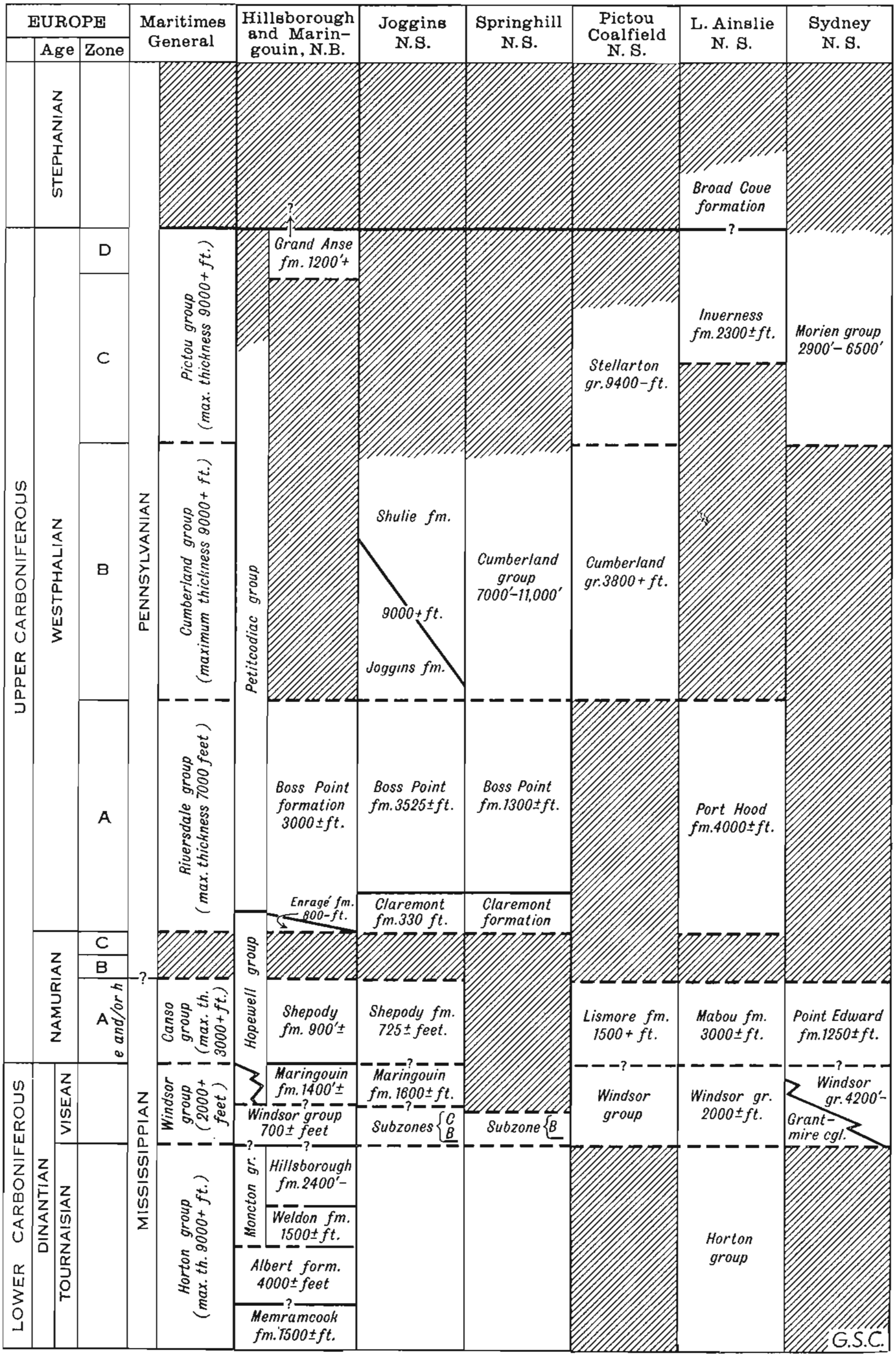


FIGURE 44. Correlation chart of Carboniferous formations of the Maritime Provinces of Canada. (By W. A. Bell.)

sandstone beds of probably Canso (late Mississippian and possibly early Pennsylvanian) age. Over one-half of New Brunswick is underlain by Carboniferous strata, and considerable areas of Nova Scotia also are covered by these rocks. They are the source of the coal, oil, gas, salt, and gypsum of the two provinces. Prince Edward Island is underlain by gently dipping red beds of late Pennsylvanian and possibly early Permian age. Figure 44 shows the succession of formations in some of the more important areas.

Mississippian

Mississippian rocks are found in western and, possibly, in central Newfoundland, through most of Nova Scotia, in New Brunswick, in Gaspé, and on the Magdalen Islands.

The oldest Carboniferous strata in Newfoundland are termed the Anguille group[1] which comprises a sequence of nonmarine conglomerate, sandstone, and shale that is more than 2,600 feet thick. These rocks underlie the Anguille Mountains and scattered small areas west of the Long Range fault, on the southeast side of St. Georges Bay. The bottom of the group is not exposed.

The Anguille is overlain with no apparent unconformity by marine sandstone, shale, limestone, and gypsum of the Codroy group. The principal areas of exposure are southwest and northeast of the Anguille Mountain, in scattered areas in the lowlands near the village of St. Georges, on the north side of St. Georges Bay, and on the north side of the Port au Port Peninsula. The Codroy is considered, on faunal evidence, to be the equivalent of the Windsor group on the mainland and to have been laid down in the same sea (the Windsor Sea).

Overlying the Codroy strata, about 4 miles south of Codroy village, is a succession of nonmarine conglomerate, coarse gritty sandstone, and arenaceous shale that are termed the Searston beds. They are believed to be equivalent in age to the Canso group of Nova Scotia and are, in part at least, Mississippian in age but may be, in part, Pennsylvanian.

Near the north end of Deer Lake, about 40 miles northeast of Corner Brook, extensive areas are underlain by conglomerate, sandstone, and shale of the Rocky Brook and Humber Falls formations. These beds are of probable Mississippian age but, as they are associated areally with coal-bearing Pennsylvanian strata—but with obscure relationships—they may possibly be the equivalent of the Searston and Canso. Some 30 miles northeast of Deer Lake, on the west side of White Bay, sandstone and shale of the lower Mississippian Spear Point formation extend for some 20 miles along the shore of the bay.

The type area of Mississippian rocks in Nova Scotia is along the lower part of Avon River south of Minas Basin. The strata belong to two groups, the Horton and the Windsor. The Horton (Plate XV) is made up of two formations, a lower known as the Horton Bluff and an upper called the Cheverie. The Horton Bluff

[1]The Anguille, and the Codroy and Barachois yet to be described, were termed 'series' by the Geological Survey of Newfoundland. The Geological Survey of Canada prefers and uses the term 'group' for such sequences.

Plate XV

Syncline in Horton beds, Tennycape River, Hants county, N.S.

consists of some 3,400 feet of dark shale, sandstone, and conglomerate; it contains plant remains, buried forests and soils, and has a fauna of ostracods and fish remains. It rests unconformably on pre-Carboniferous metamorphic and igneous rocks. The Cheverie formation is made up of 600 feet of red and grey shales, sandstone, and arkose. It rests disconformably on the Horton Bluff. The Windsor group overlies the Horton Bluff with a regional disconformity that locally may be an unconformity. This group is made up of about 1,550 feet of marine sedimentary rocks comprising limestone, gypsum, shale, sandstone, and limestone conglomerate. The limestone members are rich in fossils and have yielded one hundred and twenty-seven species, chiefly mollusca and brachiopods.

The Mississippian rocks extend eastward through a lowland belt to the Strait of Canso, and also occupy much of the lowland areas of Cape Breton Island. There the relationships between the Horton and Windsor strata vary somewhat from that found elsewhere. Where the Windsor overlies Horton rocks the lowermost Windsor member is almost invariably a distinctive black laminated limestone, but where the Windsor overlies pre-Horton rocks the lowermost member is a thick conglomerate. This is termed the Grantmire member and is succeeded by strata varying from lower to upper Windsor, but nowhere including the black laminated limestone. It is apparent that the Windsor Sea, after covering lowlands underlain by Horton rocks, spread over higher ground of pre-Horton rocks that supplied the material for the conglomerate. But the high ground was also being eroded and supplying conglomerate in Horton time so that the Grantmire member, although believed to be laid down mainly in Windsor time, undoubtedly includes some beds of Horton age.

In the Lake Ainslie area the Horton group includes about 6,000 feet of conformable, dominantly clastic sedimentary material containing a meagre flora and fauna. These rocks are intruded by dykes and sills of diabase. The succeeding Windsor beds have a thickness of about 2,000 feet. In the Arisaig region amygdaloidal lavas are interbedded with conglomerate, sandstone, and sandy shale of the Mississippian McAras Brook formation.

In New Brunswick Mississippian rocks are well developed in the Hillsborough region, in a belt extending northeast and southwest from Sussex, in the Plaster Rock area on the Tobique River, and in other areas. In the Hillsborough and Sussex regions the succession begins with the Memramcook formation consisting of red conglomerate, shale, and sandstone. This is succeeded, apparently conformably in most places at least, by the Albert formation, locally about 4,000 feet thick, consisting dominantly of grey shales, commonly bituminous, with some layers of sandstone and limestone. These beds were deposited, partly at least, under nonmarine conditions; they have yielded a considerable fish fauna and are the source of oil and gas. They are succeeded, again conformably, by conglomerate and sandstone of the Moncton group. In the Hillsborough region the Moncton beds are divided into two formations, a lower called the Weldon, consisting of some 1,500 feet of red shale and sandstone, and an upper, the Hillsborough, made up of 2,400 feet of red feldspathic grit and conglomerate. In the region southwest of Sussex, the Kennebecasis group, composed of conglomerate, sandstone, and some shale, is probably the equivalent of Albert and Moncton strata.

Overlying the Moncton and Kennebecasis beds is a marine group, the Windsor, made up of limestone and gypsum. It serves as the chief Carboniferous horizon marker of the region, and varies in thickness from about 50 feet, or less, to 700 feet. It is succeeded, in turn, by red sandstone and conglomerate of the Mississippian and Pennsylvanian (?) Hopewell group.

In the Plaster Rock area the Mississippian beds consist of semi-consolidated to well-consolidated coarse conglomerate, sandstone, thin-bedded shale, sandy shale, and gypsum-bearing strata, with a conglomerate bed at the top. The beds are mostly deep red and have the form of a basin, flat lying in the centre, and with dips up to 25 degrees on the margin. Their total thickness is believed to be about 2,000 feet.

Stretching west from Hampstead and swinging around Oromocto Lake and northwards is a belt of Mississippian sedimentary and volcanic rocks. These rocks consist mainly of red conglomerate, rhyolite, and limestone. The limestone is Windsor and is apparently younger than the red clastic beds and associated rocks which may be Moncton.

Strata of Windsor age occur on the Magdalen Islands, and include limestone, shale, shaly limestone, and gypsum, with interbedded volcanic rocks. The beds locally contain an abundance of fossils. The volcanic rocks are basaltic, fragmental types.

Mississippian and Pennsylvanian (?)

Beds of the Canso group overlie those of the Windsor in many parts of the Atlantic Provinces. They comprise a nonmarine post-Windsor sequence, which, in the lower part at least, is Mississippian in age and the whole may be of this age

Mention has been made of the Searston beds of western Newfoundland which are probably equivalent to the Canso. Beds of the Canso group are also known in northern Cape Breton, the Strait of Canso area, in the Salmon River Valley east of Truro, and around Minas Basin. The group consists of red and grey shales with local thin beds of limestone. In the Minas Basin region the strata commonly include thin bands and veinlets of iron carbonate. There are few recognizable plant remains, but those studied show affinities with Mississippian species. Freshwater shells are also present locally.

In southeastern New Brunswick Windsor beds are succeeded by red sandstone and conglomerate of the Hopewell group. In most places the basal Hopewell beds are conformable with the Windsor, but an erosional break between the two groups, or one within the Hopewell itself, is indicated by the occurrence in many places of boulders of the Windsor limestone in the Hopewell conglomerate. The Hopewell beds grade upward into strata of Pennsylvanian age, but are believed, in part at least, to be equivalent to the Canso. In the Hillsborough area the Hopewell group is composed of three formations. The lowest, the Maringouin, possibly of Mississippian age, consists of red shale and sandstone and has a thickness of about 1,400 feet. These beds are succeeded conformably by the Shepody formation, about 900 feet thick, beginning as a grey sandstone and grading into red sandstone and shale with interbeds of massive grey sandstone. The formation carries a Canso flora. It is succeeded by the Enragé formation of red shale, sandstone, and conglomerate, and this in turn is overlain by the Boss Point formation of predominantly grey sandstone.

Pennsylvanian

Upper Carboniferous beds are known in western Newfoundland, Cape Breton Island, Central Nova Scotia, east-central New Brunswick, and probably all of Prince Edward Island. The beds at many of these localities are coal-bearing.

In western Newfoundland beds of the Pennsylvanian Barachois group overlie Searston beds near St. Andrews and also occur south and southwest of St. Georges. The beds are of sandstone, shale, and conglomerate and carry numerous thin seams of coal. *Sphenoptris hoeninghausi* has been identified from these beds and they are referred to the Westphalian A zone (Figure 44), and may be considered equivalent to the Riversdale of Nova Scotia.

Coal-bearing beds of similar characteristics occur near Hawley, at the outlet of Grand Lake, and are assumed to be equivalent to the Barachois.

The upper Carboniferous rocks of Nova Scotia have been divided by Bell, on the basis of their flora, into three groups, the Riversdale, the Cumberland, and the Pictou (Figure 44). All are wholly nonmarine, so far as known, and in no one area are all three present. The oldest, wholly-Pennsylvanian group, the Riversdale, is made up of alternating red and grey sandstones and shales, including, locally, a basal conglomerate. In the Parrsboro area the Riversdale overlies the Canso beds with angular unconformity, and in the Springhill area it underlies, with similar relationships, the Cumberland group. In other localities both the lower and upper

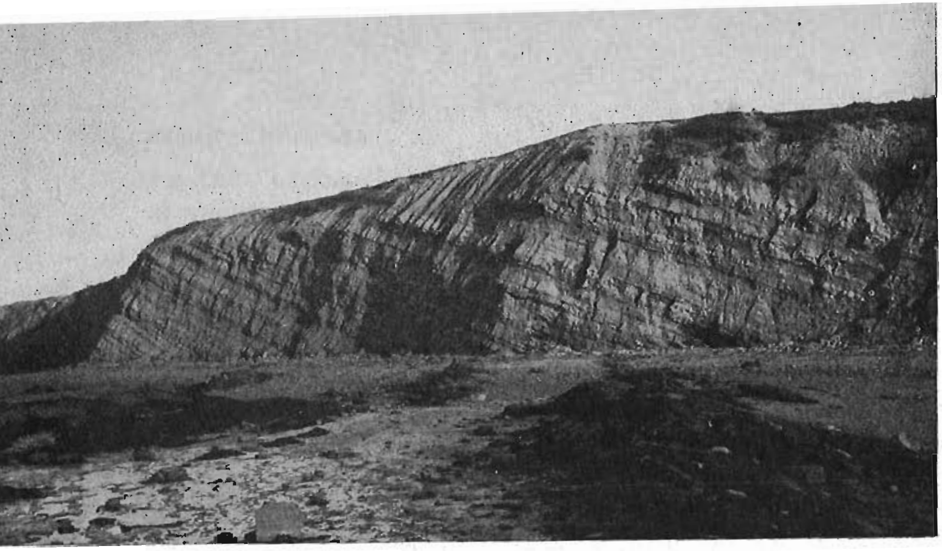


Plate XVI | *Part of Carboniferous section at Joggins, N.S.*

contacts are generally disconformities. The coals of the Port Hood area, Inverness county, and those of Richmond county are in Riversdale strata. The Cumberland group is typically exposed in the Joggins and Springhill coalfields of Cumberland county and contains the coals of these areas. The best section is exposed in the sea-cliffs of Joggins (Plate XVI), where the group shows a thickness of over 9,000 feet of nonmarine conglomerate, sandstone, shale, and coal. The youngest group, the Pictou, consists of sandstone, grit, and shale, as much as 9,000 feet thick. The coals of the Sydney, Salmon River, Inverness, and Mabou Mines areas of Cape Breton Island, those of the New Glasgow area, Pictou county, and possibly those of the Kemptown and other areas in Colchester county are in rocks of this group. The beds rest unconformably upon Carboniferous rocks older than the Cumberland and locally overlap upon pre-Carboniferous rocks. East of Springhill they lie unconformably upon the Cumberland group, but elsewhere the contact with that group is disconformable.

Pennsylvanian rocks cover much of the Carboniferous plain of eastern New Brunswick. In the Sussex and Hillsborough regions they form two groups, the Hopewell in part, and the Petitcodiac. The former has been described and is probably equivalent to the Canso. The Petitcodiac group is composed dominantly of only slightly disturbed grey sandstone and grit with pebble conglomerate and includes beds equivalent to the Riversdale and Pictou groups. The upper division of the Petitcodiac group in southeastern New Brunswick consists of reddish brown sandstone with arkose and pebble conglomerate, and is known as the Grande Anse; its beds overlie Boss Point (Riversdale) strata with marked angular unconformity.

In the Minto coal area the coal-bearing Grand Lake formation is of Pictou age. In the northeast corner of the province, strata of the same age are called the

Bathurst and Clifton formations. Along the Chaleur Bay shore between Bathurst and Dalhousie are patches of red Bonaventure conglomerate similar to those on the Gaspé coast, as described below.

Along the Bay of Fundy in the Saint John region, and extending south to Musquash Harbour, purplish sandstone and conglomerate with associated volcanic and intrusive rocks form what is known as the Mispek group. The sediments carry a few Carboniferous plant remains. The Mispek rocks are probably to be correlated with the Canso; they are overlain by sandstones of the Lancaster formation, which carry a flora of Cumberland age.

The north shore of Chaleur Bay is bordered for considerable distances by red clastic beds of the Bonaventure formation, which takes its name from Bonaventure Island at Percé. The strata consist chiefly of coarse conglomerate and sandstone with associated red shale, shaly sandstone, and, locally, limestone. The beds for the most part lie horizontally, but are locally tilted and in places are faulted. At two places near Grand River amygdaloidal basaltic flows are associated with the sediments.

Prince Edward Island is underlain by an assemblage of red sandstone and siltstone, with minor shale and conglomerate, which has been demonstrated in a drill-hole to be over 10,415 feet thick. The exact age is uncertain, but these rocks can at present be referred to as Permo-Carboniferous.

Northwest of Percé, the Cannes de Roche formation consists of three members, a lower red conglomerate, a middle division of red and green shales and shaly sandstone, and an upper division of buff sandstone and conglomerate that carries plant remains, including casts of Calamites, etc., which may indicate a late Mississippian but more probably a Pennsylvanian age. It is probable that the Cannes de Roche beds are the same age as the Bonaventure, but were formed in a different basin.

On Magdalen Islands, flat-lying beds of conglomerate and sandstone disconformably overlie Windsor sedimentary and volcanic rocks already described. The beds resemble closely those of the Bonaventure, both lithologically and structurally, and are probably the same age as that formation.

Mesozoic

Triassic

The youngest consolidated rocks in the Appalachian region are of Triassic age and occur only in the Bay of Fundy region. They rest unconformably on various Palæozoic and Precambrian formations (Plate XVII). In Nova Scotia red sandstone, shale, and conglomerate of the Annapolis formation underlie the Annapolis-Cornwallis Valley and border both sides of Minas Basin. These rocks are capped by about 1,000 feet of amygdaloidal basaltic lavas forming the North Mountain Upland. On the New Brunswick side of the Bay of Fundy patches of similar red conglomerate and sandstone occur in the St. Martins region, and at Martin Head and Waterside where they form the Quaco formation. Other areas of the same rocks are found at Red Head, near Saint John, and at Lepreau Point to

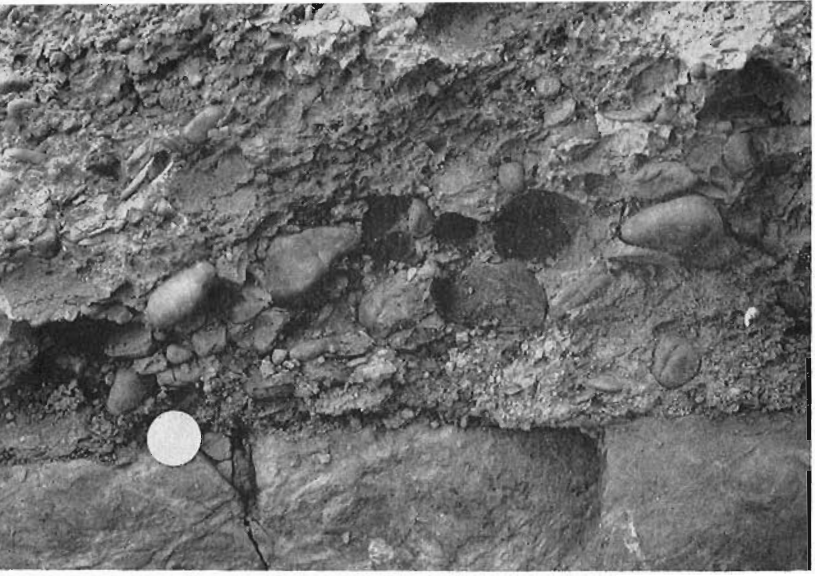


Plate XVII

Unconformity between Triassic conglomerate, above, and vertically bedded Horton shale, below; East Walton, Hants county, N.S.

the southwest. At each place the beds dip northwest and are in fault contact with older formations in that direction. A few fossil plants and some fish remains serve to correlate the beds with the Newark series of late Triassic age in New England.

The volcanic rocks that form much of Grand Manan Island are also regarded as Triassic, because of their lithological character and their association with some fresh, red, clastic beds. It is possible that dykes and bodies of basaltic rock that cut Mississippian beds were intruded in Triassic time.

Cenozoic

In southern Quebec eight masses of intrusive rocks form what are known as the Monteregian Hills. The most westerly is Mount Royal at Montreal. In the chapter on the St. Lawrence Lowlands these rocks are discussed at greater length. Three of the hills, Yamaska, Shefford, and Brome, lie east of the Logan fault and hence are in the Appalachian region. The rocks consist of alkalic varieties; they are definitely post-Lower Devonian, and have been assigned a Tertiary age by geophysical dating.

Economic Geology

Many minerals, both metallic and non-metallic, are found in the Appalachian region. The Pennsylvanian rocks contain coal, and Mississippian strata contain deposits of gypsum, salt, barite, petroleum, natural gas, oil, shale, and albertite. The ultrabasic rocks of the Eastern Townships of Quebec, of Gaspé Peninsula, and of Newfoundland carry asbestos and chromite. Devonian granitic intrusions produced widespread mineralization, giving rise to numerous occurrences of gold, iron, copper, zinc, lead, antimony, tungsten, and molybdenum minerals. Bedded deposits of iron and of manganese were formed at more than one horizon in Palæozoic strata. Manganese, in addition, has been obtained from replacement and vein deposits of several types. Monumental, building, and abrasive stone, rock fertilizer, diatomite, peat, clay, sand, and gravel are other materials that are, or have been, produced.

Coal

Coal, although not the most important mineral product of the region, has probably been of importance longer than any other. In 1955 the production from Nova Scotia was 5,731,026 tons, compared with the record output of 7,848,921 tons in 1940. Output from New Brunswick in 1955 was 877,838 tons, about 330,000 tons higher than in 1940. The Appalachian production accounted for 44 per cent of the total coal mined in Canada in 1955. The coal comes from Pennsylvanian strata and is all of bituminous rank; much of it is suitable for the production of coke and gas and is also a good steam coal. The production supplies not only the railways of the area, the local steel industries, and the domestic market, but also part of the fuel requirements of the province of Quebec and to some extent those of Ontario. The main fields (Figure 45) are those of Sydney in Cape Breton Island, Pictou and Cumberland on the mainland of Nova Scotia, and Minto in New Brunswick. The Newfoundland fields are not exploited at present.

In Newfoundland coal seams occur in three areas, namely, Howley, St. Georges, and South Branch. In all these areas the coal seams vary greatly in thickness and seldom exceed 4 feet. They are very dirty, with many partings of shale and clay interbedded with thin bands of clean coal, so that the total thickness of clean coal rarely exceeds 2 feet in any one seam. The fields are strongly faulted, resulting in truncated steeply dipping seams with shattered coal.

In the Sydney field coal was exploited by the French more than two hundred years ago during the construction of a fortress at Louisburg, and has been mined continuously for more than a century. This field supplies about 75 per cent of Nova Scotia's production. The productive area is a narrow fringe of lowland extending east-southeasterly for 30 miles along the coast. It covers a land area of about 57 square miles as well as a large area in which mining is carried out beneath the sea. The productive seams are in the Pictou (Morien) group which has a maximum thickness of about 6,450 feet, and rests with erosional contact upon strata of the Canso and Windsor groups. The Morien group consists of grey and red sandstone and shale, with included coal seams, grey arkosic grit with some pebbly conglomerate, and, near the base, some beds of limestone conglomerate. There are also thin beds of freshwater limestone, commonly carrying *Spirorbis*. The beds are thrown into broad open folds that trend northeasterly to easterly and pitch seaward at low angles. The prevailing dips throughout the field vary from 4 to 15 degrees. There are over forty seams, and even the thin ones persist for long distances. The productive seams range for the most part from 4 to 7½ feet in thickness, but seams up to 11 feet thick have been mined. The workings extend for more than 3 miles under the sea, and the coal may extend farther.

The coal areas of Inverness county on the west coast of Cape Breton Island occupy several small detached basins with seaward dips. These areas are found near Chimney Corner, St. Rose, Inverness, Mabou Mines, and Port Hood. At Chimney Corner, St. Rose, and Port Hood the coal-bearing measures are in the Riversdale group. Near Chimney Corner are two seams of possible economic

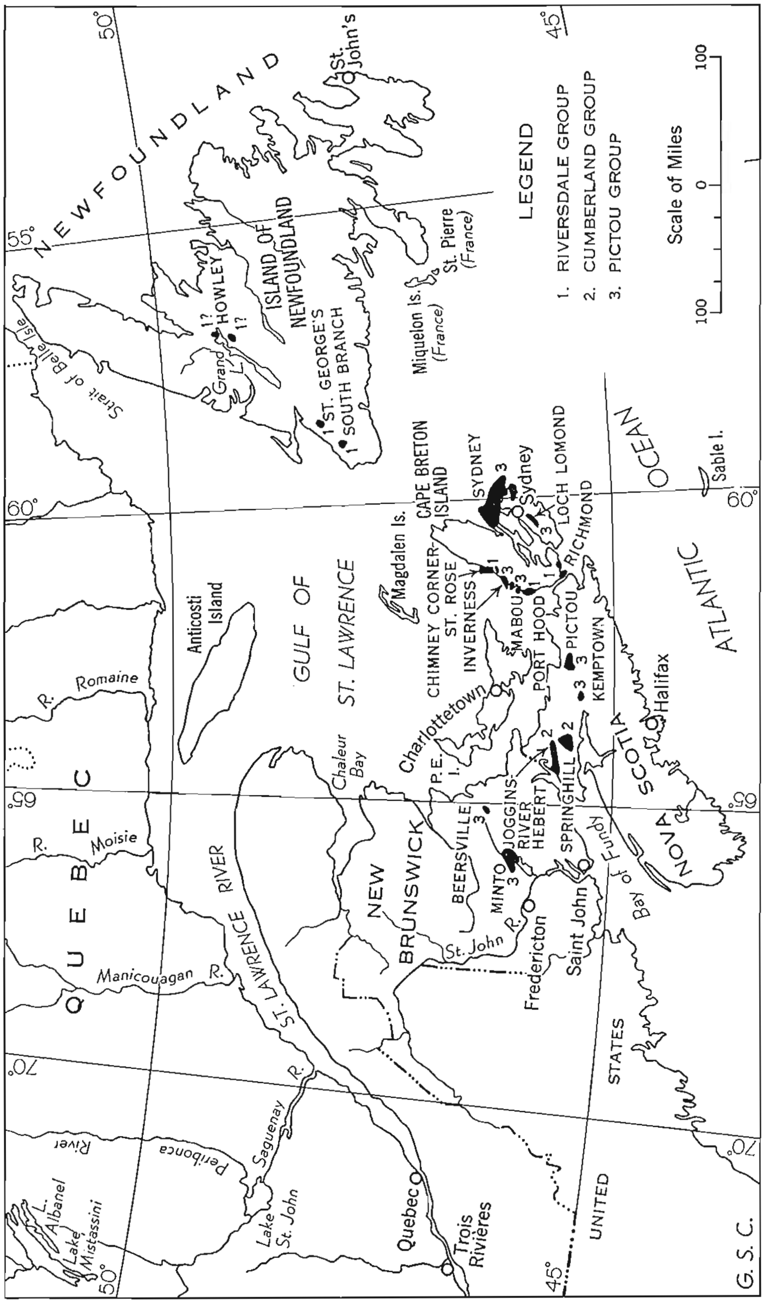


FIGURE 45. Coalfields and coal occurrences of Eastern Canada. (By B. A. Latour.)

value and these dip steeply beneath the sea. The St. Rose field, 2 miles south of Chimney Corner, contains the same seams, but a small wedge of barren strata intervenes between the two fields. Two seams of economic value are present in the Port Hood field, the uppermost seam outcropping only beneath sea-level. The coal measures near Inverness and Mabou Mines are in the Pictou group. The seams near Inverness have been largely depleted and those at Mabou Mines are not of persistent thicknesses and the workable areas are limited by faults. In addition to the above areas in Inverness county there are deposits on Cape Breton Island in Richmond county. These are in the Riversdale group and have been worked only on a small scale because of the poor quality of the coal, faulting, and thinness of the seams.

The Pictou field, covering an area roughly 10 miles by 3 miles near New Glasgow and Stellarton, N.S., has been exploited for coal for about 160 years and has produced more than 45 million tons. The economically productive measures of the field are contained within the Pictou (Stellarton) group. They form a triangular area bordered on the north, south, and east by faults, and on the west they rest disconformably on Cumberland strata and overlap unconformably upon Canso beds. The Stellarton measures are folded into open anticlines and synclines, with undulating axes trending northeasterly to easterly, and are cut by several major and numerous minor faults. There are many coal seams, but as a rule they vary greatly in workable thickness and quality within short distances. One seam, the Foord, reached a maximum thickness of 45 feet.

In Cumberland county there are two coalfields, both producing from strata of the Cumberland group. One is at Springhill, and the other is that of the Joggins-Chignecto area near the head of the Bay of Fundy. The Springhill field includes five mineable seams with a total average thickness of 37 feet in about 1,000 feet of strata. The seams thin rapidly along the strike and become unworkable to the north and south. Within the workable area they dip west at angles of 20 degrees or more, and the No. 2 seam has been mined to a maximum depth of slightly over 4,000 feet. The coals of the Joggins-Chignecto area are thought to be stratigraphically lower than those of Springhill, and comprise six seams that range from 2 to 6 feet in thickness. They pinch out 25 miles east of the shore of Chignecto Bay, and most of them were found to become thinner as they were followed down the dip.

In New Brunswick coal is mined near Minto and Chipman in measures of the Pictou group. Only one seam is present. It averages 18 inches thick, is flat lying, and has a large areal extent. It lies near the surface, and approximately 75 per cent of the production is by strip mining to a depth of about 50 feet.

Asbestos

Canada has long been the leading producer of asbestos because of large deposits in the Eastern Townships of Quebec. In 1880 the value of the Canadian output was less than $25,000; in 1920 it amounted to $14,792,201; and in 1955 to 1,063,802 tons valued at $96,191,317. The asbestos is of the fibrous serpentine,

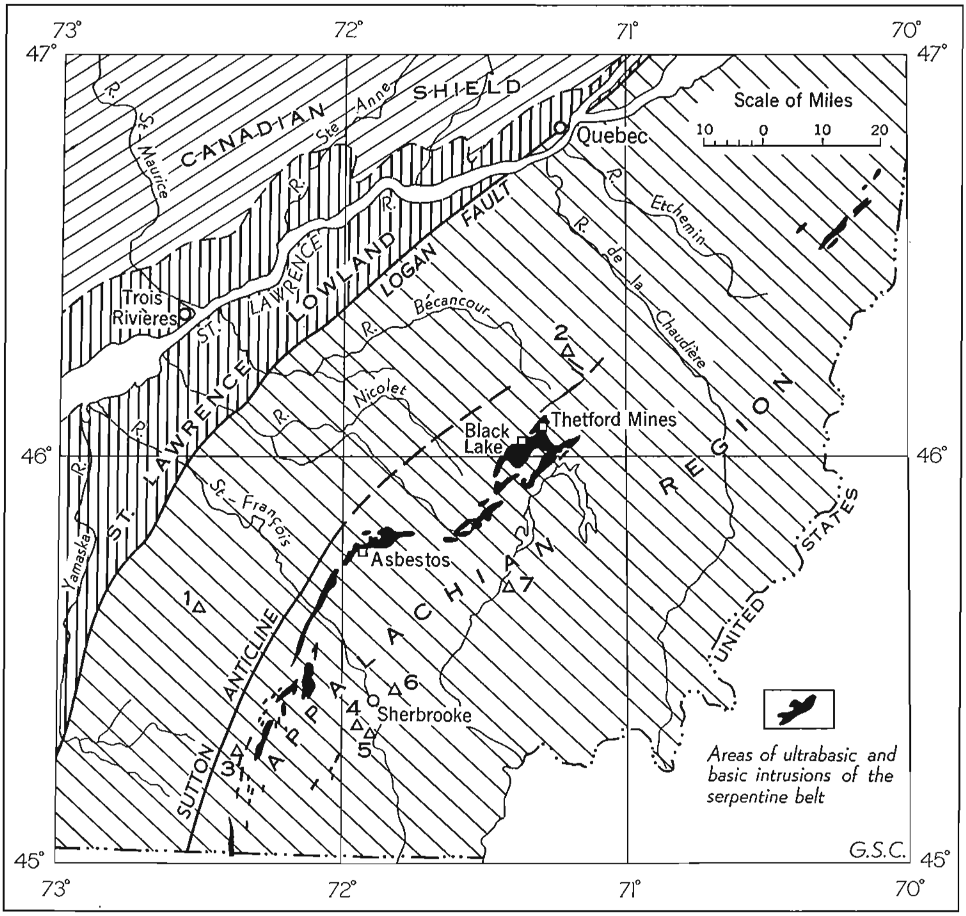


FIGURE 46. Part of southern Quebec, showing the distribution of rocks of the serpentine belt; centres of asbestos mining are indicated by a square symbol, and principal copper mines of the district by a triangular symbol and numbered thus: 1, Acton; 2, Harvey; 3, Huntingdon; 4, Suffield; 5, Eustice; 6, Moulton Hill; 7, Weedon.

or chrysotile, variety and comes from serpentinized peridotite. Mining is carried on both in open pits and underground. Most of the properties are in the vicinity of Asbestos, Black Lake, Thetford Mines, and East Broughton (Figure 46). The peridotite with associated pyroxenite occurs as sheets and stock-like masses in a narrow interrupted zone, commonly referred to as the Serpentine Belt, which extends from the Vermont border just west of Lake Memphremagog for 150 miles to the northeast.

These and other occurrences of ultrabasic rocks in the Appalachian Region are shown in Figure 47. Small areas of rocks similar to those in the Serpentine Belt occur near Lake Matapedia and at Mount Albert, Serpentine Mountain, and near Port Daniel, in Gaspé Peninsula, but these areas have produced no com-

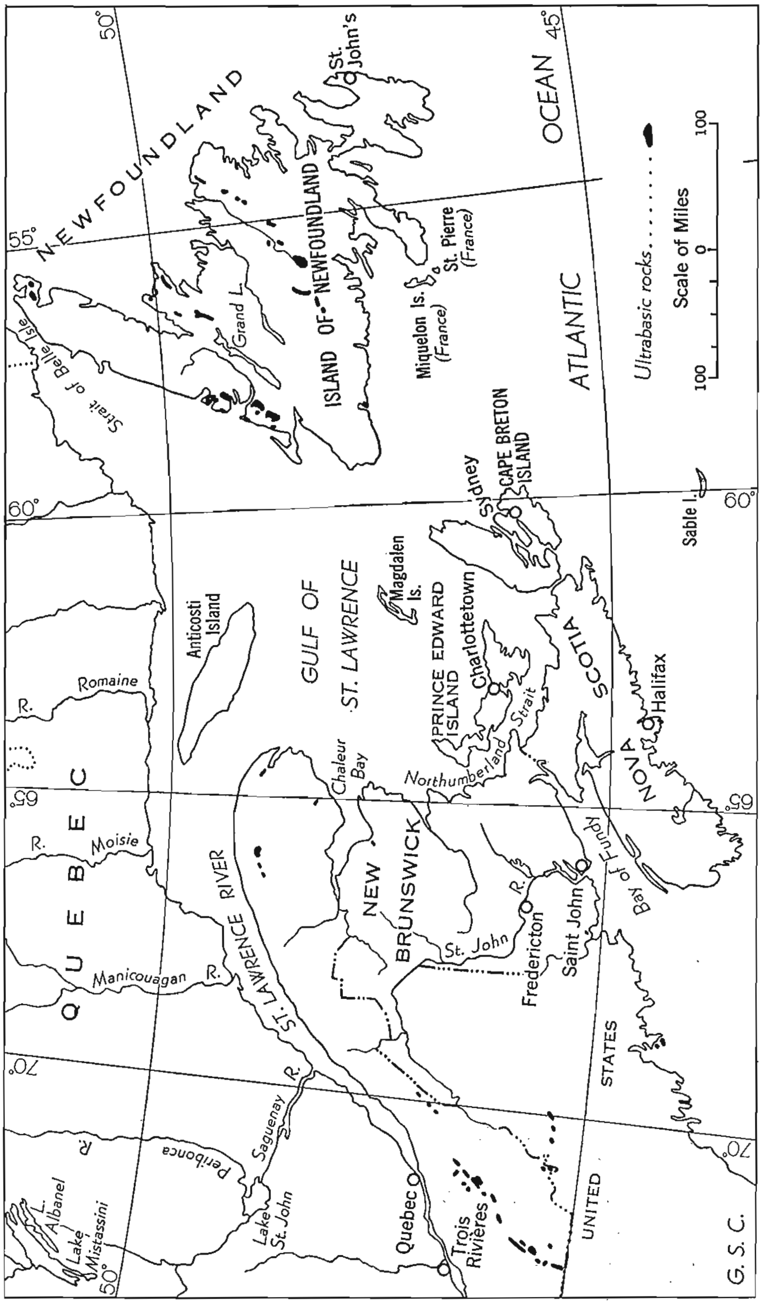


FIGURE 47. Occurrences of ultrabasic rocks in the Appalachian Region. (By C. H. Smith.)

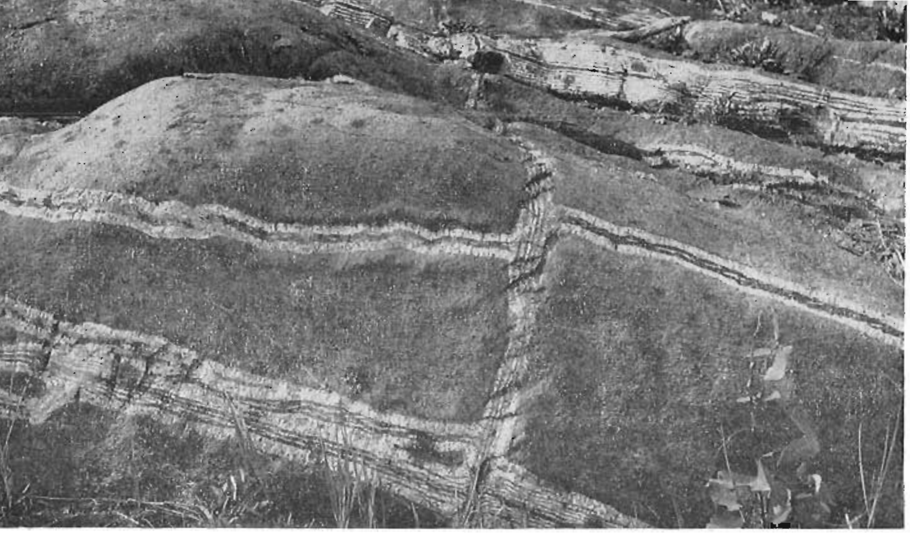


Plate XVIII — *Serpentinized peridotite at Black Lake, Quebec, showing veins of serpentine whose middle parts consist of asbestos.*

mercial fibre. Small occurrences of ultrabasic rocks are reported from central and southern New Brunswick. In Newfoundland there are at least two, and possibly more, parallel belts of ultrabasic rocks. A western belt trends northeasterly along the west coast of the island, and an eastern belt crosses the interior near Gander Lake. Smaller bodies of ultrabasic rocks are widely scattered between these two principal belts from the west side of Notre Dame Bay to La Poile Bay on the south coast. Asbestos fibre has been found in most of these bodies, but there has been no continued commercial production outside of the Eastern Townships of Quebec.

In the Thetford area the peridotite lies mainly within the Cambrian Caldwell group but also intrudes Ordovician Beauceville strata. In Newfoundland it cuts the Humber Arm group and rocks of Ordovician age near Gander Lake. It is probable that the age of the intrusions is late Ordovician, and that they were introduced at the time of the Taconic orogeny, but the possibility that they are in part of Devonian age cannot be overlooked. Small masses of granite and dykes of feldspar are associated with them; these may be differentiates of the basic magma or off-shoots from underlying masses of younger granite.

The asbestos is of two types, cross-fibre and slip-fibre. The former occurs in veins with clean-cut walls, and the fibres are arranged parallel to one another and at a high angle, or normal, to the walls. Most of the output is of this variety. Slip-fibre occurs in highly sheared serpentine and the fibres are more or less matted and lie lengthwise along the axes of slippage. The veins of cross-fibre vary in width from a hair line to 4 inches, although most veins are under three-eighths of an inch (Plate XVIII). That over three-eighths of an inch is known as 'crude', inasmuch as it is hand selected and cobbed, whereas shorter material is milled, the rock being crushed, beaten, and screened and the asbestos lifted from the

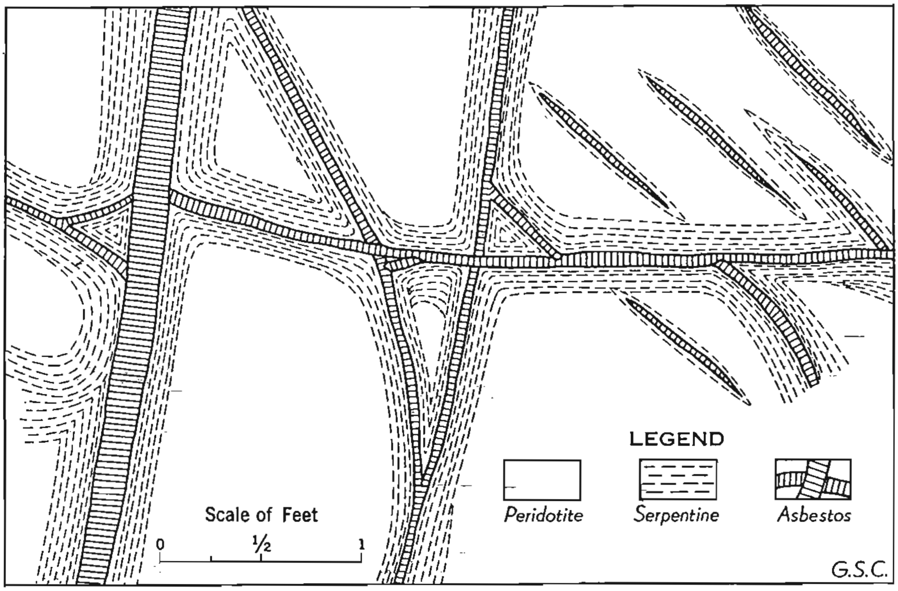


FIGURE 48. Asbestos and serpentine in peridotite, wall of pit near Standard mine, Black Lake, Quebec.

~~screens by over~~head suction. The milled variety amounts to more than 99 per cent of the total production.

The cross-fibre veins are of two types. In one a single set of fibres runs from wall to wall and is unbroken except by occasional inclusions. In the other, or two-fibre variety, the fibre extends from either wall, meeting at a central fissure that may contain serpentine similar to the wall-rock, and magnetite. Both types occur throughout the deposits. The walls of the veins consist of serpentine that passes abruptly into the ordinary partly serpentinized peridotite (Figure 48). This border zone is lighter in colour than the surrounding rock, locally contains brucite, and the edges are sufficiently sharp to enable the rock to split readily along them. The width of the altered zone, including the asbestos vein in the middle, is commonly from six to eight times the width of the vein itself. At some places bands of rock have been sliced along closely spaced, parallel or nearly parallel lines and the fractures have been filled with cross-fibre asbestos. These are known as ribbon veins and are found mostly at the Vimy Ridge mine southwest of Black Lake. The separate veinlets commonly average one-eighth to one-quarter inch in width, but occasionally reach an inch. The walls of the ribbon veins are broad bands of completely serpentinized rock, so that the whole ribbon corresponds to an individual vein of the ordinary type.

Though associated with the peridotite the asbestos is clearly of later origin. Veins cut across pyroxenite dykes and across masses of chromite in the peridotite. At one place a granite dyke was found to contain inclusions of peridotite and, in one of these inclusions, a vein of asbestos 3 feet long with a maximum width of three-quarter inch ran out from the peridotite into the surrounding granite. Evidently this asbestos was formed after the intrusion of the granite. The veins are related to fault fissuring and apparently were formed by vapours travelling along the fissures, converting the walls into serpentine. From the fissures, the vapours penetrated the pores of the rock and wherever they encountered incipient fractures they reacted with the peridotite, converting the walls into serpentine and carrying some of the excess material into the fissures to be deposited as asbestos. It is possible that this serpentinization and the production of the asbestos are related to the Devonian orogeny and accompanying intrusions. An earlier period of serpentinization probably occurred at a late stage in the consolidation of the peridotite and pyroxenite, as a result of reaction between the mineral constituents and associated magmatic waters.

Chromite

Chromite is associated with the ultrabasic intrusive rocks of the serpentine belt (Figure 47), already referred to in connection with asbestos. The first discovery of the mineral is attributed to Sir William Logan who is said to have found some loose blocks near Lake Memphremagog in 1842. From 1894 to 1909 there was a steady but small output but since then mining has been active only in war time, the known deposits being too small or too low-grade to compete with foreign sources. In 1918 shipments amounted to 15,600 tons of crude ore and 6,400 tons of concentrate. In 1944 total mill capacity of the producing properties was about 750 tons a day, compared with 200 to 300 tons in 1918. The production came from the Thetford-Black Lake area, from St. Cyr, 30 miles north of Sherbrooke, and from Webster Lake about 12 miles west of that city. Chromite was discovered in Newfoundland in 1864, but only minor production has resulted from concentrations of that mineral in the Bay of Islands complex, in the western part of the province.

The serpentinized rocks consist of three main varieties: dunite, composed wholly or almost wholly of olivine; peridotite, made up of olivine and pyroxene, the latter mineral constituting from 5 to 50 per cent of the rock; and pyroxenite, composed almost entirely of pyroxene crystals. Accessory grains of chromite occur in all three but appear to be most abundant in the dunite.

The chromite concentrations, with few exceptions, are confined to the dunite. They form deposits of three types, tabular, lenticular, and fracture-filling. The tabular bodies (Plate XIX) are relatively long in comparison with their width and may extend to considerable depth. The ore consists of grains of chromite in a groundmass of serpentine, and varies from lean disseminations to nearly massive chromite. It commonly shows a banded structure in which narrow chromite-bearing zones alternate with layers of barren or nearly barren rock. The tabular deposits are up to 2,000 feet long and 60 feet wide, but the workable ore may be confined to lenses within them. These deposits have been the source of most of the ore mined. The lenticular deposits consist of lenses and pockets or irregularly shaped bodies, and may be isolated or occur in a rather well defined zone. Each body

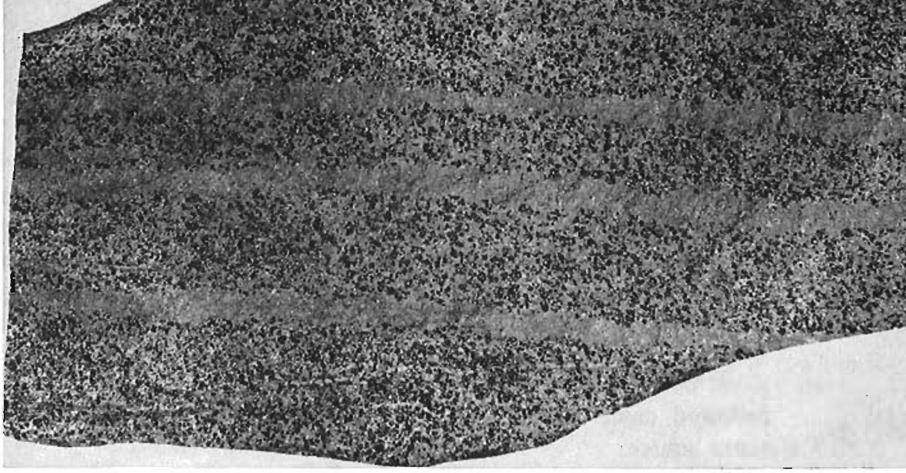


Plate XIX — *Specimen of a tabular chromite deposit in dunite, Black Lake, Quebec.*

may consist of disseminated ore, of nearly massive chromite, or of a mixture of the two. In the fracture-filling type short irregular cracks in the rock or spaces between fragments of breccia are filled with nearly massive or heavily disseminated chromite.

Chromium is an ubiquitous minor component of ultrabasic rocks, and the chromite was undoubtedly derived from the magma that produced these rocks. The chromite is generally of post-olivine age, but it formed before the consolidation and serpentinization of the host. It is probable that partial crystallization of a basic magma took place at depth, resulting in a general stratiform arrangement of an ultrabasic mush overlain by less basic differentiates. This still mobile mixture of crystals and magma was then intruded into its present site and the various rock types were intermixed as a result of the intrusive processes. The Bay of Islands complex in western Newfoundland is one of the best preserved remnants of a stratiform body in the serpentine belt, but other stratiform bodies, though more deformed, can be recognized in the Eastern Townships of Quebec. The chromite may have crystallized either before or after final emplacement of the crystal mush, but the final concentration of chromite was probably aided by a favourable chemical environment pertaining late in the history of the magma rather than by simple gravitative accumulation.

Talc, Soapstone, and Pyrophyllite

Soapstone, or massive fine-grained talc, is associated with the serpentine rocks of the Eastern Townships of Quebec and Newfoundland. Most of the production has come from the Thetford region of Quebec. In 1955 Quebec produced 12,562 tons of talc and soapstone valued at $143,895.

The soapstone of the Eastern Townships is an alteration product of serpentinized peridotite dykes that have been intruded into siliceous quartzite or schist. The soapstone bodies commonly lie at the margins of the dykes, and the schist is altered for a few feet from the contact into a mass of dark green chlorite. The soapstone has a higher silica content than the serpentine, and probably was produced by hot solutions that effected a transfer of silica from the siliceous wall-rocks. There is evidence that the formation of the soapstone took place later than that of the asbestos. In places veins of asbestos, altered to talc, are found in the soapstone bodies, and similar veins, retaining their cross-fibre structure though consisting now of talc, have been traced from the serpentine into the soapstone body. It is probable, however, that production of the asbestos and the talc followed each other closely and resulted from injections of solutions from the same source.

Talc has been observed in association with ultrabasic rocks near Tilt Cove, Notre Dame Bay; at Fleur-de-Lys, south of Mings Bight; on the north coast; and at Shoal Pond on the northeast coast of Newfoundland.

Pyrophyllite, which resembles talc in its physical properties and is used for many of the same purposes, is found at Manuels, in Conception Bay, Newfoundland. This deposit has been worked intermittently since 1904, but has had no production since the confederation of Newfoundland and Canada. The deposits lie in a narrow belt, about 6 miles long, to the south of the village. Over large areas, quartz-pyrophyllite has been formed near an intrusive granite by hydrothermal alteration of sheared rhyolite lavas and the conglomerates of the Harbour Main group of Precambrian age. Certain schist areas contain a high percentage of pyrophyllite in addition to scattered lenses of the nearly pure mineral. The formation of the pyrophyllite seems to have been influenced and localized by proximity to fissures near the granite boundary, and by the sheared condition and acid composition of the country rock.

Lead and Zinc

Lead and zinc occurrences have long been known in the Appalachian region, and the Buchans mine in Newfoundland has been producing for over 30 years. The discovery of large deposits in New Brunswick in 1952 and 1953 indicated the true potential of that region.

Newfoundland

The Buchans orebody, on the northwest shore of Red Indian Lake, was discovered in 1905 by an Indian. It was not until 1925, however, that a satisfactory separation of the sulphides was worked out and mining commenced. The orebodies, as originally developed, totalled 6,600,000 tons containing 0.05 ounce of gold and 3.1 ounces of silver a ton, 1.4 per cent copper, 8.5 per cent lead, 17.4 per cent zinc, 7.6 per cent iron, and 30 per cent barium sulphate. This total was increased in the early 1950s by the discovery of additional orebodies. The oldest rocks of the Buchans area are Middle Ordovician lavas, flow breccia, and tuff, mostly of andesitic composition, but ranging from rhyolite to basalt. Interbedded with these are arkose and minor amounts of conglomerate. These rocks are intruded by diabase, granite, andesite, dacite, and quartz porphyry. Sills and dykes of quartz porphyry, dacite, and andesite penetrate the sedimentary and volcanic rocks near the mines. The ore minerals are believed to have been introduced after the quartz porphyry. The ore is a massive, intimate mixture of fine-grained sphalerite, galena, pyrite, chalcopyrite, and a very little tetrahedrite. The gangue is composed of barite, which is present in the exceptionally large proportion of 30 per cent, and some quartz and calcite. The deposits are believed to be of the mesothermal replacement type and to be genetically related to the Acadian granite intrusions.

Veins containing lead and zinc, with varying amounts of silver, are common in the Precambrian rocks of the southeast coast. Only one mine, that at La Manche on the east shore of Placentia Bay, has to its credit any noteworthy production. The La Manche vein was discovered in the 1840s but mining operations did not begin until 1857. The mine is said to have furnished, through dividends, the capital necessary for the laying of the first trans-Atlantic cable which landed near the mine. The last active work was done on the property in 1924. The vein consists dominantly of coarse, comb calcite containing galena and very minor quantities of sphalerite, chalcopyrite, quartz, and barite. The galena occurs in scattered grains and as unusual radiating crystal aggregates up to several inches in diameter that have grown simultaneously with calcite. The vein has been traced inland from the shore of Placentia Bay for 3,000 feet. It probably reaches its maximum width at the shore and no attempt has been made to mine it under the bay. The vein has been mined to a depth of about 100 feet for a distance of about 1,500 feet but some of the old workings extend to depths of 150 to 300 feet.

Veins and some replacement deposits are found at several places on the northeast and south coasts, notably at Bear Cove, Fleur de Lys, La Poile, and Baie d'Espoir. On the west coast widespread Ordovician and Carboniferous limestones contain many small deposits of lead and zinc. The chief concentrations appear on Port au Port Peninsula as low temperature deposits, possibly of ground-water origin.

Nova Scotia

Galena, and galena and sphalerite occur at a number of places in Nova Scotia associated with Carboniferous limestones, either as fine disseminations in the rock or in veins and small pockets.

In southeastern Cape Breton Island the Mindamar lead-zinc mine at Stirling was active as a zinc producer in the late 1930s, was re-opened in 1950, and ceased production in 1956. The mine is on a number of massive lenses of mixed sulphides near a subsidiary shear zone associated with a principal fault of the region, the Stirling fault. The ore zones replace the Bourinot rocks of Middle Cambrian age that consist of greywacke, volcanic breccia, and some volcanic flows. These rocks are cut by numerous dykes of diorite and andesite that may be as much as tens of feet wide. Rocks of the Bourinot group were replaced or altered to zones or talc schist, and such zones were later replaced by sulphides that include sphalerite, pyrite, chalcopyrite, and galena.

Deposits in Carboniferous rocks of Nova Scotia include massive intergrowths of galena and sphalerite in a fissure, and as nodules, in Windsor limestone near

Jubilee, about 4 miles from Grande Narrows, Cape Breton Island, and at Smithfield, 12 miles southeast of Truro. The latter deposit consists of angular blocks of sulphides and of grey limestone embedded in a muddy matrix of finely broken ore and limestone. The sulphide masses are composed of pyrite and galena, with smaller proportions of a mixture of sphalerite and galena.

New Brunswick

Although small deposits of zinc and lead were found in New Brunswick many years ago, it was not until 1952-54, when several large deposits were discovered, that the province became a potentially important producer of these metals. These deposits are in the Bathurst-Newcastle area in the northeastern part of the province. They have been outlined by diamond drilling, and are being developed for open pit

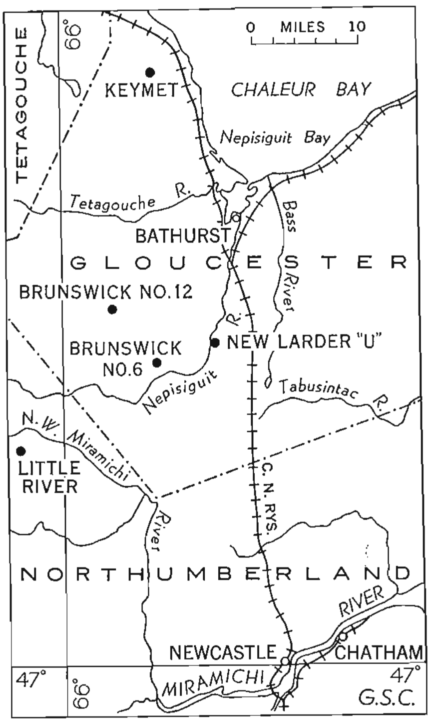


FIGURE 49. Northeastern New Brunswick showing the principal base metal sulphide deposits (black dots) being developed in 1955.

and underground mining. One of them, known as the Austin Brook, or Brunswick No. 6 deposit (Figure 49) is a lenticular mass about 1,100 feet long, from 100 to 200 feet wide, and is estimated to contain, to a depth of 1,000 feet, 28,312,000 tons averaging 4.1 per cent zinc, 1.6 per cent lead, 0.4 per cent copper and 1.4 ounces of silver a ton. The Anacon, or Brunswick No. 12 deposit, is 1,200 feet long, 80 to 200 feet wide, and is estimated to contain, to a depth of 1,000 feet, 27,440,000 tons averaging 5.3 per cent zinc, 1.9 per cent lead, 0.6 per cent copper, and 1.8 ounces of silver a ton. East of North Little River Lake eight irregular shaped deposits have been found within a belt 3 miles long, and are estimated to contain 4,200,000 tons averaging 2.90 per cent lead, 7.10 per cent zinc, and 1.10 per cent copper, and an additional 3 million tons averaging 1.20 per cent lead, 3.50 per cent zinc, and 1.30 per cent copper. At Middle Landing the new Larder "U" deposits comprise three orebodies totalling 1,173,540 tons averaging 8.2 per cent combined zinc and lead.

All of these deposits are composed of solid or nearly solid sulphides, chiefly pyrite with sphalerite and galena and locally with pyrrhotite and chalcopyrite. The sulphides are commonly fine grained, banded, and are of replacement origin. They occur in rocks of the Tetagouche group of Ordovician age comprising greywacke, slate, quartzite, iron-formation, and acid to basic volcanic rocks. Quartz-feldspar porphyry forms conformable bodies within the Tetagouche group. All of these rocks are complexly folded and intruded by small bodies of gabbro and by stocks and batholiths of Devonian granite. Most of the massive sulphide deposits occur in incompetent formations near bodies of quartz-feldspar porphyry.

The Keymet deposit, 15 miles northwest of Bathurst, is a vein that follows a fault and contains pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite in a gangue of calcite, quartz, and a little fluorite. Ore reserves above the 600-foot level are estimated at 112,000 tons averaging 4.41 per cent lead, 4.31 per cent zinc, 0.55 per cent copper, and 1.42 ounces of silver a ton. Production of lead and zinc concentrate commenced in 1954 and ceased in 1956. The deposit lies in sedimentary rocks of the Elmtree group which is probably Devonian in age.

A number of other occurrences are known in northern New Brunswick, many of which will possibly become mines on further development. One replacement sulphide deposit near the upper Tetagouche River has been traced for over a mile, but has a width of less, and in some places much less, than 30 inches. This deposit is of replacement origin in schists of supposedly Ordovician age that were derived from volcanic tuffs.

Quebec

In central Gaspé a large amount of development work has been done on occurrences of zinc and lead, but no production has yet been attempted. The mineralized area lies on the north branch of Berry Mountain Brook and on Brandy Brook, headwaters of Cascapedia River. A motor road leads from the railroad at Cascapedia, near Chaleur Bay, to the property. The rocks of the mineralized belt are Lower Devonian shales and sandstones overlain by basic volcanic flows. The volcanic rocks, in turn, are succeeded by Gaspé sandstones of Middle Devonian age. The Lower Devonian sediments are folded, faulted, and intruded by dykes and stocks of granite, syenite, diorite, and porphyry. The deposits are veins and mineralized breccia zones carrying sphalerite and galena and, in places, chalcopyrite; the gangue is quartz and carbonate. Some of the later quartz is of the amethystine variety. The veins vary up to 50 feet or so in width, and some have been traced for half a mile. They vary greatly in their mineral content. Post-mineral faulting makes it difficult to follow certain veins.

Copper

Newfoundland

Copper mining is the oldest important mineral industry of Newfoundland. Following the discovery of copper at Tilt Cove in 1857, and its successful operation, an intense search for other deposits in Notre Dame Bay was rewarded by numerous finds, of which Baie Verte, Betts Cove, Little Bay, and Phillips Island developed into substantial mines, and numerous lesser properties were worked for short periods. This industry centred around Notre Dame Bay and only a few discoveries were made elsewhere. Some of the larger mines continued in operation up to World War I, after which production waned due to the depletion of high-grade ore. Maritime Mining Corporation, Limited has been preparing its Tilt Cove Copper mine on Notre Dame Bay for production.

In addition to the true copper mines, copper is an important accessory mineral in the Buchans ore deposit; in 1955 the Buchans mine produced 6,103,516 pounds of copper. Native copper occurs at Odern Island, Placentia Bay, and in Rope Cove Canyon, Bay of Islands.

The copper deposits and occurrences on the west side of Notre Dame Bay display a genetic association with diorite, quartz diorite or granodiorite, and chloritized volcanic rocks. The deposits are of two main types. The first are pyritic replacement deposits, in which chalcopyrite and pyrite occur in chlorite schists, as lobes of massive sulphide, or disseminated veins and impregnations, and which are represented by the Tilt Cove East mine and Betts Cove. In the second type pyrite and chalcopyrite are found in numerous small and large quartz veins usually in chlorite schists, as exemplified by the Tilt Cove West mine, Little Bay, and Rogues Harbour.

Occurrences of copper are common elsewhere in the Island. In late Precambrian rocks of the Avalon Peninsula they occur as stringer and fissure fillings; on the west coast they are associated with, or in, intermediate or basic igneous rocks. In 1951 a field party of the Geological Survey of Canada discovered an occurrence of massive pyrrhotite and chalcopyrite at the contact between gabbro and sandstone about 3 miles west of the village of Bonne Bay. Assays of hand specimens averaged 2.05 per cent copper and 1.35 per cent nickel with traces of the platinum group of metals. This occurrence is still under exploration.

New Brunswick and Nova Scotia

Numerous occurrences of copper minerals are known in New Brunswick and Nova Scotia but production has been very small. Copper is, however, an important, if minor, constituent of the massive lead and zinc ores at Stirling, Nova Scotia, and in the Bathurst-Newcastle area deposits in New Brunswick.

At Cape d'Or, Cumberland county, N.S., native copper occurs in veins and long joints in Triassic diabase, and small quantities are found in some of the traps of Grand Manan Island. In southern New Brunswick, copper minerals, chiefly chalcopyrite, and locally bornite, are present in veins in igneous and schistose rocks. Occurrences are known from the islands of Passamaquoddy Bay eastward to Albert county. At St. Stephen a sulphide replacement deposit of considerable size carries a little copper and nickel. Secondary copper minerals occur in Carboniferous sandstone at a number of places in both provinces. In Nova Scotia they are found in districts bordering Northumberland Strait; in New Brunswick the principal showings are at Dorchester in Westmorland county, at New Horton in Albert county, and at Goshen near Elgin at the western border of Albert county. At these places a little chalcocite and malachite is associated with plant remains in the sandstone. Considerable development work was done at Dorchester and a small amount of copper was produced.

Quebec

Copper mineralization was discovered in 1921 near the headwaters of York River, Holland township, Gaspé Peninsula. Development by Gaspé Copper Mines Limited has proved about 70 million tons carrying between 1 and 2 per cent copper. Milling commenced on April 7, 1955, the capacity of the plant being 6,500 tons a day. The ore consists of chalcopyrite and other copper minerals, mainly replacements of skarn and other altered sedimentary rocks, but also as disseminations and fracture fillings in siltstones and in porphyry. Although chalcopyrite is the most common copper mineral, its alteration products, malachite, with lesser azurite and chrysocolla, are present. Pyrite is present locally and molybdenite has been reported.

Copper has been known in the Eastern Townships of Quebec since 1841, and from 1859 to 1866 the region was prospected by hundreds of shafts. At first the deposits were worked for their copper content alone, but commencing about 1877, sulphur also was produced from the associated pyrite. Between 1886 and 1939, 170 million pounds of copper were produced.

The deposits lie within a belt 30 to 40 miles wide and 130 miles long extending northeasterly from the Vermont border to Chaudiere River. The belt includes the Sutton Mountain anticline and extends some 20 to 25 miles to the east of it. The country east of the anticline is underlain mainly by Palæozoic sedimentary formations, minor volcanic flows, and intrusive rocks. Most of the larger copper deposits lie near the eastern and western edges of the belt. Brief accounts of some of the more important properties follow (Figure 46).

The Acton mine is near Acton Vale, west of the Sutton Mountain belt. It produced about 12,000 tons of ore averaging 12 per cent copper between 1859 and 1864. The deposits occurred in three main areas within a length of 720 feet, and lay in a band of cherty limestone, 2 to 70 feet thick, resting on black slate. The beds are of Ordovician age and are faulted and deformed. Most of the ore, which consisted of chalcopyrite and bornite, occurred as a cement around brecciated limestone fragments, or as veins or impregnations in the limestone.

The schistose rocks of the Sutton Mountain belt contain many occurrences of copper minerals, but the deposits are mostly small. The richest was the Harvey Hill mine, discovered in 1850. There three bands of slaty schist carry disseminated grains and small stringers of chalcopyrite, in places with some bornite and pyrite. The deposit was worked at intervals from 1858 to 1899; production amounted to several thousand tons of ore whose copper content ranged from 14 to 30 per cent.

East of the Sutton Mountain schistose belt are copper deposits associated with basic intrusive rocks along the serpentine belt. The intrusions are of gabbro, pyroxenite, and serpentinized peridotite; they form an almost continuous series of sill-like masses on the east side of Mississquoi Valley. Copper occurrences are scattered over a length of 10 miles and occur within or near the western contacts of the intrusions, where the rocks are schistose. The schistose zones have been impregnated with chalcopyrite and pyrite and in places carry veins and stringers of quartz containing these sulphides. The Huntingdon mine of Quebec Copper Corporation, Limited about 3 miles south of Eastman, was worked at intervals between 1865 and 1883 and in 1956 was in operation with a new plant and new equipment. The orebodies lie in altered andesite near its contact with a dyke of serpentine. The ore minerals are chalcopyrite, pyrite, pyrrhotite, and a little sphalerite.

On the eastern side of the copper belt are a number of copper occurrences that include what have been the most important deposits of the district. They follow a zone of intimate faulting and folding of Palæozoic volcanic and sedimentary rocks, sometimes referred to as the Stoke Mountain anticline, and lie, for the most part, in sericite schist or at the contact of schist and other rocks.

The Suffield mine of Ascot Metals Corporation, Limited and the nearby Albert mine have been operated intermittently since 1865 when attempts were made to hand sort the higher copper ore from an assemblage of mixed sulphides. The ore occurs in green chloritic tuff on the foot-wall side of quartzite and forms two flat lenses, the largest being 1,500 feet long and 200 feet wide. The ore contains 1 per cent copper, 5 per cent zinc, and 0.05 per cent galena, as well as minor amounts of silver and gold. In 1955 the mine was producing approximately 400 tons per day. The ore is treated at the mill of the Moulton Hill mine a few miles away.

The Eustis mine, a few miles southeast of the Suffield mine, has been the most important copper producer of the entire district. From the time it was first operated, soon after its discovery in 1865, until it was closed in June 1939 the

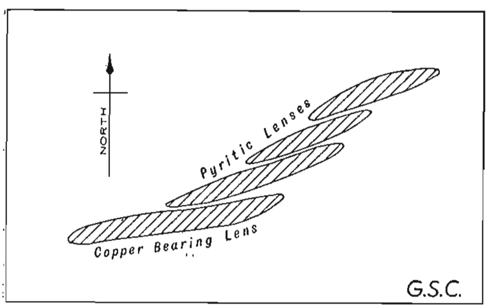


FIGURE 50. Diagrammatic plan, showing *en échelon* arrangement of sulphide lenses, Eustis mine. (After V. Douglas.)

mine produced about 2,500,000 tons of ore. The orebody, which extends over a length of 400 feet and has a maximum width of 90 feet, consists of four lenses arranged *en échelon* (Figure 50). They dip southeast, conforming with the schistosity of the country rock. The remarkable feature of the deposit is its depth: the inclined shaft in the foot-wall of the deposit has a length of more than 7,000 feet. The principal sulphide is pyrite, but there is an appreciable amount of chalcopyrite in one of the lenses. Pyrrhotite is also present and increases with depth.

The Moulton Hill mine of Ascot Metals Corporations, Limited a few miles northeast of Sherbrooke, was developed initially as a producer of pyrite, but during the early period of operation may have yielded a little copper. In 1942 a discovery was made, by the use of detailed geological and geophysical methods, near the old mine. The new deposit is along a fault or shear zone and consists of pyrite, sphalerite, galena, chalcopyrite, and a little tetrahedrite, with a gangue of barite, quartz, and calcite. Following this discovery a mill was erected and the mine was operated for a short period. The mine is inoperative at present but the mill treats ores from nearby properties.

The Weedon mine, of Weedon Pyrite and Copper Corporation, Limited, 5 miles east of Weedon station and 40 miles northeast of Sherbrooke, was an important producer of copper between 1909 and 1921. In 1951 it was dewatered, resampled, and drilled. The sampling indicated an average content of 2.09 per cent copper, 1.05 per cent zinc, and 34.8 per cent sulphur. The mine produces copper concentrates and pyrite.

Gold

Gold is recovered as a by-product from base metal sulphide ores in Newfoundland, Nova Scotia, New Brunswick, and eastern Quebec; has been extensively mined in Nova Scotia where the deposits are quartz veins; and has been recovered from placers in the Eastern Townships of Quebec.

Practically all of the gold production of Newfoundland, some 170,000 ounces, has been a by-product from base metal ores, chiefly the zinc-lead-copper ore of the Buchans mine and the pyritic copper ores of Notre Dame Bay. Only two gold mines, at Mings Bight and in Sops Arm, have been worked and during 1903 to 1906, the period of operation, each produced about 150 ounces of gold.

Gold mining began in Nova Scotia in 1862. The annual production has varied greatly and reached a high of more than $1 million in 1939; it was 3,880 ounces valued at $134,000 in 1955. Most of the production has come from the peninsular part of the province where the deposits are in slate and quartzite of the Meguma, or Gold-bearing series. In the numerous gold districts scores of properties have produced gold. The deposits are veins that occur for the most part along the bedding of the sedimentary rocks and are most abundant on anticlines or domes (Figure 51). As a rule, they are widest along the axes of the anticlines and become narrower or pinch out on the flanks, thereby forming bodies known as saddle reefs. Some cross-cutting veins also occur, and in a few districts form the

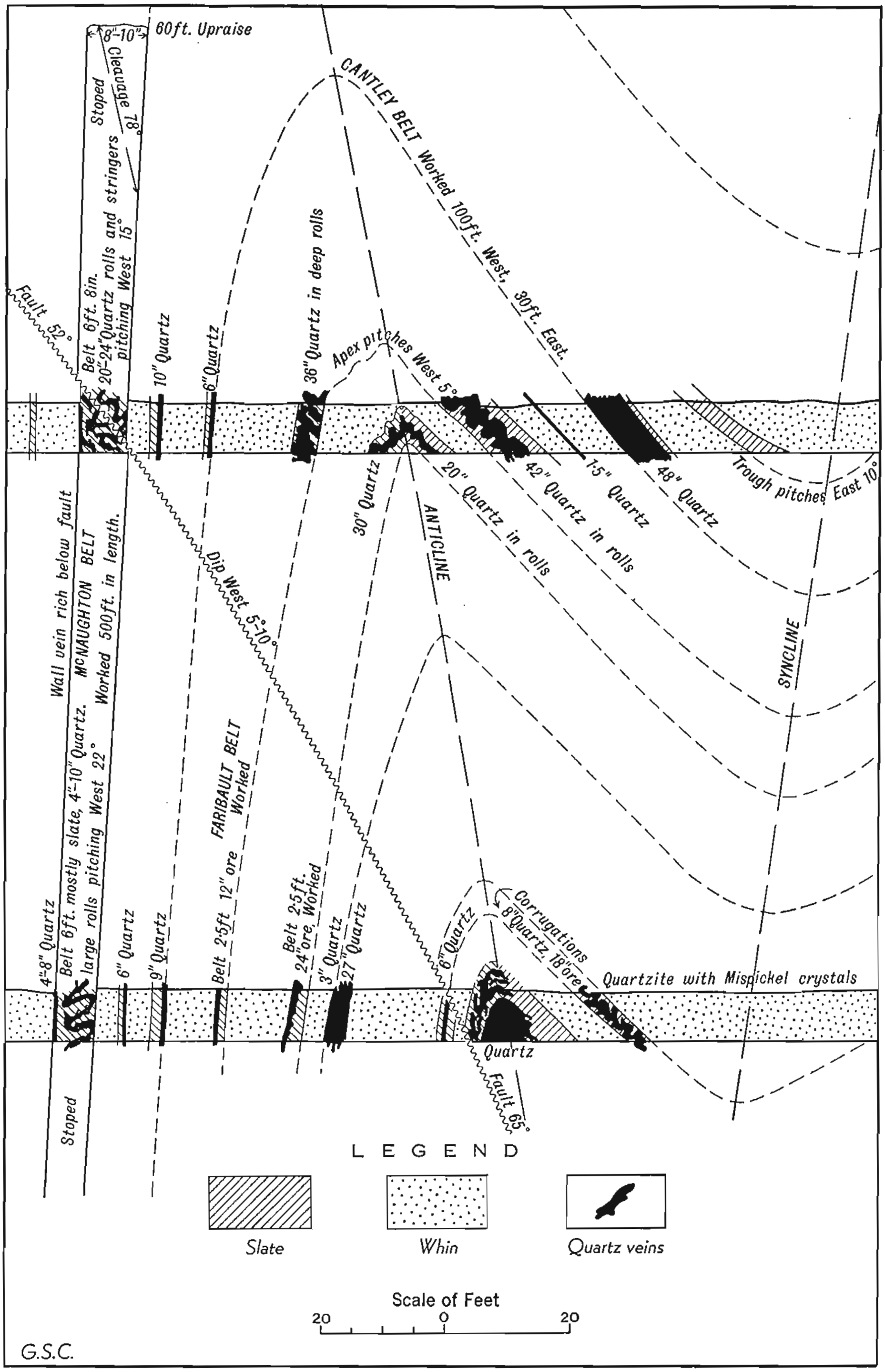


FIGURE 51. Detailed transverse section of the 280- and 364-foot levels of the Bluenose gold mine, Goldenville, Nova Scotia. (After E. R. Faribault.)

principal deposit. The minerals associated with the gold-bearing quartz are principally pyrite, arsenopyrite, calcite, and galena. Most of the gold is free and visible, but some is contained in the sulphides. The veins are not all gold-bearing and in those that are the gold is commonly concentrated in shoots. The deposits are believed to owe their origin to solutions emanating from bodies of Devonian granite that intrude the Meguma rocks.

Gold has been found in several localities in Cape Breton Island. The deposits occur in altered sedimentary rocks and intrusions of Precambrian or early Palæozoic age, which can in no way be correlated with the Meguma series of the mainland. The gold occurs in quartz veins and in placer gravels. A small production from both types of deposit was obtained on Middle River, in Victoria county.

Production of placer gold from the Eastern Townships of Quebec has been estimated to be $3 million. The first recorded discovery was in 1823, near the mouth of Gilbert River, a tributary of the Chaudiere. Mining operations began there in 1847 and as the shallow deposits became exhausted, work was carried up the Chaudiere, the Gilbert, and other tributaries, and richer deposits were located in buried channels and benches of preglacial streams. The period of most active mining was from 1875 to 1885. Apparently the placers were derived from quartz veins in the district. Evidence for this is the fact that many of the nuggets were rough and angular, with occasional bits of the vein quartz still attached, suggesting that they had not travelled far. However, although the region contained many quartz veins, none large or rich enough to mine has been found.

Iron

The Appalachian region of Canada contains a large number and many types of iron occurrences. In 1955 about 16 per cent of the Canadian production of iron ore came from the Island of Newfoundland. There are also deposits in Nova Scotia and New Brunswick. In addition, many small deposits of magnetite, hematite, and limonite occur in sedimentary rocks of Nova Scotia, New Brunswick, and southeastern Quebec but none is of present economic interest.

Newfoundland

Output of iron ore from the Bell Island deposits of Dominion Wabana Ore, Limited near St. John's, Newfoundland in 1955 was 2,030,227 tons. Shipments amounted to 2,377,237 tons, of which Dominion Steel and Coal Corporation at Sydney, N.S. took 459,500 tons, the United Kingdom, 857,500 tons and West Germany 977,000 tons.

The Wabana ores were first recognized as such in 1892, although references to "red rock" and even to an "iron mine" occur in the literature back as far as 1819. Shortly after the recognition of the ores the Nova Scotia Steel and Coal Company, Limited acquired mining areas there, and this company or its successors have mined the ore continuously since that itme.

Five zones of oolitic hematite are exposed in the Lower Ordovician rocks on the island. Three of these are mineable and are known locally as the Dominion,

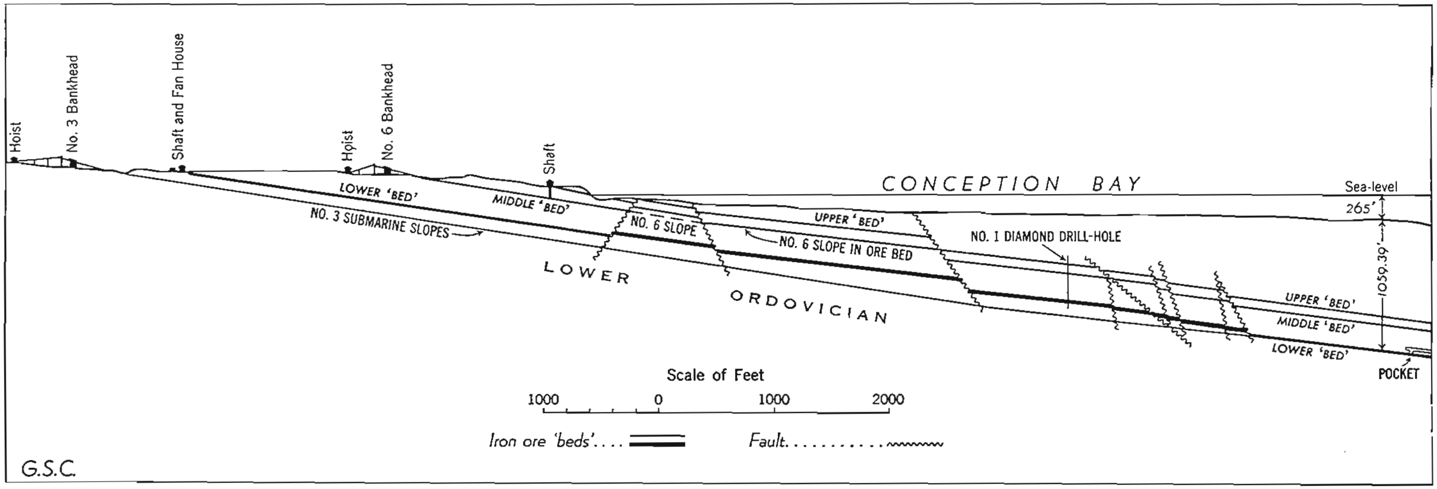


FIGURE 52. Vertical section on line of No. 3 mine submarine slopes, Wabana iron mines, Newfoundland. (After J. B. Gilliatt, 1924, corrected to March 1949, by courtesy Dominion Steel and Coal Corporation.)

the Scotia, and the Little Upper beds, or else are known as the Lower, Middle, and Upper beds. They occur in the upper part of the Lower Ordovician Bell Island and Wabana groups in the northwestern part of Bell Island. Ore and rock beds dip gently to the northwest and pass beneath Conception Bay (Figure 52). The workings in the various mines extend about 2 miles from shore. The Upper and Middle iron beds are separated by 58 feet of intervening strata, and the Middle and Lower beds, by about 240 feet, including an oolitic pyrite zone. The iron deposits are in general conformable with the bedding of the enclosing strata and are believed by many to be sedimentary in origin, although alternative theories have been proposed.

Newfoundland has a number of other iron ore deposits, some of which may have limited economic possibilities. Two such deposits are found on the Bay de Verde Peninsula in Proterozoic sedimentary rocks and the largest of these is the Workington mine, near Lower Island Cove. In 1898 seven shafts, ranging from 40 to 170 feet in depth, were sunk on red hematite which had a higher iron content than the Wabana ore and was almost free of sulphur and phosphorus. As sufficient ore for profitable mining was not developed, operations ceased in 1899. Somewhat similar ore at Snows Pond near Bay de Grave, 35 miles south of Workington, was diamond drilled in 1928 by the Bethlehem Steel Company Incorporated. This occurrence is in Proterozoic sedimentary rocks of the Conception group.

At Indian Head, on the northeast shore of St. Georges Bay, concentrations of ilmenitic magnetite with minor hematite have been mined. These are replacement deposits in gneissic syenites and granites. The iron-rich bands are parallel to the foliation of the gneiss and favour the hornblende-rich facies of the rock. Deposits of ilmenitic magnetite have been known since 1873 on the mountains of the Long Range about 3 miles east of the village of St. Georges, on the west coast of Newfoundland. Magnetite occurs as lenses and elliptical bodies in anorthosite, and there is reason to believe that it was introduced shortly after the consolidation of the anorthosite. The magnetite contains about 5 or 6 per cent titanium and 0.20 per cent vanadium. There is very little phosphorus in the ores. Some of the magnetite bodies are of considerable size and may have commercial possibilities.

Nova Scotia

The Londonderry iron deposits on the Cobequid Mountains of Cumberland county, N.S., were first developed commercially in 1849. In 1870 the first steel plant was inaugurated at Londonderry and shortly thereafter, Dr. Siemens of Germany there made his first experiments in the direct conversion of iron into steel. In 1877 the first coke ovens were built and the use of charcoal was discontinued. In 1874 the properties were purchased by the Steel Company of Canada which went into liquidation in 1899. In 1902 the Londonderry Iron and Mining Company acquired the property and continued operations until about 1908. Since then there has been no mining or smelting in the district. Approximately 2 million tons of ore have been mined from the Londonderry district. The deposits are oxide enrichments of lenticular masses of iron-bearing carbonates, of which ankerite, a calcium-magnesium-iron carbonate, is most common. The enrichment was brought about by surface waters and this factor limited development to those depths to which the waters could percolate. These depths were found to be much greater near sudden changes of topography than on the relatively flat tops of the Cobequid Mountains. In general the unenriched carbonates had no possibilities as ore. However, they may have a use, and indeed were so used in the past, as iron-bearing flux in the treatment of other ores.

Iron deposits at Nictaux and Torbrook, Annapolis county, had been known since very early in the nineteenth century. In 1825 the Annapolis Iron Mining Company was formed and a large smelter was erected on Moose River near Clementsport. Most of the ore treated came from the Nictaux-Torbrook field, near the Nictaux River. Operations in the area continued sporadically until 1916, since then there has been no activity. The iron ore is of sedimentary origin and occurs with slates and quartzites of early Devonian age. The beds are folded into a syncline and locally are crumpled, faulted, and sheared. They are intruded by dykes and masses of gabbro and diorite, and on the south are cut off by a granite batholith. The ore lies in two nearly parallel zones about a mile apart. The zones lie on opposite limbs of the syncline and probably represent the same horizon. The southern zone has been traced along the strike for about 5 miles. It is made up of interbedded slate and ferruginous rock, the whole having a thickness of some 18 feet. The iron-bearing rock is in places oolitic; locally it carries hematite, but for the most part is composed of magnetite and spherulitic green iron silicate in a cement of quartz and fine-grained argillaceous material. The northern zone has been traced for 4 miles. It includes three or more iron ore beds. Most of the production has been from ore bands that are 4 to 9 feet thick. The magnetite may be secondary after hematite or the iron silicate.

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

New Brunswick

Magnetite deposits occur on Austin Brook, about 17 miles south of Bathurst. Between 1910 and 1915 more than 200,000 tons of ore were produced from these deposits. Some mining was done in 1943, when shipping conditions made it hazardous to freight iron ore from Newfoundland to Sydney. The ore is chiefly magnetite, but some hematite is present; in places it is well banded. It is associated with quartz porphyry and diabase, of either volcanic or intrusive origin, and occurs in rocks of supposedly Ordovician age. The magnetite bodies are related, spatially at least, to the large sulphide deposits under development near Bathurst. The ore is probably of sedimentary origin and part of the original iron-formation has been altered to magnetite.

Bedded iron ores are known in the general area west of Woodstock. Manganese appears to be the more valuable metal in these deposits.

Manganese

Manganese minerals are known at many places in Nova Scotia and New Brunswick. Early attempts to develop the more important occurrences resulted in the production of some 40,000 tons of high-grade material. Bedded deposits of manganese minerals occur in Cambrian rocks surrounding Conception Bay, Newfoundland, and in lower Palæozoic rocks near Woodstock, N.B.

The deposits include a variety of types of which the more important are ores associated with Carboniferous strata, particularly the Windsor limestone; ores filling fissures in pre-Carboniferous rocks; bedded low-grade deposits of manganese minerals in lower Palæozoic rocks, usually associated with some iron minerals; and surface bog deposits.

Deposits of the first type include those at Markhamville, Turtle Creek, and Shepody Mountain in New Brunswick; Tennycape, in Nova Scotia; and the Magdalen Islands, in the Gulf of St. Lawrence.

The manganese at Markhamville, about 10 miles south of Sussex, N.B., was discovered in 1862. The property was worked sporadically until 1895 and about 23,000 tons of ore were shipped. The ore consisted of crystalline and massive pyrolusite and manganite with some psilomelane, and occurred in masses and pockets along bedding planes and joints in gently dipping Windsor limestone. Considerable quantities of ore were also found on the surface in residual clay.

At Berryton, on Turtle Creek, about 15 miles southwest of Moncton, a small tonnage of psilomelane and pyrolusite was recovered from a gently dipping band of Windsor limestone about 25 feet thick. The ore occurs at the top of the limestone, which is overlain by Pennsylvanian sandstone and conglomerate.

The Shepody Mountain Manganese mine is on the west side of Shepody Mountain, about 3 miles from Hopewell Hill, Albert county, N.B. A small tonnage of ore was recovered from a band of Windsor limestone and a thin bed of overlying red clay. The limestone rests on chlorite schist, and the clay is succeeded by conglomerate, sandstone, and shale. Most of the ore occurred as nodules in the clay between the limestone and the conglomerate.

The Tennycape mine is in the village of Tennycape, Hants county, N.S., about 1½ miles southwest of a highway bridge over Tennycape River. From 1880 to 1900 the mine was the largest producer of manganese ore in Nova Scotia. A few attempts, all unsuccessful, have since been made to re-open the mine. No orebodies are known at present. About 4,000 tons of manganese oxides were produced from this property. The orebodies lay in Windsor rocks near their contact with underlying Horton shales. Manganese oxides occurred as fissure fillings in the lowermost Windsor formation, the Macumber shaly limestone, and as nodules and replacements in the Pembroke limestone conglomerate which overlies the Macumber. As at Markhamville, much ore in the early days was recovered from residual masses of oxides in the overlying clay. Within 10 miles of the Tennycape mine are no less than 15 manganese occurrences, many of which had a production of at least several hundredweight of oxide. The manganese oxide won from these deposits was of exceptionally high grade and classed as chemical ore, thereby commanding a much higher price than ordinary ores.

Manganese oxides occur at a number of places on the Magdalen Islands, particularly on Grindstone and Amherst Islands. The ores are mainly oxides and occur as masses of float in the soil and as replacements of Windsor limestone beds near their contact with overlying red sandstone of probable Pennsylvanian age.

The second type of deposits, those filling fissures in pre-Carboniferous rocks, occur at Gowland Mountain, Jordan Mountain, and Tetagouche Falls in New Brunswick, and at New Ross, N.S. Manganese ores at Gowland Mountain, near Elgin, and Jordan Mountain, near Sussex, N.B., are vein fillings in rocks of probable Precambrian age. The original source of the manganiferous material is believed to have been the surrounding volcanic rocks, and the concentration in veins was effected by surface water solutions. The Gowland Mountain deposit was developed during the Second World War and a small tonnage was shipped. At Jordan Mountain mine manganese ores occur as fracture fillings in Precambrian felsites, but in addition occur nearby as fracture fillings and as matrix in Carboniferous conglomerate and breccia.

Near Tetagouche Falls on the Tetagouche River, about 8 miles west of Bathurst, N.B., manganese minerals occur as narrow seams and plates, mainly of manganite, in quartz veins, and as veinlets in red slate of the middle Ordovician Tetagouche group. In places the veinlets of manganite are plentiful enough to allow consideration of the occurrence as a low-grade, high-tonnage proposition. The principal objection to such an operation is that the ores occur beneath the Tetagouche River at the bottom of an extremely deep gorge.

The manganese mines at New Ross are in the northern corner of Lunenburg county, N.S., about 8 miles from the village of New Ross. Manganese was discovered in this district about 1891 and three mines were operated, two of them being about 2 miles west of the third. Mining continued sporadically until 1921 and was resumed in 1942. In that year the Geological Survey of Canada, acting for the Metals Controller, examined and diamond drilled the deposits. Some ore was found at a distance from the old workings but widths were narrow and it was not considered an attractive proposition at that time. The orebodies lie in lenticular masses occupying fault- and crush-zones in Devonian granite. The north walls of the orebodies are in general sharp and lie against undeformed granite. On the south the lenticular masses of manganese oxide are bordered by an extensive zone of crushed and altered granite containing much hematite, limonite, and some calcite. The mining operations indicated that the ores did not extend to depths in excess of 200 feet, and the deposits, therefore, are considered to have been formed, or enriched, by surface waters.

The third type, those of bedded low-grade material in lower Palæozoic rocks and usually associated with some iron minerals, occur around Conception and Trinity Bays in Newfoundland and near Woodstock in New Brunswick.

Manganese-bearing beds surrounding Conception Bay, and to a lesser extent, Trinity Bay, occur in Middle Cambrian strata which exist as erosional remnants on the Precambrian rocks. Manganese is believed to have been leached from the Precambrian rocks during Middle Cambrian time, transported in the form of the bicarbonate, and deposited in sedimentary basins as the carbonate by the loss of carbon dioxide. The beds vary in thickness from ¾ foot to 4.5 feet, and usually exist in a zone of much greater width which contains less manganese. Such beds are found at Topsail, Manuels, Long Pond, Kelligrews, Chapel Cove, and Brigus in Conception Bay, and at Smiths Point, Trinity Bay.

Low-grade deposits of iron-rich manganese ore lie west and northwest of Jacksonville, a village 4 miles northwest of Woodstock, and minor occurrences are known elsewhere in the general country west of Woodstock, and between it and the International Boundary. The deposits were mined as a source of iron intermittently from 1848 to 1884. About 70,000 tons of ore were smelted and the iron obtained was reportedly used for gun boats of the British Navy. The deposits occur in rocks of Silurian age and apparently were originally iron-formation. They consist of low-grade manganiferous hematite interbedded with red and green slates. The rocks have been folded into a series of steeply plunging folds. The manganese content of the two principal occurrences varies between 9.30 per cent and 22.38 per cent, and the content of iron is generally higher than that of the manganese. Stratmat Limited, a Canadian subsidiary of Strategic Materials Corporation, has been investigating the deposits and is treating the ore in its recently erected pilot smelter at Niagara Falls, Ontario.

The fourth type, bog manganese deposits, is common throughout the entire Appalachian region and in general is not attractive commercially. At Dawson settlement, about 5½ miles northwest of Hillsborough, N.B., a large deposit was mined between 1887 and 1900. The deposits are below and near the orifices of a series of mineral springs, from which the manganese has been, and is being, deposited. Deposits on the Renour River are similar, but the depositing springs have not been located.

Antimony

Antimony has been mined at four localities in the Appalachian region: at Moretons Harbour, Newfoundland; at West Gore, N.S.; at Lake George, N.B.; and at South Ham, southeastern Quebec.

Antimony was discovered at Moretons Harbour shortly before 1890 and was worked sporadically until the early part of the First World War. The ore deposit occurs along the sheared contacts of a 6-foot rhyolite dyke which intrudes chloritized andesitic lavas. The main ore vein, which runs along the east wall of the dyke, varies in width from a few inches to 1 foot and has been traced for a distance of about half a mile. The vein material includes quartz, chalcopyrite, arsenopyrite, pyrite, sphalerite, galena, stibnite, and calcite.

Antimony was discovered at West Gore, in 1880 and the first mine was opened in 1884. The ore occurred in a quartz fissure vein cutting Meguma slates normal to the bedding, and consisted of stibnite, a little kermesite, and traces of native antimony. The property was worked sporadically until 1942.

At Lake George, about 25 miles west of Fredericton, antimony occurs in veins cutting pre-Silurian slate and quartzite near masses of diabase and Devonian granite. The vein material is quartz carrying stibnite and minor amounts of native antimony.

In the township of South Ham, about 18 miles east of Asbestos, Quebec, native antimony with subordinate amounts of stibnite, occurs as flakes along cleavage planes in slaty and schistose rock at a contact with a basic intrusion.

Tungsten

An occurrence of scheelite, with some secondary tungstite, was found by a party of the Geological Survey of Canada on the west shore of Gander Bay, Newfoundland, in 1952. A massive quartz vein 6 to 15 feet wide has been traced with some gaps for 3 miles and the tungsten minerals occur at the junction of this vein and a narrow branch vein about 4 feet wide. No development work has been done.

In the Moose River district of Halifax county, N.S., narrow quartz veins in folded beds of the Meguma series carry scheelite, accompanied by arsenopyrite and tourmaline. At Waverley, in the same county, scheelite-bearing veins occur along bedding planes of similar rocks.

Tungsten was discovered in 1953 on the south shore of Chedabucto Bay about 4 miles west of the town of Canso, N.S. A zone in quartzite of the Meguma series, near a granite contact, contains up to 2.2 per cent of tungsten and up to 15 per cent of manganese, which occurs in a manganese garnet. The ore zone has been traced for 1,200 feet, has a width of 7 feet, and an average tungsten content of 1.25 per cent.

In New Brunswick, about 25 miles northwest of Boiestown, near the junction of Burnt Hill Brook with the Southwest Miramichi River, a large number of small quartz veins carry wolframite, molybdenite, pyrite, anatase, chalcopyrite, and native bismuth. Exploratory work has been carried out at intervals. The quartz veins cut metamorphosed sedimentary rocks, chiefly slates, near a granite contact.

Vanadium

Vanadium was present in all samples assayed for iron that were collected by the Geological Survey of Newfoundland from the titaniferous magnetite occurrences 3 miles east of St. Georges, Newfoundland (see under *Iron*).

Titanium

Titanium is a constituent of the magnetite ores 3 miles west of St. Georges, and at Indian Head on the north side of St. Georges Bay, Newfoundland. Although at present considered merely an adulterant of the iron ores, concentrations possibly exist that would permit the bodies to be used as ores of titanium (see under *Iron*).

Strontium

Celestite (strontium sulphate) occurs in western Newfoundland near the village of Aguathuna and the settlement of Boswarlos, both on the Port au Port Peninsula. The celestite is associated with barite and for many years its presence was not suspected. The celestite and barite replace Mississippian Codroy calcareous beds that lie in pre-Carboniferous topographic depressions in the erosion surface of Ordovician beds. Some of the deposits have been diamond drilled and one is estimated to contain a minimum of 150,000 tons of mixed strontium and barium sulphate ores.

Tin

Tin occurs as a minor constituent in pegmatites within light-coloured, medium-grained, muscovite granite near New Ross, about 16 miles north of Mahone Bay, N.S. Tin is also a minor constituent of the lead-zinc-copper deposits near Bathurst, N.B.

Molybdenum

High-grade but apparently small deposits of molybdenite are found in serpentine and gneisses of unknown age which are intruded by granite pegmatite at Fleur de Lys, between White and Notre Dame Bays, Newfoundland.

Molybdenite was discovered near Rencontre East, Fortune Bay, Newfoundland, previous to 1892 but there has been no production although the property has been explored at various times. The molybdenite occurs in microgranite near the contact with rhyolite which it intrudes.

Molybdenite is present as flakes and crystals in a fine-grained granite which intrudes volcanic rocks on the north side of Gabarus Bay, near Deep Cove, Cape Breton Island. No development has been undertaken.

Molybdenite occurs in a quartz vein cutting beds of micaceous quartzite and schist 3½ miles north of Jordan Falls on the east side of Jordan River, Shelburne county, N.S.

Petroleum, Natural Gas, and Oil Shale

The Stony Creek oil and gas field is the only commercially productive field in the Appalachian region of Canada and is in New Brunswick about 9 miles south of Moncton (Figure 53). It was discovered in 1909 and, to the end of 1955 had yielded about 546,000 barrels of crude oil and 24,755,000M cubic feet of natural gas. Production in 1955 was 12,548 barrels of oil and 186,549M cubic feet of gas.

The production comes from the Albert formation of early Mississippian age. These strata outcrop from the Memramcook River Valley, southeast of Moncton, as far west as Sussex. In the Stony Creek field the Albert formation consists of

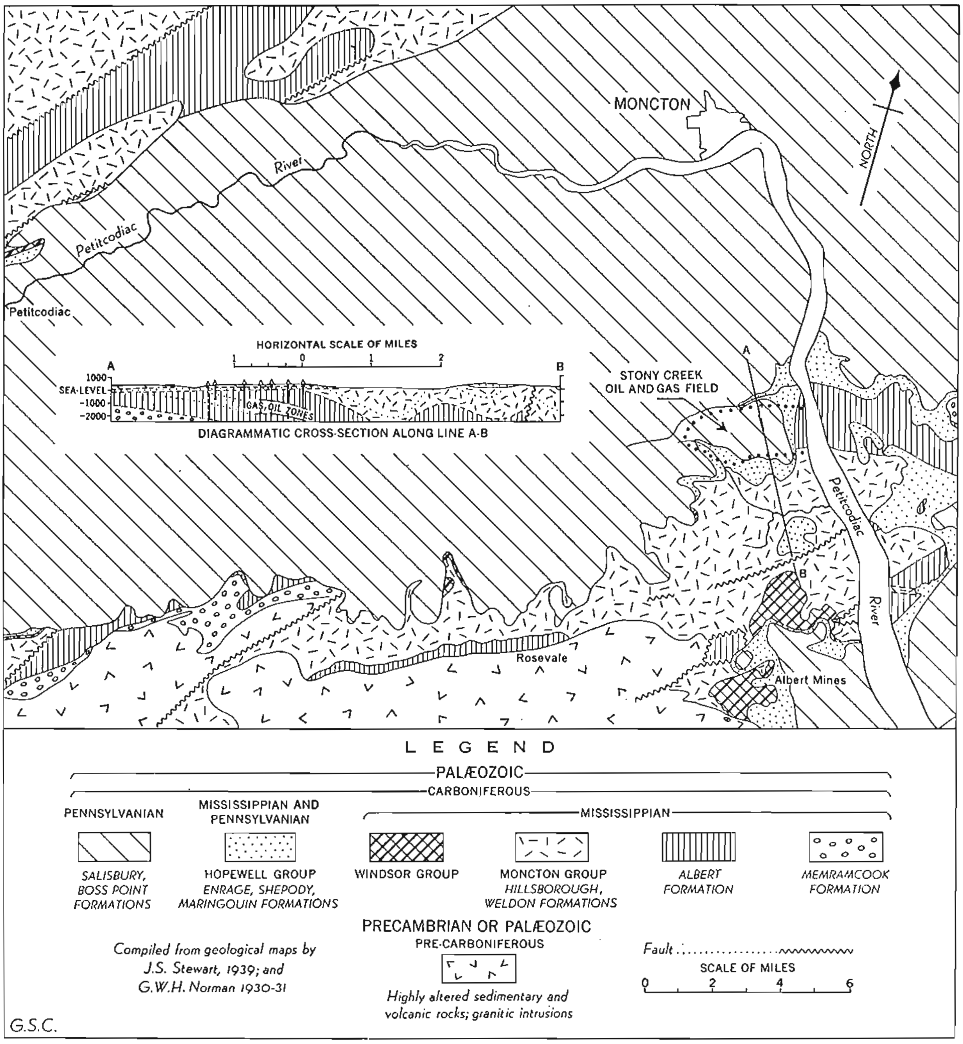


FIGURE 53. Moncton Basin showing the Stony Creek oil and gas field, New Brunswick.

grey, grey-green, and black shale, bituminous shale, calcareous shale, siltstone, and some limestone with layers of fine-grained quartzose sandstone. The sandstone occurs in zones, which vary in number from well to well and reach a maximum of about thirty. These zones are present in groups separated by 50 to 350 feet of predominantly non-bituminous shale. Six groups are known but the main oil production is from the lower four. The field is on a gently dipping monoclinal fold on the north limb of a syncline and has a proven area of about 1,600 acres.

About 145 wells were drilled in the Stony Creek field during the period 1909 to 1956, and of these, 115 were successful. Initial production of natural gas ran up to 5,000M cubic feet a day. Initial production of oil wells was small. Figures for individual wells are not available, but it is estimated that the average production of all wells since discovery was less than 3 barrels a day. Practically no drilling took place in this field during the past several years, but attempts are being made to find new productive areas and several wells are being drilled.

The Albert formation locally contains oil shales and this material has attracted particular interest at Rosevale and Albert Mines in Albert county, and at Taylor village in Westmorland county (Figure 53). Extensive diamond drilling was carried out in 1942 on each of these occurrences and more than 3,000 analyses were made for oil content of the shale. This work indicated that the shale is not rich enough for economic recovery of the oil at present.

The Albert beds also contain, locally, a solid hydrocarbon known as albertite. The largest deposit at Albert Mines was discovered in 1851 and mining was carried on for some 15 years. Originally, the material was thought to be coal but subsequently it was found to occur as a vein injected into a fracture crossing the bedding of enclosing shales. The vein had an irregular strike, a steep dip, and varied in width up to 28 feet, averaging about 8 feet. It was followed by underground workings to a depth of 1,400 feet and for a length of 3,000 feet. Over 200,000 tons of albertite were shipped to the United States, where it was used for the enrichment of coal gas, the yield being 14,500 cubic feet a ton.

The eastern Gaspé region of Quebec has long attracted attention as a potential oil area. Seepages were recorded as early as 1836. Between 1860 and 1956 more than 70 wells were drilled. Many of these are reported to have encountered small quantities of oil but no production of commercial significance has been obtained. Bituminous shales are present in the Ordovician system, and reef limestones of Silurian age outcrop at several localities. In addition, bituminous shales and limestones with strong petroliferous odour occur in the Middle and Lower Devonian series, respectively. Surface geological structures have been mapped, which, if sufficiently buried, should be favourable traps to migrating oil, but only drilling can determine whether porosity and permeability favourable to the accumulation of oil and gas are present. However, drilling in the York River district encountered small non-commercial quantities of oil in the Gaspé sandstone and Gaspé limestone of Devonian age and these strata are considered as being potentially productive.

Petroleum is said to have been discovered on the west coast of Newfoundland as early as 1812, but no effort was made to develop this resource until the last part of the nineteenth century. Results have not been encouraging. Oil seepages indicate that the petroliferous source beds appear to be either the Green Point (Lower Ordovician) or Humber Arm groups (Middle and Upper Ordovician). The strata are highly deformed at the locality where the Ordovician rocks yield seepages and where some of them have been drilled, namely, at Shoal Point on Port au Port Bay, at St. Paul's Bay, and at Parsons Pond, all on the west coast.

Gypsum

Gypsum occurs in western Newfoundland, in central and eastern Nova Scotia, in southern New Brunswick, and on the Magdalen Islands. All the deposits are in beds of the Windsor group of Mississippian age, or of its correlative, the Codroy group. In Newfoundland, Codroy strata are extensively developed in the lowland bordering St. Georges Bay, and gypsum is found at a number of places throughout this belt. In Nova Scotia the Windsor strata are developed extensively in the Carboniferous areas of Cape Breton Island, on the mainland east of Minas Basin, in areas along Northumberland Strait, and on Cumberland Basin at the head of Chignecto Bay. In New Brunswick the group is exposed in a belt around Moncton, extending southwest to Sussex and Norton. The main gypsum deposits of Nova Scotia are in the Windsor district of Hants county and have been productive for more than 100 years. Other large deposits occur at Little Narrows and at Dingwall, Cape Breton Island. In New Brunswick production is confined to the Hillsborough area of Albert county. In 1955 Nova Scotia produced 3,838,847 tons valued at $6,061,922. The production in New Brunswick in 1955 was 90,096 tons and in Newfoundland, 46,459 tons.

In the Windsor district the Windsor group has an estimated thickness of not less than 1,550 feet and contains four or five zones of calcium sulphate, including both gypsum and anhydrite, each of which is probably more than 40 feet thick. These are separated by varying amounts of red shale, fossiliferous limestone, and thin magnesian sandy shale. The deposits were obviously derived directly by precipitation from sea-water. Deposition probably took place in a series of partly land-locked basins after withdrawal of the once continuous Windsor sea.

Salt

Salt is associated with strata of the Windsor group in various places in Nova Scotia and New Brunswick, and salt springs have been noted in several places in western Newfoundland in areas underlain by strata of the Codroy group.

In Nova Scotia salt production in 1955 amounted to 144,862 tons valued at $1,808,302. It comes from the Malagash rock salt mine on Northumberland Strait and from Sifto Salt Company's brining operations near Amherst. The Malagash mine is now largely exhausted and the company is developing a new property at Pugwash, N.S. The Windsor beds on Northumberland Strait are folded and faulted, and the salt zone, apparently, immediately overlies the gypsum. The salt was encountered at a depth of less than 100 feet and workings have extended to a vertical depth of more than 1,000 feet. Two main layers are of white salt and other zones are of reddish salt.

A drill-hole bored at Nappan, near Amherst, in search of oil and gas, intersected 500 feet of salt, beginning at a depth of 2,990 feet. Other holes drilled near Mabou, Inverness county, N.S., and in the region southwest of Moncton, N.B., also cut salt beds.

Barite

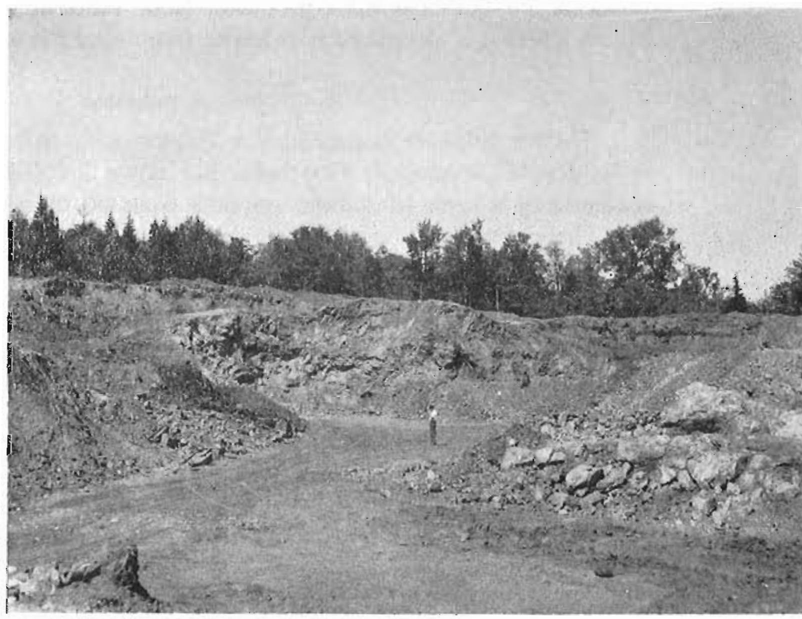
Nova Scotia has supplied most of the barite produced in Canada and contains the country's largest known reserves. A deposit discovered at Pembroke, near Walton, Hants county, in 1940 has been proved by drilling to contain more than 3 million tons and is one of the largest known barite deposits in the world.

Production began in 1941 and 6,000 tons were shipped in that year, the amount produced in 1955 being 244,271 tons.

The deposit lies in a limestone-conglomerate zone 200 feet thick that forms the basal beds of the Mississippian Windsor group. Above the limestone conglomerate is gypsum, and below it is a thin shaly limestone, also of Windsor age, which, in turn, is underlain by sandstone and argillite of the Horton group. The barite body is a replacement of the limestone conglomerate on the flank of a syncline that is part of a large drag-fold. Faulting produced a zone of brecciation that served as a locus for the replacement. The deposit reaches the surface and its large area permits open-cut methods of mining (Plate XX).

Plate XX

Open-cut barite mine, Pembroke, Hants county, N.S.



Prior to the discovery of the Walton deposit the chief production from Nova Scotia was from deposits at Lake Ainslie, Inverness county, Cape Breton Island. There the deposits are veins traversing pre-Carboniferous rocks. For lengths of several hundreds of feet, veins have widths varying from 8 to 18 feet and are locally paralleled by smaller veins. Though the vein material is largely barite, it contains, in places, considerable calcite and fluorite. Barite-bearing veins occur also at North Cheticamp, 44 miles north of Lake Ainslie. Near Five Islands on the north side of Minas Basin, barite deposits occur in a brecciated zone traversing folded slate and sandstone of Carboniferous or earlier age.

Although Newfoundland has produced no barite, the mineral is a common vein material and in many places occurs as a gangue. It is a major constituent of the replacement celestite deposits at Port au Port (see under *Strontium*).

Fluorite

Almost all of the Canadian production of fluorite is derived from mines in the St. Lawrence district, Burin Peninsula, Newfoundland, and this district is one of the world's leading centres of fluorite mining. The first shipment took place in 1933 and from then until the end of 1955 total production amounted to 856,900 tons. The fluorite occurs as epithermal veins in fault-fissures chiefly in granite and rhyolite porphyry. The veins dip between 70 and 90 degrees and vary in thickness from less than 1 inch to more than 50 feet. The average thickness of the higher grade veins is between 4 and 5 feet and that of the lower grade veins is between 15 and 20 feet. Fluorite mineralization has been traced in some veins for more than a mile and many workable lenses may be present in that distance.

Fluorite has also been produced from veins at Lake Ainslie, Cape Breton Island, where it is associated with barite (see under *Barite*).

Sodium Sulphate

Sodium sulphate occurs in the Weldon area, Albert county, N.B., and may some day be developed. Two holes put down 3,400 feet apart in search of gas encountered a layer of sodium sulphate from 60 to 100 feet thick overlying rock salt. There appears to be a considerable tonnage present.

Diatomite

Diatomite, consisting of microscopic siliceous shells of unicellular organisms known as diatoms, occurs at a large number of places in the Appalachian region. The material is of recent freshwater origin. Diatomite is known in a number of lakes on the Avalon Peninsula of Newfoundland; in Nova Scotia there are deposits near New Annan, Digby Neck, and elsewhere; and in New Brunswick, at Pollet and McNair Lakes near Mechanic Settlement in Kings county, and at Flood Lake, 16 miles southeast of Sussex.

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CHAPTER IV

THE ST. LAWRENCE AND HUDSON BAY LOWLANDS, AND PALÆOZOIC OUTLIERS

(J. F. Caley and B. A. Liberty)

The St. Lawrence Lowlands border the Canadian Shield on its south side and extend from the west end of Lake Huron and the head of Lake Erie northeasterly to Anticosti Island (Figure 1). They occupy an area of about 42,800 square miles. This area is the oldest settled part of Canada and constitutes a first-ranking industrial and agricultural region (Plate XXI). About half the total population of Canada is within the area of the St. Lawrence Lowlands.

The Hudson Bay Lowland borders James Bay on the south and west and extends along Hudson Bay to Churchill River in Manitoba. West of James Bay it averages about 200 miles in width but narrows northwestward to less than 100 miles. This lowland area is bordered on the south and west by the Canadian Shield and occupies an area of about 125,000 square miles.

Many outliers of Palæozoic strata are found on the Canadian Shield between the two lowland areas.

Physical Features

St. Lawrence Lowlands

The St. Lawrence Lowlands are plain-like areas floored by unfolded Palæozoic rocks. For descriptive purposes these lowlands may be divided into three parts.

The most westerly of these parts lies west of the Frontenac axis, a projection of the Canadian Shield that crosses the St. Lawrence River at the foot of Lake Ontario between Kingston and Brockville (Figure 54). This division includes the St. Mary River district, Manitoulin Island, and the part of southwestern Ontario that fronts on Lake Erie and Lake Ontario. The division is broken into two parts by the Niagara escarpment which extends westward from Niagara River (Plate XXII) to Hamilton from where it follows a sinuous northwesterly course to Georgian Bay, continues along the Bruce Peninsula and the Manitoulin Islands and finally passes through St. Joseph Island into northern Michigan (Figure 57). The escarpment faces northeast and is the result of erosion of strata that dip generally southwest and consist of resistant formations underlain by more easily eroded beds. The escarpment forms a prominent physiographic feature; in its southerly part it attains an elevation of about 650 feet and presents an abrupt rise of 250 to 300 feet above lower ground to the northeast. To the northwest it forms

Plate XXI — *Agricultural area in the St. Lawrence Lowlands just east of the Niagara escarpment, Brampton, Ontario.*

part of a narrow belt of rapidly rising land that in the district south of Collingwood attains an elevation of 1,700 feet, about 1,000 above the lowland stretching eastward to Lake Ontario. From this high ground the Niagara cuesta drops gradually southwestward through an area of rolling topography of low relief to the level of Lake Erie, which is about 572 feet above sea-level. East of the escarpment the land rises gently northward from the level of Lake Ontario, 246 feet, to a maximum height of 1,000 feet in the district south of Georgian Bay. At several places east of Lake Simcoe the north boundary of this area is marked by a second escarpment with an abrupt drop to the Precambrian rocks of the Canadian Shield.

The second division of the St. Lawrence Lowlands extends from the east side of the Frontenac axis to a point a few miles below Quebec City. It occupies the area between the Ottawa and St. Lawrence Rivers, straddles the St. Lawrence to Quebec City and from there extends a short distance along the north shore. East of the St. Lawrence the division is bounded by "Logan's line", a fault or fault zone that marks the northwestern border of the folded and hilly Appalachian region. To the north of the Ottawa and St. Lawrence Rivers the Palæozoic formations of the lowlands either fault against, or overlap upon, the crystalline Precambrian rocks of the Canadian Shield. Within this division of the Lowlands the ground nowhere rises more than 500 feet above the sea, except for a few isolated hills of

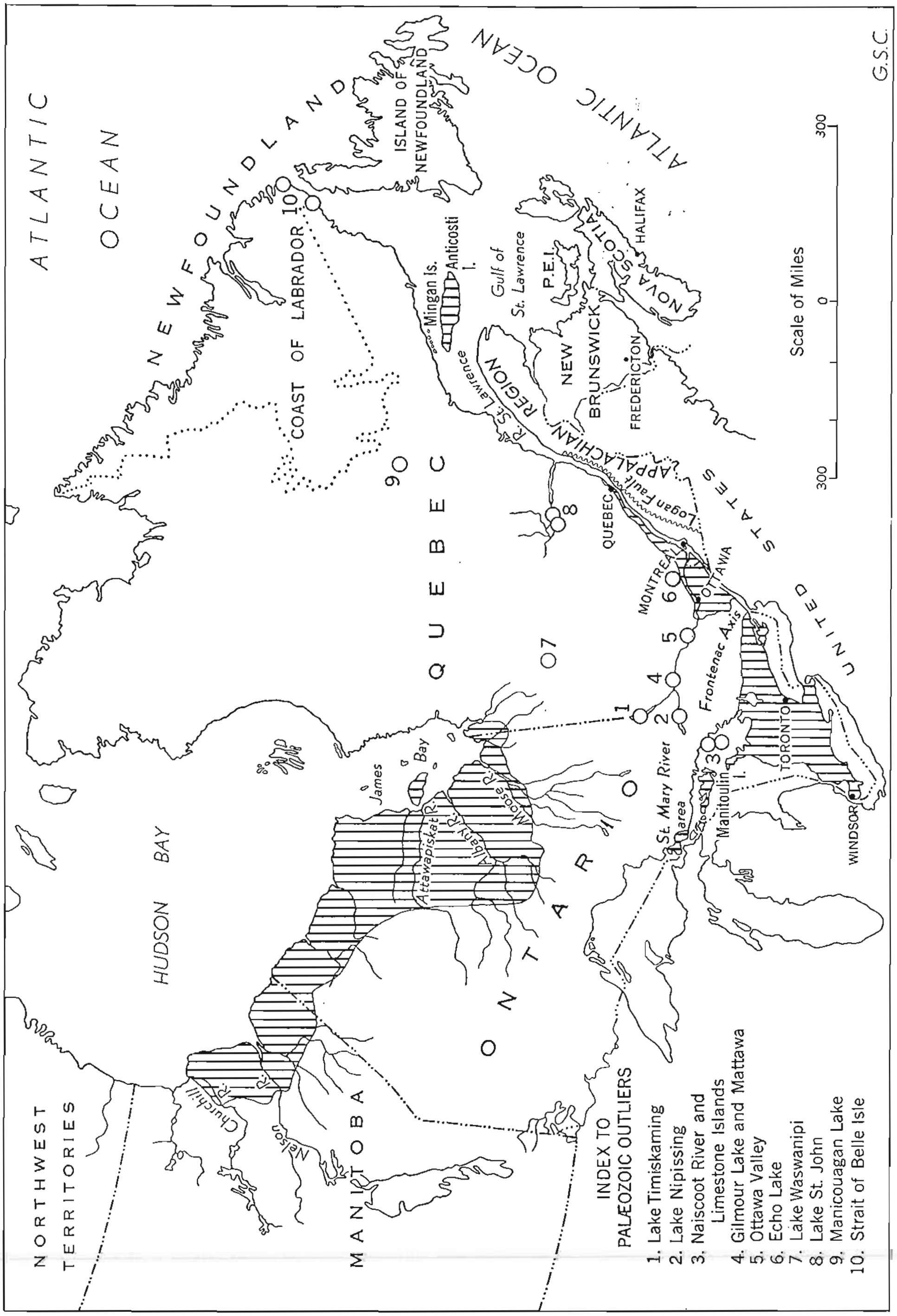

FIGURE 54. Hudson Bay and St. Lawrence Lowlands (shown by pattern), and Palæozoic outliers.

intrusive igneous rocks that penetrate surrounding Palæozoic formations. Below Montreal the land bordering the St. Lawrence does not exceed 100 feet in elevation, but farther back rises to heights of nearly 300 feet above the sea.

The third division of the St. Lawrence Lowlands lies east of, and is separated from, the second by about 360 miles of St. Lawrence River. It comprises Anticosti Island, Mingan Islands, and a narrow strip of the north shore of the St. Lawrence opposite these islands. Anticosti Island is about 125 miles long with a maximum width of about 35 miles. It is a partly submerged, southerly dipping cuesta with a north-facing escarpment. Terraces occur on both north and south sides of the island; those on the north are generally narrow, whereas some of those on the south are several miles wide. More than a score of such terraces are known and the highest is more than 400 feet above the sea. Most of them, even the highest, are covered with gravel apparently of beach origin. The Mingan Islands fringe the Quebec coast north of Anticosti for a distance of 60 miles. They are twenty-two in number, fifteen are of fair size and the others small. The regional dip of the strata is southward resulting in steep cliffs along the north sides of the islands. Some of the islands have accumulations of gravel both at and above sea-level.

Hudson Bay Lowland

The Hudson Bay Lowland is a plain underlain by almost flat-lying strata, chiefly of Palæozoic age. In the Moose River drainage basin the plain slopes sea-

Plate XXII | *View of Niagara escarpment at Niagara Falls, showing American Falls, New York, in foreground and Horseshoe Falls, Ontario, in background.*

ward at about 3½ feet a mile. The most prominent topographic feature in this basin is a low escarpment at the south boundary of the coastal plain. It is most conspicuous where cut by the Missinaibi, Opazatika, and Mattagami Rivers, where it marks the northern limit of Precambrian exposures.

Within the lowland area most of the rivers flow across the belt of sedimentary rocks, and due to the low swampy character of much of the interstream areas, rock outcrops are mainly along the banks of the larger streams.

Historical Review

St. Lawrence Lowlands

The history of exploration in the St. Lawrence Lowlands dates back to 1535 when Jacques Cartier sailed up the St. Lawrence to the Indian villages of Stadacona (Quebec) and Hochelaga (Montreal). In 1603 Champlain examined the lower part of Richelieu River, and in 1608 founded the city of Quebec, commencing thereby the permanent settlement of Canada. Three years later Champlain selected a trading site near the old Indian village of Hochelaga. This was Place Royale, later to become the city of Montreal. In 1615 he ascended the Ottawa to the mouth of Mattawa River and thence by small streams to Lake Nipissing and down French River to Georgian Bay. He then proceeded east to Lake Simcoe and via the Trent water system to Bay of Quinte and Lake Ontario.

In 1667 La Salle appeared on the Canadian scene, and made a home at Lachine on the Island of Montreal. In company with de Casson and Galinée, two missionaries, he travelled up the St. Lawrence and along the north shore of Lake Ontario as far as Burlington Bay. There the party separated and La Salle attempted to find his way to the Mississippi. In 1669 de Casson and Galinée left Burlington Bay and after 3 days reached Grand River, which they followed to Lake Erie. They wintered on the shore of the lake at the site of the present town of Port Dover and then returned to Montreal by way of Sault Ste. Marie, French River, Lake Nipissing, and the Ottawa River.

In 1679 La Salle again set out for the west. He raised a fort at the mouth of Niagara River, and built the *Griffin,* the first sailing vessel on the upper lakes. He sailed the entire length of Lake Erie, up Detroit River, across Lake St. Clair, and through the narrow passage of St. Clair River into Lake Huron.

Serious attempts to study the geological history of the area commenced in the early 1820s. About 1823 Major General Braddeley of the Royal Engineers wrote what is perhaps the first published account of the Palæozoic limestones at Lake St. John and Murray Bay. Beginning at about the same time and continuing over a period of several years Dr. J. J. Bigsby, then Secretary to the Boundary Commission, carried on geological investigations extending from Quebec City to Lake Superior; his "Sketch of the Geology of the Island of Montreal", published in 1825, is an important and accurate contribution. Geological and mineralogical observations made in the vicinity of Kingston by Captain R. H. Bonnycastle, R.E. are contained in Silliman's Journal for the year 1831.

Establishment of the Geological Survey of Canada in 1842 inaugurated a systematic and continuing program of geological investigation and mapping in Canada. The Survey's first Director, Sir William E. Logan, worked in various districts extending from Windsor to Montreal, and on the Mingan Islands. In 1843 his assistant, Alexander Murray, investigated the country between Georgian Bay and Lake Erie, and about 4 years later visited Manitoulin Island. In 1857 James Richardson, another member of the Survey, visited Anticosti and Mingan Islands. He also investigated both sides of the Ottawa River from Pembroke to Grenville, and examined the north shore of the St. Lawrence River between Montreal and St. Maurice. In 1863 Logan published his "Geology of Canada", a comprehensive work that still remains a standard reference. Credit for Logan's success must be shared also by Elkanah Billings, on whom fell the important and laborious task of identifying and describing the huge fossil collections.

Logan was followed during the latter part of the last century by many other investigators. Among these were Robert Bell, who worked on Manitoulin Island in 1865; R. W. Ells, in the Eastern Townships, Quebec, and in Ontario between 1886 and 1906; and A. P. Low, in parts of Portneuf and Montmorency counties, Quebec, in 1890-91. In 1876 Professor E. J. Chapman's "Outline of the Geology of Canada" was published. It was prepared as a basis for a course of lectures given at the University of Toronto, and is in part compiled from previous works and in part from the results of the author's own observations.

Since the beginning of the present century geological work has continued in many parts of the St. Lawrence Lowlands. Many geologists have taken part in this work, and although each has made important contributions, the following are perhaps among those that are best known: W. H. Twenhofel, for his work on Anticosti and the Mingan Islands; F. D. Adams, J. A. Dresser, and G. A. Young, for their work on the Monteregian Hills; L. C. Cummings, on the artesian wells of Montreal; W. A. Parks, on natural gas in the St. Lawrence Valley and building stones of Quebec; M. Y. Williams, on Manitoulin Island; T. H. Clark, for his contributions to the stratigraphy, palæontology, and structure of the Palæozoic formations of Quebec; A. E. Foerste, on the Ordovician formations of Ontario and Quebec; A. E. Wilson for her exhaustive study of the stratigraphy, palæontology, and structure of the sedimentary formations in the Ottawa Valley; and P. E. Raymond, E. M. Kindle, H. M. Ami, and J. F. Whiteaves, for their contributions to the palæontology of formations in Ontario.

The southwestern peninsula of Ontario deserves separate mention. Over 80 per cent of the total Canadian output of salt, as well as important quantities of gypsum, come from this part of the St. Lawrence Lowlands. There, also, are the Ontario oil and gas fields, which have the distinction of being among the oldest in North America.

Geological work in this part of Ontario covers a period of more than 100 years. Our present geological knowledge of this region is, therefore, the combined contribution of geologists, both Canadian and foreign, many of whom were eminent in their respective fields of research. Among the earliest workers, Alexander Murray and T. Sterry Hunt deserve special mention. They were the first to undertake systematic work on the Palæozoic rocks of the region. More recently the work of C. R. Stauffer and M. Y. Williams on the stratigraphy and palæontology of the Devonian and Silurian rocks, respectively, are important contributions. W. A. Parks made extensive contributions to the Ordovician geology of the region as well as to the palæontology of both the Silurian and Devonian rocks. The names of other geologists of the Geological Survey of Canada who have made detailed and more recent studies of the areas are to be found in the lists of publications issued by the Survey.

Hudson Bay Lowland

Hudson Bay has been known since 1610, when Henry Hudson, in searching for a northwest passage, sailed down the east side of that great "inland sea" and wintered on the bleak shores of James Bay. Prior to that time other explorers, particularly Martin Frobisher (1567, 1577, 1578) and John Davis (1585, 1586, 1587), had passed the mouth of Hudson Strait, but apparently failed to navigate its entire length and enter Hudson Bay. Hudson was followed by many others—Sir Thomas Button (1613), Robert Bylot and William Baffin (1615, 1616), Jens Munck (1619), and Thomas James and Luke Foxe (1631). Button is credited with being the first white man to cross to the west side of Hudson Bay, and Button and Munck wintered at or near the two places where the Hudson's Bay Company was later to establish York Factory and Fort Churchill, its two main trading posts on Hudson Bay.

Thus far little or no attempt seems to have been made to explore the inland region south of Hudson Bay. However, during the 100 years following the establishment in 1670 of the Hudson's Bay Company, several of the Company's men, notably Henry Kelsey, Anthony Hendy, and Mathew Cocking, travelled some of the waterways between the bay and the Saskatchewan River. During the eighteenth century an extensive system of inland posts was inaugurated, and rival English and Canadian companies traded throughout the region until about 1821, when the North-West Company and Hudson's Bay Company were amalgamated under the name of the latter.

Perhaps the earliest geological exploration in the Hudson Bay Lowland was made by Robert Bell of the Geological Survey. Between the years 1875 and 1880 he traversed the country from the shore of Lake Huron to Moose Factory on James Bay, examined much of the coast of James and Hudson Bays, and explored the valleys of Churchill, Nelson, Hayes, Attawapiskat, Albany, and Moose Rivers. His reports constitute a comprehensive account of the drainage basins of these rivers, and describe the Palæozoic rocks exposed in their valleys.

Between 1880 and 1911 several geologists contributed further to our general knowledge of the geology of the region. Chief among these may be mentioned: A. P. Low (1900), J. B. Tyrrell (1897), D. B. Dowling (1901), W. J. Wilson (1902), J. M. Bell (1904), Charles Camsell (1904), O. O'Sullivan (1904),

Table X

Correlation Chart, Hudson Bay and St. Lawrence Lowlands and Palæozoic Outliers

SYSTEM	SERIES	STAGE	HUDSON BAY LOWLANDS	ST. LAWRENCE LOWLANDS — ONTARIO — WEST OF FRONTENAC AXIS — ST. MARY RIVER AREA	MANITOULIN ISLAND	BRUCE PEN. & LONDON AREA	NIAGARA PEN. & TORONTO AREA	ONTARIO — EAST OF FRONTENAC AXIS	QUEBEC — MONTREAL-NICOLET RIVER	QUEBEC — ANTICOSTI AND MINGAN IS.	OUTLIERS
TERTIARY									Monteregian Intrusions		
CRETACEOUS			Mattagami								
MISSISSIPPIAN	LOWER					Pt. Lambton					
DEVONIAN	UPPER		Long Rapids Williams Island			Kettle Pt.					
DEVONIAN	MIDDLE		Abitibi River			Hamilton Dundee (Delaware) Columbus Detroit River Bois Blanc	Dundee (Delaware) Bois Blanc (Onondaga)				
DEVONIAN	LOWER		Sextant				Oriskany		Oriskany Helderberg		
SILURIAN	CAYUGAN		Kenogami River / ?			Bass Island Salina	Bertie-Akron Salina				
SILURIAN	NIAGARAN		Kenogami River / Attawapiskat Pagwa River / Ekwan River ? / ?		ALBEMARLE: Amabel CLINTON: Fossil Hill	Guelph Amabel Fossil Hill	Guelph Lockport De Cew Rochester Irondequoit Reynales			Chicotte Jupiter	L. Timiskaming, Ont.
SILURIAN	ALEXANDRIAN		Severn River Port Nelson		CLINTON: St. Edmund Wingfield Dyer Bay CATARACT: Cabot Head Manitoulin	Wingfield Dyer Bay Cabot Head Manitoulin	Neahga Thorold Grimsby Power Glen Whirlpool			Gun River Becscie	L. Timiskaming, Ont.

St. Lawrence and Hudson Bay Lowlands

ORDOVICIAN	CINCINNATIAN	GAMACHIAN								Ellis Bay
			Shammattawa Nelson River	'Hudson River formation'	Kagawong Meaford Wekwemi-kongsing	Queenston Dundas-Meaford	Queenston Dundas-Meaford	Queenston Russell	Bécancour R. Pontgravé R.	Vauréal English Head
		MAYSVILLIAN			Sheguiandah	Blue Mt.	Blue Mt.	Carlsbad	Nicolet R. Leclercville	?
		EDENIAN: GLOUCESTER		'Utica formation'			Gloucester	Billings	Lotbinière	
		EDENIAN: COLLINGWOOD			Collingwood	Collingwood	Collingwood	Eastview	Lachine	Makasti
	CHAMPLAINIAN	MOHAWKIAN: TRENTON		'Trenton group strata'	Cobourg Unnamed beds Cloche Island	Cobourg Sherman Fall Kirkfield	Cobourg Sherman Fall Kirkfield	OTTAWA FORMATION: Cobourg Sherman Fall Hull Rockland	Terrebonne Tetreauville Montreal Mile End ——	?
		MOHAWKIAN: BLACK RIVER		'Black River strata'	Swift Current Basal beds	Coboconk Gull River Shadow Lake	Coboconk Gull River Shadow Lake / Rideau	OTTAWA FORMATION: Leray Lowville Pamelia	Leray Lowville Pamelia	— ? —
		CHAZYAN						St. Martin Rockcliffe	LAVAL: St. Martin St. Thérèse	Mingan — ? —
	CANADIAN	BEEKMANTOWN						Oxford March	Beauharnois Theresa (?)	— ? — Romaine — ? —
CAMBRO-ORDOVICIAN								Nepean		
CAMBRIAN	UPPER			Lake Superior		BASAL GROUP: Mt. Simon Eau Claire Jacobsville	Mt. Simon | Potsdam		Potsdam	
	MIDDLE									
	LOWER									
PRECAMBRIAN										

L. Timiskaming, Ont.
L. Waswanipi, Que.
L. Manicouagan, Que.
L. St. John, Que.
Ottawa Valley, Ont.,
Mattawa, Ont., Que.
Gilmour L., Ont.
L. Nipissing, Ont.
Strait of Belle Isle, Labrador

G.S.C.

W. S. Dobs (1905), and M. B. Baker (1911). In 1912 the Ontario Bureau of Mines published a comprehensive report by W. G. Miller incorporating reports by most of the above-named workers and also including work by Robert Bell and A. W. G. Wilson. In 1913 the Geological Survey published a report by William McInnes on the basins of Nelson and Churchill Rivers, a comprehensive work descriptive of some 220,000 square miles of territory, much of which had been explored earlier by several of the aforementioned geologists as well as by the author.

More recently detailed studies have been made of local areas within the Lowlands region. The work of Savage and Van Tuyl (1919) on the stratigraphy of the Palæozoic rocks of James and Hudson Bays, and of W. S. Dyer (1928) on the geology and economic deposits of the Moose River basin deserve special mention. Other important contributions are those by M. Y. Williams (1920), on the geology of Mattagami and Abitibi Rivers; E. M. Kindle (1923), on the northern part of Moose River; F. H. McLearn (1926), on the Mesozoic and Pleistocene deposits of the lower Missinaibi, Opazatika, and Mattagami Rivers; and W. S. Dyer and A. R. Crozier on the Onakawana lignite field.

During the years 1948-51, the Ontario Department of Mines drilled three vertical diamond drill-holes for the purpose of providing additional information on the thickness and age of the sedimentary succession in the general James Bay Lowland area. The results of this drilling have been included in a report on the petroleum possibilities of the James Bay Lowland area prepared by N. W. Martison of the Shell Oil Company of Canada, Limited, and published in 1953 by the Ontario Department of Mines. In 1950, J. S. Nelson investigated the Churchill, Nelson, and North and South Knife River areas for the Geological Survey and this work served to extend known distribution of Ordovician and Silurian strata some distance northward. Finally, from 1950 to 1953, M. A. Fritz investigated the Devonian section from Coral Rapids to Williams Island on the Abitibi River.

Geology

St. Lawrence Lowlands

The seas in which the several groups of Palæozoic rocks were deposited did not at all times extend continuously over the entire region of the St. Lawrence Lowlands. During the various advances and retreats parts of the region were flooded, or they emerged, before others. The results are that the stratigraphic sequence is not everywhere the same, that rocks of the same age are not necessarily present in all parts of the region, and that contemporaneous sediments may differ in lithology from place to place. For convenience in describing the geology, the region is here divided into the following parts: Ontario west of the Frontenac axis and including Manitoulin Island and the St. Mary River area; Ontario and Quebec east of the Frontenac axis; and Anticosti and the Mingan Islands and adjacent coast (Figure 54; Table X).

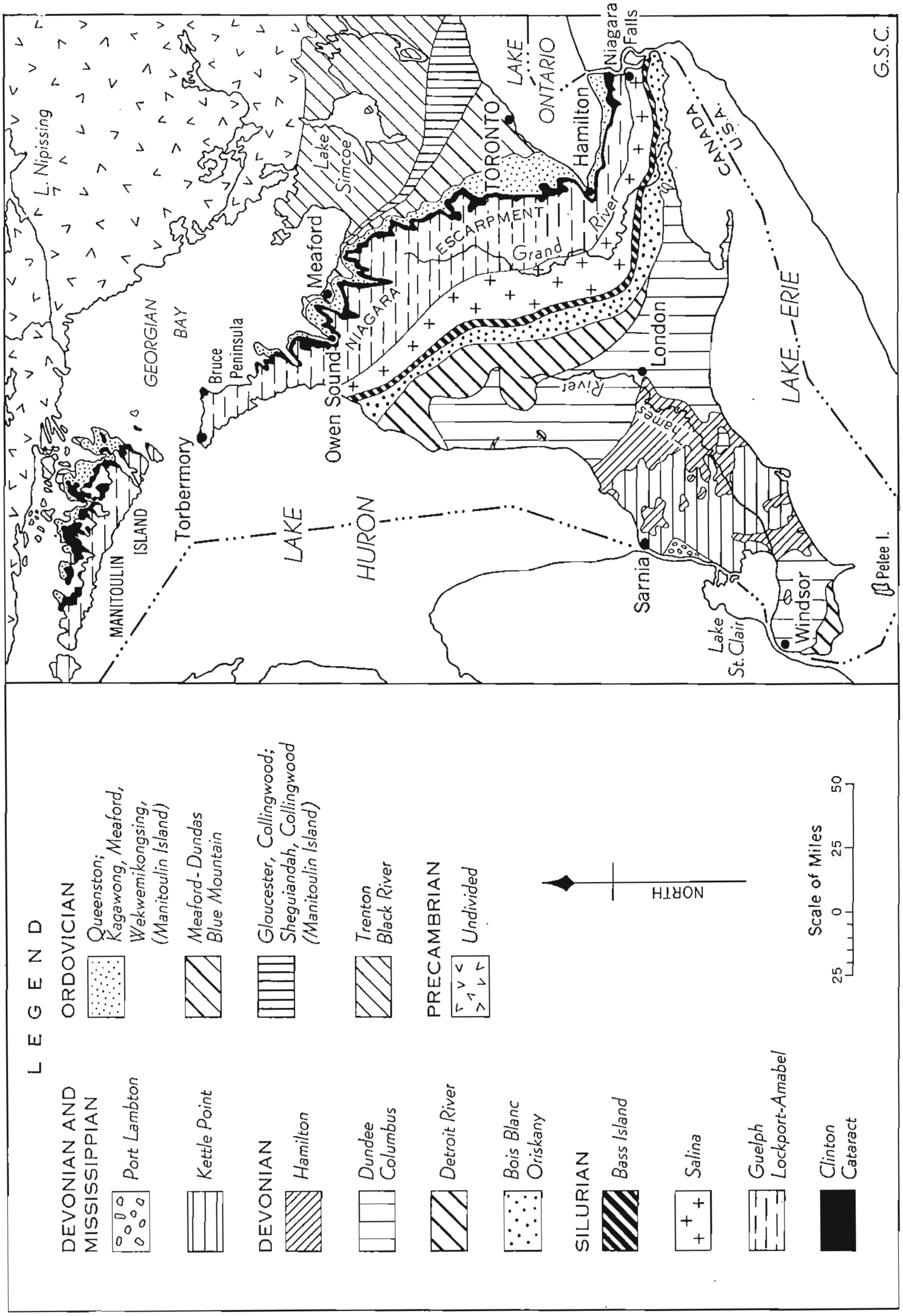

FIGURE 55. Generalized geological map of southwestern Ontario.

TABLE XI

Formational Names
Ontario West of the Frontenac Axis

		Thickness Feet
Devonian and Mississippian		
Bois Blanc (Onondaga) formation	brown dolomitic limestone, abundant chert	65-265
Columbus formation	grey limestone containing fine quartz sand	35
Detroit River formation	grey and brown dolomite and limestone	300
Dundee (Delaware) formation	grey, fine-grained to finely crystalline limestone	240
Hamilton formation	grey shale, limestone	140-300
Kettle Point formation	black shale	335
Oriskany formation	light grey or yellow, coarse-grained sandstone	20
Port Lambton formation	grey shale with siltstones (Mississippian)	200
Silurian		
Amabel formation	brown, grey and bluish grey, finely crystalline dolomite	130
Bass Island formation	buff, fine-grained dolomite; oolitic zones	60-395
Bertie-Akron formation	grey dolomite, waterlimes, dark grey shale	35
Cabot Head formation	red and green shale	34-60
DeCew member	dark grey, fine-grained, dolomitic limestone	6-12
Dyer Bay formation	bluish grey and brown, fine-grained dolomite	10-35
Fossil Hill formation	brown, finely crystalline limestone and dolomite	8-90
Grimsby formation	red and grey mottled sandstone and shale	12-45
Guelph formation	buff, fine-grained to crystalline dolomite	85-500
Irondequoit formation	grey, finely crystalline, crinoidal limestone	4-7
Lockport formation	grey to bluish grey, finely crystalline dolomite	72-125
Manitoulin formation	brown, finely crystalline dolomite	25-60
Neahga formation	soft, grey shale	1-6
Power Glen formation	green to dark grey shale	0-48
Reynales formation	massive, grey dolomitic limestone and dolomite	8-14
Rochester formation	black to grey calcareous shale	2-50
Salina formation	brown dolomite, grey limy shale, gypsum, salt	300-1,500
St. Edmund formation	brown to tan, fine-grained to lithographic dolomite	0-90
Thorold formation	grey, fine-grained sandstone	5-13
Whirlpool formation	light, grey, fine-grained sandstone	6-30
Wingfield formation	green, red and green shale; brownish grey argillaceous dolomite; fine-grained, to finely crystalline, to sublithographic dolomite	20
Ordovician		
Basal beds	green and red sandstone, arenaceous shale (Manitoulin Island), may be in part Cambrian	0-60
Blue Mountain formation	soft, grey and bluish grey shale	120-170
Cloche Island formation	brown and grey, fine-grained and crystalline limestone (Manitoulin Island)	50
Coboconk formation	grey, fine-grained, argillaceous limestone	25
Cobourg formation	grey, fine-grained, argillaceous limestone and dolomite	40-240

Collingwood beds	black, fissile, calcareous, and bituminous shale; some black fine-grained limestone on Manitoulin Island	20-60
Dundas-Meaford formation	interbedded bluish grey shale, hardbands of limestone and dolomite; argillaceous limestone unit in uppermost strata	418-580
Gloucester beds	soft, grey and brown shale	90
Gull River formation	grey, lithographic and sublithographic limestone; some buff dolomitic limestone	65-400
Kagawong formation	bluish grey, fine-grained, and finely crystalline limestone and dolomite (Manitoulin Island)	90
Kirkfield formation	brownish grey, fine to medium calcarenitic and fine to medium crystalline limestone; some sublithographic limestone	60
Meaford formation	grey, fine-grained to finely crystalline argillaceous limestone (Manitoulin Island)	60
Queenston formation	red, red mottled green, and green shale	240-963
Rideau beds	green and maroon sandstone, shale, conglomerate, breccia	0-25
Shadow Lake formation	grey arkose; red and green arenaceous shale; belongs to Basal group	0-40
Sheguiandah formation	soft, grey, brown, and green shale (Manitoulin Island)	100
Sherman Fall beds	interbedded grey shale and shale partings; grey, fine-grained, argillaceous and sublithographic limestone	200
Swift Current formation*	brown, fine-grained limestone, argillaceous limestone, grey lithographic limestone (Manitoulin Island)	130
Unnamed beds	grey, fine-grained, argillaceous, and light blue, sublithographic to fine-grained limestone (Manitoulin Island)	30
Wekwemikongsing formation	interbedded green and grey shale, hard bands of grey crystalline limestone (Manitoulin Island)	150
Cambrian		
Basal group	essentially clean sandstone and dolomite, some shale and glauconite; includes the Potsdam, Jacobsville, Mount Simon, Eau Claire, and the Ordovician Shadow Lake, Rideau, and Basal beds	451
Eau Claire formation	grey sandstone, buff dolomite, glauconite	136
Jacobsville formation	brown, green, and purplish sandstone, arkosic in basal part	45
Lake Superior formation	red, green, white, and brown, calcareous sandstone	80
Mount Simon formation	light grey to clear, medium-grained sandstone	270
Potsdam formation	grey, tan, red, and red mottled green, fine-grained sandstone and calcareous sandstone	0-60

*Term preoccupied but not as yet replaced.

Ontario West of the Frontenac Axis

The region west of the Frontenac axis has been divided into the St. Mary River area, Manitoulin Island, Bruce Peninsula and London area, and the Niagara Peninsula and Toronto area (Figure 55). The region is underlain by marine sedimentary strata of Cambrian, Ordovician, Silurian, Devonian, and Mississippian ages. These rocks rest upon the uneven surface of the Precambrian basement that outcrops to the north as part of the Canadian Shield. The rocks dip generally southwestward from the Canadian Shield at a few feet a mile, and outcrop areas of the Ordovician, Silurian, and Devonian form successive northwest-trending belts. The sedimentary formations have an aggregate maximum known thickness of about 5,877 feet, of which 275 feet are Cambrian, 2,414 feet are Ordovician, 1,888 feet are Silurian, 1,100 feet are Devonian, and 200 feet are Mississippian in age. The thickest section penetrated by drilling is about 4,727 feet, comprising 186 feet of Cambrian, 1,553 feet of Ordovician, 1,888 feet of Silurian, and 1,100 feet of Devonian strata. These rocks have been divided into about 45 formations ranging in thickness from 20 to nearly 1,500 feet (Tables X and XI).

The entire area has been glaciated and, except along the Niagara escarpment and on Manitoulin Island, the bedrock is largely concealed beneath a mantle of unconsolidated material consisting of boulder clay, sand, gravel, and clay which ranges from a few feet to more than 600 feet in thickness.

Cambrian. The oldest exposed rocks are the Lake Superior sandstone of Cambrian age. These rocks may be traced from the vicinity of Sault Ste. Marie westward into northern Michigan. In the Windsor-Sarnia district, rocks of Cambrian age have been penetrated by wells. These strata constitute the Jacobsville, Eau Claire, and Mount Simon formations; they consist mainly of arkose, grey, green, and purplish sandstone, and buff dolomite. Although not all these formations are known to be present at any one locality, they attain a combined thickness of about 450 feet. Whereas Potsdam strata in the vicinity of Kingston are Cambrian in age, only a part of the Basal beds on Manitoulin Island may be so considered.

Ordovician. The oldest rocks of Ordovician age are represented by the Shadow Lake formation which outcrops in the general district east of Lake Simcoe and consists of grey arkose and red and green calcareous shale. This formation is considered to be Middle Ordovician in age because it appears to be continuous with overlying strata enclosing a fauna of this age. Eastward from Lake Simcoe to the vicinity of Kingston, the Shadow Lake formation may be traced into the Rideau formation consisting of sandstone, shale, conglomerate, and breccia. Westward, however, the Shadow Lake passes into the Basal beds of Manitoulin Island. The succeeding strata deposited during Black River and Trenton time consist of a sequence of dominantly calcareous rocks. They outcrop at many localities along the north shore of Manitoulin Island and throughout most of the area from Georgian Bay to the Frontenac axis, and dip gently beneath younger Palæozoic strata to the southwest. These rocks have been subdivided lithologically into the Gull River, Coboconk, Kirkfield, Sherman Fall, and Cobourg formations, the whole reaching a maximum thickness of about 935 feet. On Manitoulin Island equivalent strata are essentially limestone and include Swift Current formation, Cloche Island formation, unnamed beds, and Cobourg formation, with a maximum combined thickness of about 285 feet.

Following deposition of the Cobourg strata, the Trenton sea withdrew from at least the northern part of the area as disconformable relations between the Cobourg formation and the succeeding Collingwood shale are in evidence both in the Georgian Bay district and on Manitoulin Island. This hiatus is thought to have been of short duration, after which the sea again advanced and remained, with perhaps minor oscillations, until the close of Ordovician time.

The first deposits of this sea are black bituminous shales enclosing trilobites and graptolites of Collingwood age, and ranging in thickness from 20 feet on Georgian Bay to 60 feet on Manitoulin Island. These shales are followed in the Toronto area by 90 feet of soft brown shales containing a Gloucester fauna; these shales are not present on Georgian Bay where about 120 feet of soft, bluish grey shale (Blue Mountain formation) occur. On Manitoulin Island contemporaneous strata, the Sheguiandah formation, attain a thickness of about 100 feet and consist largely of soft, brown, maroon, and grey shale. The Blue Mountain formation is followed by a succession of grey shales with occasional thin limestone beds below (Dundas) and interbedded grey shale, silty limestone, and dolomite above (Meaford). The Dundas (Lorraine) and Meaford (Richmond) are difficult to separate on lithology and have therefore been referred to under the hyphenated term Dundas-Meaford formation. Maximum thickness of the Dundas and Meaford is 465 and 115 feet, respectively. On Manitoulin Island, strata partly equivalent to the Dundas are called the Wekwemikongsing formation and consist of about 150 feet of shale with interbedded limestone layers. The Meaford of Manitoulin Island consists essentially of argillaceous limestone and attains a thickness of 60 feet. The entire Dundas-Meaford succession is fossiliferous with bryozoa and brachiopods among the diagnostic forms. Both bryozoan and coral reefs are present in the Meaford beds. On Manitoulin Island the Meaford is overlain by the Kagawong formation consisting of about 90 feet of bluish grey argillaceous limestone and dolomite enclosing a Richmond fauna and representing the youngest Ordovician strata in that area. Southward into the Bruce Peninsula the Kagawong grades into the Queenston red shale, believed to be its facies equivalent. Two grey marine limestone biostromes, enclosing Kagawong fossils, interfinger with the Queenston red shale as far south as the Meaford-Owen Sound district. In the southwestern part of the area the Queenston consists of brick red shale with a maximum thickness of about 963 feet.

At the close of Richmond time the Ordovician sea withdrew from this region, initiating a period of erosion.

Silurian. The oldest Silurian strata consist of a variable group of rocks included under the term Cataract group. These rocks outcrop at the base of the Niagara escarpment from Niagara River to Manitoulin Island but vary in lithology from place to place. The initial Silurian deposit is the grey Whirlpool sandstone (Plate XXIII), 25 to 30 feet thick, extending from Niagara River to Georgian

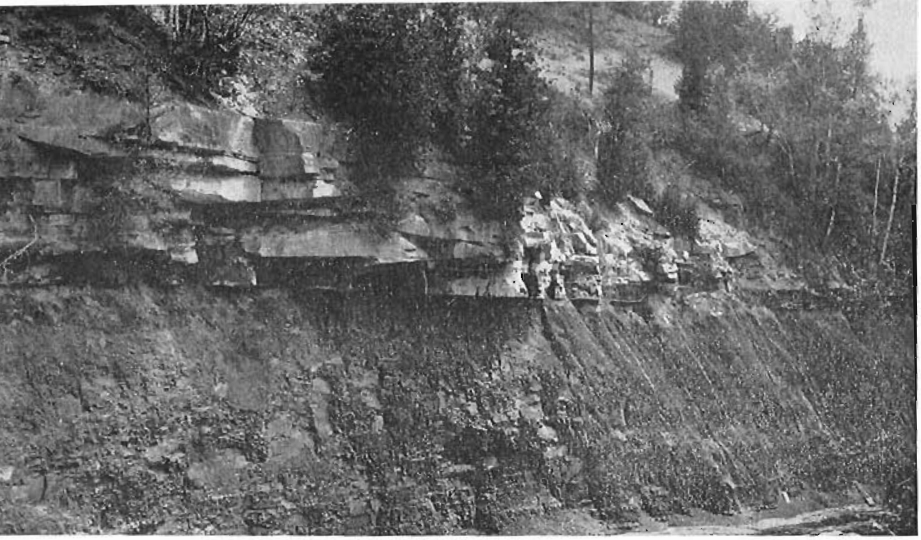

Plate XXIII | Contact between Ordovician Queenston shale and overlying Silurian Whirlpool sandstone on Credit River at Cataract, Ontario.

Bay where it disappears. The succeeding Manitoulin and Cabot Head formations are present throughout the entire area and consist typically of brown finely crystalline dolomite and red and green shale, respectively, and have a combined maximum thickness of about 120 feet. In the Niagara district these formations are not separable but grade into a single lithological unit consisting of arenaceous shale with sandstone interbeds known as the Power Glen formation. The Grimsby formation, typically a reddish sandstone and shale, overlies the Power Glen formation and, like the Whirlpool, reaches its maximum development in the Niagara district where it attains a thickness of 45 feet and from where it thins both to the north and to the west.

The succeeding Clinton and Albemarle groups were deposited in two basins separated by a shelf area extending roughly from Hamilton to Owen Sound. This intervening shelf produced the difference in facies now recognized in the Middle Silurian formations of the Michigan Basin area and those of the same age in the Appalachian region.

The Clinton group in Niagara Peninsula is divided into six formations. The Thorold formation, consisting of 5 to 13 feet of grey quartz sandstone, initiates the group. This is followed by 1 foot to 6 feet of greenish black shale (Neahga formation) which is in turn overlain by 8 to 14 feet of grey crystalline dolomite of the Reynales formation enclosing *Pentamerus oblongus*. The Irondequoit formation, consisting of 4 to 7 feet of grey crystalline dolomite, overlies the Reynales and is succeeded by 2 to 50 feet of dark grey to black calcareous Rochester shale. The DeCew formation completes the Clinton group in Niagara Peninsula. It consists of 6 to 12 feet of grey argillaceous dolomite or dolomitic limestone and is generally difficult to separate from the underlying Rochester owing to the dolomitic nature of the latter beds. The DeCew beds are confined to the Niagara Peninsula and disappear along the escarpment in the vicinity of the city of Hamilton.

In the Bruce Peninsula-Manitoulin area the Clinton group comprises the Dyer Bay, Wingfield, and Fossil Hill formations. The Dyer Bay consists of 10 to 35 feet of bluish grey fine-grained argillaceous dolomite with green shale partings. It rests upon the Cabot Head shales with sharp contact and is exposed at a number of places along the east side of Bruce Peninsula north of Owen Sound. Green to greenish grey shales with interbedded green argillaceous dolomite 15 to 20 feet thick overlie the Dyer Bay and are referred to as the Wingfield formation from their typical development around Wingfield basin at the northeast end of Bruce Peninsula. The Fossil Hill formation forms the top of the Clinton group and consists of 8 to 90 feet of brown, fine-grained to crystalline dolomite enclosing *Pentamerus oblongus,* several species of the genera *Halysites, Favosites, Syringopora,* and *Arachnophyllum pentagonum.* Once considered a part of the Lockport dolomite of Manitoulin Island these beds are now known, by tracing southward from Owen Sound on to the shelf area, to be lithologically and faunally similar to the Reynales formation of the Niagara district; they have, therefore, been placed in the Clinton group.

The Albemarle rests upon the Clinton. In the Niagara district this group consists, in ascending order, of 72 to 125 feet of grey crystalline dolomite (Lockport formation), overlain by 170 to 220 feet of buff granular dolomite (Guelph formation). In Bruce Peninsula the Albemarle is divided into the Amabel formation, consisting of 70 to 120 feet of brown, grey, and bluish grey mottled dolomite, followed by the Guelph formation which there comprises about 120 feet of buff granular dolomite enclosing *Megalomus canadensis* and *Trimerella grandis.* Biohermal reef structures are present both at the outcrop and in the subsurface and, in the extreme southwestern part of the area, drilling for oil and gas has revealed the presence of pinnacle-like reefs, some having a relief of more than 400 feet.

The foregoing Silurian strata have been cut by the great gorge of the Niagara River. This has been caused by the recession of the falls, the present position of which is about 7 miles above the foot of the Niagara escarpment at Queenston. The stratigraphic succession at the falls comprises, in descending order: Lockport dolomite, 66 feet thick; Clinton limestone, shale and sandstone, 99 feet; Cataract shale and sandstone, 119 feet; and the soft Queenston shale in which the river bed is cut (Figure 56). Lowermost Clinton limestones form a ledge about 15 feet above the level of the river at the foot of the falls, and the underlying formations are submerged beneath water level. The several formations through which the gorge is cut are well exposed along its sides and, as they have a fairly uniform southerly dip of about 31 feet a mile, their position beneath the river at the falls can be determined. Recession of the falls takes place by undermining the hard capping dolomite and the resistant lowermost Clinton limestone. The soft Rochester shale is eroded by wind-driven spray generated by the falling water. This leaves the capping dolomite unsupported. Undermining of the Clinton limestone takes place by erosion, beneath the water, of the soft Cataract shale and sandstone, and is effected by the action of boulders and stones carried by the currents.

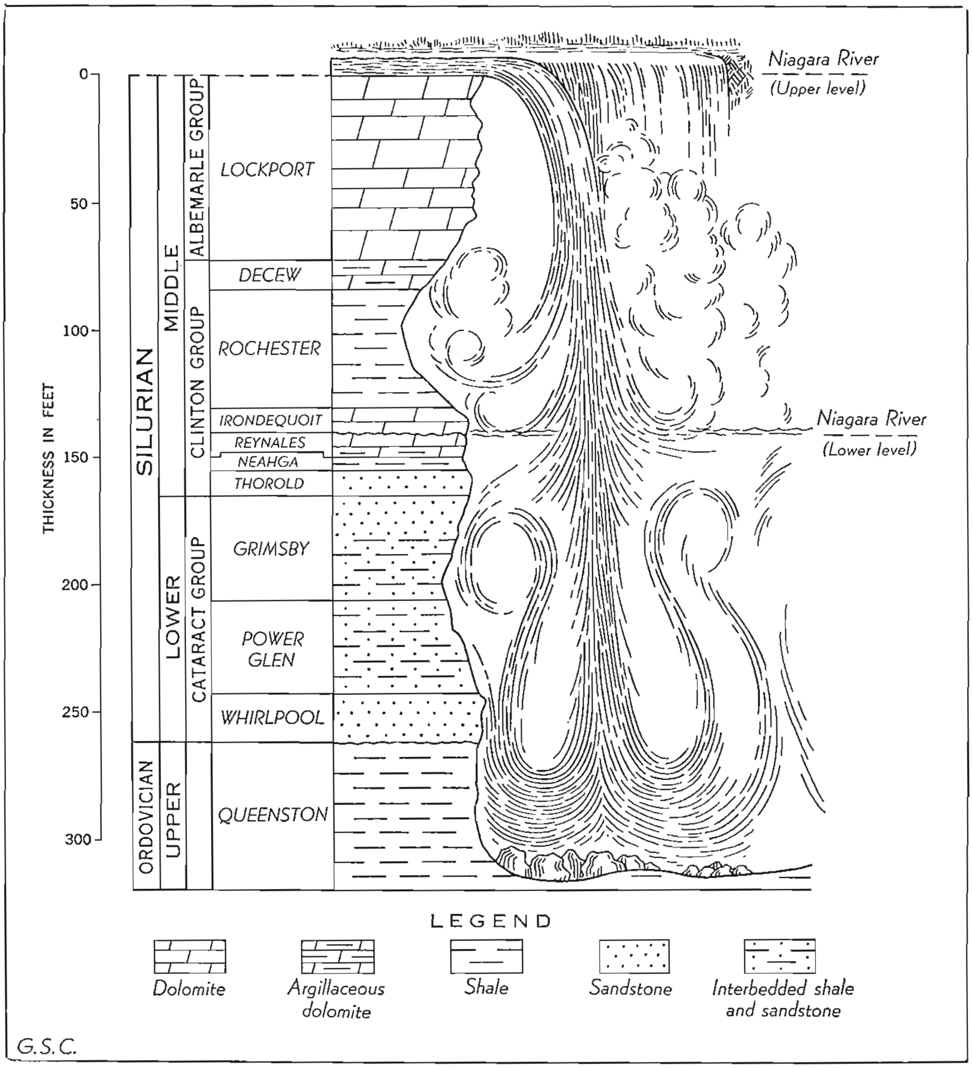

FIGURE 56. Stratigraphic section at Niagara Falls.

Undermining of the Lockport dolomite and the Clinton limestone results in the maintenance of a vertical falls as recession proceeds.

In the region between Lake Huron and Lake Erie, the Albemarle group is overlain by the Salina formation of Upper Silurian age (Cayugan). This formation consists typically of dolomite, limestone, dolomitic limestone, shaly dolomite, shale, anhydrite, gypsum, and salt. The salt is confined to the western part of the area and is not known east of London. It occurs in several beds or zones and may have an aggregate thickness of more than 650 feet. The formation, including the salt beds, ranges from 300 to more than 1,500 feet thick and the evaporite sediments are considered to have accumulated under more or less closed-basin conditions.

The youngest Silurian strata overlie the Salina and are represented by the Bass Island formation, also Cayugan in age. In the Niagara district these beds are referred to under the term Bertie-Akron and consist of about 35 feet of grey to brown dense dolomite with some dark calcareous shale. Westward the shale disappears and the unit (Bass Island) consists of grey to buff and brown finely crystalline dolomite characterized by one or more oolitic zones. The thickness of the Bass Island formation varies from 60 to 395 feet, this variation being due in part at least to erosion of the Silurian rocks prior to deposition of the overlying Devonian strata.

At the close of Cayugan time the region was uplifted and the sea withdrew. A period of erosion followed after which the sea again returned initiating Lower Devonian time.

Devonian. In Niagara Peninsula, the oldest Devonian rocks are represented by the Oriskany formation of light grey, medium-grained, glauconitic sandstone that rests upon the eroded surface of the Silurian dolomite. This sandstone was itself subjected to erosion and its distribution is therefore patchy and nowhere is there more than 20 feet of this rock present. The contained fauna is characterized by a preponderance of brachiopods and these determine the Lower Devonian age of the formation. West of the Niagara Peninsula the Oriskany has not been identified.

The Bois Blanc formation disconformably overlies the Oriskany or, where the Oriskany is absent, the Silurian Bass Island formation. It consists typically of limestone, sandy limestone, dolomite, and chert. At some localities in the Niagara district a sandstone facies, the Springvale, is present a few feet above the base and, more rarely, at the base of the formation. This sandstone is similar in appearance to the Oriskany and, where it rests directly upon the Bass Island dolomite, has been mistaken for it. The Bois Blanc formation has a maximum thickness of about 265 feet; it encloses an *Amphigenia* fauna and is correlated with the lower Onondaga (Middle Devonian) of New York State.

The Bois Blanc is succeeded by the Detroit River group, a succession consisting largely of brown finely crystalline to granular dolomite with interbedded limestone. At some localities, notably at Amherstburg and Beachville in the southwestern part of the area, the typical dolomite in the upper part of the group is replaced by finely crystalline or sublithographic, high-calcium limestone. South of Lake St. Clair the Sylvania sandstone facies forms a basal unit of the group and reaches a maximum thickness of about 125 feet. The entire group has a maximum thickness of about 300 feet. It encloses the *Prosserella* fauna and is correlated with the middle Onondaga of New York State.

The Columbus formation, consisting of calcareous sandstone, sandy limestone, and dolomite, disconformably overlies the Detroit River group. Examination of cuttings from wells drilled for oil indicates that these beds are present only in the district south and west of London and that they have a maximum thickness of about 35 feet. They have been mapped with the overlying Dundee formation but are correlated with the Columbus formation of Ohio and the upper Onondaga of New York State.

The term Dundee (Delaware) formation is here used for the strata between the Columbus formation or, where the Columbus is absent, the Detroit River group below and the Hamilton formation above. The Dundee consists typically of a lower, buff, crinoidal, and arenaceous limestone with chert, succeeded by buff to brown finely crystalline limestone and chert with interbeds of black bituminous shale near the eastern limit of the formation. It overlaps both the Columbus formation and the Detroit River group and to the east rests directly upon the Bois Blanc formation. The Dundee formation, as here described, is correlated with the Delaware formation of Ohio and the Marcellus formation of New York and has a maximum thickness of about 200 feet.

Grey calcareous shale and shaly limestone, reaching a thickness of 300 feet, overlie the Dundee limestone. These beds have been mapped under the term Hamilton formation; they are divisible generally into four lithological units which are not everywhere recognizable in well cuttings. The Hamilton formation as here described is correlated with rocks of the same age typically exposed at Hamilton, New York, but it constitutes only a part of the Hamilton group in that state.

Devonian and Mississippian. The Hamilton formation is succeeded by the Kettle Point formation which consists of black to brown bituminous fissile shale with interbeds of green shale and is characterized by a profusion of small amber coloured spore cases usually referred to as *Protosalvinia (Sporangites) huronensis.* Where typically exposed, at Kettle Point on Lake Huron, the formation contains spherical concretions up to several feet in diameter that have been referred to as "kettles". The Kettle Point beds are correlated with the Huron shales of Ohio and with the lower part of the Antrim formation of Michigan and have a maximum thickness of about 335 feet.

The Port Lambton beds constitute the youngest Palæozoic rocks in Ontario. They are present in a small area south of Sarnia and are known only from well cuttings which show them to consist of grey fissile shale and dolomitic sandstone overlain by black fissile shale. They reach a maximum thickness of 200 feet and are correlated with the Mississippian Bedford shale, Berea sandstone, and the Sunbury shale of Michigan.

Although the lower part of the Kettle Point formation is considered to be Devonian in age, the upper part and the overlying Port Lambton beds have been assigned to the Mississippian period.

Ontario and Quebec, East of the Frontenac Axis

The central part of the St. Lawrence Lowlands extends east from the Frontenac axis to a short distance below Quebec City. As in the western part of the Lowlands this area is underlain by unfolded Palæozoic strata. Only the Cambrian and Ordovician systems are represented and these are intruded locally by the igneous rock of the Monteregian Hills. In eastern Ontario the maximum thickness of Palæozoic rock is about 2,200 feet but in Quebec (Nicolet River district) at least 10,000 feet of these strata are known (Tables X, XII, and XIII).

Table XII

Table of Formations, Ontario East of the Frontenac Axis

(*adapted from* A. E. Wilson)

Period	"Sub-Epoch"	Formation	Description	Thickness Feet
Ordovician	Richmond	Queenston	Red shale; red mottled green, and green shale	100
		Russell	Grey shale with interbedded rusty dolomitic limestone	
	Lorraine	Carlsbad	Grey shale with limestone interbeds	500-800
	Utica: Gloucester	Billings	Brown to black shale	260-300
	Utica: Collingwood	Eastview	Dark grey, fine-grained limestone with interbedded dark shale	about 20
	Trenton-Black River	Ottawa: Cobourg	Massive, grey, fine-grained limestone	450-475
		Sherman Fall	Rusty limestone, shale partings	
		Hull	Grey, crystalline limestone	150
		Rockland Leray	Grey to dark grey limestone, some chert	
		Lowville	Interbedded lithographic and thin-bedded limestone	100
		Pamelia	Grey limestone, dolomite with shale	
	Chazy	St. Martins	Grey limestone to dolomitic limestone	30-155
		Rockcliffe	Green shale with sandstone lenses	160
	Beekmantown	Oxford	Rusty dolomite and limestone	240-320
		March	Alternating grey sandstone and dolomite	25-30
Cambro-Ordovician		Nepean	Cream coloured sandstone	0-500

TABLE XIII

Composite Section, Montreal-Nicolet River

(*adapted from* T. H. Clark)

Period	"Group"	Formation	Description	Thickness Feet
Tertiary or Cretaceous		Monteregian intrusions		
Lower Devonian		Oriskany Helderger	Dolomite and limestone	
Ordovician	Richmond	Bécancour R. Pontgravé R.	Red and blue clay shales Thin-bedded shale and limestone	1,500+ 156
	Lorraine	Nicolet R. Leclercville	Thin-bedded, grey shale, limestone and sandstone	3,357+
	Utica	Lachine \ Lotbinière	Black shale	300+
	Trenton	Terrebonne	Thin-bedded dark limestone	270
		Tetreauville	Dense bluish black limestone, shale partings	270
		Montreal: Rosemount Montreal: St. Michel	Crystalline and argillaceous limestone, shale partings	250 120
		Mile End	Crystalline limestone	25
		Rockland	—?—	—
	Black River	Leray	Dark grey, granular and dense limestone	24
		Lowville	Dove, oolitic and lithographic limestone	11
		Pamelia	Bluish grey magnesian limestone	9
	Chazy	Laval: St. Martin St. Thérèse	Dominantly limestone with shale, some sandstone at base	280
	Beekmantown	Beauharnois Theresa?	Grey dolomite with shale and limestone Dolomitic sandstone	595 60
Cambrian		Potsdam	White quartz sandstone	0-1,696

The varying extent, direction of advance, and local oscillations of the several seas that invaded this area during Palæozoic time have produced lateral and vertical differences in the accumulated sediments. Formations of more or less local extent have thus been recognized and these have been given local names.

The oldest strata are represented in Quebec by the Potsdam sandstone accumulated perhaps in late Cambrian time on an undulating Precambrian surface. The thickness of this sandstone varies greatly from place to place and is known to reach 1,700 feet. It is practically devoid of organic remains, fossils being confined to small brachiopods of which only *Lingulella acuminata* has been found in this area and constitutes the basis for assigning a Cambrian age to the enclosing rock. *Climatichnites* and *Protichnites,* thought to be trails of invertebrate animals, and the burrow *Scolithus* have been observed at many outcrops.

In Ontario the Precambrian is overlain first by the Nepean sandstone similar in lithology to the Potsdam. However, as there is no discernible break between the Nepean and the overlying March formation of undoubted Ordovician age, it is possible that the Nepean formation is also of that age.

Following Potsdam deposition the sea appears to have withdrawn from Quebec. The beds (Theresa?) at the base of the Ordovician in this area are composed of rounded and frosted sand grains, whereas the Potsdam is composed chiefly of angular quartz grains.

The Potsdam-Nepean strata are succeeded by beds of Beekmantown age commencing with a sandy phase and ending with dolomite. Rocks of Beekmantown age comprise two formations described under different names in Ontario and Quebec. In Ontario their maximum combined thickness is about 350 feet, whereas in Quebec at least 1,060 feet of strata are represented. The enclosed marine fauna determines the Beekmantown age of these formations.

At the close of Beekmantown time the sea withdrew resulting in complete emergence until the invasion of the Chazy sea which transgressed the St. Lawrence region from the east. Chazy time is represented in both eastern Ontario and Quebec by two formations commencing with sandstone and followed by shale and limestone. Their combined thickness in Ontario is about 200 feet, increasing eastward to about 300 feet in Quebec.

At the end of Chazy time the sea again withdrew probably to the east and, after what is believed to have been a relatively short period of emergence, the sea again advanced but this time from the west and resulted in one of the most widespread submergences of Palæozoic time. Thus was initiated Black River and Trenton time during which about 800 feet of strata were laid down. In Ontario these rocks (Ottawa formation) comprise limestone with some sand, shale, and dolomite at the base. In Quebec the entire succession is mainly limestone and has been subdivided into seven formations with an aggregate thickness of about 980 feet.

Trenton time may have been succeeded in Ontario by a short period of non-deposition but otherwise the sea appears to have covered the St. Lawrence region until late Ordovician time.

The Ottawa formation is succeeded by more than 250 feet of dark shale with interbedded limestone at the base (Eastview and Billings formations). In Quebec contemporaneous deposits are entirely shale and reach a maximum thickness of 1,000 feet. They comprise the Lotbinière and Lachine formations and are considered to be of Utica age.

Succeeding the Utica is the Lorraine represented in Ontario by the Carlsbad formation consisting of 500 to 800 feet of grey shale with dolomite bands enclosing a fauna of post-Utica age. In Quebec, equivalent rocks consist typically of shales with subordinate amounts of limestone and sandstone. These rocks have been subdivided into the Leclercville and Nicolet River formations. A section measuring 2,274 feet is present on Nicolet River and a boring south of the St. Lawrence River penetrates 3,340 feet of grey shales probably of Lorraine age.

The Lorraine is overlain by strata of Richmond age. In Ontario these consist of grey dolomite (Russell formation) overlain by brick red shale and green mottled shale (Queenston formation), the whole being about 100 feet thick. In Quebec the sequence begins with the Pontgravé River formation consisting of 156 feet of grey shale and limestone separable from the underlying formation only on calcareous content. This formation is succeeded by at least 1,500 feet of red and blue non-fossiliferous shales referred to as the Bécancour River formation.

During late Richmond time the sea had already begun to withdraw and except during part of the Lower Devonian epoch the region appears to have remained an area of non-deposition until Pleistocene time. It is, however, worthy of note that the presence of Palæozoic outliers suggests that Ordovician and Silurian rocks covered large parts of the area now occupied by the Canadian Shield.

Much of St. Helen Island, Montreal, is formed of a breccia consisting of blocks of all sizes up to 20 feet across, embedded in a matrix that appears to consist of smaller fragments of the same rock. The blocks are from Precambrian granite and gneiss, Potsdam sandstone, the several Ordovician limestones, and Devonian limestone. Fossils collected from some of these last mentioned blocks include both Helderberg and Oriskany forms and indicate that at least part of the region was covered by a Devonian sea whose deposits are now represented only by the breccia. The lack of igneous material in the matrix has led to the conclusion that the rock is the result of brecciation of a column of overlying rock caused by gas pressures from an underground magma connected with the Monteregian intrusions.

The Monteregian Hills, except for Mount Johnson, lie along a somewhat curved line extending easterly from Montreal for a distance of about 50 miles. They are eight in number, five of which rise more than 1,000 feet above the surrounding plain, the others to heights of 600 to 700 feet. Their names are Mount Royal, St. Bruno, St. Hilaire, Rougemont, Johnson, Yamaska, Shefford, and Brome. The last three mentioned intrude the folded and faulted Palæozoic rocks east of the Logan fault, and are, therefore, within the Appalachian region. The hills are circular or oval in outline, each only a few square miles in area. Their cores consist of igneous rocks of alkaline types, including such varieties as alkali syenite, nepheline syenite, and essexite, and are intrusive into Palæozoic formations ranging in age from Beekmantown to Richmond. Brome and Shefford

Mountains are thought to be unroofed laccoliths, or perhaps parts of a single laccolith still covered by sedimentary strata in the 2½-mile interval of lower land between the hills. The other hills appear to be volcanic necks with nearly vertical walls.

The age of the intrusions is Devonian or younger. Evidence for this, in addition to that supplied by the St. Helen Island breccia, is afforded by Yamaska, Shefford, and Brome Mountains, which lie within the folded Appalachian region. The intrusive masses show no effects of deformation, and hence must have been intruded after the last folding that affected this region in Middle Devonian time. It has also been noted that, in the Monteregian intrusive rocks, pleochroic haloes surrounding crystals of zircon and titanite are invariably poorly developed and immature. In this they resemble those in Tertiary intrusive rocks, whereas, in certain Devonian granites haloes are numerous and prominent. The suggestion has, therefore, been advanced that the igneous rocks of the Monteregian Hills may be as young as Tertiary.

Anticosti Island, Mingan Islands, and Adjacent Coast

This most easterly of the three divisions of the St. Lawrence Lowlands is separated from the others by several hundred miles of water, but represents part of a much more extensive development of Ordovician and Silurian rocks.

Both Ordovician and Silurian systems are represented on Anticosti Island (Tables X and XIV). The oldest beds are those of the Macasty black bituminous

TABLE XIV

Table of Formations, Anticosti Island

(*adapted from* W. H. Twenhofel)

Period	Series or Stage	Formation	Description	Thickness Feet
Silurian	Niagaran	Chicotte	Crinoidal and reef limestone	73
		Jupiter	Limestone and shale	653
	Anticostian	Gun River	Alternating limestone and shale	308
	(Alexandrian)	Becscie	Limestone with shale partings	189
Ordovician	Gamachian	Ellis Bay	Shale and limestone on the south shore; sandstone followed by limestone on north shore	200
	Richmond	Vauréal	Interbedded limestone and shale	730
		English Head	Limestone and shale	228
	Lorraine	?	—	—
	Utica	Macasty	Black shale, only on north shore and not in place	?

shales. These beds have not been seen in place but their presence is indicated by blocks thrown up by the waves along the north shore of the island. The blocks enclose graptolites and trilobites indicating a Utica age for the rock.

The oldest exposed formations represent a continuous sequence of limestone and shale totalling about 958 feet in thickness. This succession has been divided on palæontological evidence into two "formations", the English Head and the overlying Vauréal, both of Richmond age.

The Vauréal formation is overlain by about 200 feet of rock consisting mainly of limestone but containing also some beds of sandstone and a bed of quartz-pebble conglomerate. This is the Ellis Bay formation; it encloses a fauna the preponderance of whose species does not pass into the next succeeding formation. The assemblage is unknown elsewhere in America and the fauna has, on the one hand, a decidedly Richmond (Ordovician) aspect whereas, on the other hand, certain species bear close resemblance to Silurian forms.

The Ellis Bay formation is succeeded by the Becscie formation consisting of a basal limestone conglomerate, indicating possible disconformable relations, followed by grey limestone with shale partings, the whole about 200 feet thick. A number of fossil species persist into this formation from the underlying Ellis Bay beds and these forms, together with the introduction of some thirty new species, comprise the Becscie fauna. This fauna suggests a Silurian age of about the time of the Cataract beds of Ontario.

Overlying the Becscie is about 300 feet of alternating limestone and shale comprising the Gun River formation. These rocks exhibit evidence of shallow water deposition and their contained fauna indicates a time equivalent to that of the Cataract to Clinton.

The Gun River formation is succeeded by the Jupiter formation consisting of about 650 feet of limestone and shale containing a fauna suggesting equivalence with the Clinton strata of Ontario. Overlying it, is the Chicotte formation comprising about 73 feet of crinoidal and reefal limestone. Corals constitute an important element of the Chicotte fauna which is correlated with that of the Rochester and lower part of the Lockport formations and is, therefore, Niagaran in age.

TABLE XV

Table of Formations, Mingan Islands and Adjacent Coast

(*by* W. H. Twenhofel)

Period	Series or Stage	Formation	Description	Thickness Feet
Ordovician	Chazy	Mingan	Limestone, shale and sandstone	135+
	Beekmantown	Romaine	Dolomite with some shale	262+

The Anticosti section is one of the most interesting in North America as the Ellis Bay beds bridge in a large measure a gap that in many places exists between the Ordovician and Silurian systems. According to Twenhofel: "In almost unbroken sequence are recorded the changes of life from the Ordovician to the Silurian, the stratigraphic break between the two having been apparently of brief duration". To these strata the term Gamachian has been applied, representing some of the youngest Ordovician strata on the North American continent.

The rocks of the Mingan Islands and the adjacent coast belong to the Ordovician system and have been divided into two formations, the Romaine and Mingan, of Beekmantown and Chazy age, respectively (Tables X and XV). The Romaine formation consists of thick-bedded dolomite containing some chert and reaching a thickness of about 263 feet. A sparse fauna of about thirty-seven species indicates a late Beekmantown age. The Mingan formation rests unconformably

TABLE XVI

Table of Formations, Hudson Bay Lowland

<table>
<tr><th>Period</th><th colspan="3">Formation</th><th colspan="2">Description</th><th>Thickness Feet</th></tr>
<tr><td>Lower Cretaceous or Upper Jurassic</td><td colspan="3">Mattagami</td><td colspan="2">Fire clay, sand, lignite</td><td>170</td></tr>
<tr><td rowspan="6">Devonian</td><td colspan="3">Long Rapids</td><td colspan="2">Bituminous black and grey shale</td><td>285</td></tr>
<tr><td colspan="3">Williams Island</td><td colspan="2">Limestone, red and grey shale</td><td>301</td></tr>
<tr><td rowspan="3">Abitibi River</td><td>Upper</td><td></td><td colspan="2">Grey, fossiliferous limestone</td><td>48</td></tr>
<tr><td>Middle</td><td>(Moose River)</td><td colspan="2">Limestone, gypsum, shale, sandstone</td><td>254</td></tr>
<tr><td>Lower</td><td></td><td colspan="2">Cherty limestone, some sandstone</td><td>42</td></tr>
<tr><td colspan="3">Sextant</td><td colspan="2">Arkose, shale, sandstone</td><td>91</td></tr>
<tr><td rowspan="4">Silurian</td><td>Attawapiskat</td><td>Limestone, coral reef</td><td>85</td><td>Kenogami R.</td><td>Dolomite, siltstone, shale, limestone</td><td>296</td></tr>
<tr><td>Ekwan River</td><td>Limestone, cherty dolomite</td><td>100</td><td>Pagwa R.</td><td>Grey, fossiliferous limestone, chert</td><td>61</td></tr>
<tr><td colspan="3">Severn River</td><td colspan="2">Dolomite, limestone, some sandstone</td><td>26-75</td></tr>
<tr><td colspan="3">Port Nelson</td><td colspan="2">Limestone</td><td>35</td></tr>
<tr><td rowspan="2">Ordovician</td><td>Shammattawa</td><td>Limestone</td><td>80</td><td rowspan="2">Richmond strata</td><td rowspan="2">Dolomite limestone, sandstone</td><td rowspan="2">30</td></tr>
<tr><td>Nelson River</td><td>Limestone</td><td>70</td></tr>
</table>

upon the Romaine and consists of a basal sandstone succeeded by limestone with some shale, the whole attaining a thickness of about 135 feet. A fauna of more than one hundred species has been described from this formation and, although fifty-three of the species are not known elsewhere, the total fauna indicates a Chazy age for the enclosing strata.

Hudson Bay Lowland

The oldest sedimentary rocks of the Hudson Bay Lowland are of Ordovician age (Tables X and XVI). The main body, at the northwest part of the lowland area outcrops along Nelson River. It has been divided into two formations, the Nelson River, of which a thickness of 70 feet of limestone has been measured, and the overlying Shammattawa, with an exposed thickness of 80 feet of limestone. The Nelson River formation is correlated with the Liskeard formation of the Palæozoic outlier at Lake Timiskaming and is considered to be Richmond in age. The fauna of the Shammattawa formation determines its Richmond age and permits correlation with the Stony Mountain formation of the Lake Winnipeg region. In the Churchill area correlatives of the Red River and Stony Mountain formations of southern Manitoba have been recognized within a sequence of some 300 feet of Ordovician strata. A second body of Ordovician rocks occurs in the southern part of the Hudson Bay Lowland; these rocks have not been subdivided but have been described under the term Richmond.

The Silurian rocks are well exposed along the Severn, Winisk, Ekwan, and Attawapiskat Rivers, in the central part of the lowlands. The lowest formation is the Port Nelson, comprising about 35 feet of limestone. Its most characteristic fossil is *Virgiana decussata*, indicating a Lower Silurian age. The formation is correlated with the basal part of the Stonewall formation of Manitoba. The Port Nelson is succeeded by the Severn River, a formation 26 to 75 feet thick, composed of dolomite, limestone, some sandstone, and enclosing a fauna of about the same age as the Cataract of Ontario. The Port Nelson and Severn River formations have been correlated with the Alexandrian (Lower Silurian) of the Michigan-Ohio area. The Lower Silurian strata are succeeded by the Ekwan River formation, consisting of about 100 feet of limestone with some cherty dolomite. This in turn is overlain by the Attawapiskat formation comprising about 85 feet of limestone and coral reef. The Ekwan River formation represents about the time of lower or middle Lockport deposition and the Attawapiskat coral reef about that of the upper Lockport; both are therefore Niagaran (Middle Silurian) in age. In the southern part of the Hudson Bay Lowland, the terms Pagwa River and Kenogami River formations have been proposed for strata of the same age as the Ekwan and Attawapiskat Rivers formations. The Pagwa River overlies the Severn River and consists of about 61 feet of fossiliferous limestone with chert. The succeeding Kenogami River formation is divided into five members consisting, in ascending order, of 57 feet of buff dolomite; 47 feet of green dolomite; 100 feet of red and green siltstone and shale with some honeycomb limestone; 62 feet of green and red siltstone and shale with interbedded limestone; and 30 feet of buff dolomite with some oolitic limestone.

Following is a summarized log of the core from a boring made by the Ontario Department of Mines at Puskwuche Point on the west shore of James Bay 45 miles north of Moosonee.

Elevation, 8 feet above mean high tide.

Depth Feet	Thickness Feet	Description	Formation	Correlation	Age
0– 18	18	Sand, gravel, clay			Pleistocene
18– 22	4	Broken rock			
22– 68	46	Buff, grey, and cream limestones	Abitibi River, Upper	Bois Blanc	Devonian
68– 93	25	Buff and grey limestones, chert, carbonaceous material	Kenogami River, Member 5	Bass Island	Silurian
93– 147	54	Cream limestone, oolites			
147– 199	52	Buff and grey dolomites, oolites			
199– 205	6	Grey limestone breccia			
205– 216	11	Grey calcareous silt and clay with sandstone bands	Kenogami River, Members 3 and 4	Salina	
216– 757	541	Mottled red and green siltstone, with sandy or intraformational breccia interbeds, gypsum			
757– 767	10	Green to grey dolomite, selenite veinlets	Kenogami River, Member 1		
767– 930	163	Cream to buff dolomite, gypsum, selenite			
930– 960	30	Buff and grey fossiliferous limestones; coral reef	Pagwa River	Guelph and Niagaran	
960–1,010	50	Argillaceous limestone with carbonaceous material, interbeds of coarsely crystalline fossiliferous limestone			
1,010–1,089	79	Interbedded coarse- and fine-grained limestones			
1,089–1,094	5	Cream limestone with layers of crystalline limestone	Severn River	Medina and Cataract	
1,094–1,110	16	Buff limestone			
1,110–1,132	22	Mottled buff limestone			
1,132–1,147	15	Grey limestone			
1,147–1,160	13	Buff, argillaceous limestone	Port Nelson		
1,160–1,184	24	Mottled grey limestone			
1,184–1,190	6	Argillaceous limestone			
1,190–1,210	20	Grey argillaceous limestone, in part mottled buff			
1,210–1,220	10	Grey fossiliferous limestone			
1,220–1,229	9	Grey limestone with layers of coarsely crystalline limestone			
1,229–1,257	28	Grey argillaceous mottled limestone			

1,257–1,286	29	Grey and buff dolomitic limestones	Basal		
1,286–1,311	25	Grey, buff and cream dolomitic limestones			
1,311–1,316	5	Dolomitic limestone, clay, sandstone, gypsum			
1,316–1,320	4	Mud or shale, gypsum, sand			
1,320–1,330	10	Grey buff limestones, gypsum			
1,330–1,334	4	Grey limestone			
1,334–1,340	6	Mud, shale, sand, argillaceous limestone, gypsum			
1,340–1,346	6	Light grey limestone			
1,346–1,354	8	Light grey limestone, sand grains			
1,354–1,374	20	Light grey and dark shaly limestones with mica, much gypsum			
1,374–1,394	20	Dark grey limestone, selenite			
1,394–1,414	20	Grey limestones with mica, selenite			
1,414–1,426	12	Light grey limestone, dark silty limestone, selenite			
1,426–1,442	16	Grey sandstone with gypsum flecks			
1,442–1,467	23	Largely lost, small buttons of sandstone recovered			
1,467–1,485	18	Grey sandstone			
1,485–1,497	12	Red-brown sandstone, interbeds green shale and grey sandstone			
1,497–1,499	2	Green-grey limestone, interbeds sandstone			
1,499–1,529	30	Red-brown sandstone			
1,529–1,536	7	Diabase, weathered 1,529-1,529⅜, fractures filled with brown sandstone			Precambrian
1,536		End of hole, June 15, 1951			

Devonian rocks are well exposed in the Moose River basin where Lower, Middle, and Upper Devonian epochs are represented. A section of these rocks is furnished by diamond-drill core from a boring located near the axis of a broad synclinal region, known as the Moose River basin in which remnants of Mesozoic strata are preserved. This core shows that rocks of Devonian age rest directly upon the Precambrian basement. The Sextant formation comprises the oldest Devonian strata represented. It is thought to be of continental origin and consists of about 90 feet of red, and green to yellow conglomerate, red and green mottled siltstone, sandstone, and arkose, and includes lenses of black shale enclosing plant fragments indicating a Lower Devonian age. The Abitibi River formation overlies the Sextant; it has been divided into three members, consisting of a lower member of 42 feet of cherty limestone with some fossiliferous sandstones; a middle member (Moose River) of 254 feet of grey limestone, gypsum, shale and unfossiliferous sandstones; and an upper member of 48 feet of grey to buff fossiliferous limestone with coral reefs. Overlying the Abitibi River formation is the Williams Island formation. As found in Drill Hole A, Onakawana Lignite Field, this formation has been divided into three members consisting of about 149 feet of massive grey shale, succeeded by 32 feet of red gypsiferous shale, the whole capped by 120 feet of buff and grey cavernous limestone and calcareous shale. About 87 feet of this formation is exposed at the head of Williams Island. The fauna collected there shows a mixture of Upper and Middle Devonian species. The Long Rapids formation represents the youngest Palæozoic strata in this region and consists typically of about 285 feet of dark grey to black bituminous shale and greenish grey calcareous clay shale. The dark shales contain plant spores referred to *Protosalvinia (Sporangites) huronensis*. On Mattagami River grey fissile shales with interbeds of nodular limestone enclose the fossils *Pugnax pugnus* and *Leiorhynchus* cf. *kelloggi*; an Upper Devonian age for the formation is thus indicated.

The Mesozoic rocks of the Hudson Bay Lowland are termed the Mattagami formation. Two facies are represented, a lower facies of light grey, brown, red and buff, fine-grained, plastic fire clay with white quartz sand and kaolin, and an upper facies of grey to black fire clay and brown and yellow micaceous sand with seams of argillaceous lignite and fragments of lignified tree trunks. The total thickness as indicated by drilling is about 170 feet and lignite seams 3, 14, 22, and 43 feet thick have been observed. Plants collected from a lignite seam exposed at the Great Bend on Mattagami River have been referred to Upper Jurassic or early Lower Cretaceous with preference towards the latter because of the presence of *Pityophyllum graminaefolium*; this species is widespread in the Kootenay formation of Western Canada.

Palæozoic Outliers

Northward from the St. Lawrence Lowlands lies the peneplain of the Canadian Shield within whose present boundaries lie outliers of Palæozoic strata (Figure 54; Tables X and XVII).

Most of the outliers are small, a square mile or less in extent, and exhibit a relatively thin section of rock. The Timiskaming outlier, however, is about 25 miles long and 9 miles wide and exhibits more than 1,100 feet of rock, both the Ordovician and Silurian systems being represented. The Liskeard formation of this locality was formerly assigned a Trenton age. Due however to the recognition of a recurrence of certain Trenton species in the Richmond, the Liskeard is now considered to be Richmond in age and not Trenton. In general, the outliers consist of grey fine-grained to finely crystalline fossiliferous limestone and dolomite. However, at Lake Clear, Collingwood black shale is present and interbedded shale and sandstone occur with the limestone at Gilmour Lake. At this locality the sandstone consists largely of quartz, feldspar, and garnet.

The age of the rocks forming these outliers ranges from Cambrian on the north side of Strait of Belle Isle to upper Niagaran (Middle Silurian) at Lake Timiskaming. The presence of the outliers suggests that the part of the Canadian Shield marginal to the St. Lawrence Lowlands was once covered by the Palæozoic

TABLE XVII

Table of Formations, Palæozoic Outliers

Location	Period	Series or Stage	Formation or Lithology	Thickness Feet
Lake Timiskaming, Ont.	Silurian Silurian Ordovician	Niagaran Niagaran Richmond	Thornloe Wabi Liskeard	807 120 250
Lake Nipissing, Ont.	Ordovician	Trenton-Black River	Grey limestone	—
Gilmour Lake, Ont.	Ordovician	Black River Chazy	Grey argillaceous limestone, limestone, sandstone, shale	504+
Mattawa outliers, Ont. and Que.	Ordovician	Trenton-Black River	Grey argillaceous limestone	—
Ottawa Valley, Ont. and Que.	Ordovician	Utica Trenton-Black River	Collingwood beds — black shale Ottawa fm. — limestone	—
Georgian Bay, Ont. Naiscoot River Limestone Islands	Ordovician	Black River	Grey limestone	—
Echo Lake, Que.	Ordovician		Limestone	—
Lake Waswanipi, Que.	Ordovician	Richmond	Limestone	—
Lake St. John, Que.	Ordovician	Utica Trenton Black River	Gloucester strata, shale {Galet beds, limestone Shipshaw beds, limestone Simard beds, limestone} Tremblay beds, limestone arkose	25 15 60 63 15
Manicouagan Lake, Que.	Ordovician	Richmond	Grey, argillaceous limestone	—
Labrador, north side Strait of Belle Isle	Cambrian	Lower	Forteau, limestone and shale Bradore, conglom. and sandstone	185 72

seas and that arms of these seas may have spread across the Shield to connect with the Hudson Bay Lowland area and the Arctic region.

Economic Geology

St. Lawrence Lowlands

The principal economic products of the Palæozoic formations in the St. Lawrence Lowlands are non-metallic, the more important being salt, natural gas and petroleum, gypsum, and structural materials. Galena-bearing veins in the Precambrian rocks north of Kingston may be related to post-Ordovician igneous activity as similar veins east of the Frontenac axis cut the overlying Ordovician limestones.

Natural Gas and Oil

The commercially productive oil and gas fields are all in the inter-lake peninsula area of Ontario (Figure 57), and most are south of a line joining the west end of Lake Ontario and the foot of Lake Huron. Small quantities of oil have been found on Manitoulin Island and near Collingwood on Georgian Bay; some natural gas has been produced in the southern part of Bruce Peninsula, but to date no field of commercial significance has been found in these areas. A well with an open flow potential of 8.2 million cubic feet a day was completed near Bayfield in Huron county in 1956. The productive zone is of Silurian age at a depth of 1,520 feet. In general, the gas and oil fields in Ontario are separate and yield from different geological zones. Exceptions are the Dawn and Dover fields, which yield both oil and gas.

The first natural gas field was discovered in Essex county in 1889 and is still productive, though on a small scale. Subsequent discoveries have been made in the general area bordering Lake Erie and extending from Essex county eastward to Niagara River, and in 1955 these fields produced 10,850,000M cubic feet of gas having a retail value of more than $12 million. The gas fields are mainly in Niagara Peninsula, and in Norfolk, Kent, Middlesex, Lambton and Essex counties. In the Niagara district productive formations are all of Silurian age, chief among which are the Whirlpool, Grimsby, and Thorold sandstones and the Irondequoit limestone. West of London the productive zones are in the Guelph and Salina formations (Silurian) except at the Dover field which yields from the Black River-Trenton limestone (Ordovician). In Niagara Peninsula porosity seems to be the chief factor controlling accumulation of natural gas. To the southwest, however, anticlines and dome structures are present, and of special importance are bioherms and pinnacle-like reef structures in the Guelph formation, some of which have a relief of more than 400 feet. The Dover gas and oil field is of interest in that it is a faulted syncline and accumulation is thought to be due in part at least to the absence of water in the reservoir rock.

Exploration beneath the water of Lake Erie has been carried on for a number of years, and a number of productive gas wells have been drilled from 1 mile to 4 miles from shore. More recently, drilling has also been extended into Lake St. Clair with some success.

The oil industry in Ontario began in 1857 with development of tarry seepages long known to occur along Black Creek near the village of Oil Springs in Lambton county. Drilling commenced about 1859 and many flowing wells were quickly completed. Initial flows of 2,000 and 5,000 barrels a day were common and one well is reported to have flowed 7,500 barrels of oil a day. Drilling soon spread to the Petrolia district and this area is still one of the main productive regions in Ontario. Production of oil in Ontario in 1955 was 525,510 barrels, of which more than 63,000 barrels came from the Oil Springs and Petrolia fields.

All productive oil fields are in the southwestern part of the peninsula. Main production is from the Dundee limestone (Devonian) at depths of 380 to 500 feet. Smaller yields are from the Salina and Guelph formations (Silurian) and

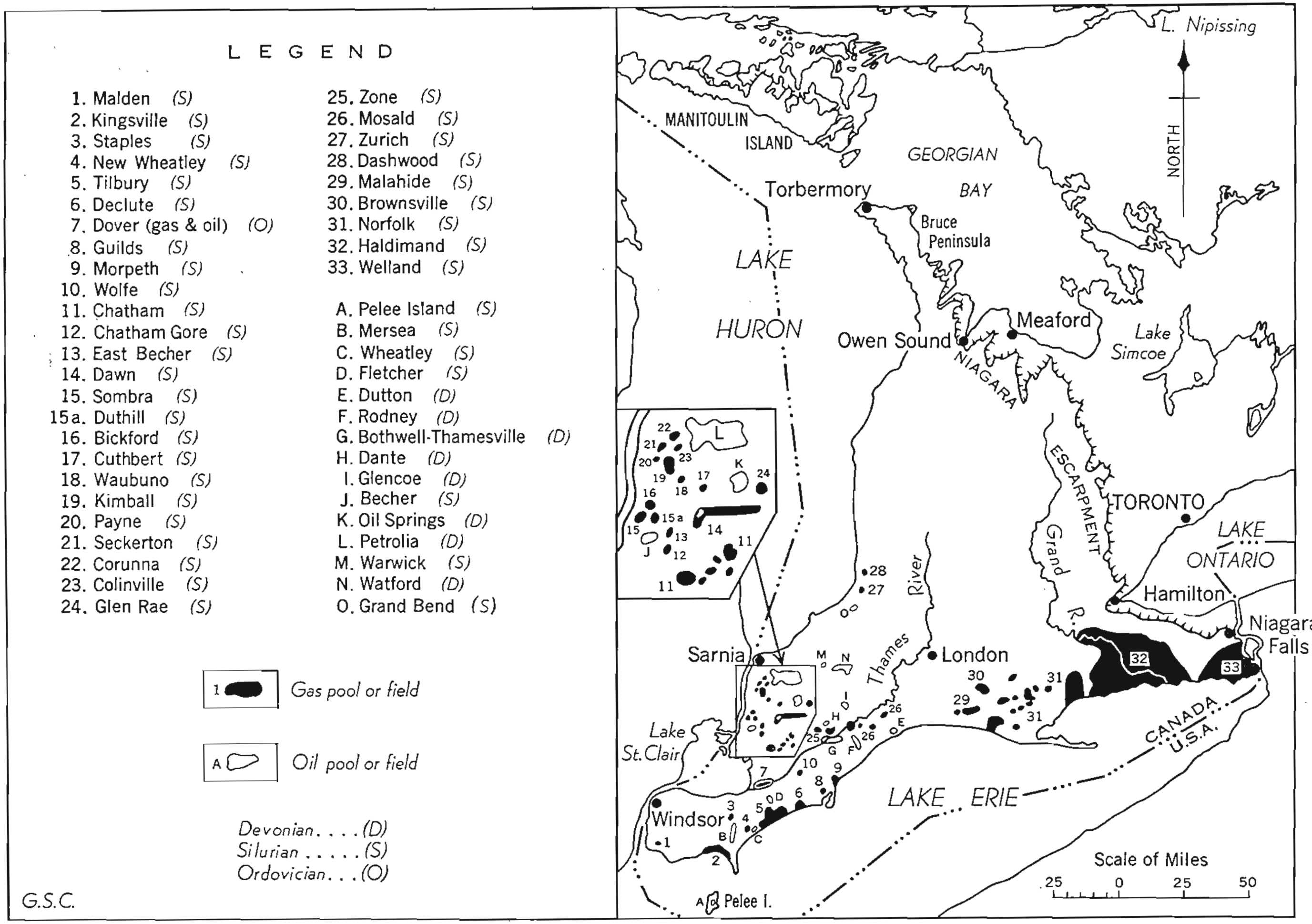

FIGURE 57. Principal oil and gas fields of southwestern Ontario.

from the Black River-Trenton limestone (Ordovician) in the Dover field. The Trenton has also yielded small quantities of oil in the Georgian Bay district and on Manitoulin Island. A few barrels of oil are recovered annually from the Whirlpool sandstone (Silurian) in Niagara Peninsula.

Salt

Production of salt in Ontario in 1955 was 998,789 short tons valued at $5,845,340, the output being about 80 per cent of the Canadian total for that year. It was obtained from southwestern Ontario (Figure 58).

Salt was discovered in Ontario in 1866 when a company was formed at Goderich for the purpose of drilling for oil. The first well was drilled on the north

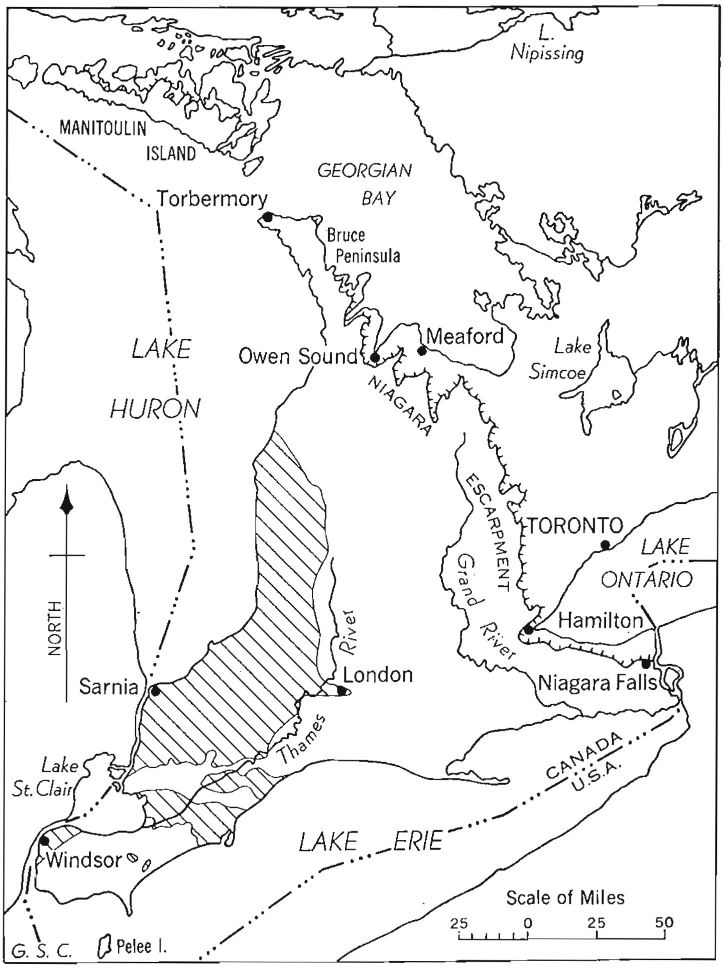

FIGURE 58. Approximate area underlain by salt (shown by pattern), southwestern Ontario.

side of Maitland River a short distance above the highway bridge at Goderich, but instead of striking oil, a bed of rock salt was encountered at a depth of 964 feet; the salt was interstratified with rock but aggregated 30 feet in thickness. The exact boundaries of the salt basin are not known, but on a basis of the many gas and oil wells that pass through the salt-bearing formation the general area underlain by salt includes most of Huron, Middlesex, and Lambton counties, the western part of Elgin county, and parts of Kent and Essex counties. The salt is not continuous beneath this large area, as a number of wells have penetrated the entire salt-bearing formation without encountering salt. However, drilling records point to considerable continuity of the salt beds and suggest that, within the general area outlined, there are relatively few places where salt is absent.

The salt forms part of the Salina formation. From one to ten separate beds are known, separated by variable thicknesses of dolomite or limy shale. Single beds range in thickness from 5 to 295 feet and their aggregate known thickness reaches a maximum of 650 feet in Sarnia township. Apparently the beds are lenticular in form, the thickness of a single bed varying greatly from well to well. In drilling, the first salt is commonly encountered at a depth between 320 and 450 feet below the top of the Salina formation, but in a few places it has been found within the upper 150 feet. Salt, however, is rarely found within 100 feet of the base of the formation.

Towards the close of Niagaran time the Lockport sea gradually receded, and a partly isolated basin was formed throughout much of southwestern Ontario. This basin underwent desiccation, with resultant formation of beds of gypsum, dolomite, and salt. These precipitates were interbedded with muds, which were products of the erosion of older Silurian beds exposed in the surrounding areas. An intermittent communication with the open sea was maintained, thus adding periodically to the quantity of salts available for precipitation and giving rise to a variable succession of strata from place to place.

The salt is obtained by evaporation of artificial brine. Wells are drilled into the salt beds, cased, and then tubing of smaller diameter is placed inside the casing. Fresh water is commonly forced into the well through the outer tube, though at Goderich, where the wells pierce a water-bearing horizon above the salt, this water is allowed to run down naturally into the well whose casing has been perforated to permit the water to enter. After the water has dissolved the salt (it takes up approximately a third of its weight) it is pumped to the surface through the inner tube. The brine is evaporated by two general methods. In the vacuum pan process a partial vacuum is maintained in closed vessels, and under the reduced pressure evaporation proceeds rapidly at relatively low temperatures. Crystallization is rapid so that the salt has a fine grain. To this fine salt may be added about 1 per cent of magnesium carbonate to make it free-flowing, or about 0.01 per cent of potassium iodide to make an iodized salt of standard grade. In the open pan process, the brine is evaporated in open vats. The resulting salt is coarse, and is usually marketed in bulk or in bags for use by dairies, meat packers, and others

Gypsum

It is well over 100 years since gypsum was first discovered in Ontario, the first mine being opened about 1822 by William Holmes near the site of the present city of Paris. At first the product was utilized solely for fertilizer or land plaster, and the market was local. In 1955 the Ontario output was 366,416 tons, valued at $808,424. This output was about 8 per cent of the Canadian total for that year.

All the output is from Grand River Valley, the most important workable deposits being in Seneca, Oneida, and North Cayuga townships. The deposits are lenticular and occur at different horizons within the Salina formation. Some are as much as 11 feet thick. Canadian Gypsum Company Limited operates the mine at Hagersville, and Gypsum, Lime and Alabastine, Canada Limited the mine at Caledonia.

Fluorite

Fluorite has been obtained in commercial quantities from veins in Black River (Ordovician) limestone in Madoc township, Ontario. The width of the vein material ranges from 2 inches to 8 feet and the chief associated minerals are barite and calcite. Production from the area has been small, the shipments in 1955 being 730 tons.

Fluorite also occurs in cavities in Devonian dolomite at Amherstburg, Essex county, and in Lockport (Silurian) dolomite at Niagara Falls. These occurrences are of mineralogical interest only.

Lead and Zinc

Lead- and zinc-bearing veins near Carleton Place in Lanark county, Ontario, intersect Ordovician strata and are, therefore, Ordovician or later in age. Associated with these minerals is some pyrite and chalcopyrite. The gangue is commonly calcite. These occurrences received some active development attention for a short period several years ago. They are of interest in furnishing evidence on the age of the calcite-barite-bearing veins in eastern Ontario, which are mostly in Precambrian rocks. However, as they are similar to those near Carleton Place in both mineralogy and general character, they are presumably also of Palæozoic age.

Sphalerite prospects were worked in the past in the Bruce Peninsula, near Wiarton and Cabot Head. These deposits are of Middle Silurian age, in Amabel-Guelph contact strata, and are of good grade. They are small and spotty.

Structural Materials

The St. Lawrence Lowlands is underlain by almost undisturbed Palæozoic rocks, the limestones, shales, and sandstones of which furnish supplies for much of the structural needs of the large and rapidly increasing population of the region.

The chief structural products of the limestone quarries are crushed stone for road metal, railway ballast, and concrete aggregate; stone for lime and Portland cement; building stone, flux, stucco dash, terrazzo, and stone for manufacture of rock wool. Other important products are chemical limestone, used in the manufacture of calcium carbide and in making beet sugar and sulphite pulp. Almost all the limestone formations of the Ordovician, Silurian, and Devonian systems are used in making one or more of the foregoing products.

Brick and tile are the chief materials manufactured from the shales. The red shale of the Queenston and shales of the Dundas-Meaford formations are the most widely used, although the Cataract, Cabot Head shales also possess economic possibilities.

Chief use made of the sandstones is for building stone, and both the Whirlpool sandstone (Silurian) and the Oriskany sandstone (Devonian) have been used extensively for this purpose.

Hudson Bay Lowland

Gypsum

Extensive deposits of gypsum are known in the Moose River formation at several localities in the Moose River basin. At Moose River a maximum thickness of 15 feet has been observed; on Cheepash River it reaches a thickness of 20 feet and cliffs from 10 to 17 feet high are common; at Gypsum Mountain, between Abitibi and French Rivers, cliffs of gypsum 15 feet high with neither top nor bottom exposed, have been reported. The gypsum is of excellent quality but its great distance from markets reduces its present economic importance.

Lignite

Lignite deposits of economic interest underlie an area of at least 6 square miles on the west side of Abitibi River, near Blacksmith Rapids (Onakawana). The deposits are in the Mattagami formation of Lower Cretaceous age, and lie at an average depth of about 65 feet. They occur in two main seams separated by a parting of clay. The lower seam has a fairly uniform thickness of 14 to 22 feet throughout the middle and eastern parts of the field, but thickens to between 25 and 30 feet in the southwestern part. The upper seam has been more subject to glacial erosion and shows a much greater variation in thickness. In places, part or all of this seam has been eroded away but thicknesses of 40 to 43 feet are known.

Refractory clay occurs mainly at two horizons in the lignite field, one above the upper lignite seam and the other between the two seams.

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CHAPTER V

THE INTERIOR PLAINS

(R. T. D. Wickenden)

The Interior Plains occupy that part of Western Canada between the Precambrian Shield on the east and the Cordilleran region on the west (Figure 1). They are a continuation of the Interior Plains of the United States beginning at the Gulf of Mexico and extending in a narrowing belt northwestward through Canada, where they include parts of Manitoba, Saskatchewan, Alberta, British Columbia, and the Northwest Territories. Altogether in Canada they occupy an area of about 775,000 square miles, of which about 375,000 square miles is within the Prairie Provinces and includes almost all the arable land, consisting of open prairies in the south (Plate XXIV) bordered on the east and north by park lands with poplar groves (Plate XXV), which, farther north, merge into more heavily timbered areas of poplar and evergreen forests. Still farther north, in the Mackenzie Lowlands, the Plains extend into the scantily timbered and barren lands of the Arctic regions.

Along the eastern edge the region either merges into the Canadian Shield without any noticeable topographic break, or else a sudden drop of a few score feet or less may mark the division between the smoothly rolling or nearly level plains on the west and the hummocky or low, hilly country of the Canadian Shield on the east. On the west the Interior Plains merge with the Foothills of the Rocky Mountains.

Physical Features

The northern part of the Interior Plains drains northward through the Athabasca, Peace and Liard River systems into the Mackenzie River and thence to the Arctic Ocean. Most of the remaining area drains northeastward through the Saskatchewan and Red River systems into Hudson Bay. Milk River in Alberta and a few small streams in southern Saskatchewan drain south into the Milk and Missouri Rivers. The drainage is largely controlled by a general north and northeast slope of the land which falls from an elevation of about 4,000 feet on the eastern edge of the Foothills to 500 feet in southeastern Manitoba and to sea-level at the mouth of the Mackenzie River. Due to the dry climate, few large tributaries originate in the prairies and most of the water comes from the mountains in the west.

Although the name "plain" suggests a level tableland, many irregularities of topography are present, both as deeply dissected river valleys (Plate XXIV) and as prominent hills rising well above the prairie land. All the larger drainage courses

Plate XXIV

Open prairie and steep-walled stream valley. Pothole Coulee, near Magrath, Alberta.

and many of the smaller ones are cut well below the plain level, in places as much as 400 feet, and occupy valleys 1 mile to 2 miles wide with steep banks and flat bottomlands. In many areas, particularly in the southern Plain, valleys that contained large streams, perhaps during Pleistocene time, are now dry, or are occupied only by minor streams in wet seasons or by remnants of lakes, now largely alkaline and without outward drainage. In many other parts of the southern Interior Plains alkaline lakes fill shallow depressions. In dry periods these lakes either dry completely, leaving white alkaline flats, or they dry in part, leaving a white salt fringe as a rim around the lake shores.

In the interstream areas, especially in the south, a large part of the Interior Plains is flat or gently rolling. In other interstream areas large moraines have been deposited in belts within which irregular hills and hollows present an uneven topography. In still other areas there are extensive sand deposits, partly blown into

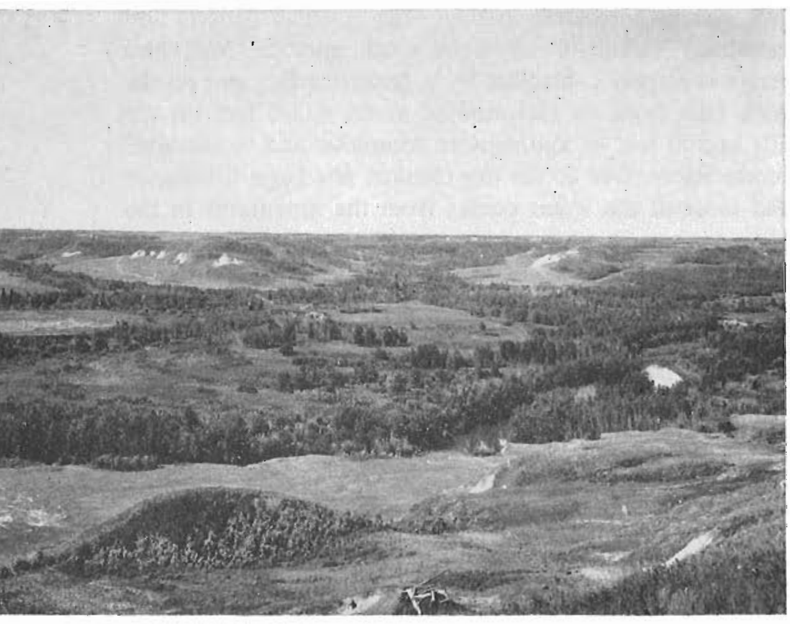

Plate XXV

Park lands in Battle River Valley, near Donalda, Alta.

dunes. In southeastern Manitoba a low area of glacial lake deposits, known as the Manitoba Lowland, forms a narrow fringe bordering the Canadian Shield.

The contrast in relief between the prairie level and the rather deeply incised river valleys is still further increased by a considerable number of flat-topped hills that are erosion remnants of a higher and more extensive plateau level. These include the Cypress Hills in Saskatchewan and Alberta, the Hand, Neutral and Misty Hills in southern Alberta, the Swan Hills and Caribou Mountains of northern Alberta, the Horn Mountains north of the west end of Great Slave Lake, the Missouri Coteau, the Wood and Moose Mountains and Touchwood Hills in southern Saskatchewan, Turtle Mountain in southern Manitoba, and many others of less height and area. The Cypress Hills reach an elevation of over 4,700 feet and stand as much as 1,200 feet above the surrounding plains; the others have a relief of 200 to 600 feet.

In addition to these hills, the prairie level in the southeast is interrupted by an eastward-facing escarpment known as the Manitoba Escarpment, which faces the Manitoba Lowland and rises 500 to 1,900 feet above it. It is formed of Mesozoic beds that dip gently southwest. The escarpment face has been dissected by erosion and is cut by several wide valleys. Viewed from the east it appears as a group of hills known from south to north as the Pembina, Riding, Duck, and Porcupine Mountains, and the Pasquia Hills. The ground falls gently westward from the escarpment and, viewed from that direction, most of the hills are hardly noticeable.

A few places in the central Plains are featured by "badland" topography (Plate XXVI). This is developed as a result of easy erosion of soft beds under dry climatic conditions which limit the growth of protective vegetation. The land is deeply dissected by sharp valleys between knobs or hills of variable size, height, and shape, almost entirely devoid of vegetation. Fantastic landforms develop but, though spectacular, do not occupy large areas. In Alberta they are present along

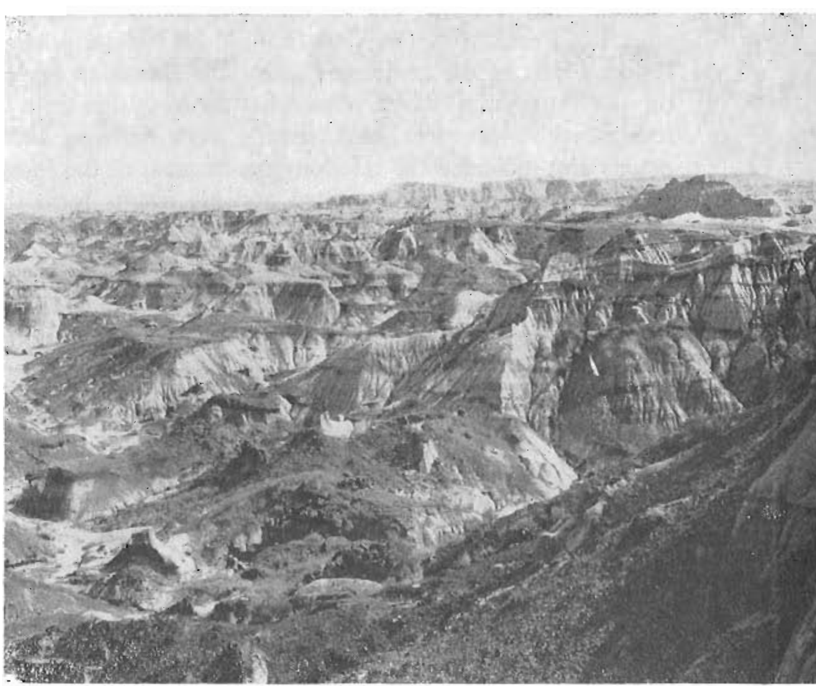

Plate XXVI

"Badlands" on Red Deer River, east of Steveville, Alberta.

Red Deer River Valley from Drumheller to and beyond Steveville, and along Milk River. More restricted areas occur at Mud Buttes near Monitor and in the Tit Hills southwest of Czar. In southern Saskatchewan, badlands occur in an area near the International Boundary south of Wood Mountain Plateau, along the Lake-of-the-Rivers and Big Muddy Valleys, and along Frenchman River Valley near Eastend.

Previous Geological Studies

Some records of the geology along the eastern border of the Interior Plains were made by Sir John Richardson while on the Franklin Expeditions in the 1820s, and later while heading an expedition in search for Sir John Franklin. The first geological studies of the southern prairies were those of James Hector who accompanied the expedition of Captain John Palliser in 1857, as surgeon and geologist. He recognized some of the age groups and described sections including one of lignite-bearing strata near Estevan, Saskatchewan. In 1857 and 1858 Henry Youle Hind, a professor of chemistry and geology at the University of Toronto, headed an expedition to Manitoba and one into Saskatchewan. The fossils he collected were identified by E. Billings, palæontologist of the Geological Survey of Canada. As geologist for the North American Boundary Commission, G. M. Dawson reported on the geology along the 49th Parallel in 1874. Later, under the auspices of the Geological Survey, he studied the geology of the Bow and Belly Rivers. R. J. McConnell, who assisted Dawson in 1881, contributed to the report on this work and, in later years, studied the formations farther north on the Athabasca, Peace, and Liard Rivers and established the sequence of formations over much of the region. J. B. Tyrrell, with D. B. Dowling as assistant, studied and described the sequence of formations, giving considerable details for many localities, along the Manitoba escarpment and the eastern part of the Interior Plains in that province. Dowling continued a study of the stratigraphy and economic geology of much of the Plains until his death in 1925. The first record of geological interest in the northern Plains was the mention of the occurrence of bituminous sand by Peter Pond in 1788. Sir John Richardson recorded observations about rocks outcropping along the Mackenzie River in his part of the reports of the Franklin expedition of 1825-26-27. He added to this information as a result of his trip in search of Franklin in 1848. In 1855 A. K. Isbister published a map on which was included part of the northern Plains. The Devonian age of the limestones exposed on the Athabasca River near what is now the town of Fort McMurray was recognized at this time. McConnell's work between 1879 and 1892 added more details and indicated the relationships of most of the formations; many of McConnell's divisions are still accepted and his results form the basis for much of the stratigraphy in the area.

Since 1900 more detailed surveys have been made of the strata exposed in the Interior Plains. In the south, Allan, Baillie, Dowling, Hume, Kindle, Kirk, McLearn, Whittaker, and Williams, established details of correlations and introduced many of the formational names that are still used for units of Upper Cretaceous and Tertiary age in the Plains as well as for older units on the fringes.

Intensive drilling for oil and gas since 1946 has resulted in a great increase in the knowledge of the subsurface geology. Correlations have been established between widely separated areas and this has resulted in the elimination of some formational names previously used. Some new formations have been found and new names have been introduced. The study of facies relations has developed, and a more thorough consideration of conditions of deposition has resulted in a more complicated nomenclature.

Committees from associations, such as the Alberta Society of Petroleum Geologists and the Saskatchewan Geological Society, have suggested correlations and nomenclature as a result of studies by geologists from companies engaged in developing oil and gas resources. During the last few years, provincial government departments and individuals have also contributed publications describing the subsurface.

Geology

The formations of the Interior Plains consist mostly of sedimentary rocks of Palæozoic or later age (Table XVIII, in pocket). These rest unconformably on a basement of Precambrian igneous and metamorphic rocks. The basement rocks are an extension of the Canadian Shield rather than of less metamorphosed, predominantly sedimentary rocks of Precambrian age in the Rocky Mountains, and the basement, therefore, is stable.

The surface of the basement slopes gently downward to the west and southwest from the edge of the Canadian Shield towards the mountains. In the western part of the Plains it reaches a depth of 10,000 feet, giving a slope of 15 feet to the mile. Drilling to the basement, however, has been infrequent and little is known about local variations in the surface but, undoubtedly, there are many small topographic features of local importance similar to some protruding through the later sedimentary rocks near the border of the Plains in Manitoba and elsewhere. It is known, however, that broad, low areas on the basement were the sites of sedimentary basins, and that higher parts stood out as broad islands during some or much of Palæozoic time. In southern Saskatchewan the Williston basin, which is in part called the Moose Jaw syncline, is, in some degree, the result of a low area on the basement surface. A large area that appears to have been above the level of deposition, and therefore probably an island until after Middle Devonian time, lies between the town of Peace River and the British Columbia border. Another area that may represent a topographic high is known as the Sweet Grass Arch. It lies in southern Alberta and extends northward from a point near the Sweet Grass Hill to the vicinity of the Cypress Hills. This area was not as high as that in the Peace River area and prevented deposition of only part of the Cambrian. Its present elevation may be partly structural in origin.

In many places the surface of the Precambrian basement has weathered into an arkose or similar clastic deposit. This may vary in age from place to place and is frequently referred to as granite wash. In much of the area it must be Cambrian or older but in the Peace River topographic high it may be Middle Devonian or even early Upper Devonian in age.

Cambrian

The oldest Palæozoic formations under the Plains appear to be of Cambrian age. These strata do not outcrop and the information concerning them is all from deep wells. Deep drilling has revealed their presence south of a boundary extending a little south of east from a point near township 76, at the eastern boundary of British Columbia, to a point near township 72, at the eastern border of Alberta, and thence in an eastward-bulging arc diagonally southeastward across Saskatchewan to the southwestern part of Manitoba.

The beds consist mostly of sand and sandstone commonly glauconitic, silty, and green, and maroon micaceous shale. These rocks pinch out at the eroded edges in the east and around the western part of the Peace River topographic high and are 2,000 feet thick in west-central Alberta.

Fossils include various inarticulate brachiopods and fragments of trilobites. Some of the fossils appear to be closely related to those in Upper Cambrian beds in the north-central States. It is possible that some older Cambrian beds occur beneath the Upper Cambrian in some of the thicker sections in Alberta and Saskatchewan.

The sandy beds found under the Plains are probably related to formations of shale, dolomite, and limestone that are of similar age and are exposed in the Rocky Mountains in southern Alberta and in the Richardson and Franklin Mountains of the Northwest Territories.

Ordovician

Ordovician strata are exposed along the eastern edge of the Interior Plains in Manitoba and for about 100 miles into Saskatchewan. They extend westward under the Plains to southeastern Alberta where they wedge out, probably due to erosion. None is found along the border of the Canadian Shield between a point 100 miles west of the Manitoba-Saskatchewan boundary and Great Slave Lake, but an Ordovician age has been indicated for rocks exposed in the vicinity of this lake.

Westward from this area formations of this age probably extend beneath the surface under the Mackenzie Valley and may even occur a short distance south in northern Alberta. No other beds of Ordovician age are known in the northern part of the Interior Plains but rocks of this age outcrop in northeastern British Columbia and in Yukon Territory and it is probable that similar formations occur beneath the lower Mackenzie Valley and in western Alberta.

The best known sections of the Ordovician are in Manitoba where four formations are recognized. In ascending order these are the Winnipeg, Red River, Stony Mountain, and Stonewall.

The Winnipeg formation consists of sandstone, siltstone, and greenish shale resting on the eroded surface of the Precambrian, where exposed, and on the shale and sandstone of the Cambrian in the subsurface. A few fossils that have been found in the upper part belong to Upper Ordovician species, and the age of the formation is considered to be Middle or Upper Ordovician. This indicates that a considerable amount of erosion may have taken place between the time when Cambrian and Ordovician rocks were laid down. The Winnipeg has been recognized in many wells in Saskatchewan and, according to one interpretation, the formation extends into eastern Alberta. In much of Saskatchewan there is some difficulty in distinguishing the Winnipeg sandstone from that of the underlying Cambrian.

The Red River formation is made up mostly of dolomitic limestone. This includes the Tyndall limestone which is used as a building stone in many parts of Canada. From the exposed section in Manitoba, the formation extends to the west in the subsurface and has been recognized as far west as Unity, Saskatchewan. It seems to disappear due to erosion and does not occur as far west as the underlying Winnipeg formation, although some strata in southern Alberta may be equivalent to either the Red River or Silurian beds. The thickness is about 250 feet in the outcrop area in Manitoba and apparently reaches nearly 1,000 feet in south-central Saskatchewan. Lack of identifiable fossils and a lithological similarity to some overlying formations make it difficult to identify the contact between the Red River and other formations in the well sections.

The Stony Mountain occurs between the Red River and the overlying Stonewall formation. It is made up of dolomite, calcareous shale, and limestone with some sandy zones near the top. In Manitoba the thickness varies from about 140 to 185 feet. It becomes less shaly to the west where it is difficult to distinguish from the underlying Red River. It probably disappears considerably east of the western boundary of the Red River formation and was not recognized in cores from a deep well near Unity, Saskatchewan.

The name Stonewall was first applied to strata near Stonewall, Manitoba, and was intended to apply to all the strata of Silurian age in Manitoba. More recent study has shown that the Stonewall beds at Stonewall are of Ordovician age, and the term has been redefined to include these beds only. Thus the formation represents the uppermost Ordovician. It is composed of dolomite and dolomite conglomerate about 30 to 40 feet thick. It shows disconformable relations to the underlying Stony Mountain formation and to overlying beds of Middle Silurian age. The Stonewall outcrops at several places in Manitoba from the vicinity of the Saskatchewan border, northwest of The Pas, to Stonewall, a few miles north of Winnipeg. It is difficult to recognize in the subsurface and its extent under the Plains is not yet known.

Silurian

Like the Ordovician, the Silurian is exposed near the eastern border of the Interior Plains in Manitoba and at various places near the Canadian Shield such as at Fort Fitzgerald, at Great Slave Lake, and along the Mackenzie Valley.

All the Manitoba outcrop section has been assigned to the Interlake group made up of six formations, which are called in ascending order, the Fisher, Branch, Moose Lake, Atikameg, East Arm, and Cedar Lake. The formations are all of various types of dolomite with little or no indication of breaks in deposition between the rock units. The Interlake group is about 290 feet thick. Interpretation of the various faunas indicates that all the formations are of Middle Silurian age, suggesting a lack of deposition and erosion during part of Lower Silurian time, in the Manitoba area at least.

Some gypsum deposits occur at Gypsumville near Lake St. Martin. Because of the location these have generally been considered of Silurian age, but no evidence has been found to indicate in what part of the Silurian they belong. No similar deposits, either exposed or in wells, have been found anywhere else in Manitoba. There is a possibility that these deposits are correlatives of the Amaranth of Mesozoic age which lie unconformably on the Devonian.

Over much of the Plains the Silurian is easily recognized in the subsurface because it lies beneath red beds of the Ashern. Where shale and sandy beds of the Stony Mountain are missing it is somewhat difficult, or impossible, to place the contact between the Silurian and Ordovician where both are composed of granular dolomite. It is probable that the Silurian extends farther west into Alberta than the Ordovician and that it continues northwest along the border of the Plains to Great Slave Lake and the Mackenzie Valley.

In the Great Slave Lake area some gypsum and anhydrite beds have been assigned to the Silurian because of their proximity to Silurian formations and not on the basis of fossils. Future studies may discover better evidence of age.

Devonian

Formations of Devonian age occupy a much greater area than those of older periods. They also include a large variety of lithological types and present greater facies changes. These formations contain some of the most important oil and gas reservoirs in the Plains and for that reason have been carefully studied in surface exposures and by examination of drill cuttings, cores, and other information from deep wells.

The presence of Lower Devonian rocks under the Interior Plains has not been proven, although the age of some beds underlying definite Middle Devonian is still uncertain. Some formations, believed to be of Lower Devonian age, have been reported from the Richardson Mountains and it is possible that they extend under parts of the northern Plains.

Middle and Upper Devonian beds are exposed along the eastern border of the Plains in Manitoba. Related beds are also exposed along the border of the Canadian Shield and in the vicinity of Great Slave Lake and the Mackenzie Valley. Some of the youngest Devonian formations are covered by beds of Mississippian and Mesozoic age and are exposed only in the mountains of the Cordillera.

Middle Devonian

Most of the Middle Devonian of the plains is included in the Elk Point group. However, parts of some higher units contain Middle Devonian fossils and in many localities the exact boundary between Middle and Upper Devonian is still uncertain.

The Elk Point group in Manitoba includes the Ashern, Elm Point, and Winnipegosis formations.

The Ashern overlies Middle Silurian beds unconformably and, as it is Middle Devonian in age, the unconformity is of fair magnitude. This formation consists of 10 to 15 feet of reddish dolomite, dolomitic shale, and silt with some sandstone. In many localities there is a brecciated zone at the base. Fossils are scarce and, in the subsurface, the age may vary somewhat. This formation has been recognized across the Plains well into Alberta.

The Elm Point is a yellowish grey limestone about 50 feet thick that overlies the Ashern in the outcrop area in Manitoba. To the west, in Saskatchewan, it grades into dolomite, and the equivalent beds are included with the Winnipegosis.

The Winnipegosis overlies the Elm Point conformably and the contact is probably gradational. The contact with the overlying, Upper Devonian, Manitoba group varies to some extent. In the outcrop area it is sharp, between buff and brown dolomite below, and red and green shaly beds of the Manitoba group above. Farther west the Winnipegosis is overlain by salt, and/or anhydrite and similar evaporites of the Prairie Evaporites. The composition of the Winnipegosis is mostly dolomite of various sorts formed from reef and inter-reef deposits. The thicknesses in Manitoba vary from 100 to 400 feet, the thicker sections being located on the sites of biohermal reefs. The Winnipegosis extends under the Prairie region, far to the west into Alberta, and may join formations of similar age in the Northwest Territories. Changes in depositional environment make it difficult to correlate between outcrop areas.

The upper part of the Elk Point group in Saskatchewan and Alberta is made up of evaporites, that is, salt, anhydrite, and dolomite, deposited in basins partly cut off from the rest of the sea. These have been called the Prairie Evaporites. They have a maximum total thickness of 640 feet in the Imperial Davidson well in Saskatchewan and attain a thickness of 1,200 feet in a well near Elk Point, Alberta. The salt basin extends for about 800 miles from the northern part of North Dakota, northwestward across Saskatchewan and Alberta, to a point near the town of Peace River. In many places the width of the basin is nearly 200 miles. Potash salts are fairly common in parts of the basin in Saskatchewan. In the southern Plains the Elk Point group seems to thin towards the mountains and may disappear altogether in that direction.

In the north, formations equivalent to the Elk Point group are found in the vicinity of Great Slave Lake and in the Mackenzie Valley. Near Great Slave Lake equivalent rocks are called the Pine Point and Presqu'ile formations. The former is mostly limestone and the latter is dolomite. The Pine Point underlies the Presqu'ile in all the areas and in some parts, where dolomitization has not occurred, is the equivalent of the Presqu'ile as well. Southwestward from Great Slave Lake drilling has revealed that this part of the section is occupied by a set of beds representing a different environment from that in which either the Pine Point-Presqu'ile group or the Elk Point group were deposited. These are, in upward succession, the Chinchaga, Keg River, and Muskeg formations, made up, respectively, of evaporite and dolomite, dolomite and evaporite, and dolomite.

The drilling has shown that the Middle Devonian is present near Norman Wells. It is called the Ramparts formation and undoubtedly extends into and along the valley under the plains to the south and north. It is composed mostly of limestone. It may be found to merge with the Pine Point and Presqu'ile, when sufficient drilling is done in the intervening area.

Upper Devonian

The boundary between the Middle and Upper Devonian is rather indefinite, and some beds included in the following description of the Upper Devonian are considered to be partly Middle Devonian in some places.

The formations included in the Upper Devonian are among the most widespread and variable in Western Canada. Depositional environment varied a great deal during this time. Many high reefs developed in Alberta, basins were practically cut off from the open sea by extensive banks or barrier reefs and, in other areas, normal unobstructed marine conditions prevailed. The formations that were deposited under such variable circumstances lack uniformity and, as deep wells are the only source of information in most of the region, considerable interpretation has to be made concerning undrilled areas.

The Manitoba group overlies the Winnipegosis in the exposed section in Manitoba. The Waterways formation overlies the equivalent of the Elk Point group in the Athabasca and Clearwater River area, the Slave Point formation overlies the Elk Point group or its equivalent, the Presqu'ile, in the Great Slave region, and down the Mackenzie Valley the Fort Creek formation overlies the Ramparts formation. It is possible that, when more information becomes available, two or more of these formations will be found to be a continuous unit.

The exposed section in Manitoba is called the Manitoba group. At the base the Dawson Bay formation of shale and limestone contains Middle Devonian fossils and may correlate with part of the Presqu'ile and Ramparts. It is probable that the upper boundary of the Dawson Bay formation is equivalent to the top of the Elk Point group in western Saskatchewan and Alberta. The remainder of the Manitoba group in the outcrop area is a succession of limestone and shale that has not been given a formation name, although a 50-foot limestone unit near the base in Manitoba has been named the Point Wilkins member and a section of evaporites near the middle of the group, found only in wells in Saskatchewan, is called the Davidson Evaporite. The top three-quarters of the Manitoba group is known from well sections only. Total thickness of the group varies from about 310 feet in Manitoba to 400 feet in southwestern Saskatchewan.

In Alberta the Beaverhill Lake formation is equivalent to the Manitoba group. It is found in the subsurface on the Plains. Although part of these beds probably continue into the mountains, their development there is less extensive and distinct and they have been included with other formations. The Beaverhill Lake comprises limestones and shaly limestones. In the type area it consists of 722 feet of alternating fragmental and argillaceous limestone. It becomes more shaly to the north and some evaporites occur in the south.

To the north the Waterways formation, exposed along the Athabasca River, is probably a continuation, or the equivalent, of the Beaverhill Lake. In the Great Slave Lake and upper Mackenzie River areas, the equivalent of the Manitoba group and Beaverhill formation is the lower part of a thick shale and limestone unit called the Hay River shale. Near Great Slave Lake the Slave Point limestone occurs between the Hay River-Simpson and the Presqu'ile but its age and correlations are uncertain.

The part of the Devonian above the equivalents of the Manitoba group and Beaverhill Lake formation is exposed only in the Mackenzie Valley and in the Rocky Mountains. In the upper Mackenzie Valley these rocks comprise what was originally called the Simpson shale, the Hay River shale, and the Hay River limestone. The Simpson shale was thought to underlie the Hay River shale but recent studies indicate that it is a phase of the Hay River. All of these rocks are now included in the Hay River-Simpson group. Wells drilled north of Fort Simpson in the Mackenzie Valley passed through over 2,500 feet of shales and related rock. This thickness is much greater than that found elsewhere and the apparent thickening of the Hay River-Simpson group is not yet completely understood, but apparently the shale deposition there may have lasted much longer than elsewhere in the region.

Elsewhere in the Plains, beds above the Beaverhill Lake formation are known from subsurface studies of information made available from the great amount of drilling done for oil and gas. Most names have originated in south-central Alberta. There the Upper Devonian above the Beaverhill Lake is divided, in ascending order, into the Woodbend, Winterburn, and Wabamun groups.

The Woodbend is divided, in ascending order, into the Cooking Lake, Duvernay, Leduc, and Ireton formations. The Cooking Lake is made up of grey to brown limestone, in part dolomitic, is about 240 feet thick, and extends over most of Alberta. The Duvernay is composed of dark grey to brown, and nearly black, shale and limestone. It occurs over parts of Alberta and has a more irregular distribution than the other formations because it probably represented special conditions of deposition where reefs limited circulation of ocean waters. The Leduc is a reef deposit equivalent in age to the Duvernay and probably to other non-reef deposits. Its occurrences are related to the distribution of reef chains of Upper Devonian time. The name is derived from the Leduc oil field where oil was first discovered in this formation. The Ireton consists mostly of grey and green shales which are in part the same age as the Leduc but which also overlie it in many places. All these formations are related to certain conditions of deposition found in southern and central Alberta. Elsewhere different conditions existed and other formation names are being used for rocks of the same ages. In Saskatchewan part of the Saskatchewan group is equivalent to the Woodbend. It comprises an unnamed formation and another assumed to be the Nisku formation, as described below.

Above the Woodbend in Alberta is the Winterburn group divided, in ascending order, into the Nisku, Calmar, and Graminia formations. The Nisku is a dolomite, about 156 feet thick, with a thin siltstone unit near the top. There is some evidence that this formation pinches out in eastern Alberta, and some doubt has been expressed that a similar formation found in Saskatchewan is actually continuous with the Nisku of the Leduc area. The Calmar formation includes, in the type area, 44 feet of red and green siltstone, somewhat dolomitic. The lateral extent of this formation is somewhat limited to the south; elsewhere it may merge with the overlying Graminia formation composed of about 50 feet of anhydrite and siltstone. In Saskatchewan a succession of red dolomitic silt and shale, called the Lyleton formation, occupies the same place in the Devonian section as the Graminia and occurs at the base of the Qu'Appelle group.

Overlying the Graminia formation in the Leduc area is the Wabamun group made up of 562 feet of buff dolomite with some limestone beds and a few thin shale partings near the base. The lithology changes to the south and east where the upper part, the Big Valley formation, is composed dominantly of shale. This formation is frequently called the Three Forks formation, although its relation to the Three Forks of Montana is uncertain. In the southeast the lower part of the Wabamun group has been named the Stettler formation. The term Wabamun group has been used for the uppermost Devonian beds pierced by wells in northwestern Alberta and its equivalent may occur in the exposed section in the Nahanni River-Root River area. In the northern wells the section is mostly limestone with little dolomite and has a maximum thickness of 770 feet. Undoubtedly, future study in the north will bring about formational names for this group.

Mississippian or Devonian

Overlying the Wabamun or equivalent beds in much of Alberta and Saskatchewan is a dark brownish grey to black shale, called the Exshaw formation. There are indications of a disconformity between this formation and the underlying strata. A difference of opinion exists about the identification and age significance of its contained fossils. The contact with overlying beds of Mississippian age is gradational and, on this account, most geologists at present include the Exshaw with the Mississippian. The Exshaw is exposed in the mountains where it is about 30 feet thick. On the Plains it varies in thickness up to 50 feet. It is distributed throughout the southern part of the Plains as far east as southwestern Manitoba and extends north to about township 90 in Alberta.

The term Bakken formation is sometimes used for the Exshaw in Saskatchewan. The name was first used in North Dakota for subsurface beds that include the Exshaw as a basal member and the formation is considered to be Mississippian in age.

Mississippian

The only outcrops of rocks of Mississippian age on the Plains are found in a small area in northeastern British Columbia and in the southwestern part of the Northwest Territories. In the subsurface they occur west and south of a line that trends northwest across southwestern Manitoba, west-northwest across Saskatchewan and Alberta to a point south of Edmonton, turns north and passes west of Edmonton, and gradually veers northwest to the northwest corner of Alberta. The upper surface of the Mississippian is a major erosional unconformity. East of the line all Mississippian beds have been removed by erosion; to the west they have been partly removed and their thickness, accordingly, varies greatly from place to place. In Saskatchewan only the lower part remains. In Alberta at a few localities where erosion has been slight nearly all of the Mississippian is represented. The thickest section in Saskatchewan is about 1,000 feet, in southern Alberta from 1,000 to 1,500 feet, and in northeastern British Columbia it is over 2,500 feet.

Study of material from wells indicates that the formations are closely related to those exposed along the front of the Rocky Mountains. The mountain sections have been divided into the Banff and Rundle groups and these terms are commonly used in the Plains near the Foothills. Lower silty and shaly beds are usually considered to belong to the Banff, and upper, dolomitic limestone beds are placed in the Rundle. The two groups transcend time boundaries to some extent.

The formations in Saskatchewan are, in part, closely related to those in North Dakota and Montana. The formation names, Bakken, Lodgepole, Mission Canyon, and Charles, are used in Saskatchewan and, by some geologists, in southern Alberta.

The Bakken consists in upward succession of Exshaw shale, Coleville sand, and a second black shale similar to the Exshaw. The Lodgepole, which overlies the Bakken, is usually a granular limestone with some clastic beds. The Mission Canyon consists of fairly coarse-grained limestone with little or no clastic material. The Charles is composed of limestone with much evaporite, or it may be entirely of evaporite, usually anhydrite. In the eastern part of Saskatchewan the Lodgepole and Mission Canyon are lithologically much alike and are difficult to separate.

Pennsylvanian and/or Permian

In northwestern Alberta and northeastern British Columbia the youngest Mississippian formations pierced by wells are overlain by beds assumed to be of Pennsylvanian or Permian age. They resemble beds of this age found in the Rocky Mountains. These strata are successions of chert overlain by sandstone and siltstone. The thickness varies from very thin at the eastern eroded edge to about 500 feet in the thickest part near Fort St. John. In the Plains they bulge eastward from the Foothills of the Peace River region approximately to the town of Peace River, and continue northwest across northwestern Alberta and northeastern British Columbia to south of Fort Nelson.

Triassic

Triassic beds have been found by drilling in the Peace River region of British Columbia and Alberta. These formations are similar to those exposed in the Foothills and mountains in northeastern British Columbia, but contain, in addition, some units that have not been recognized in outcrops. The subsurface Triassic is divided into two groups. The lower one is made up of silty shale, sandstone, and impure limestone and is about 1,500 feet thick; the upper group is about 1,000 feet thick and includes limestone, shale, impure limestone, and anhydrite with a 50-foot sandstone member at the base. The lower group is considered to be of Lower Triassic age and the upper one, Middle and Upper Triassic. The Triassic beds thin to the east and pinch out in the vicinity of the town of Peace River. Their distribution follows a pattern similar to that of the Pennsylvanian-Permian although overlapping the latter beds in most places. The thinning of the Triassic is due to non-deposition of its lower units in the east and to erosion of the upper strata before deposition of the overlying Jurassic.

At the base of the Mesozoic in southern Saskatchewan and Manitoba there are red dolomitic silts, shale, and sandstones which some authors assume to be Jurassic and others, Triassic. The Amaranth in Manitoba is an example of such a formation. It occurs as an uneven filling on the eroded surface of Devonian rocks in the southwestern part of the province, a little east of the Manitoba escarpment between Dauphin and Swan River. It probably does not overlie the Mississippian beds in the extreme southwest corner of the province.

Jurassic

Formations of Jurassic age overlie Triassic, Mississippian, and Devonian strata over parts of western and southern Alberta and across southern Saskatchewan and southwestern Manitoba. The Sundance and the underlying Gypsum Springs formations have been recognized in Manitoba and eastern Saskatchewan and appear to be closely related to those exposed in South Dakota. Several new formational names have been applied to the same beds in Saskatchewan. In ascending order these are the Watrous, Gravelbourg, Shaunavon, and Vanguard. In southwestern Saskatchewan and southern Alberta the formational names Piper, Sawtooth, Rierdon, and Swift are used to some extent and there is some overlap with the terms previously mentioned.

The Jurassic formations consist of limestone, calcareous shale, and sandstone. The total thickness increases from the eroded edge in Manitoba to from 1,200 to 1,400 feet in southern Saskatchewan at the International Boundary south of Moose Jaw; the formations thin again westward to about 400 feet in southern Alberta. In western Alberta the eastern side of the Fernie group, which represents much of Jurassic time in the mountains, extends under the plains in a northerly direction from near Calgary to near Peace River town and then northwesterly to northeastern British Columbia. The Fernie of the Plains area in this region consists mostly of dark grey shale with minor limestone and some sandstone. The thickness reaches a maximum of about 500 feet in the Peace River region of British Columbia.

Overlying the Fernie group in the Plains of northeastern British Columbia wells have penetrated sandstone beds correlated with the Nikanassin formation of the foothills region of Alberta. These beds are in part, at least, of Jurassic age although in some localities the Nikanassin is also considered to include beds of Lower Cretaceous age.

Cretaceous

The Cretaceous period was one of widespread deposition throughout the Interior Plains. Sometime during the early Cretaceous, however, erosion was active and some of the Jurassic and older beds were removed.

Exposures of both Lower and Upper Cretaceous formations are found in many localities. The Lower Cretaceous is exposed mostly near the eastern or northeastern edge of the region. In Manitoba outcrops are found near the base of the Manitoba escarpment at many places between Dauphin and the Saskatchewan River. Between this locality and Clearwater River, near Fort McMurray, outcrops are very scarce and little is known about Lower Cretaceous rocks. Along the Athabasca River for about 150 miles above and 75 miles below Fort McMurray and up the Clearwater River, formations of this age are well exposed and include the McMurray bituminous sands. Exposures of Lower Cretaceous formations are also found in the Peace River Valley and its tributaries from a point above Fort Vermilion to a point a short distance above the junction of the Smoky River. Beds of this age are also exposed in the Peace River Valley and its tributaries from the junction of Fort St. John Creek to the Foothills. It is probable that exposure of Lower Cretaceous rocks also occurs farther north in the Plains but little is known about the outcrops except in adjacent disturbed areas such as the Norman Wells area. The Upper Cretaceous is exposed at many places throughout the Interior Plains from the Manitoba escarpment, or elsewhere near the border of the Canadian Shield, westward to the Foothills.

With such widespread deposition variation in the type of deposits occurs and, in part due to the isolated studies that have been made, the nomenclature varies from place to place. The section in Manitoba includes in ascending order the Swan River, Ashville, Favel, Vermilion River, Riding Mountain, and Boissevain formations. The division between the Upper and Lower Cretaceous occurs in the upper part of the Ashville. To the west the Swan River merges with the Mannville group in the Plains, and with that part of the Blairmore that lies in the Foothills and mountains. The Ashville appears to be equivalent to several formations in the west, namely, the Joli Fou, Viking, and an unnamed shale unit. The Bow Island sand formation in southern Alberta is in part equivalent to the Viking in central Alberta, and to the Pelican formation in the north. The Mannville group contains formations named from subsurface studies in central Alberta and these, to some extent, are equivalent to the McMurray, Clearwater, and Grand Rapids formations exposed on Athabasca River. In the Plains of the Peace River region approximately equivalent beds, and probably some older ones, are in ascending order the Bullhead group and the Fort St. John group. The latter has been divided into the Bluesky, Spirit River, Peace River, and Shaftsbury formations. The Shaftsbury is equivalent to most of the Ashville and related beds already mentioned.

The Upper Cretaceous Favel formation and the Boyne member of the Vermilion River formation are grey, calcareous shales speckled with small white chalky lime inclusions and they are commonly referred to as the speckled shale zones or, in the subsurface of most of the Plains region they are called, respectively, the "second and first white specks". These two units probably are the most widespread of any found in the Interior Plains of Canada and they extend into north-central United States where they are part of the Colorado group. This group is the equivalent of the Ashville, Favel, and Vermilion River formations.

The Upper Cretaceous above the Colorado group includes a variety of formations related to different environments during the time of deposition. During Upper Cretaceous time continental fresh- and brackish-water conditions prevailed in the west and marine deposits were laid down in the east, although at times marine conditions extended over all the central and southern Plains. The uppermost formations are missing in northern Alberta. In southern Alberta and southwestern Saskatchewan the equivalents of the Riding Mountain formation are in ascending order the Milk River, Pakowki, Foremost, and Oldman formations, and probably the Bearpaw formation. In central Alberta and central western Saskatchewan this part of the Upper Cretaceous includes the Lea Park formation, Belly River group, and Bearpaw formation.

In southern Saskatchewan and southeastern Alberta the equivalent of the Boissevain, or at least the formations above the Riding Mountain formation, includes the Eastend, Whitemud, Battle, and Frenchman formations. Farther west in central and south-central Alberta, the Edmonton formation is equivalent to the Whitemud and some higher Cretaceous formations, the St. Mary's River and Willow Creek in the southwestern part of the province.

The Upper Cretaceous of the Peace River region of the Plains, including the drainage of the Smoky and Little Smoky Rivers, has been divided into formations in a somewhat different manner than in other regions. The basal formation is the Dunvegan, a sandstone formation which is continuous to the northern Foothills. Above this is the Smoky River group made up of the Kaskapaw, Bighorn (Cardium), Wapiabi, and Wapiti formations. The Wapiti is relatively thick and appears to include everything equivalent to the Cretaceous formations overlying the Colorado group in southern Alberta.

The thickness of the Cretaceous deposits, disregarding the effects of erosion, varies considerably in different localities. In general, the thickest deposits occur in the western part near the Foothills and all formations are considerably thinner near the Canadian Shield. The Lower Cretaceous is about 200 to 250 feet thick in the Manitoba escarpment and, except for some local underlying topographic highs, increases in thickness to about 1,000 feet in southern Alberta and to 3,000 feet in northeastern British Columbia. The Upper Cretaceous also follows this pattern, although due to erosion of the upper beds it is not possible to get complete sections in as many places. Near Boissevain in southern Manitoba it appears to be about 1,700 to 1,800 feet thick, near the Foothills in southern Alberta the equivalent section is about 5,500 feet thick, and in the Peace River area it may reach 3,700 feet. Over most of the Interior Plains erosion has removed part of the Upper Cretaceous, and beds of this age occupy a smaller area than those of the underlying Lower Cretaceous.

Tertiary

Tertiary formations are found in a small area in Turtle Mountain in Manitoba, in a wide area in southern Saskatchewan, in various highland areas in southern Saskatchewan and Alberta, in a large area east of the Foothills in Alberta and extending as far north as the start of the Smoky River drainage, and in small areas in the lower Mackenzie Valley. The oldest formations are Paleocene in age and comprise fine-grained sands and silts that seem to indicate a gradual transition from the Cretaceous. Younger Tertiary deposits contain coarse sands and gravel and indicate a marked change in conditions of deposition.

The Turtle Mountain formation in Manitoba is believed to be of early Tertiary age. It consists of fine sand, some clay, shale, and several small coal seams. The area in which it occurs is covered with glacial deposits, and the exact thickness is uncertain but is estimated at more than 100 feet.

The Ravenscrag formation of Paleocene age occurs in southeastern Saskatchewan and in some places in the southwestern part of that province as well as in southeastern Alberta. The general indications are that it is of continental origin. The formation is made up of fine sand, silt, and clay with some lignite seams. The thickness varies from about 500 feet in the Estevan area to 170 feet in the Cypress Hills in western Saskatchewan. In western and central Alberta the Paskapoo is equivalent to the Ravenscrag and the two may have been a single unit at one time. The Paskapoo is made up of fine sand and sandstone. It occurs immediately in front of the Foothills and on some of the high areas farther out, such as the Swan Hills and Hand Hills. The thickness varies from as much as 2,000 feet near Calgary to 360 feet in the Hand Hills.

The younger Tertiary deposits overlie those of Paleocene age and vary somewhat in age. A thickness of about 50 feet of late Eocene gravel outcrops southeast of Swift Current, Saskatchewan, and is called the Swift Current Creek formation. On the Cypress Hill, at elevations ranging from 4,500 feet down to about 3,350 feet, is the Cypress Hill formation, a conglomerate of Oligocene age about 300 feet thick at the most. Oligocene gravels also cap the Hand Hills. In the Wood Mountain area of southern Saskatchewan similar gravels of Miocene age, called the Wood Mountain beds, occur above the Ravenscrag.

Gravels made of quartzite pebbles occur under glacial drift in many valleys of central and southern Alberta. These appear to be the youngest Tertiary deposits in the region. The occurrences are irregular and in some places are cut by small streams that obviously had nothing to do with their deposition. In some localities these occurrences are 50 feet thick. These gravels have been called the Saskatchewan gravels; they may be of Pliocene or very early Pleistocene age.

Structural Geology

The site of the Interior Plains has been relatively stable for a long time. The basement rock is a continuation of that found on the Canadian Shield which is considered to be the backbone of the continent. The surface of the basement rock must have been at or above sea-level for a long time because it appears to have been eroded down to a level very much like that of the present Canadian Shield. The fact that no Palæozoic formations older than Middle or Upper Cambrian rest on the basement suggests that erosion continued well into Cambrian time. Throughout later periods the types of sedimentary rocks found in the region are mostly those associated with a continental shelf. From time to time the region was raised above sea-level and erosion of some formations took place but such fluctuations were on a broad regional basis.

At times sedimentation probably extended over part of the present Shield. Faunas and types of rocks found in Ordovician, Silurian, and Devonian formations in the vicinity of James Bay are closely related to those of the Plains of Manitoba and it is possible that there were direct connections between the two areas. The easternmost exposures of some Upper Cretaceous marine formations contain no strata that might be identified as beach or near-shore types and it is probable that the sea covered parts of the Canadian Shield during that time.

Some areas of the region tended to rise or sink a little more than others and high areas and basins were formed. A greater thickness of sediments accumulated or was preserved from erosion in the basins. The Williston basin, which extends from southern Saskatchewan into North Dakota, is one of the best known of these features. Isopach maps of the sedimentary material deposited during various periods indicate that the centre of the basin shifted from time to time. During Cambrian time the centre was in southwestern Saskatchewan and Montana, in Devonian time it was in southeastern Saskatchewan, and in Mississippian time, in northwestern North Dakota. Some geologists consider that the basin practically disappeared during Upper Devonian time. A feature closely related to this basin was the deposition of salt during the Middle Devonian. The salt was deposited in a basin nearly a thousand miles long and it is possible that this down-bowed area was partly cut off from the open sea during the time of deposition. Another well-developed basin is found in the vicinity of Fort St. John in the Peace River district. The results of drilling in this locality indicate that there are over 14,000 feet of sedimentary formations above basement rock. In other areas up-bowing took place and sedimentary deposits are thinner. The Sweet Grass Arch in southeastern Alberta is an example of such a feature. This is a broad low arched area that extends north from southeastern Alberta for perhaps 60 miles. Jurassic and other formations are thin over the arch. Apparently it was a feature that rose slightly at several times and formations of some periods are affected more than others.

The fact that erosion rather than deposition was dominant during parts of several geological periods is indicated in the discussion on the stratigraphy. Uplift of most or all of the region took place during these times but there is no indication that much warping occurred and the surfaces of the older beds appear to have been planed for the most part conformably and uniformly. The angular discordance between beds above and below such an erosion surface is almost impossible to recognize except where the two formations are carefully studied over wide areas. This condition is true of the erosional intervals between the Ordovician and Silurian and between the Silurian and Devonian. The most extensive time of erosion, other than that which determined the surface of the basement rock, followed deposition of Mississippian formations. In the Peace River area it lasted only until late Pennsylvanian time but in parts of eastern Alberta and Saskatchewan it probably went on until Lower Cretaceous time. The beds deposited above this erosion surface show a distinct angular unconformity of several feet per mile with respect to the beds below. Much of the difference in attitude must have developed before Jurassic time because the Jurassic strata of the southern Plains are about parallel with the overlying beds. However, there is indication of erosion having been uneven because the youngest beds are missing in some places and not in others. The effects of still younger erosion intervals are not very pronounced and most of them appear to be of local importance only.

Stratigraphic traps and a related structure, namely, traps formed by the overlap of younger beds over the eroded bevelled edges of older beds below an unconformity, are very important structural features of the Plains. Among the stratigraphic traps are the various types of reefs that grew during Upper Devonian time. Of these the island-like bioherm reefs that developed in central Alberta formed the oil and gas reservoir in the Leduc, Redwater, Stettler, and other fields. Extensive sand bars found in the Lower Cretaceous Viking formation are among the most important reservoirs for oil and gas in Alberta and, to some extent, in Saskatchewan. Another type of trap was formed where sand pinches out by grading into a shale formation. The Cardium formation does this in places east of the mountains, and the Pembina oil field in Alberta is being developed on this type of structure. Oil and gas traps have formed where sands have been deposited on a sloping, eroded surface of an older formation and are later overlapped by shale or other non-pervious formations. Deltaic deposits also contain sand beds and lenses where oil or gas has been trapped. The McMurray formation on Athabasca River where a great quantity of bitumen is found is of this type. It is also probable that some of the oil sands at Lloydminster were originally laid down in a delta. In southeastern Saskatchewan and southwestern Manitoba Mississippian beds at the edge of the Williston basin have been up-bowed, eroded, and covered with impervious formations. Most of the oil fields in this part of the Plains are in traps of this sort.

Some folds occur in the region and all are relatively gentle. The Williston basin may be regarded as a broadly folded area. At various other places dips give evidence of the presence of anticlines and synclines. Some dips may be due to differential compaction where clays and sands have been deposited in irregular masses adjacent to, or over, each other. The compaction of beds over hard masses, such as reef or erosional remnants of limestone, is also considered to be a cause of changes in dip.

In some parts of the Plains apparent folding and faulting may have originated from compressive forces. In a few places dips up to 2 or 3 degrees have been noted but in most places they are less than 50 feet per mile. Differences in elevation, small repetition, or disappearance of beds between adjacent wells have been interpreted as evidence of thrust or normal faults. There is evidence of such faulting in the older formations in the Peace River district. Faulting took place in the Canadian Shield long after Precambrian time and similar deformation is to be expected in the basement and overlying rocks of the Plains.

Economic Geology

The rich soils of the prairies have been the basis of a great agricultural development. These were formed as a result of the weathering of the various types of underlying formations and of the deposits resulting from Pleistocene glaciation. The richest grain-growing areas are over clays and silts that settled on the bottoms of great lakes that existed during this ice age. The annual value of mineral production is now nearly as great as that of agriculture and in a few years it will probably be greater. Although large reserves of lead and zinc ores are found in the Northwest Territories south of Great Slave Lake and a little gold has been panned from the Saskatchewan gravels, metal production to date has been relatively small, the

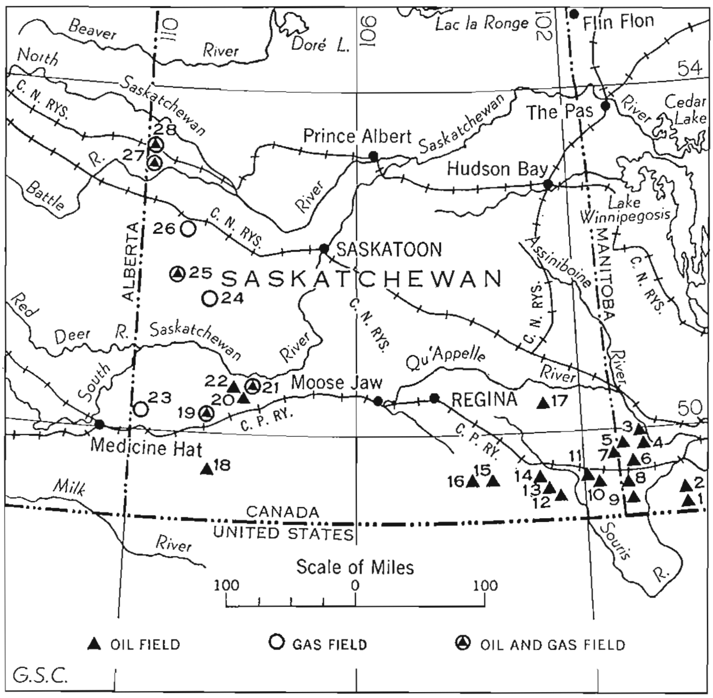

FIGURE 59. Principal oil and gas fields of Manitoba and Saskatchewan: 1, Lulu Lake; 2, Whitewater; 3, North Virden; 4, Virden, Roselea; 5, Daly; 6, Woodnorth; 7, Ebor; 8, Tilston; 9, Pierson; 10, Nottingham; 11, Alida; 12, Frobisher; 13, Steelman; 14, Lampman; 15, Midale; 16, Weyburn; 17, Wapella; 18, Dollard; 19, Gull Lake; 20, Cantuar; 21, Success; 22, Fosterton; 23, Hatton; 24, Brock; 25, Coleville-Smiley; 26, Unity; 27, Lone Rock; 28, Lloydminster.

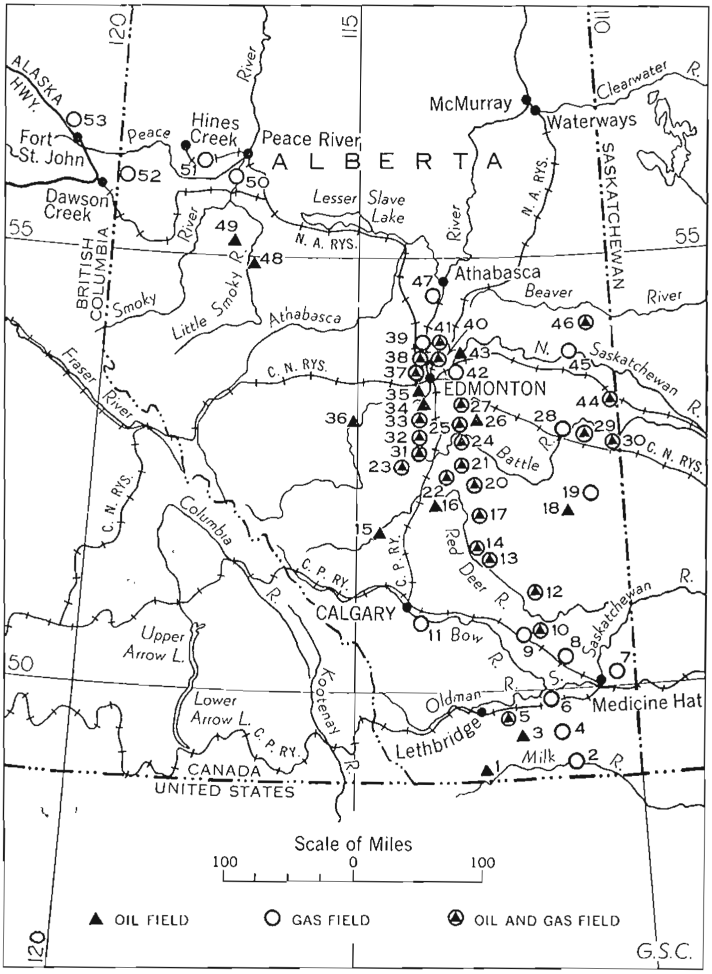

FIGURE 60. Principal oil and gas fields of the Plains of Alberta and British Columbia: 1, Del Bonita; 2, Pendant d'Oreille; 3, Conrad; 4, Foremost; 5, Taber; 6, Bow Island; 7, Medicine Hat; 8, Ralston; 9, Brooks; 10, Princess; 11, Okotoks; 12, Cessford; 13, Drumheller; 14, West Drumheller; 15, Westward Ho-Sundre; 16, Joffre; 17, Fenn-Big Valley; 18, Hamilton Lake; 19, Provost; 20, Erskine; 21, Bashaw; 22, Clive; 23, Home, Glen, Rimbey; 24, Duhamel; 25, Malmo, New Norway; 26, Battle, Battle North, Battle South; 27, Joarcam; 28, Viking-Kinsella-Fabyan; 29, Wainwright; 30, Chauvin; 31, Westerose; 32, Bonnie Glen; 33, Wizard Lake, Glen Park; 34, Leduc-Woodbend; 35, Golden Spike; 36, Pembina; 37, Acheson; 38, St. Albert; 39, Morinville; 40, Excelsior; 41, Fairydell-Bon Accord; 42, Fort Saskatchewan; 43, Redwater; 44, Lloydminster; 45, Elk Point; 46, Bonnyville; 47, Athabasca; 48, Sturgeon Lake South; 49, Sturgeon Lake; 50, Tangent; 51, Whitelaw; 52, Pouce Coupe; 53, Fort St. John.

important mineral products being oil, gas, and coal. The distribution of the principal oil and gas fields of the Interior Plains is shown in Figures 59 and 60.

Crude Petroleum

Although exploration for oil has been carried out on the Plains for over 50 years, results were mostly poor until February 1947 when oil was discovered in the Leduc field. Since 1950 the development in all parts of the Plains except the Northwest Territories and Yukon, which have received only limited exploratory attention for oil as yet, has been successful and in 1956 the region accounted for over 95 per cent of Canada's output of crude petroleum.

The oil is produced from formations varying in age from Upper Devonian to Upper Cretaceous. The quality of the oil varies from very heavy to light, the gravity being usually heavier in the younger age groups.

Manitoba

Commercial oil wells have been found only in the southwestern part of the province, where the first oil in significant quantities was recovered early in 1951. Production increased from 2,148,184 barrels in 1954 to 4,145,756 barrels in 1955. The oil is found in reservoirs formed in the Lodgepole formation of Mississippian age. Whereas the formation is rather silty or sandy in other areas farther west, in the southwestern part of Manitoba it is made up of fragmental limestone and dolomite. A trap is formed by the sealing of the weathered, bevelled edges of the Lodgepole and Mission Canyon formations by overlying beds of Jurassic age. Depths of drilling vary from about 2,000 feet in the northeastern fields to 2,600 feet in the southwestern fields. The principal fields are the Daly, Woodnorth, and Ebor near Cromer, and the Virden, Roselea, and North Virden near Virden. The fields making up each group are very near one another and eventually, development may prove two large fields only. The oil from these fields is obtained from the crinoidal limestone of the Lodgepole formation.

Oil discoveries have been made at Lulu Lake, Pierson, Tilston, and White Water. These are relatively small fields but some may prove to be larger with more drilling. The oil in the Pierson and Tilston fields occurs in the Mission Canyon formation.

Saskatchewan

Production of crude petroleum in Saskatchewan in 1955 was 11,317,168 barrels, compared with 5,422,899 barrels in 1954. The oil occurs in four districts with several fields in each. These are the southeastern, southwestern, west-central, and Lloydminster.

Southeastern District. Oil in this district has been obtained in the Mission Canyon and Charles formations of Mississippian age. The oil is usually within a hundred feet below the unconformity on top of the Mississippian and porosity near the unconformity is a controlling factor. Oil was first discovered in this area in 1954 and since then several pools have been found. It is probable that continued exploration will extend the present fields and find others. The principal fields are: Frobisher, Lampman, and Midale, all producing from the Charles and Mission

Canyon formations; the Alida, Nottingham, and Weyburn producing from the Mission Canyon formation; and the Steelman producing from the Charles formation. The Midale is the largest and has a reported area of about 18½ square miles. The others are considerably smaller. The drilling depths vary. In the Alida or easternmost field, and in the Nottingham, oil is obtained at depths of about 3,700 and 3,550 feet, respectively; the Steelman has the deepest production, at over 4,800 feet. The oil from the Midale field is of medium gravity and that from the others is of light gravity.

The Wapella field near Wapella, north of the Mississippian fields, might also be considered to lie in the southeastern district. Oil is obtained from Jurassic and Lower Cretaceous sands. A trap seems to have been formed by the wedging out of these sands along the northeastern flank of the Williston basin. The drilling depth of the producing sand in the discovery well was 2,426 feet.

Southwestern District. None of the shows of oil found in wells in the central part of the Williston basin has proved commercial.

The western side of the basin has several fields in Jurassic and Cretaceous formations. These are scattered along a north-trending line from near Loomis (township 4, range 20, west of 3rd meridian) in the south to near Pennant in the north. Most of the fourteen fields in this area have six wells or less.

The oil occurs in stratigraphic traps possibly related in part to structural highs. The porous sands are locally small in extent and some fields are in the high, pinched-out ends of sand lenses. The lowest sands occur in the Shaunavon formation of Jurrassic age, others are in the Vanguard formation, which is the uppermost Jurassic of the area, and still others are in basal beds of Lower Cretaceous age. The southernmost fields produce from the Shaunavon only; the northernmost produce from the Vanguard and Lower Cretaceous; in some of the intermediate fields oil is obtained from all three horizons. The drilling depths vary from 3,200 feet in the north to 4,700 feet in the south. The oil is mostly of medium gravity ranging from 20 to 23 degrees A.P.I., although a few wells in the north produce oil of 12 to 15 degrees A.P.I.

The larger fields are the Dollard in the south, the Gull Lake in the intermediate area, and the Fosterton, Cantuar, and Success in the north. The upper part of the Shaunavon is the source of oil in the Dollard field and drilling depth is about 4,600 feet. In the Gull Lake field oil is obtained from six different horizons or pools: four are from the Shaunavon formation, one from the Vanguard, and one from the basal Lower Cretaceous. The sands and porous horizons are discontinuous. Drilling depths vary from 3,585 to 3,900 feet and the field has a proven area of about 5 square miles. The Fosterton, Cantuar, and Success fields produce mostly from the Roseray sand of Upper Jurassic age and from the Cantuar sand of Lower Cretaceous age. The drilling depth is about 3,200 feet. Some heavy oil has been obtained in the Cantuar field.

West-Central District. In an area centring about 20 miles northwest of the town of Kindersley, oil production has been developed from beds of Cretaceous

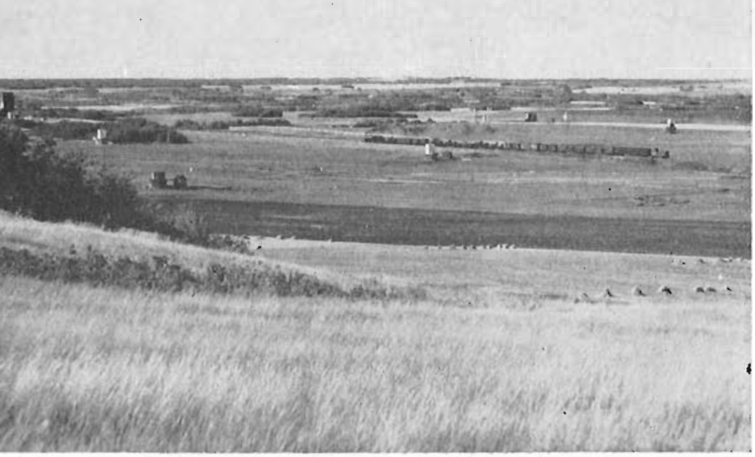

Plate XXVII

Part of Lone Rock oil field,

and Mississippian age. This area is called the Smiley-Coleville field. At Coleville heavy oil is found in sand in the lower part of the Mississippian section at a depth of about 2,750 feet. In the Smiley part of the field light gravity oil is found in the Viking sand near the top of the Lower Cretaceous section at a depth of about 2,400 feet. Altogether the field had 439 wells capable of production in mid-1956. The oil in the Mississippian is trapped beneath the unconformity at the erosional edge of the lower part of the Lodgepole formation; that in the Cretaceous is related to porosity in a lens of the Viking sand.

Other occurrences of oil in this area are found in the basal beds of the Cretaceous, which have been formed from detrital chert derived from the Mississippian. The small Hoosier field is an example of this. Oil has also been found south of Kindersley at Eatonia in some higher beds of Lower Cretaceous age.

Lloydminster Area. The Lloydminster area includes several fields in Saskatchewan and Alberta near the border between the two provinces. Oil is found mostly in sands of Lower Cretaceous age about 150 feet below the top of the Mannville group. Other sands a little above and below this horizon have also produced some oil. The gravity of the oil is heavy, varying from 8 to 18 degrees A.P.I. The sand lenses in which the oil occurs are perhaps related to deltaic deposits. Depths of drilling vary from about 1,600 feet to as much as 2,200 feet.

Although the principal fields are in the vicinity of Lloydminster and Lone Rock (Plate XXVII), similar fields occur here and there for 25 miles to the east and for 20 miles to the south and west.

Occurrences of oil in the Lloydminster area are also found in Alberta near Chauvin, Wainwright, and Vermilion. Some heavy oil was produced in the vicinity of Wainwright as early as 1926, although the main development at Lloydminster did not take place until nearly 20 years later.

Alberta

Oil production from the Plains area of Alberta is much greater than from the other two Prairie Provinces and in 1955 amounted to 110,814,369 barrels, compared with 85,466,524 barrels in 1954. The fields are numerous and vary in types of occurrences. Chief contributors to the production in 1955 were the

Redwater, Leduc-Woodbend, and Pembina, in that order. During 1956, however, Pembina became the chief contributor. In mid-1956, sixty-six fields were listed by the Petroleum and Natural Gas Conservation Board as having wells capable of production. Only the major fields or those illustrating some interesting geological feature are considered in the descriptions that follow. To facilitate discussion the oil occurrences are described under three divisions: a southern division including townships 1 to 30; a central division including townships 31 to 65; and a northern division covering the country north of township 65.

Southern Division. Near the United States border at Del Bonita some light gravity oil is produced from wells in the Mississippian just below the unconformity. The drilling depth is about 5,150 feet. From one well in this field oil is obtained from beds equivalent to the Banff at about 6,200 feet.

At Conrad medium gravity oil is produced from sand beds of Jurassic age at about 3,100 feet. This field is drilled in what appears to be a stratigraphic trap in sands in the Sawtooth formation. The area of the field is about a square mile, and production is decreasing gradually.

The Taber field is similar to the Conrad in that a medium gravity oil is found in a clean sand at the base of the Lower Cretaceous. The occurrence is near the eroded edge of the Jurassic and it is possible that the oil comes from the same source as that at Conrad. In other wells in the vicinity oil has been found in beds of Lower Cretaceous and Jurassic age but no fields have been developed.

In the small oil field in the vicinity of Cessford the production comes from sand in the basal part of the Colorado group. This occurrence is at a depth of about 2,900 feet and the oil is of medium gravity.

Examples of other types of oil occurrence are found near the towns of Drumheller and West Drumheller. Oil from the former is of high to medium gravity and comes from the Devonian Winterburn group at a depth of 5,400 feet. The oil is in a dolomite of reef origin. At West Drumheller the oil comes from similar reef deposits in the Winterburn and Woodbend groups at about 5,500 feet and 5,650 feet, respectively. The oil is between 37 and 43 degrees A.P.I. gravity.

Central Division. The plains of central Alberta contain the largest oil fields in Canada, the Pembina, Redwater, and Leduc-Woodbend, and many lesser fields. The 1,765-mile Interprovincial pipeline, completed to Sarnia, Ontario, in 1953, brings oil from the fields to refineries in Ontario, and the 718-mile Trans Mountain Oil pipeline also completed in 1953 links the oil fields with refineries in Vancouver and in the State of Washington.

The oil is found in beds of Upper Devonian, Mississippian, Lower Cretaceous, and Upper Cretaceous age. Most of the reservoirs in the Devonian are ancient reefs that grew either in a chain-like series or as bank or off-shore reefs. The chain-like reefs are surrounded by areas of mud and various clastic sediments.

The Leduc-Woodbend field, about 15 miles southwest of Edmonton, was the first to produce from the reef chain. It was discovered by Imperial Oil Limited in February, 1947. The main production is from the Leduc formation, a reef dolomite in the Woodbend group, as well as from other reef horizons in the Winterburn group. The oil has a gravity of about 39 degrees A.P.I. and drilling depth is about 5,000 to 5,300 feet. Drilling has outlined the limits of the reef, the indications being that its sides are relatively steep and well defined. The area of the field is about 44 square miles. Some wells also produce from sands at the base of the Lower Cretaceous. These occurrences are at a depth of 4,200 to 4,300 feet. The oil is of the same gravity and very similar to that in Devonian beds.

The Golden Spike field lies a short distance northwest of the Leduc-Woodbend. It was discovered in a relatively small reef which seems to have formed a sort of pinnacle in the sea during Upper Devonian time. The first well drilled penetrated 544 feet of oil-bearing porous dolomite but the producing area covers less than 2 square miles.

The Redwater is another major field in which production is obtained from a large reef in the Leduc formation. It was discovered by Imperial Oil Limited in 1948 and drilling since then has completely outlined the field and has shown that it covers about 58 square miles. The drilling depth is about 3,200 feet. The gravity of the oil is 33 to 36 degrees A.P.I. The field is considered to be fully developed, and by the end of 1955 had produced more oil than any other field in Canada. Hot water injection is being tried in the hope that, with careful control of production, the maximum recovery of oil will be obtained. At the end of 1955 the field was producing 81,318 barrels of oil a day but it was estimated that the production could be increased to 150,000 barrels.

Although the Leduc-Woodbend and Redwater are the largest fields producing oil from Devonian reefs in central Alberta, several others yield oil from reefs of this age. South of the Leduc-Woodbend and apparently in the same reef chain are the Glen Park, Wizard Lake, Westerose, and Rimbey oil fields. Production in all these is from the Leduc formation. The Glen Park also produces oil from the Winterburn group and from basal beds of Lower Cretaceous age. North of the Leduc-Woodbend field the Devonian reefs produce oil in the Acheson, the Leduc and Winterburn-Leduc, St. Albert, Excelsior, Winterburn and Fairydell-Bon Accord, and Winterburn fields. To the east and south several other fields produce from Devonian reefs. The largest of these is the Fenn-Big Valley south of the town of Stettler. This field covers over 17 square miles and yields oil of about 32 degrees gravity from the Winterburn group at a depth of about 5,250 feet. Included in this group, north of the Fenn-Big Valley, are the Stettler, Clive, Malmo, New Norway, and Duhamel fields. All produce from reefs in the Leduc formation and Winterburn group. At Erskine and Bashaw production is from reefs in the Leduc formation only.

In the southwestern part of the central region the Sundre and Westward Ho fields are at the edge of the Plains in township 35, range 5, west of 5th meridian and township 34, range 4, west of 5th meridian. The oil is light gravity occurring in the beds of the Rundle group of Mississippian age. The discovery well in the Sundre field obtained production at a depth of 9,130 feet and in the Westward Ho field at 8,790 feet. The fields are only partly developed and they may prove to be of fair size, and other discoveries may be made in the same horizon at nearby locations.

The third large field, the Pembina, is still only partly developed and its limits have not been accurately determined. Present estimates are that the area covers about 78 square miles. Since its discovery in 1953 it has developed rapidly and is one of the greatest oil fields on the continent. The oil occurs along the eastern seaward limit of the Bighorn (Cardium) formation of Upper Cretaceous age. The regional dip is west and the oil has accumulated in the up-dip end of the sand formation which is sealed off by marine shales. Some lenses of the sand occur farther east and the pattern of disappearance of porous sand is probably an irregular one. Depths of drilling vary from about 4,600 feet in the east to 5,800 feet in the west. The oil has a gravity of 38 degrees A.P.I. In the Pembina field some oil has been found in beds of Mississippian age, but most wells have not tested these deep horizons. A few wells are also producing oil from a sand in the Upper Cretaceous Belly River group. Production from this sand is still relatively small.

A number of other fields produce from formations of Cretaceous age, chiefly from the Viking sand which is a reservoir for gas and oil. Two fairly large fields, the Joarcam and Joffre, and several small ones produce oil from this sand. The Joarcam is a long narrow field which extends for about 24 miles northwest from a point near Camrose. The first discovery was made in 1949 in a well near Joseph Lake, and what was thought to be another field was drilled near Armena and Camrose in 1951. Development has shown that these constitute one field. Drilling depths vary from about 3,200 to 3,350 feet. The oil has a gravity of 37 degrees A.P.I. The discovery well in the Joffre field was drilled about 12 miles east of Red Deer in 1953. Development has since extended the field so that it now covers about 9 square miles. The limits are not established and it may prove to be one of the major fields. The depth of drilling is about 4,900 to 5,000 feet and the oil is light, of 39 degrees A.P.I. Other smaller fields that produce oil from the Viking are the Hamilton Lake, Battle South, Battle North, and Legal.

In some small fields oil has been found in older, Lower Cretaceous formations in the Mannville group. At Bonnyville heavy oil is produced from a sand 130 to 150 feet below the top of the Mannville. This may be the equivalent to some of the producing sands at Lloydminster. The Hamilton Lake, Battle North, Battle South, and Legal fields in addition to producing oil from the Viking yield light oil from sands near the base of the Mannville.

Northern Division. Two oil fields had been discovered in northern Alberta by the end of 1955. These are the Sturgeon Lake and Sturgeon Lake South. Fair shows of oil have been found in various wells outside these fields.

The Sturgeon Lake field is north of Sturgeon Lake, 55 miles east of Grande Prairie. It was discovered in 1952 by Amerada Petroleum Corporation. The production is from Devonian reef deposits considered to be equivalent to the Leduc formation. The oil is of light gravity and drilling depth is about 8,850 feet.

About 1½ square miles have been developed and it is considered that the limits of the field are not determined.

The Sturgeon Lake South field is about 10 miles southeast of the Sturgeon Lake field. Except for one well that produces from a formation of Triassic age, production, as in the Sturgeon Lake field, is from Devonian reef deposits. The area producing from the Devonian covers about 3½ square miles, but the limits are not completely determined. The drilling depth is about 8,600 feet and the oil has a gravity of 37-38 degrees A.P.I.

Various wells have obtained fair shows of oil in other parts of northern Alberta but the gas ratio has been too high to warrant development until a market is available for gas.

Northeastern British Columbia and Northwest Territories

Some oil has been found with the gas formations of Mississippian, Triassic, and Lower Cretaceous age in northeastern British Columbia and five oil wells were in production in 1956.

No oil in commercial quantities has been found in the Plains of the Northwest Territories. Drilling is scattered and the area has not been explored to a great extent.

Natural Gas

Natural gas is closely associated with oil in the Interior Plains and most of the discoveries have been made incidental to the search for oil. Now, however, with construction of the Trans-Canada and Westcoast Transmission pipelines under way and the consequent prospects of larger markets, exploration for gas is more active.

Manitoba

Manitoba has no commercial gas fields, but small amounts of natural gas have been produced for many years in the southwestern part of the province for use on a few farms. This gas occurs in fractured shale in the Riding Mountain formation. The quantities of gas found with oil have been too small to supply the nearby towns.

Saskatchewan

Several gas fields have been developed in the southwestern part of Saskatchewan. Production from the province increased from 3,333,077M cubic feet in 1954 to 6,706,743 in 1955.

Hatton. Near Hatton a fairly large field has been outlined by drilling but production on a commercial scale has not been undertaken. This field is supplied by a gas sand about 100 feet below the top of the Colorado group, perhaps similar to the gas sand in the Medicine Hat field in Alberta.

Coleville-Smiley, Brock. Farther north in the vicinity of Coleville and Smiley gas occurs in the Viking sand and there is a similar occurrence near Brock to the southeast. These fields are connected to a pipeline that supplies Saskatoon and several nearby towns. Several wells elsewhere in the general area have obtained gas, and new fields will probably be found in this district.

Unity. At Unity, north of the field just mentioned, two horizons are producing gas. It occurs in lenses of sand in the Viking and at the base of the Mannville group. The latter sand is in the Cumming member, which also occurs near Lloydminster about two-thirds of the way from the top of the Mannville group. The beds below the sand are missing at Unity. The occurrence of porous sand at these two horizons seems to be a local development and wells drilled a few miles away have penetrated only silt and shale. The gas from the Unity field is used in the town of Unity and for running a plant to supply electricity to the surrounding district.

Lloydminster. Gas development at Lloydminster preceded the oil development by several years. The gas was found in 1934 in a sand 260 feet below the top of the Mannville group. The supply in this sand was limited and a higher sand a few feet below the top of the Mannville group proved to be a more reliable source and is still used. Other sands associated with the oil sand at about 150 feet below the top of the Mannville group have also proved to be good sources of gas. The gas is produced at other localities in the vicinity of Lloydminster, some near Blackfoot in Alberta, and some near Lone Rock in Saskatchewan.

Alberta

Natural gas was discovered by drilling at Medicine Hat in 1890. Since then, and more particularly since 1935, huge quantities have been disclosed, the estimated reserves of natural gas in the province in mid-1956 being 18.5 trillion cubic feet. Further large quantities are being disclosed each year. Many fields have been drilled and the wells have been capped awaiting market outlets. One such outlet will be to the Vancouver area and northwestern United States via Westcoast Transmission Company's pipeline which is expected to come into operation in 1957. When completed the Trans-Canada pipeline to eastern Canada will provide a market outlet for large quantities of gas from the central and southern Plains and from fields in the Foothills of Alberta. With the completion of this line many localities with only one or two wells at present will possibly be developed into producing fields in a few years. However, at present consideration can be given only to fields that have been proved by considerable drilling or are in production.

Production from the Plains area of Alberta increased from 89,957,122M cubic feet in 1954 to 116,427,782 in 1955.

Pendant d'Oreille. This is the southernmost producing field. It is a long narrow field south of Foremost and extends southwest from Lake Pokowki for nearly 30 miles. The gas is in the Bow Island sand at a depth of about 2,100 feet. The field supplies mining projects in Montana.

Foremost. Gas from this field has been used since 1923 to supply cities and towns in southern Alberta. The field is now used mostly as a standby. The gas comes from the Bow Island sand at about 2,150 feet.

Bow Island. This field was drilled in 1912 to supply gas for Calgary, but by 1919 it began to show signs of depletion. The gas was found in the Lower Cretaceous Bow Island sand at about 2,200 feet. As already noted, this sand is in part equivalent to the Viking of central Alberta and Saskatchewan. In 1930 the Bow Island field was used to store surplus gas from Turner Valley and by 1939 it was brought back to about three-quarters of its original pressure. Since then production has been intermittent.

Medicine Hat. The first wells in this field were supplied by a sand in the Milk River formation at a depth of about 650 feet. This sand proved inadequate and a deeper sand at 1,100 to 1,200 feet was found. This latter sand, the Medicine Hat gas sand, is about 100 feet below the top of the Colorado group. The field is still an important source of gas, and exploratory drilling in recent years has shown that it extends for several miles beyond the city limits.

Elsewhere in southeastern Alberta small supplies are obtained from the Milk River sand. The towns of Brooks and Ralston and many farms are supplied from this source.

Princess and Cessford. During search for oil in this field, gas was found at several horizons in the Mississippian and Lower Cretaceous. At Cessford systematic development was carried out to provide a field for the export of gas but there has been no production. The gas occurs at the basal beds of the Colorado group and in sand in the lower part of the Mannville. The field extends for nearly 36 miles, averages 2 to 3 miles in width over most of this distance, and reaches a maximum width of nearly 10 miles in the middle.

Okotoks. Natural gas occurs in this field, which is near Okotoks southeast of Calgary, but the field has not been developed. The gas is in the Upper Devonian Wabamun group at over 8,000 feet and has a hydrogen sulphide content of over 30 per cent. If the field is developed it should prove to be a good source of sulphur as well as of gas.

Provost. The Provost field, in township 39 near the eastern border of Alberta, has been drilled to a considerable extent, but has had no production. The gas is in the Viking formation of Lower Cretaceous age at a depth of about 2,350 feet and the field is estimated to cover more than 10 square miles.

Viking-Kinsella-Fabyan. This field covers more than 500 square miles and is the largest in area on the Plains. The area, however, is not uniformly productive. The first gas well was drilled in 1914 near the town of Viking and the name Viking was given to the productive sand. The gas was piped to Edmonton in 1923 and since then has been piped to a number of towns to the south. Drilling depths vary around 2,350 feet.

Devonian Fields. Gas is associated with oil in the Devonian fields, especially those at Leduc and to the south. At Leduc there is a gas cap above the oil. The proportion of gas is greater in the fields to the south and some are essentially wet gas fields. Much of the surplus gas from these oil fields is used in the vicinity of Edmonton for domestic and industrial purposes and some is used in the oil fields.

Pembina. In this oil field a considerable amount of gas occurs with the oil but it is not used extensively.

Fort Saskatchewan. A gas field has been developed at Fort Saskatchewan to supply the Sherritt Gordon nickel refinery there. The field is of fair size and has been developed in the Viking at a depth of about 2,500 feet. The gas is used as a source of fuel and energy and for the production of chemicals used in the nickel-refining process.

Some of the oil fields near Edmonton such as the Fairydell, Morinville, and Acheson, also produce some gas.

Elk Point. At Elk Point gas is produced from the Viking at a depth of 1,250 to 1,300 feet. It is used in a process producing salt.

Athabasca. Gas obtained from the top of the Mannville formation at about 1,650 feet is used in supplying the nearby town of Athabasca. The gas in this part of the Mannville is usually confined to local lenses of porous sand. Such fields are not large but the supply is often adequate for local use. The towns of Bonnyville and Lloydminster are supplied from similar occurrences.

Northwestern Alberta. In several places in northwestern Alberta wells drilled for oil have yielded gas instead and some development drilling of such gas fields has taken place. The only field in production is the Pouce Coupe, on the river of that name. The field is in Alberta near the British Columbia border about 15 miles northeast of Dawson Creek, and is used to supply that town. The gas is in the Lower Cretaceous Cadotte formation at a depth of about 2,150 to 2,250 feet. Some gas has also been found in a lower sand, called the Cadomin, of Lower Cretaceous age and showings have been found in formations of Triassic age.

Elsewhere in northwestern Alberta some potential gas fields have been drilled enough to prove a fair supply. These include the Dunvegan, Tangent, and Whitelaw. In all these fields the gas is in the Cadotte and Cadomin formations and showings are found in some formations of Triassic age.

Northeastern British Columbia

Reserves of natural gas available in this section of British Columbia in 1956 were estimated at about 4 trillion cubic feet. The gas has been found in many localities and the largest potential fields have been developed near Fort St. John. The gas is obtained from about ten horizons in formations of Permian or Pennsylvanian, Triassic, and Lower Cretaceous ages. The largest quantities are found in the Cadomin formation and in beds of Triassic, Permian, and Pennsylvanian ages. Development of this area is going ahead rapidly in order to meet the requirements of the Westcoast Transmission pipeline which will supply northwestern United States, Vancouver and other cities in Canada.

Bituminous Sands

The sands of the McMurray formation exposed along the valley of the Athabasca River and along some of its tributaries above and below the town of Fort McMurray are impregnated with bitumen. The exposures occur for more than 100 miles along the Athabasca Valley. Above Fort McMurray the sides of the valley are fairly steep and the width is not great so that the area of the exposed section

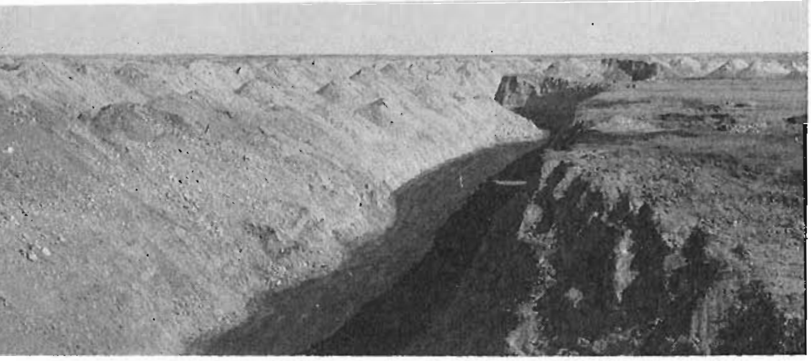

Plate XXVIII

Strip mining of lignite near Estevan, Sask.

in the valley is relatively narrow. Below Fort McMurray the valley is somewhat wider, tributary valleys are more numerous, and a wider area of the sands is exposed. The sand varies in thickness from 170 to 250 feet. It is fine to medium grained and there are many beds of silt and some shale. The bitumen content varies and reaches a maximum of 19 per cent. Usually the silty parts contain less bitumen than the sand.

Early in 1957 Royalite Oil Company Limited announced a $50-million development program following two years of research in devising an economic method of separating the oil from the sand.

The quantities of bitumen available are very large but, because of overburden and variations in the grade of the deposit, exact figures cannot be given except for well explored areas. It has been estimated that a 3-square-mile section of the Mildred-Ruth Lakes area, where exploratory drilling revealed a very rich deposit, contains more than 500 million barrels of bitumen.

Coal

Coal has been mined in many parts of the Interior Plains. Production from Saskatchewan, all lignite, increased from 2,116,740 tons in 1954 to 2,293,816 tons in 1955; that from the Plains area of Alberta dropped from 2,611,499 tons in 1954 to 2,340,215 tons in 1955. Manitoba has little coal, although some lignite occurs in the Turtle Mountain formation near the International Boundary. This has been mined locally but is of poor quality and has a limited extent.

In Saskatchewan, almost all the coal produced is strip mined. Lignite is mined in the southern part of the province in the Ravenscrag formation, most of the output being from Estevan district (Plate XXVIII). The many other coal mines in southern Saskatchewan are used mostly to meet local needs.

The coal deposits in the Plains of Alberta occur mostly in formations of Upper Cretaceous age but a few mineable beds are found in formations of Paleocene age. The most important of the Upper Cretaceous formations are the Foremost, Oldman, and Edmonton. Coal seams in the Foremost are mined at Taber and Milk River as well as at other smaller mines as far east as Medicine Hat. At Lethbridge and Magrath the Oldman contains several coal seams. These are a good grade of volatile bituminous coal, as contrasted with the subbituminous grade of most other coal of this age in the Plains. Beds equivalent to the Foremost and Oldman also have mineable coal seams farther north in the Peace River region near High Prairie and Valhalla. The Edmonton formation is the main source of coal in central Alberta. Most of the coal is mined from the Drumheller and Edmonton areas but there is some intermittent mining at other places. Five workable seams are known in the Drumheller area and many smaller ones occur in the 1,224 feet of the Edmonton formation. The coal is subbituminous, non-coking, and fairly friable.

Cement

Cement is manufactured near Winnipeg from limestone quarried at Lake Manitoba and local clay from Lake Agassiz deposits of Pleistocene age.

Clay and Clay Products

Various types of clay occur in the Plains. Fire clay and other high quality clays for ceramic use form part of the uppermost Cretaceous formations in southern Saskatchewan and southeastern Alberta. Fire brick and similar material are made from some of these clays at Clay Bank, Saskatchewan. At Medicine Hat, Alberta, these clays are used for making various articles such as drain and sewer pipes, and stone and household ware.

In many parts of the Plains building bricks are made from local clays. These bricks vary in quality. Some of the better types are made from clays deposited in lakes that existed during the Pleistocene glacial period.

Bentonitic types of clay are being exploited in parts of the region. Beds of cream coloured bentonite in the base of Pembina member of the Vermilion River formation are quarried near Thornhill in southern Manitoba. This is treated and sold mostly as activated bentonite.

Near Drumheller, Alberta, bentonite beds have been used to make drilling mud. The clay is not of the highest grade and has limited use.

Glass Sand

Some glass sand has been found in formations of Lower Cretaceous age along the Manitoba escarpment in Manitoba and eastern Saskatchewan, and along the Peace River near the town of Peace River. Some of the Peace River deposits are being developed at present.

Gypsum

The only deposits of gypsum that have been exploited are in Manitoba, at Gypsumville and Amaranth. The Gypsumville deposits are of possible Silurian or Devonian age. At Amaranth the gypsum is part of the formation of that name and is of Triassic or Jurassic age.

Building Stone

The limestone of the Red River formation of Ordovician age near Tyndall and Garson, Manitoba, is used extensively as a building stone in many parts of Canada. The stone has good colour and can be cut into blocks of almost any size and shape.

Sandstone in the Boissevain formation in southern Manitoba has been used locally. A similar buff-brown sandstone has been used in the vicinity of Calgary. This was quarried from the local outcrops of the Paskapoo formation.

Potash

Some potassium salt is mixed with common salt in the upper salt beds of the Elk Point group. The potassium minerals are mostly sylvite and carnallite. The best showings have been found near Vera and southeast of Saskatoon, and elsewhere towards the Manitoba border. The rich but deeply buried potash beds extend across the central part of Saskatchewan and are estimated to contain upwards of 100 billion tons. Thirteen companies have been engaged in the exploration and development of the beds, and one of these, Potash Company of America Limited, expects to have its property at Patience Lake, 15 miles east of Saskatoon, in production by the end of 1958. The deposits in Saskatchewan are as much as 3,400 feet below the surface.

Salt

Common salt, sodium chloride, is produced at three localities on the prairies. At Neepawa in Manitoba brine is found in beds of Devonian age at about 1,200 feet below the surface and various grades of salt are produced by The Canadian Salt Company Limited.

The salt formation of the Elk Point group has been pierced by wells and water is forced into the formation to form a brine which is later pumped out and evaporated to obtain salt. One such project is near Lindbergh, Alberta, about 150 miles east-northeast of Edmonton, the producer being Canadian Salt Company. In a similar development near Unity in west-central Saskatchewan, the salt is produced by Sifto Salt Limited. In both of these places a supply of cheap gas fuel and adequate water have facilitated operations.

Sodium Sulphate

Sodium sulphate occurs either in glacial drift or at the top of bedrock at several localities in Saskatchewan. Canadian production in 1955, all from Saskatchewan, amounted to 178,888 tons valued at $2,799,715, the value of output being a new record. Development of these deposits has taken place at Palo, Alsask, Chaplin Lake, Bishopric, Ormston, Oban, and Gladmar. The four producers of natural sodium sulphate in 1956 were: Ormston Mining and Smelting Company Limited at Ormston; Midwest Chemicals Limited at Palo; Sybouts Sodium Sulphate Company Limited at Gladmar and Saskatchewan Minerals (Sodium Sulphate Division) at Chaplin (Plate XXIX) and Bishopric. The last named company is owned by the Saskatchewan Government.

Volcanic Ash

Volcanic ash is found near Swift Current, Sask., and has been used as an abrasive or scouring powder. Similar ash of glacial or post-glacial age occurs in parts of southern Alberta near Lethbridge and in localities to the northeast.

Lead and Zinc

Sphalerite, galena, and minor amounts of pyrite occur in the lower part of the Presqu'ile formation at Pine Point on the south shore of Great Slave Lake. The dolomite is fairly porous and the metallic minerals fill these pores. This deposit

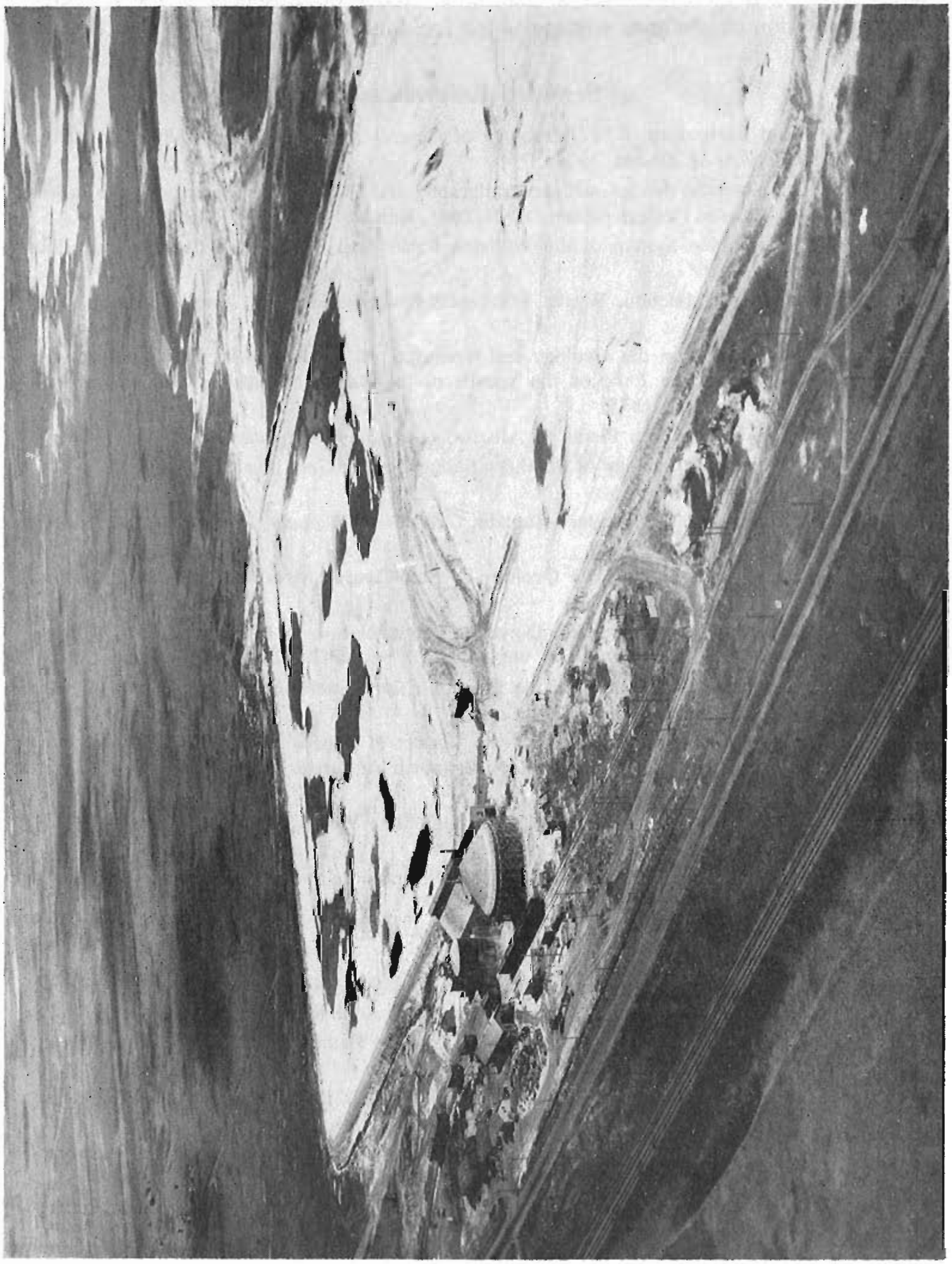

Plate XXIX | *Sodium sulphate plant at Chaplin, Sask.*

has been explored by diamond drilling by Pine Point Mines Limited and large tonnages have been indicated over a wide area. Active development of the property awaits provision of adequate transportation facilities.

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CHAPTER VI

THE CORDILLERAN REGION

*(H. S. Bostock, R. Mulligan and R. J. W. Douglas)**

The Cordilleran region in Canada embraces the mountainous belt of country, some 500 miles wide, that borders the Pacific Ocean (Figure 1). It is part of the great mountain barrier that extends along the western part of the continent. In Canada the region includes Yukon Territory and most of British Columbia, as well as part of southwestern Alberta and a narrow strip of the Northwest Territories. Its western boundaries are the Pacific Ocean and Alaska, and it extends more than 1,500 miles southeasterly from the Arctic Ocean to the International Boundary. On the east it is bordered by the Interior Plains of Canada, a nearly flat area underlain by almost horizontal sedimentary strata, in sharp contrast with the mountainous terrain, wide variety of rocks, and complex structure of the Cordilleran region. The boundary between the Cordilleran and Plains regions lies a little west of Calgary in southern Alberta, and close to Hudson Hope on Peace River; it passes through the extreme southeast corner of Yukon Territory, crosses to the east side of Mackenzie River about 50 miles below Fort Simpson, crosses Great Bear River, and re-crosses to the west side of Mackenzie River above Fort Good Hope; thence it reaches the Arctic coast at the west edge of the Mackenzie delta.

Except in the far north the Cordilleran region is largely a forested country, but the mountains project above timber-line, and in the southern interior grasslands and sparse woodlands spread over the lower dry hills and valleys. The region has contributed nearly one-quarter of all mineral wealth produced in Canada, outstanding mineral products being copper, gold, lead, silver, zinc, coal, natural gas, and petroleum.

Physical Features

The Cordilleran region includes three northwesterly trending physiographic sub-provinces: a western system of mountains, an interior system of plateaux and mountains, and an eastern system of mainly mountains. Each of these three sub-provinces is divided into several physiographic units (Figure 61). The southern part of the interior system is bounded on the east by a long trough known as the Rocky Mountain Trench.

*H. S. Bostock prepared the general statement and the section dealing with physical features. R. Mulligan prepared the sections on early geological work, the geology of the southwestern and northwestern Cordillera, and the metalliferous and industrial minerals. R. J. W. Douglas wrote the account of the geology of the eastern Cordillera and the section on fuels.

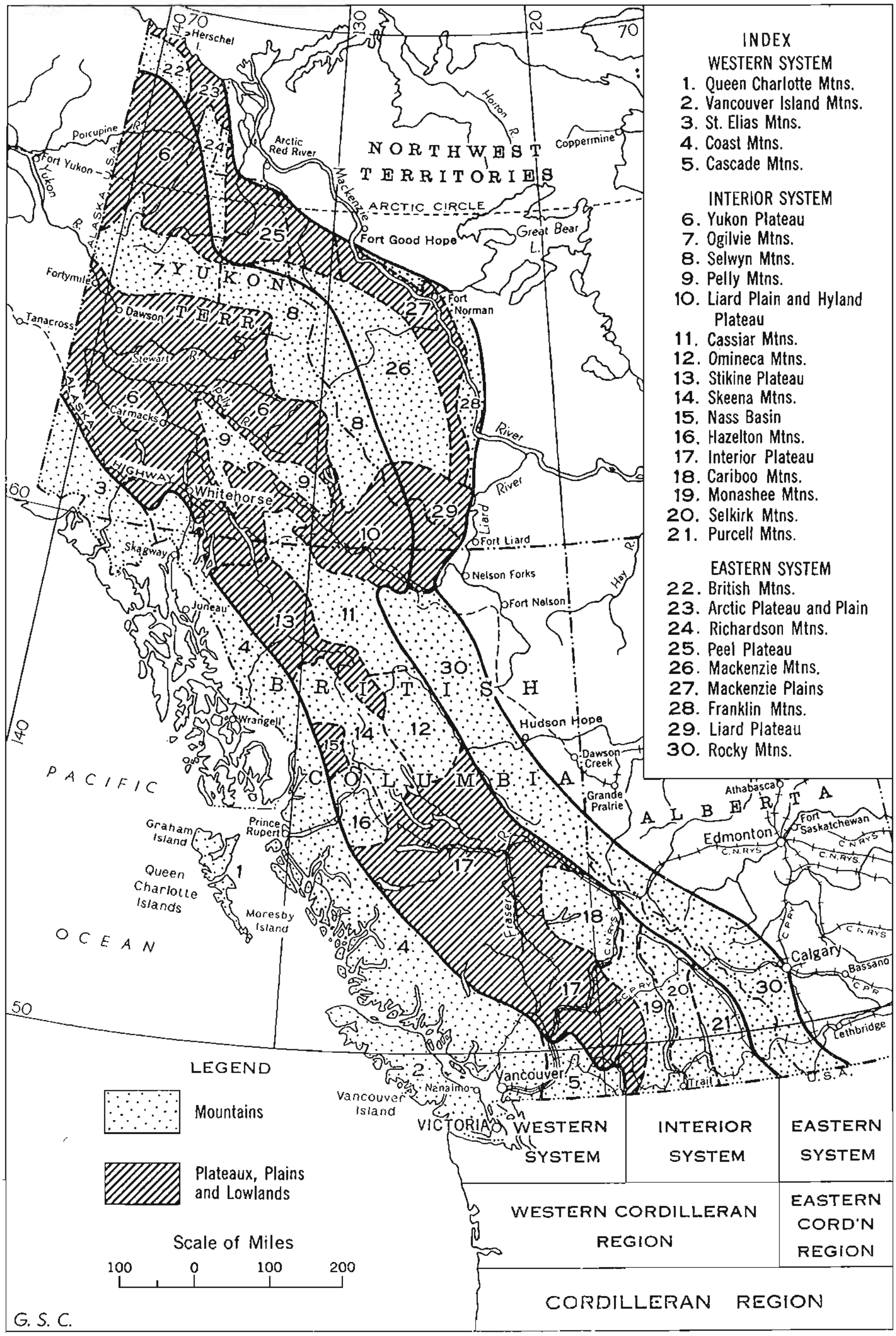


FIGURE 61. Physiographic division, of the Cordilleran region.

Western System

The western system includes the St. Elias Mountains, the ranges of Queen Charlotte and Vancouver Islands, and the Coast and Cascade Mountains.

The St. Elias Mountains occupy an area in southwestern Yukon and the adjacent, extreme northwest corner of British Columbia. They are extremely rugged, and in large part covered by ice-fields. The elevation of Mount Logan, the highest peak in Canada, is 19,850 feet, and several other peaks exceed 15,000 feet.

Mountains, bordered by areas of lowland on their northeast sides, occupy most of Queen Charlotte and Vancouver Islands. In the Queen Charlottes they reach 3,000 feet or more, and on Vancouver Island they culminate, in the central part, in peaks 5,000 to 7,000 feet or more above sea-level. Deep valleys cut across the islands, and the western coasts are indented by long fiords.

The Coast Mountains form a belt 100 miles wide and 1,000 miles long, and border the Pacific coast from Yukon southeast almost to the International Boundary at the 49th Parallel. They rise abruptly from the sea, and towards the axis of the range are characterized by rugged peaks and saw-toothed ridges rising to elevations from 7,000 to more than 13,000 feet (Plate XXX). Alpine glaciers and ice-fields are common and, in a few places in the north half of the mountains, valley glaciers extend to sea-level. The western margin of the mountains is dissected by numerous long fiords and deep U-shaped valleys, some of which cross the system and form the courses of rivers draining the interior plateaux and mountains.

The Cascade Mountains project into British Columbia from the State of Washington and are more than 100 miles wide where they cross the boundary. They lie on the east side of lower Fraser River Valley, which separates them from

Plate XXX | Coast Mountains, Skeena River, B.C.

the Coast Mountains, and extend as far north as Thompson River. Many of the higher peaks and ridges near the International Boundary attain elevations between 7,000 and 8,500 feet; in the west they are fully as rugged as the adjacent Coast Mountains, and, like them, hold alpine glaciers.

Interior System

The interior system, composed of dissected plateaux and scattered mountain ranges, occupies a belt that averages more than 200 miles wide and extends southeast from Alaska to the southern boundary of British Columbia. In Yukon Territory its main divisions are the Yukon Plateau and the Ogilvie, Selwyn, and Pelly Mountains. In northern British Columbia it includes the Stikine Plateau and the Skeena, Hazelton, Cassiar, and Omineca Mountains. In the southern part of the province it comprises the Interior Plateau and the Cariboo, Monashee, Selkirk, and Purcell Mountains.

The Yukon Plateau covers much of the drainage basin of Yukon River and, commencing in northern British Columbia near Atlin and Teslin Lakes, extends northwestward through Yukon Territory into Alaska. In Alaska the plateau connects with a large, basin-like, unglaciated area of plateau and plain, which is drained by the Porcupine River and is separated from the main body of the plateau in Canada by the Ogilvie Mountains. This part of the Yukon Plateau is sometimes called the Porcupine Plateau. The Yukon Plateau was formerly a widespread rolling surface but has now been dissected by river valleys as much as 1,500 to 2,500 feet deep. In the northwestern unglaciated part the former surface has been reduced to long, connected, round-topped ridges, and in the glaciated parts to the south and east has been eroded to a series of undulating uplands separated by a network of large valleys. The Ogilvie and Selwyn Mountains border the main body of the plateau on the north and northeast, respectively, and the Pelly Mountains form an elevated area in its southeastern part. The Tintina and Shakwak Valleys are important features of the Yukon Plateau and form long, northwest-trending lineaments. The Tintina Valley crosses the plateau between the Pelly and Ogilvie Mountains and is nearly in line with the Rocky Mountain Trench but does not connect with it. The Shakwak Valley lies close to the St. Elias Mountains.

The Ogilvie Mountains extend eastward for 150 miles from the Alaska boundary near latitude 65 degrees. Their south half is composed of a compact mass of ranges reaching heights of a little more than 7,000 feet. North of the divide to Peel River elevations are lower and broad valleys separate groups of long ridges following elliptical and hairpin fold-patterns.

From the east end of the Ogilvie Mountains, the Selwyn Mountains extend southeastward for 400 miles to lower country east of Frances River near latitude 61 degrees. They rise from the Yukon Plateau along an irregular front, and are divided by embayments of plateaux and lowlands into three main parts called, from northwest to southeast, the Wernecke, Hess, and Logan Mountains. These are broken into groups by a network of broad valleys. Alpine glaciers occur in the higher areas and the highest peaks reach close to 9,000 feet above sea-level.

Pelly Mountains form a triangular area in the southeastern part of the Yukon Plateau with corners near Teslin, Frances, and Little Salmon Lakes. In all parts their highest summits reach more than 7,000 feet above sea-level. The peaks have been carved by glaciation from hills that stood above the plateau level and their lower spurs and ridges show remnants of the former rolling surface. South slopes are prevailingly steep and smooth but north slopes commonly show cirques with precipitous headwalls.

Southeast of the Yukon Plateau and south of the Selwyn Mountains, is an area of relatively low, subdued topography covered by the Liard Plain and Hyland Plateau.

The Cassiar and Omineca Mountains constitute a continuous belt stretching from Yukon to near Takla Lake in British Columbia and spreading 50 to 75 miles west from the Liard Plain and the Rocky Mountain Trench. These mountains comprise many ranges separated by broad, transverse and longitudinal valleys commonly 3,000 to 4,000 feet deep. The higher peaks and ridges in most parts range from 6,500 to 7,500 feet in elevation, but along the middle of the belt a few rise to more than 8,500 feet and alpine glaciers lie around the highest summits.

The Stikine Plateau extends southeastward from the Yukon Plateau between the Coast Mountains and the Cassiar and Omineca Mountains and occupies much of the drainage basin of Stikine River. Its general surface is about 1,000 feet higher than that of the Yukon Plateau and it is dissected on a coarser scale, having broader interstream areas. These are separated by deep, narrow valleys of the Taku and Stikine Rivers and their main tributaries. The broad uplands are surmounted by mountains formed from wide volcanic piles that commonly stand 7,000 feet above sea-level and reach their highest point in Edziza Peak at 9,143 feet.

To the south the surface of the Stikine Plateau rises into the Skeena Mountains which form a broad barrier 100 miles wide from the Coast Mountains to the Omineca Mountains between the Stikine Plateau to the north and the Interior Plateau to the south. The Skeena Mountains are cut into a mass of small ranges by a network of short, narrow valleys, 2,000 to 3,000 feet deep. Most of their higher peaks are more than 7,000 feet in elevation and a few reach above 8,000 feet. Several groups of alpine glaciers occur in the central parts opposite gaps in the Coast Mountains.

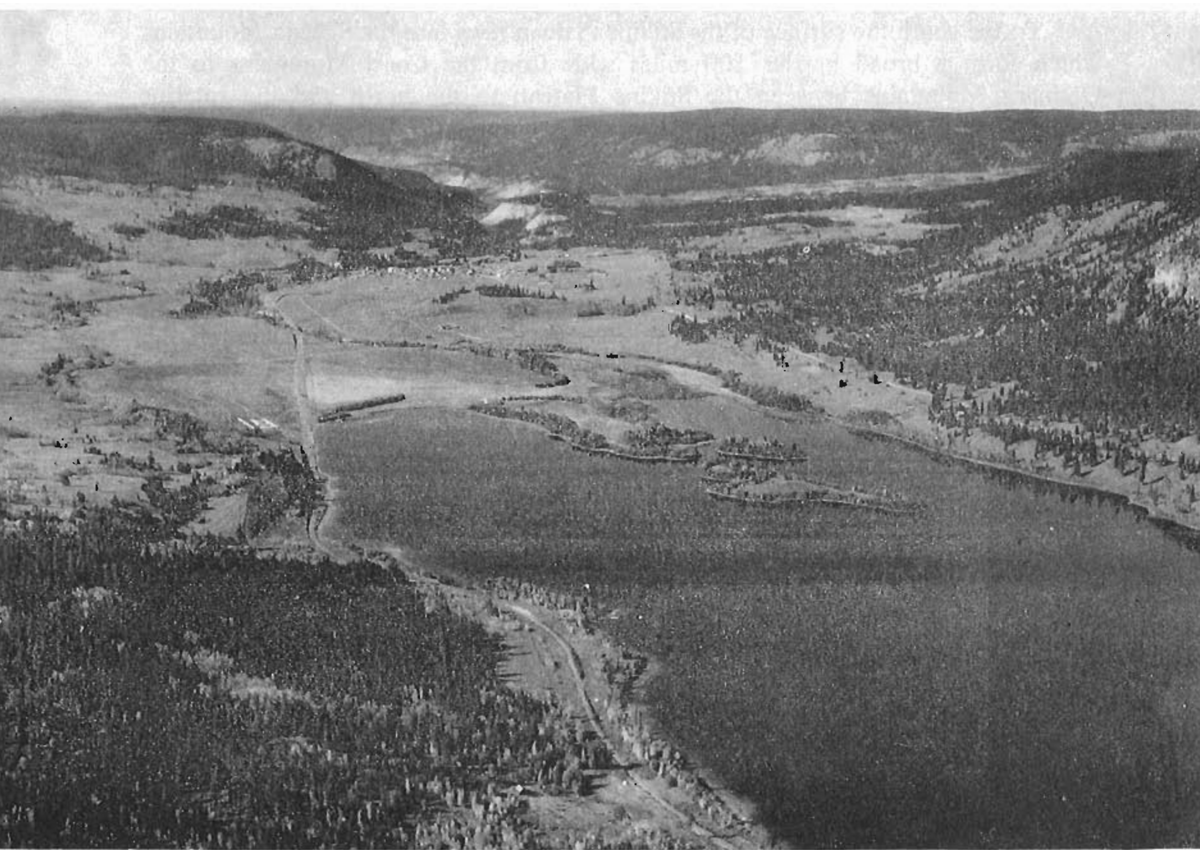
A low, triangular area, the Nass Basin, containing the valleys of the Nass and Kispiox Rivers, lies southwest of the Skeena Mountains and between them and the Coast and Hazelton Mountains. The general floor of the basin is below 2,000 feet but a few hills in and around it rise to about 5,000 feet.

The Hazelton Mountains form a massive block on the south side of the Nass Basin and are separated from the southwest corner of the Skeena Mountains by the Bulkley Valley. These mountains are cut in two by the Skeena River Valley and are surrounded by other large valleys whose floors are only a few hundred feet above sea-level. Their highest summits are over 8,000 feet in elevation but most of their peaks reach little more than 6,000 feet. A number of alpine glaciers occur in their western and higher parts.

The Interior Plateau stretches 500 miles southward from the Omineca, Skeena, and Hazelton Mountains to the 49th Parallel. In its northern part it occupies the full 200-mile breadth of the Interior System between the Coast Mountains and the Rocky Mountain Trench, but it narrows southward to less than 50 miles at the International Boundary. Its dominant feature is an old, undulating, dissected, upland surface that rises gradually southward from about 3,500 feet in the north to near 6,000 feet at the Boundary (Plate XXXI). In the northern part a broad plain lies below the upland surface and has a general level of about 2,300 feet. Surrounding hills rise less than 1,000 feet above the plain, and valleys through it have been cut to about the same depth. Drainage is southward from the plain and the deepening valleys, together with increasing height of the plateau, result in rapidly increased relief until near the International Boundary valley floors are as much as 4,000 feet below the high uplands.

The Cariboo, Monashee, Selkirk, and Purcell Mountains form a compact triangle lying between the Interior Plateau and the Rocky Mountain Trench and having its base at the International Boundary and its apex to the north at the big bend of the Fraser River. The four mountain groups are distinctly separated from

Plate XXXI | *Interior Plateau, looking northwest from Williams Lake, B.C.*



one another by great trench-like valleys that trend north and northwest. All four contain cores of exceeding ruggedness where summits are more than 10,000 feet in elevation, and, with the exception of the Monashee Mountains, their highest peaks reach more than 11,000 feet.

Eastern System

The eastern system includes the British, Richardson, Mackenzie, Franklin, and Rocky Mountains, and intervening plateau and plain areas.

In British Columbia the eastern and central systems are separated by the Rocky Mountain Trench, a great, slightly sinuous, furrow that extends northwesterly from the International Boundary nearly to the southern boundary of Yukon where it opens into the Liard Plain. The Rocky Mountain Trench includes aligned parts of the Kootenay, Columbia, Fraser, Parsnip, Finlay, and Kechika Rivers. The boundary between the eastern and central systems is less defined beyond the northern end of the Trench. It enters Yukon west of longitude 126 degrees and extends northerly into the Northwest Territories; it then swings to the northwest and is arbitrarily placed between the more mature surface and scattered intrusions of the Selwyn Mountains and the youthful topography of the Mackenzie Mountains; it re-enters Yukon near latitude 65 degrees and thence continues northwesterly passing along the west flank of the Richardson Mountains and the southwest slope of the British Mountains until it intersects the Alaska boundary near latitude 69 degrees.

The British Mountains reach their highest elevations, about 6,000 feet, near the Alaska boundary. There they trend nearly east, but they bend southeastward towards the Richardson Mountains, from which they are separated by the Arctic Plateau. This plateau extends along the northern borders of both mountain ranges and spreads between them to merge with the northern part of the Yukon Plateau drained by the Porcupine River.

The Richardson Mountains form a ridge extending 175 miles southerly from the Arctic Plateau to near latitude 66 degrees. In the north they are more than 40 miles wide, and contain rugged, northerly trending, asymmetrical ridges with peaks rising to heights of 5,000 feet or more. Throughout most of their length, however, they comprise a narrower belt of steep-sided ridges, whose smooth, rounded tops lie mainly below 4,000 feet. No evidence of alpine glaciation has been found in them but continental ice reached their east flank and penetrated some of their northern passes.

The south end of Richardson Mountains is separated from the north front of Mackenzie Mountains by a plateau and plain about 60 miles wide. On the southeast of this the Mackenzie Mountains occupy a broad crescent-shaped area having an abrupt front convex towards the Peel Plateau on the north and towards the lowland along Mackenzie River on the northeast. The Mackenzie Mountains stretch 425 miles southeasterly from a point south of Peel River, near longitude 134 degrees, to the South Nahanni River. Their maximum width exceeds 100 miles. In the main they are rugged and youthful and form a compact mass of conspicu-

Plate XXXII | *Rocky Mountains south of Banff, Alberta, showing bedding of Palæozoic sedimentary rocks, and Mount Assiniboine, elevation 11,870 feet.*

ously stratified, northerly and northwesterly trending ridges topped by peaks that are commonly 7,000 feet or more in elevation, and in some places exceed 9,000 feet. Small alpine glaciers occur in their higher parts, and in Pleistocene time valley glaciers extended down their main valleys. The Canyon Ranges, which form their northeastern front and occupy a belt up to 40 miles wide, include more subdued mountains and high plateau areas traversed by deeply incised river valleys.

To the northeast of the Mackenzie Mountains, the Franklin Mountains rise above surrounding plains as a long, narrow arc averaging less than 30 miles wide. From Fort Good Hope they extend more than 400 miles southeasterly to the mouth of the South Nahanni River. The mountains comprise several ranges, each composed of one or more north to northwesterly trending ridges. The highest points reach 5,000 feet in a few places.

The Mackenzie Mountains are separated from the Franklin Mountains by the Mackenzie Plain. For most of its length this plain forms the valley of the Mackenzie River.

The Liard Plateau extends from South Nahanni River southward for 150 miles to the Rocky Mountains on the south side of Liard River. The plateau forms a broad saddle across the eastern system and joins the Liard Plain and Hyland Plateau of the central system. It is composed of high uplands in the north and these change southward to long, widely separated ridges with relatively uniform summits at about 4,000 feet in elevation.

The Rocky Mountains with their foothills form a continuous belt as much as 100 miles in width, stretching from Liard River to the 49th Parallel. Their eastern boundary forms the front of the Cordilleran region against the Interior Plains and rises along a gently sinuous line trending north to northwesterly. On the west they are limited by the Rocky Mountain Trench which follows an approximately parallel course. Their ranges have been carved from a thick series of sedimentary strata, rather simply folded, and the stratification, emphasized by weathering and visible from great distances, distinguishes them from most mountains of the interior and western systems (Plate XXXII). Their foothills contain parts as high and rugged as some of the mountain ranges but in general comprise an outer belt of lower, less rough topography. Mountains and foothills consist of parallel, aligned, or overlapping ranges following the main north to north-northwesterly trend and on the whole have precipitous eastern faces and more gentle western slopes. Individual ranges and groups of ranges are broken or terminated by deep cross-valleys; the Peace River is the only stream that traverses the whole mountain mass, and the few passes whose divides are below 4,000 feet follow zigzag routes. South of Peace River many of the highest peaks are more than 11,000 feet in elevation and the highest are between 12,000 and 13,000 feet. North of the river, though the Rocky Mountains attain their greatest width there, the highest peaks are between 9,000 and 10,000 feet.

Early Geological Work

The first comprehensive geological exploration in the Cordillera in Canada was made by H. Bauerman who explored the country along the 49th Parallel for the Boundary Commission Expedition of 1859-61, and made the first report and structural section across the mountains from the sea to the Interior Plains. Exploration in the Cordillera by the Geological Survey of Canada dates from 1871. In that year British Columbia became part of Canada, and the Geological Survey agreed to extend its services to that province. Dr. A. R. C. Selwyn, then Director of the Survey, with James Richardson as his assistant, arrived in Victoria in the spring of 1871. Selwyn immediately embarked on an exploratory survey from Kamloops to Moose Lake near Yellowhead, and Richardson commenced an examination of the Vancouver Island coalfields. A report on this work was published in 1872, accompanied by a map of the Vancouver Island coalfields on a scale of 1 inch to 10 miles. This was the first geological map of any part of British Columbia.

Geological exploration was pursued enthusiastically by a small staff of geologists from 1871 to about 1908. Besides his exploratory trip, in 1875 Selwyn made an exploration from the mouth of the Fraser to the junction of Smoky and Peace Rivers. In the same season Dr. G. M. Dawson, one of the outstanding figures in the history of Canadian geology, entered the field and explored a route from Soda Creek to Fort George via Chilcotin and Nasko Rivers. From that time until 1892, when he became Director of the Survey, Dawson was the central figure in western Canadian geology. In 1879, starting at Port Simpson on the Pacific coast, he completed a route survey easterly through the mountains via Skeena River, Babine and Stewart Lakes, Fort McLeod, and lower Pine River, to Edmonton in Alberta. An even more remarkable exploration was undertaken in 1887, as a result of which he has been called the real discoverer of, and the first to describe, Yukon Territory; the capital city, Dawson, was later named in his honour. Leaving the coast town of Wrangell, Alaska, in the spring, he travelled more than 1,300 miles via Stikine River, Dease Lake, Dease River, Lower Post, Liard, and Frances Rivers, Frances Lake, Pelly River, Fort Selkirk, and Lewes River to cross the Chilkoot Pass and reach the coast at the head of Lynn Canal in the autumn of the same year. This journey, completed in 4 months, nearly circumscribed an area of about 63,000 square miles, and provided much geological information on Yukon nearly a decade before the discovery of the spectacular placer deposits of the tributaries of Klondike River.

In 1882 Dawson explored the region between Bow and Belly Rivers, Alberta, and drew attention to its important coal deposits. In 1885 he explored the Rocky Mountain region between latitudes 49° and 51°30′ and published a report and map with structure-sections of the Cascade coal basin. Dawson's principal field, however, lay in the Interior Plateau region of southern British Columbia, where he is perhaps best known for his Kamloops and Shuswap map-sheets, published on a scale of 1 inch to 4 miles and including about 6,400 square miles each.

R. G. McConnell in 1886 measured a section across the Rocky Mountains in the vicinity of the Canadian Pacific Railway and illustrated his report with several structure-sections. In 1887 he embarked on one of the most extensive explorations ever undertaken by an officer of the Survey. He had accompanied Dawson from Wrangell to Lower Post on Liard River; from that point he descended the treacherous Liard to its mouth, part of the way with two companions and part way entirely alone. After wintering at Fort Providence on the Mackenzie, he journeyed downstream to the mouth of Peel River well north of the Arctic Circle, up Peel River, westerly across the mountains by way of the Rat River portage to Porcupine River, thence downstream to Yukon River, and up that stream and its tributary, the Lewes, to reach the coast at Lynn Canal by way of Chilkoot Pass. He completed this remarkable journey in September 1888, after covering about 4,200 miles by water and on foot in some 7 months' working time. In 1894 McConnell commenced mapping the West Kootenay sheet in southern British Columbia, but in 1898 returned to Yukon and examined the Klondike placer field, then experiencing its unprecedented rush of gold seekers. During the following decade he continued his studies of Yukon, involving explorations of Stewart, Macmillan, and White Rivers, a report on the Klondike region, and examinations of a number of lode mining districts.

Among the last of the truly exploratory geological expeditions were those undertaken by Charles Camsell, a Deputy Minister of the former Department of Mines and Resources, and by Joseph Keele. Camsell left Dawson in May 1904 and travelled by way of Stewart River and Braine Pass into the basin of Wind River, the latter being followed to its confluence with Peel River, which in turn was examined to its junction with the Mackenzie; the return journey was made via Rat, Bell, and Porcupine Rivers, Dawson being reached in September 1904. Joseph Keele, in 1907 and 1908, made the first geological traverse of Mackenzie Mountains. Leaving Dawson in the early summer of 1907, he reached the divide by way of Pelly and Ross Rivers, hauled his outfit over the 100-mile portage during the late winter, and descended Gravel River to the Mackenzie in 1908.

The officers engaged in this exploratory work were of necessity more than geologists. Besides carrying out the necessary topographic surveys they collected a wealth of information on geography, natural history, and resources, as well as geological data pertaining to the regions examined.

International Boundary surveys provided excellent opportunities for studying geological sections across the Cordillera. Based on his field work between 1901 and 1906, R. A. Daly wrote a memoir entitled "Geology of the North American Cordillera at the Forty-Ninth Parallel". In the far north D. D. Cairnes examined the geology along the Yukon-Alaska boundary between the Yukon and Porcupine Rivers during 1911 and 1912, and the following year he examined an area adjacent to the same boundary on the upper White River.

As the broad general features of the physiography and geology became fairly well known, the need for more detailed work became apparent and systematic mapping on a scale of 1 inch to 4 miles was instituted. Work for the Shuswap sheet by Dawson and James McEvoy was completed in 1896, and for the West Kootenay sheet by McConnell and Brock, in 1900.

By about 1900 the lode mining industry of southern British Columbia was well established and the demand arose for still more accurate and detailed studies of the mineralized areas. Some of the outstanding investigations of mining districts prior to 1910 were made by McConnell in southern Yukon and northwestern British Columbia, by R. W. Brock in the Boundary, Lardeau, and Rossland districts, by Charles Camsell at Hedley and in the Tulameen district, and by D. D. Cairnes in the coal areas of Yukon and in the mining areas of Wheaton River and Atlin. The work of D. B. Dowling in the early years of the century is noteworthy for its many contributions on the coalfields and coal resources of the Cordillera.

Many other geologists are noted for their later work in Cordilleran areas. The names of those of the Geological Survey of Canada are to be found in the lists of publications issued by the Survey; and those of officers of the British Columbia Department of Mines, in the Bulletins and Annual Reports issued by that body.

Geology

The Cordilleran region is readily divisible into two contrasting geological provinces: the western Cordilleran region, and the eastern Cordilleran region. The former includes, briefly, all of Canada west of the Rocky and Mackenzie Mountains, and south of about latitude 65 degrees it is approximately coextensive with the western and interior physiographic divisions (Figure 61). The eastern Cordilleran region includes, besides the eastern physiographic division, all of the Cordillera north of about latitude 65 degrees. This is for convenience in description, since the geology and economic minerals are for the most part typical of the eastern Cordillera. The British Mountains, which lie within that area, are more nearly related to the western Cordillera but little is known of their geology or possible mineral deposits.

The western Cordilleran region is one of great geological complexity (Map 1045A, in pocket). Sedimentary and volcanic strata range in age from Proterozoic to Recent. They record a number of periods of crustal disturbance accompanied or followed by uplift and erosion. These varied greatly in intensity, and probably somewhat in time, from place to place, but those of late Mesozoic to early Tertiary time are outstanding. During this interval the folded and faulted strata were invaded extensively by deep-seated granitic bodies, including the Coast, Nelson, Cassiar-Omineca, and other batholiths, and by a host of smaller intrusions. The Precambrian, Palæozoic, and Mesozoic strata now lie for the most part in northwesterly trending folds on the flanks of intrusive bodies such as the Coast and Cassiar-Omineca batholiths. The Tertiary deposits include vast areas of only slightly disturbed volcanic rocks.

Widespread metallization, resulting in numerous deposits of copper, gold, lead, silver, zinc, and other ores accompanied or closely followed the Mesozoic and early Tertiary intrusions. A few metalliferous deposits, some of them of commercial importance, are thought to be of other ages. Coal seams are found in late Mesozoic and Tertiary strata.

The eastern Cordilleran region is underlain by great thicknesses of Proterozoic, Palæozoic, Mesozoic, and some early Tertiary sedimentary rocks, for the most part succeeding one another without pronounced angular discordance and, in general, unaccompanied by plutonic or volcanic rocks. They now form, in great part, lofty mountains of comparatively simple structure, although the Rocky Mountains are bordered on the east by an intricately folded and overthrust Foothills belt. The region contains extensive coal deposits and important accumulations of petroleum and natural gas, but only one known commercial metalliferous deposit.

For purposes of description the Cordilleran region is divided into three parts, the southwestern, the northwestern, and the eastern.

Southwestern Cordillera

The Rocky Mountain Trench forms the eastern boundary of the southwestern Cordilleran region, whose northern limit is here arbitrarily defined by a broad expanse of poorly explored country lying northeast of the head of Portland Canal, at about latitude 56 degrees. Within this region an eastern marginal belt is underlain almost exclusively by Proterozoic and early Palæozoic rocks, mainly sedimentary and only in part metamorphosed. They are not known to outcrop farther west although metamorphic rocks of this general age project far into the interior, forming the so-called Shuswap terrain. Late Palæozoic sedimentary and volcanic rocks form one prominent trough within the eastern marginal belt and occur here and there with similar Mesozoic strata that occupy the greater part of the remaining area, on both sides of the Coast Range intrusive belt.

Practically all the rocks up to Lower Cretaceous in age are intensely folded and intruded by abundant granitic and more basic rocks. Late Cretaceous and early Tertiary deposits in scattered basins are only mildly deformed and cut by minor late intrusions. Flat-lying late Tertiary lavas cover great areas, especially in the central interior.

The rock formations are described in the following paragraphs and are shown in Tables XIX and XX (in pocket).

Precambrian

Precambrian rocks of the southwestern Cordillera include the Purcell and the Windermere systems, consisting chiefly of sedimentary and metamorphosed sedimentary rocks of presumed Proterozoic age. Rocks of the Wolverine complex and the Shuswap complex are, in part, possibly of Precambrian age. The Purcell system is divided into the Lower Purcell and Upper Purcell series.

Distribution. The Purcell, Windermere, and Wolverine rocks lie in a belt that closely borders the Rocky Mountain Trench. The Lower Purcell series outcrops only in the southernmost part of the belt, where it occupies the core of a broad northwesterly trending anticlinorium. At the International Boundary these rocks underlie practically the whole of the Purcell Mountains, as well as adjoining parts of the Selkirk and Rocky Mountains. They represent the northward extension into Canada of the widespread "Belt Terrain" of Montana and Idaho. The Lower Purcell is flanked on the west and east by Upper Purcell and these, in turn, by Windermere and Palæozoic strata. Northward these progressively younger assemblages succeed one another along the axis of the anticlinorium, but rocks probably of the uppermost Windermere are among those that have been traced far to northwestward towards the Big Bend of the Columbia River. Some 120 miles farther northwest, in an area north of Quesnel Lake, similar rocks underlie Lower Cambrian strata of the Cariboo group. Again some 150 miles beyond the big bend of the Fraser River a Proterozoic age has been assigned to part of the Wolverine complex in the vicinity of latitude 56 degrees.

The Shuswap complex occupies a large area west of Revelstoke that includes Adam and Shuswap Lakes and extends southward along the east shore of Okanagan Lake and River.

Purcell. The Purcell system is a conformable succession of formations whose total thickness is estimated at 45,000 feet. This figure includes the exposed thickness of the Fort Steele formation which, however, does not outcrop in the western Cordillera.

The Lower Purcell series comprises in ascending order the Aldridge, Creston, Kitchener, and Siyeh formations. The Aldridge formation, 16,000 feet thick, and the Creston, 6,300 feet thick, consist chiefly of quartzite, argillaceous quartzite, and argillite, the Aldridge being distinguished chiefly by its predominantly rusty weathering. The Kitchener and Siyeh formations, together some 8,000 feet thick, both consist chiefly of variously coloured calcareous, dolomitic, and argillaceous rocks, and are commonly mapped as a single unit.

In the vicinity of Cranbrook the Purcell sedimentary sequence is interrupted by basalt flows, called the Purcell lavas, and this horizon is taken as the top of the Siyeh and the base of the Upper Purcell series, here represented by the Gateway formation. To the west and north, however, lavas are not present and the rocks overlying the Siyeh, and referred to the Upper Purcell, are subdivided into the Dutch Creek and Mount Nelson formations. These formations, about 4,300 and 3,400 feet thick, respectively, each consist of grey, green and black laminated argillite, magnesian limestone, argillaceous limestone and quartzite. The two formations are very much alike but the Mount Nelson has perhaps more and larger beds of magnesian limestone than the Dutch Creek, and a thick band of light quartzite at the base forms a good horizon marker in some places.

Primary structures such as ripple-marks, crossbedding, and mud-cracks are common in the Purcell strata and are particularly well preserved in the lower clastic formations. These features indicate shallow-water conditions of sedimentation and suggest deposition in a slowly sinking sea.

Intrusive into the Purcell rock, particularly into the lower formations, are numerous sills and dykes of the average composition of quartz-diorite, and called the "Moyie" or "Purcell" intrusions. They are most prominent in the area where Purcell lavas are present, and were originally thought to be genetically related to these extrusions. However, similar sills occur in formations at least as young as the Mount Nelson and the age of the intrusions, while generally considered to be Precambrian, remains in doubt.

Windermere. The Windermere was originally defined as a Precambrian system comprising the Toby formation, which is a basal conglomerate, and the overlying Horsethief formation (renamed Horsethief Creek series). The latter was seen to be overlain with erosional unconformity by fossiliferous Lower Cambrian strata along the Rocky Mountain Trench. Later on the west slope of the Purcell Range a conformable succession of formations, the Hamill, Badshot, and Lardeau, was found to overlie the Horsethief Creek with apparent conformity. Lacking fossil evidence to the contrary, the succession was included in the Windermere system. These three units are stratigraphically equivalent to strata now known to be of Lower Cambrian and later age, although the base of the Cambrian cannot be accurately placed on the basis of present information. In this discussion, the Windermere is tentatively restricted to the Toby, the Horsethief Creek, and their equivalents.

As previously stated, Windermere strata outcrop mainly to the west and north of the outcrop area of Purcell formations within the Purcell Mountains, crossing into the Selkirks near the south end of Kootenay Lake. On the north the Toby formation apparently passes beneath the surface at about latitude 51 degrees, but Horsethief Creek and younger strata outcrop far to northward across the Selkirk Mountains.

Although the Toby conglomerate overlies different members of the Upper Purcell in different places, indicating a major erosional unconformity, the angular discordance is generally slight and nowhere more than 45 degrees. Thus any intervening deformation must have been gentle. However, the presence of a high landmass nearby during Horsethief Creek time is attested by the recurrence of coarse clastic material throughout the series. The material of the Toby conglomerate varies markedly from place to place, consisting chiefly of boulders and fragments of immediately underlying Purcell rocks and including some feldspar pebbles. The Horsethief Creek series, about 5,000 feet thick, is made up chiefly of grey, green and purplish slate, lenticular beds of coarse quartzite and pebble conglomerate, and thin interbeds of crystalline limestone. West of Kootenay Lake near latitude 49 degrees, the Toby is interbedded with and partly overlain by the Irene volcanic formation, consisting essentially of sheared fine-grained greenstone. Also in this locality the upper part of the Horsethief Creek grades laterally into the coarse grits of the Three Sisters formation, and the lower, more typical, facies is known as the Monk formation of west Kootenay and the northeastern part of the State of Washington.

The oldest exposed rocks in the Cariboo district are schists and metagreywackes that conformably underlie Lower Cambrian strata of the Cariboo group, and are of Horsethief Creek type. On this basis they may be, at least in part, Proterozoic, according to the restricted definition used in this report. The Cariboo group, formerly considered all Precambrian, consists of quartzite, limestone, and argillite. These strata are intricately folded and cut by altered porphyry dykes known as the Prosperine intrusions, that are not known to occur in overlying, less severely deformed, Mississippian strata.

Wolverine. The Wolverine complex lies in a belt extending northwesterly from near latitude 55 degrees to beyond latitude 57. In the Aiken Lake area, north of latitude 56, two roughly conformable assemblages, the Tenakihi and Ingenika groups, have been separated from more highly granitized parts of the complex. The lower, Tenakihi group, comprises about 13,000 feet of quartzite and quartz-mica, feldspar, garnet, cyanite, and staurolite schists. The upper, Ingenika group, comprises various schists, crystalline limestone, and quartzitic conglomerate, and includes Lower Cambrian beds. Throughout both groups the grade of metamorphism increases regularly with increasing stratigraphic depth. Planes of schistosity and cleavage are notably parallel with the bedding, both on the limbs and at the crests of major folds. A uniformly-oriented linear crumpling of the schists, and some anomalous fold structures, appear to be crossed by broader, dominating fold structures. These mineralogical and structural features are taken as evidence that the regional metamorphism characteristic of the Wolverine complex was accomplished prior to the major Cordilleran orogeny which produced the present dominant fold structures. This regional metamorphism did not affect the Mississippian and younger assemblages of the area. These assemblages, moreover, include conglomerate made up partly of rocks similar to those of the Wolverine complex. On these grounds it is concluded that the metamorphism is post-Cambrian and pre-Mississippian in age.

Shuswap. The Shuswap complex presents a somewhat analogous situation. In the type area, the "Shuswap Terrain", a highly metamorphosed assemblage of sedimentary and volcanic strata, named the Mount Ida group and estimated to be 60,000 feet thick, has been mapped separately from more highly granitized rocks to the north and east. This assemblage is cut by intrusions of peridotite, serpentine, and pegmatite, and the whole is overlain unconformably by only slightly metamorphosed Carboniferous (?) and Permian strata referred to the Cache Creek group. A conglomerate marks the unconformity and contains pebbles of granite and diorite among others composed of typical Shuswap rocks.

The Shuswap rocks are characterized by gently dipping planar structures that apparently represent the nearly horizontal limbs of small-scale recumbent dragfolds. A pervasive lineation strikes in a general northeasterly direction, in contrast to the northwesterly trending large-scale folds on which these minor structures appear as anomalous complications. This large-scale folding on northwesterly trending axes is attributed to the late Mesozoic orogeny that affected the younger rocks and characterizes the Cordilleran region generally. The anomalous northeasterly trending structures, and the regional metamorphism that typifies the Shuswap complex, are attributed to a pre-Carboniferous period of deep-seated orogeny, metamorphism, and intrusion. The granitic gneisses and other high-grade metamorphic rocks that lie to the north and east of Shuswap Lake and make up the remainder of the Shuswap complex are believed to be granitized equivalents of Mount Ida or still older strata. However, they have not been distinguished from gneisses closely associated with the Nelson batholith of late Mesozoic age and thought to be derived partly from upper Palæozoic and Mesozoic strata.

Palæozoic

Lower Palæozoic. All known lower Palæozoic rocks in the southwestern Cordillera lie within the same general areas as the Proterozoic rocks described above and are closely associated with them.

The most complete section is found in the vicinity of Golden where the Rocky Mountain Trench, there occupied by the north-flowing Columbia River, is crossed by the main line of the Canadian Pacific Railway. In the Dogtooth Mountains near Golden the section consists of a quartzite-argillite-quartzite sequence about 5,300 feet thick. It is correlated with the strikingly similar Fort Mountain-Lake Louise-St. Piran early Cambrian succession of the Field map-area. The Fort Mountain formation rests on a gently undulating erosion surface of Horsethief Creek strata, overlying different horizons in different places with no measurable angular unconformity. The St. Piran is overlain unconformably by fossiliferous limestone of the Lower Cambrian Donald formation which thins rapidly to southeast from 1,500 to 200 feet. Middle Cambrian (?) Canyon Creek strata, chiefly slates, are in fault contact with St. Piran and Donald formations, but Middle to Upper Cambrian Jubilee limestone, 2,000 feet thick, overlies the Donald on Jubilee Mountain. It, in turn, is overlain by limestone and shale of the McKay group, which ranges from Upper Cambrian to Ordovician in age. These Palæozoic formations cross into the Rocky Mountains at a point about 60 miles south of Golden. However, in a small isolated area about 12 miles west of that point an Upper Cambrian to Devonian sequence including the Beaverfoot-Brisco, Mount Forster, and Starbird formations, lies unconformably on Horsethief Creek strata.

Several isolated remnants of the Lower Cambrian Cranbrook and Eager formations overlie Purcell strata with erosional unconformity in the southern Purcell Range. The Cranbrook formation includes abundant conglomerate, quartzite, and an important bed of magnesite. Devonian to Mississippian limestone (Jefferson and Wardner formations) fringes the Rocky Mountain Trench in a small area about 30 miles north of latitude 49 degrees. The strata apparently lie unconformably on members of the Siyeh and Gateway formations.

In the vicinity of Kootenay Lake the Horsethief Creek series is, as previously stated, overlain on the west with apparent conformity by the Hamill, Badshot, and Lardeau succession. The Hamill formation consists of 7,500 to 10,000 feet of quartzite grading up into argillaceous quartzite and schist. It appears to lie along the strike of, and to correspond stratigraphically to, the Quartzite Range and Reno formations west of Kootenay Lake near latitude 49 degrees, which have been placed in the Cambrian. The Badshot, a thin but persistent limestone formation, corresponds similarly to the basal limestone of the Lower Laib group of definite Lower Cambrian age. The succeeding Lardeau series, possibly 15,000 feet thick, consists of slate and schist, with quartzite, and several prominent layers of limestone. It has been in large part severely metamorphosed and intruded by numerous granite bodies. It is overlain unconformably by strata, probably Carboniferous, of the Milford group.

West of southern Kootenay Lake the corresponding Palæozoic sequence above the Lower Laib limestone comprises a complex folded and faulted assemblage of slate, schist, limestone, and quartzite. Strata of definitely Middle Cambrian and Ordovician ages are represented in the Nelway and Active formations, respectively.

Rocks of the Hamill, Badshot, and Lardeau succession have been traced from Kootenay Lake northwestward to Upper Arrow Lake and the main line of the Canadian Pacific Railway near Revelstoke, and undoubtedly underlie a large part of the northern Selkirk Mountains within the loop of the Columbia River. They are bounded on the west by upper Palæozoic and Mesozoic strata and by granitic and highly metamorphosed rocks. Elsewhere the Lower Cambrian occurrences of the Cariboo district and Aiken Lake area are the only known representatives of the lower Palæozoic west of the Rocky Mountain Trench. Carboniferous and Permian strata, on the other hand, are widely distributed throughout and are typically of a facies quite different from that of the lower Palæozoic formations. Their character and contact relationships provide an important key to the early Palæozoic history of the western Cordilleran region.

Upper Palæozoic. Carboniferous and Permian rocks are so widely distributed and everywhere so much alike that it seems virtually certain they originally covered practically the whole of the western Cordillera. Presumably large areas have since been destroyed by erosion or igneous intrusion, or remain covered by Mesozoic and Tertiary formations.

The classic name, "Cache Creek Group", derived from its type locality near Ashcroft, has been widely applied to groups of this general age in the interior of British Columbia. Lithologically, these groups are heterogeneous assemblages of greenstones, clastic sedimentary rocks, cherts, and limestone, as variable in their internal stratigraphy as they are homogeneous in their overall makeup. The greenstones are chiefly altered andesitic and basaltic lavas, tuff, breccia, and agglomerate. Much of the chert is banded, in beds a few inches thick separated by thin shaly partings. Commonly described as "ribbon chert", it forms probably the most distinctive lithological type. Limestone ranges from thin lenticular intercalations to massive bodies probably thousands of feet thick, as, for example, the "Marble Canyon" formation of the Cache Creek group. Crinoid fragments and corals are very abundant in some beds, and foraminifera of the fusilinid type are among the most generally useful diagnostic fossils. Clastic rocks include abundant argillite, siltstone, quartzite, and greywacke. Conglomerate is comparatively rare, except in those few areas where the base of the upper Palæozoic has been recognized. Estimates of total thickness range as high as 20,000 feet. Age determinations range from Mississippian to latest Permian. Both Pennsylvanian and Permian are represented in many places; the bulk of the limestone appears to be in the Permian. Some assemblages carrying Mississippian fauna, such as the Asitka group of northern areas, are doubtfully correlated with the Cache Creek.

Upper Palæozoic strata outcrop in restricted areas in south-central Vancouver Island. None has been recognized farther north along the coastal belt, nor along the east flank of the Coast Mountains north of Bridge River (Bralorne), except for minor remnants in the Terrace area. None apparently remains in the Purcell Mountains south of the railway through Glacier.

West of Kootenay Lake an intermittent conglomerate bed marks the base of the Milford group, which rests without noticeable angular unconformity on widely separated horizons of the Lardeau group. The Milford is an apparently continuous succession of volcanic and clastic rocks, limestone, and ribbon chert, that carries fossils of Mississippian (?), Pennsylvanian, and Triassic ages.

In the Cariboo district the basal conglomerate of the Slide Mountain series contains detritus of underlying Cariboo formations, and of igneous rocks, vein quartz, and pyrite, and even contains placer gold. The series is notably less metamorphosed than the Cariboo group and is not known to be cut by the Prosperine intrusions. Greenstone and ribbon chert are prominent among the component strata, and limestone just above the basal conglomerate carries a Mississippian fauna.

Basal conglomerates of upper Palæozoic groups in the Aiken Lake area farther north and in the Shuswap terrain contain cobbles of metamorphic and igneous rocks similar to those of underlying stratigraphic units. Further structural evidence of supposed pre-Carboniferous regional and igneous processes in these areas has been cited in the Precambrian section. In the Aiken Lake area these processes have been dated as post-Cambrian, but in the Shuswap terrain their maximum age has not been established.

In summary, it seems probable on the available evidence that most of the southwestern Cordillera was uplifted and exposed to erosion during some part of early Palæozoic time, that deep-seated regional metamorphic and intrusive processes were active in widely separated areas, and that resubmergence became general during the early Carboniferous period. The upper Palæozoic rocks are typical of a marine geosynclinal environment that persisted, apparently without major or extensive disturbance, into Triassic and later times.

Mesozoic

The Mesozoic record begins with the Upper Triassic, which is represented chiefly by volcanic rocks, with minor intercalated clastic sedimentary rocks and thick limestone bodies prominent in many places. Such assemblages are difficult to distinguish from those of late Palæozoic age where palæontological evidence is lacking. No definite horizon marks a break between Palæozoic and Mesozoic rocks and, in the case of the Milford group, as already described, the record appears to be continuous. However, no Lower or Middle Triassic has been identified and, moreover, there is evidence of an erosional interval in post-Permian, pre-Upper Triassic time in several places, and of deformation and minor intrusion in at least one.

Marine conditions of deposition typify the Triassic and early Jurassic periods, but continental conditions become increasingly evident in late Jurassic and early Cretaceous times and doubtless mark the onset of the great Jura-Cretaceous mountain-building movement, the major revolution of the western Cordilleran region. Post-orogenic, late Cretaceous strata are almost everywhere continental in nature and commonly merge with early Tertiary deposits.

Triassic. Most Triassic assemblages in the southern interior of British Columbia have been referred to, or correlated with, the Nicola group. In its type area near Merritt this group consists principally of volcanic rocks, with which are associated minor amounts of limestone, argillite, and conglomerate. The volcanic rocks include aphanitic and coarsely porphyritic andesitic lavas, breccias, and agglomerate. Diagnostic Upper Triassic fossils occur in sedimentary lenses. Conglomerate occurs at several horizons and one massive bed marks part of the base of the group. It is discontinuous however, and elsewhere the base is marked by a massive greenstone member that appears to rest on an erosion surface of Cache Creek rocks. Farther south near Hedley interbedded limestone and quartzite make up a substantial part of the group.

West of Kootenay Lake the Triassic beds of the Milford group are overlain in part by greenstone of the lenticular Kaslo series. This is followed by the Slocan series with an intermittent basal conglomerate containing fragments of Kaslo rocks. The Slocan consists mainly of argillite with some quartzite and a minor though important amount of limestone, and carries fossils of probable Triassic age. The Ymir formation farther south is lithologically like the Slocan and grades upward into the Upper Triassic or Lower Jurassic Elise volcanic formation.

Triassic rocks outcrop extensively along the east flank of the Coast Mountains from Bridge River (Bralorne) to Bella Coola, and include abundant argillite, conglomerate, and limestone, as well as volcanic rocks. In the Bridge River and Tyaughton Lake areas the basal Noel formation contains fragments of rocks like those of the underlying, upper Palæozoic Fergusson group. The Hurley group, the upper member of the conformable sequence, is characteristically limy. Limestone is prominent also in the Tyaughton group, a structurally isolated, distinctive sedimentary assemblage of definite Upper Triassic age.

The Sutton and Quatsino limestone formations are the main Upper Triassic marker horizons of the Vancouver group on Vancouver Island, though the lower, mainly sedimentary part of the Bonanza group is also Triassic. The lower subdivisions of the Vancouver are mainly volcanic, and the base of the Triassic is not sharply defined.

Upper Triassic limestone, interbedded with argillite and volcanic rocks, underlies most of southern Queen Charlotte Islands. Crystalline limestone, with slate, schist, and greenstone make up the Triassic of north coastal areas.

East of the northern Coast Mountains the Triassic is represented mainly by the widespread Takla group, which includes Jurassic strata in most places. Lithologically variable, the group comprises andesitic and basaltic lavas and fragmental rocks, conglomerate, greywacke, shale, and limestone. It is in part continental and may not be a conformable sequence. Conglomerate near Fort St. James contains serpentine pebbles and chromite grains, presumably derived from ultrabasic Trembleur intrusions that cut the nearby Cache Creek but apparently not the Takla strata. The latter, moreover, are distinctly less metamorphosed than the Cache Creek. Thus it appears that a disturbance of some magnitude occurred in post-Permian, pre-Upper Triassic time in this locality. Farther west near Terrace limestone boulders carrying Permian fossils occur in conglomerate of presumed Upper Triassic age.

Jurassic. Lower Jurassic strata overlie Triassic conformably in most places, and such major groups as the Vancouver and Takla include rocks of both ages. Middle and Upper Jurassic rocks overlie older formations with major unconformity in some areas, and important unconformities, some related to early intrusions, occur at several horizons within the system.

In West Kootenay district, a dominantly volcanic sequence characterized by augite andesite, basalt, and fragmental rocks, conformably overlies the Triassic (?) Ymir group. In restricted areas it is subdivided into two volcanic formations, the Elise and Beaver Mountain, separated by the lenticular sedimentary Hall formation. The Hall is in part probably Lower to early Middle Jurassic in age.

Middle and Upper Jurassic shale, conglomerate, and sandstone occupy a synclinal area near Ashcroft and overlie granite of the Guichon batholith unconformably. Contemporary sedimentary and volcanic assemblages near Harrison Lake include the conglomeratic Agassiz formation. Similar conglomerate and other clastic rocks are prominent in the Ladner and Dewdney Creek formations that underlie a belt east of Fraser River near Hope. They include both Upper Jurassic and Lower Cretaceous strata. In the Tyaughton Lake area north of Bralorne, Lower and Middle Jurassic beds, mainly marine calcareous shales, overlie the upper Triassic Tyaughton strata conformably. The Taylor group, isolated by faults, is characterized by much conglomerate and is partly continental in origin. It is thought to overlie the known Lower and Middle Jurassic beds unconformably and to be of Middle or Upper Jurassic age. The marine Eldorado group comprises an Upper Jurassic, mainly argillaceous, and a Lower Cretaceous, arenaceous and conglomeratic subdivision.

On Vancouver Island the upper, mainly volcanic part of the Bonanza group includes probably Jurassic strata; and some overlying sedimentary beds were deposited towards the end of early Jurassic time. Some minor late Jurassic beds, possibly post-intrusive, are overlain unconformably by others of Lower Cretaceous age. On Queen Charlotte Islands, the Maude and Yakoun formations comprise marine sedimentary and pyroclastic rocks of late Lower to early Upper Jurassic age.

Rocks ranging in age from late Lower Jurassic to Lower Cretaceous outcrop extensively in a broad belt east of the northern Coast Mountains, where they have been mapped as the Hazelton group. Farther east similar Lower to mid-Upper Jurassic rocks are included in an upper division of the Takla group, separated by local disconformity from the Lower, mainly Triassic division. The Hazelton group comprises abundant acid and basic lavas and fragmental rocks, and some conglomerate, greywacke, sandstone, argillite, minor limestone, chert, and coal. Coal occurs mainly in Lower Cretaceous (Blairmore) horizons, but also in some Upper Jurassic continental beds. The coal measures, named "Skeena Series" by early explorers, extend north to the "Groundhog Field", at about latitude 57 degrees. In the Nechako River area an unconformity separates the Hazelton group from lower Jurassic beds of the Takla group. The basal conglomerate contains detritus from the Topley granitic intrusions. In Terrace area Upper Jurassic to Lower Cretaceous strata overlie typical Hazelton with probable unconformity.

The Quesnel River series east of Fraser River comprises volcanic and intercalated sedimentary rocks similar to Jurassic groups elsewhere.

Cretaceous. The Cretaceous period is largely one of widespread and prolonged orogeny, intrusion, and erosion, and the depositional records are discontinuous.

Lower Cretaceous rocks extend along the east flank of the southern Coast Mountains in two narrow belts, merging in the vicinity of Lillooet. The eastern of these comprises the Kingsvale and Spences Bridge formations. Both consist of andesite, basalt, and fragmental rocks, with minor continental sedimentary beds, and are middle to late Lower Cretaceous. They overlie older and are cut by younger

Coast Range intrusions. The western belt includes the Dewdney Creek group, in part Jurassic, the Jackass Mountain, Brew, and Lillooet marine clastic formations, and the Pasayten continental beds.

In the Bridge River area the Leckie group of volcanic fragmental rocks overlies lower Cretaceous strata of the Eldorado group conformably. Plant remains indicate that the Leckie rocks are late Lower or early Upper Cretaceous. Farther north near Chilco Lake sandstone and shale beds carry plant remains and Lower Cretaceous marine shells. These and the Leckie group are cut by the main Coast Range intrusions.

Lower Cretaceous conglomerate, sandstone, and shale, with thin coal seams, occur in scattered northern localities on Vancouver Island and are younger than the Coast Range intrusions. The Cowichan group includes the Upper Cretaceous Nanaimo series and Comox formations of the east coast, which contain economically important coal measures. The Nanaimo series, in part marine, comprises about 10,000 feet of conglomerate, sandstone, and shale. The series occurs in several structural basins and is moderately folded and faulted.

On Queen Charlotte Islands the coal-bearing Haida formation and the Honna and Skidegate clastic formations, 9,000 feet in total thickness, make up the Queen Charlotte series of late Lower to Upper Cretaceous age. These postdate the Coast Range intrusions, but are warped and faulted, locally closely folded, and cut by Tertiary dykes.

East of the northern Coast Mountains, the coal-bearing Lower Cretaceous continental beds are mostly mapped with the Hazelton group. These and the younger lower Cretaceous sedimentary and volcanic rocks in the Whitesail Lake area are older than the latest Mesozoic intrusions. Farther east the Uslika conglomerate, sandstone, and shale overlie the Omineca intrusions and may be mainly of later Cretaceous age. The Sustut group comprises up to 3,000 feet of conglomerate, sandstone, and shale, with some coal. It is mainly flat-lying, and is in part Upper Cretaceous, in part Paleocene in age.

Cenozoic

Tertiary. The early Tertiary was a time of adjustment and renewed folding, faulting, and intrusion attendant on the Laramide revolution, which formed the Rocky Mountains. Uplift in the western Cordillera resulted in renewed erosion, with deposition prevailing in local, mainly freshwater basins. Periodic vulcanism reached a climax probably in the Miocene epoch, burying much of the land surface of that time beneath thousands of feet of mainly basaltic rocks throughout most of the central intermontane plateau. Most younger volcanic and sedimentary deposits are confined to valleys. Intermittent vulcanism continued in a few places until recent times. Tertiary stream deposits are the source of some economic gold placers, and Tertiary coal deposits are important in the Princeton area.

The Sifton clastic formation, late Cretaceous or early Tertiary in age, extends for at least 120 miles along the northern Rocky Mountain Trench. It is correlated with the Sustut formation, and may have been downfaulted to its present position.

However, Tertiary, probably Miocene, poorly consolidated deposits also occur far to the south near Cranbrook, and suggest that the Rocky Mountain Trench had been carved to about its present depth by that time. Tertiary valley deposits likewise indicate that other prominent trenches were in existence at that time. Scattered conglomerate occurrences of the Sophie formation on ridge tops near Rossland are of late Cretaceous or Tertiary age and mark a former erosion surface. The rocks are cut by dykes related to the Coryell batholith.

The Tertiary deposits of southern interior areas have been described under many names and vary considerably from place to place in stratigraphy and age-range. In southern Okanagan Valley, talus, conglomerate, sandstone, shale, and some coal, Eocene or possibly Paleocene in age, are valley deposits that lie on an erosion surface of moderate to high relief. They are overlain by 4,500 feet of mainly andesite, basalt, and pyroclastic rocks, that buried the former valleys. Younger coal-bearing clastic strata, as much as 4,000 feet thick, are succeeded in most places by massive basaltic lavas. The older beds are locally tilted to high angles but the uppermost lavas are nearly flat lying. Near Princeton the coal-bearing Allenby clastic formation is in part separated from underlying Triassic rocks by up to 4,500 feet of basalt and andesite. The Allenby, about 3,500 feet thick, is presumably Oligocene in age. It is folded, and is unconformably overlain by flat-lying basalt of probable Miocene age. The Tertiary Kamloops group is widely exposed along Thompson River. The basal Coldwater beds of conglomerate, sandstone, and shale containing important coal seams are in places sharply folded and overlain unconformably by basaltic rocks interbedded with the Tranquille beds. These widespread "Plateau Basalts" are probably Miocene in age. Flat-lying basalts along valley walls may be interglacial deposits of Pleistocene age.

Similar "Plateau Basalts", with local undifferentiated sedimentary accumulations, form the constructional surface of the central interior. In the northern areas they are commonly known as the Endako group and include, or have locally been mapped separately from, sedimentary deposits that in places contain lignitic coal.

Tertiary deposits of the lower Fraser Valley include the Huntington and Abbotsford formations and in the Vancouver area, the Burrard and Kitsilano formations. The Burrard and overlying Kitsilano, about 2,000 and 1,500 feet thick, respectively, are clastic deposits, partly of marine origin, and are Eocene to early Miocene in age.

On Vancouver Island the Metchosin volcanics, possibly 7,500 feet thick, are unconformably overlain by mid-Tertiary sandstone and conglomerate of the Sooke formation. The unconformity, which may correspond to an erosion interval between the Burrard and Kitsilano formations, is marked by gabbroic intrusions.

The Skonum formation of Queen Charlotte Islands consists of 1,000 feet or more of semi-consolidated, partly marine, clastic beds, with prominent lignite bands. Fossil shells indicate a Miocene or Pliocene age. The beds are folded and intruded by andesite, and are probably overlain by the basaltic lavas and agglomerates of the Masset formation.

Quaternary. During Pleistocene time probably the whole of the southern Canadian Cordillera was covered by ice, and the record is mainly one of erosion. However, deposition prevailed a short distance south of the International Boundary, and influenced the valley forms and drainage in the southern interior. Pleistocene and younger deposits are prominent near Vancouver and in scattered areas elsewhere, and are described in the chapter on Pleistocene geology.

Intermittent vulcanism of the Tertiary persisted on a small scale until recent times. For example, on islands in Mathieson Channel stratified tuffs and flows up to 1,000 feet thick rest on glaciated rocks and till. Other recent deposits include lavas near Squamish and on North Thompson River, and ash-beds in the Bridge River area.

Intrusive Rocks

Intrusive rocks make up a large part of the outcrop area of the southwestern Cordillera, with the exception of the central part of the Interior Plateau and the mountains to the east. Only the larger individual bodies are shown on the geological map of Canada (Map 1045A). In general, intrusive rocks appear most abundant where most detailed mapping has been done, but the area mapped as Coast Range intrusions includes a considerable proportion of metamorphosed septa, roof pendants, and larger remnants of metamorphosed sedimentary and volcanic rocks. Much granitic gneiss is included in the Shuswap terrain and Wolverine complex, mapped as the lower unit of the late Proterozoic.

Four ages of intrusion are inferred from more or less definite non-conformities and from major gaps in the stratigraphic sequence. They are: post-Lower Cambrian, pre-Carboniferous; post-Permian, pre-Upper Triassic; post-Triassic, pre-Tertiary; Tertiary. Some details regarding stratigraphic relationships are given in the foregoing section.

Not included in these are the Purcell dioritic intrusions, of indefinite (Precambrian?) age, or hypothetical intrusions from which feldspar pebbles in the Proterozoic Toby formation may have been derived. The pre-Permian igneous rocks of the Shuswap terrain may conceivably be Precambrian but may belong with the post-Cambrian, pre-Carboniferous group, to which the Prosperine intrusions and those of the Wolverine complex are assigned. The Shuswap igneous rocks include dykes of granite, pegmatite, aplite, and serpentinized peridotite, and probably large areas of granitic gneiss. The Prosperine sills and dykes of quartz porphyry, felsite, and aplite in the Cariboo district are dated mainly on negative evidence. The igneous rocks of the Wolverine complex, near Fort St. James, comprise granodiorite, granite, pegmatite, and granitic gneiss.

A post-Permian, pre-Upper Triassic age of local intrusion is suggested for the Trembleur ultramafic rocks near Pinchi Lake.

The ultramafic rocks of Shulaps Range near Bralorne are late Triassic or early Jurassic. The Guichon granite batholith near Ashcroft and the Topley granite and granodiorite bodies of the Nechako River and Fort St. James areas are early

Jurassic. As these do not correspond to major gaps in the general stratigraphic record, they may be broadly considered as early phases of the Coast Range intrusions. In northern Vancouver Island the intrusions may be as old as mid-Jurassic, and on Queen Charlotte Islands they are late Jurassic or early Lower Cretaceous. In the Hope and Ashcroft areas both Upper Jurassic and Lower Cretaceous intrusions are known. Elsewhere on the east flank of the Coast Mountains the intrusions cut Lower and possibly early Upper Cretaceous strata. Farther east the Omineca batholith and related intrusions in the north are Lower or mid-Cretaceous, and the Nelson batholith and other bodies in the south are probably of about the same age. This Jura-Cretaceous intrusive period ranks as a major revolution throughout the North American Cordillera, and it is to this that by far the greatest part of the intrusive rocks in the region have been referred. The Tertiary intrusions and various ultrabasic rocks are discussed below.

The main zone of multiple intrusions known as the Coast Range batholith is a complex of many phases and of numerous successive irruptions, the younger of which show sharp intrusive contacts with the older. The phases vary from granite to gabbro, but granodiorite and quartz-diorite predominate. In general, the various lithological phases tend to occupy elongated areas whose long axes are parallel with the axis of the range and with the strike of bedded rocks in inclusions, septa, and other remnants. Some leucocratic granite bodies are comparatively irregular in outline and are thought to be considerably younger than the normal, more dioritic phases. Classification of the intrusive rocks, partly according to type and content of mafic minerals, facilitates the mapping of various phases. The rocks are commonly massive and uncrushed and well developed gneissic textures are not common.

The Omineca batholith in the north and the Nelson in the south appear to be connected with the Coast Range intrusions by belts in which similar intrusions are abundant. The Omineca batholith is mainly granodiorite, but grades from granite to gabbro. Various phases and separate intrusions differ in composition and probably in age. The main bodies are elongated in a northwesterly direction and are mostly massive. The Nelson batholith and related intrusions lying east and west of it are likewise composite in nature, but are chiefly granodiorite and granite, with dioritic phases common in border zones and minor satellites. In the main area of the Nelson batholith, porphyritic and non-porphyritic phases of both granite and granodiorite grade into one another. Pegmatite-rich gneissic patches are common along the northern and western borders, near the mapped contact with the Shuswap terrain. In places they contain numerous inclusions of metamorphosed bedded rocks that are less steeply tilted or closely folded than the bedded rocks outside the batholithic area. The trend of the eastern contact is arcuate, conforming in general with the strike of intruded formations. In places, however, contacts cut sharply across fold structures, and a few bodies appear to have been localized by faults.

Intrusive bodies of more or less definite Tertiary age include numerous dykes and stocks, and a few small batholiths. A few intrude late Cretaceous or early Tertiary bedded rocks that overlie pre-Tertiary intrusions; others closely resemble, and are presumably related to Tertiary lavas; and still others cut pre-Tertiary granitic rocks. These young intrusions include granite, syenite, monzonite, gabbro, and other rock types. Many are distinctly alkaline, and porphyritic textures are common. Intrusions of this description are especially numerous in southeastern British Columbia, where they include the Coryell batholith west of Rossland, the Kuskanax at Upper Arrow Lake, and various syenite and monzonite bodies of the Nelson, Kettle River, and Okanagan areas. Others occur in the Princeton and Nicola areas, in southern Vancouver Island, and in the northeastern areas where they include the Kastberg porphyries. The Ice River alkaline complex, the only important intrusion of the southeastern Cordillera, almost certainly belongs with this Tertiary group.

Ultramafic rocks such as peridotite, pyroxenite, dunite, serpentine, and related gabbro, are prominent in the Fort St. James, McConnell Creek, and Aiken Lake areas of the north, and in the Bridge River, Hope, Princeton, and other areas of the southern interior. They outcrop in long narrow belts, also as stocks and irregular bodies as much as 100 square miles in area. No commercial asbestos or important chromite bodies are known, but local ultramafic rocks are considered the source of placer platinum in the Tulameen (Princeton) area. The ultramafic rocks have commonly been considered to be early phases of the Mesozoic intrusions and to be of Jurassic to Cretaceous age. However, the Trembleur intrusions of northeastern areas are referred to a pre-Upper Triassic interval, and the Shulaps Range intrusions, to a late Triassic or early Jurassic period. Both are spatially related to prominent fault zones.

Structure

The structure of the southwestern Cordillera is extremely complex, and few generalizations can be made. In those few places where old rocks outcrop and are identifiable, several ages of deformation are inferred from the contact relationships of the various stratigraphic units. In a few of these places, remnants of pre-Mesozoic structures have been recognized. For the most part, however, any older structures have been overwhelmed by those resulting from the late Mesozoic orogeny. Early Tertiary disturbance, which played the dominant role in forming the Rocky Mountains, apparently resulted in relatively minor deformation in the southwestern Cordillera, and by mid-Tertiary time such activity had practically ceased.

Mainly as a result of the late Mesozoic orogeny, the pre-Tertiary bedded rocks now lie in generally northwesterly trending folds on the flanks of major intrusive bodies. These folds and accompanying longitudinal faults outline subparallel belts, along which stratigraphic units can be traced for considerable distances. However, the belts are cut by numerous lesser intrusive bodies and transverse faults and, in some areas, the terrain has been broken into separate blocks with unrelated structures. As a general rule, formations near major batholiths are more intensely deformed than those farther away. Only a few outstanding features will be described. These are shown in Figure 62 and are referred to by corresponding numbers in the following descriptions.

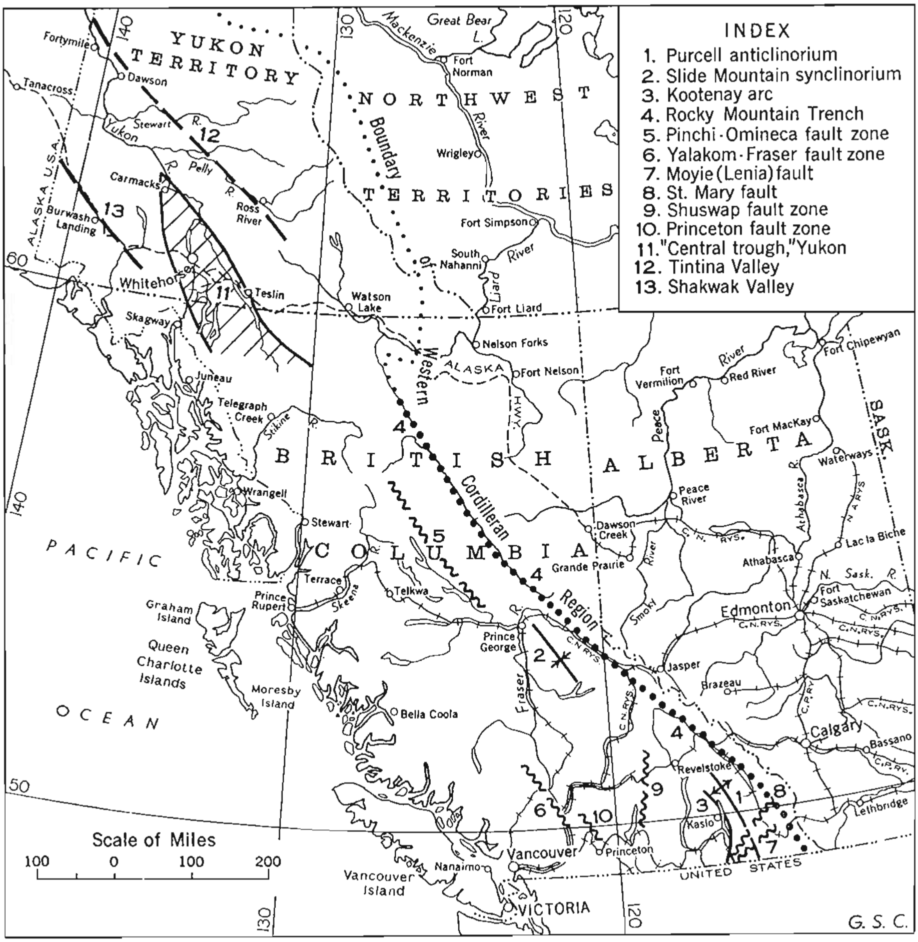


FIGURE 62. Structural features of the western Cordillera.

The regional anticlinorium (1) that controls the outcrop pattern of the southern Purcell Mountains is not recognizable beyond latitude 51 degrees. Northeast of Revelstoke one or more adjacent northwesterly trending synclines enclose the youngest formations. In the Cariboo district a northwesterly plunging synclinorium (2) encloses the upper Palæozoic Slide Mountain series, and is flanked on the west by an anticlinal arch of intricately folded strata of the Cariboo group. The trend of formational contacts and structures east of the Nelson batholith is distinctly arcuate (3), swinging from east of north at the 49th Parallel to west of north beyond latitude 50. The structures involve several tight to isoclinal folds, with axial planes commonly dipping east.

The Rocky Mountain Trench (4) is the outstanding topographic lineament in the Cordillera of British Columbia, although in the country between the big bend of the Fraser River and latitude 55 degrees it is not sharply defined. Throughout most of its length it forms the approximate boundary between intensely deformed, altered, and intruded rocks characteristic of the western Cordillera, and the moderately deformed and comparatively unmetamorphosed strata that typify the eastern Cordillera. However, the trench does not everywhere coincide with this geological boundary; in several places it obliquely transects structures on both sides and, south of about latitude 50 degrees, the geological boundary lies east of the trench. North of this latitude the trench is known in several places to be the locus of extensive faulting and may have been an active feature since the oldest Cordilleran disturbances. From latitude 50° to latitude 51°30′ or beyond, several longitudinal faults pass into the trench at small angles. Westerly dipping thrust faults cut the rocks of the Dogtooth Mountains into slices, and such a fault or fault zone is assumed to underlie the floor of the trench for many miles. Easterly dipping faults east of this part of the trench have been interpreted as underthrusts. Some long straight steep faults, such as the Redwall, may be dominantly strike-slip faults. North of Finlay Forks, rocks of the Sifton formation that floor the trench have been tilted and cut into long narrow slices by closely spaced faults that strike parallel with the trench. The fault slices transect, at a small angle, the strike of the Sifton strata and that of structures immediately east of the trench.

The Pinchi-Omineca fault zone (5) has been traced for more than 200 miles and is 10 miles or more wide in places. It is believed to represent a zone of major thrust faulting from the west. Other parallel faults have been mapped between this zone and the Rocky Mountain Trench. Another major fault zone (6) extends along Yalakom River for at least 40 miles northwest of Lillooet and is probably coextensive with a fault zone that follows Fraser Valley at least as far south as latitude 50. The Yalakom zone as a whole brings older rocks on the west into contact with younger rocks on the east, but the dips of observed fault planes are steep.

The most prominent transverse faults so far recognized are the Moyie (Lenia) and St. Mary faults of the southern Purcell Mountains area. The Moyie fault (7) follows a north to northwesterly course from Troy, Montana, to the Canadian boundary at Kingsgate, where it swings to a northeasterly course across the Purcell Mountains, and probably extends into the Rocky Mountains. The St. Mary fault (8) is a few miles north of, and approximately parallel with, the Moyie. It swings from a northwesterly course to cross the south end of Kootenay Lake, thence runs northeast and east and probably enters the Rocky Mountains east of Kimberley. These are steep faults on which the northwest side has moved relatively upward.

Northwestern Cordillera

Towards latitude 60 degrees the Rocky Mountain Trench loses its identity as a major geological boundary separating the western Cordilleran province from the eastern. Hence the boundary of the western Cordillera, as more or less arbitrarily defined, swings northeastward from the vicinity of Lower Post to enclose mapped areas of intrusive and Proterozoic rocks south of latitude 65.

An outstanding feature of the northwestern Cordillera is a tapering geosyncline or trough of folded upper Palæozoic and Mesozoic rocks whose apex lies northwest of Carmacks, Yukon Territory, and which extends southeastward into northern British Columbia. It is called the "Central trough" (Figure 62). Proterozoic rocks of the Yukon group delimit the northern part of the trough. Farther south the bordering rocks have been in large part overwhelmed by granitic intrusions of the Coast Range, Cassiar, and other batholiths. On the east stratified rocks are known to range from Cambrian to Mississippian in age. West of the trough their age is mainly unknown but the underlying metamorphic assemblages include Mississippian strata near the lower part of Stikine River.

In Yukon west of Shakwak Valley and the main zone of Coast Range intrusions, strata of early and late Palæozoic and Mesozoic ages are present although definite Carboniferous and Jurassic rocks are not abundantly represented.

Intrusive rocks of the northwest Cordillera include large bodies of ultramafic rocks as well as granitic and intermediate types. Undeformed Tertiary and more recent volcanic rocks cover broad areas especially in north-central British Columbia.

The various formations are shown in Table XXI (in pocket) and are described below.

Precambrian

In the northwestern Cordillera the Precambrian is represented mainly by the Yukon group, which consists for the most part of metamorphic rocks of sedimentary, volcanic, and uncertain origin and includes rocks of unproven but probably of later age.

The rocks of the Yukon group form a broad platform underlying the main part of the Yukon Plateau. Rocks correlated with them extend southward and southeastward, on both sides of the central late Palæozoic-Mesozoic trough, to about latitude 59 degrees, forming parts of the Coast, Cassiar, and Logan Mountains. In the plateau the Yukon group is separable into two divisions by a boundary approximately along Tintina Valley (Figure 62). To the southwest of the valley the degree of metamorphism is commonly higher than to the northeast and the rocks resemble some of those of the Shuswap terrain. In the Klondike district the name "Nasina series" has been used for a thick section of coarse schist, quartzite, and paragneiss, intermingled in the upper part with limestone, phyllite, and slate, possibly of Palæozoic age. The lower part of this section is continuous with Precambrian rocks in Alaska. These rocks are accompanied by bodies of deformed intrusive rocks, now altered to sericite and chlorite schists, called the "Klondike Schist", and by granite gneiss, the "Pelly gneiss", which though younger than the Yukon group strata, are of uncertain age.

Northeast of Tintina Valley quartzitic sedimentary rocks are prominent and a lower degree of metamorphism is apparent. In the Mayo area the group consists of several tens of thousands of feet of strata in which no stratigraphic break has been found. The lower part of the section contains distinctive massive blue-grey quartzites interbedded with phyllitic quartzite, graphitic phyllite, quartz-mica and chlorite schists, and pods of limestone along some horizons. The upper part consists largely of pebbly quartzite and schist, with slate and some limestone. These rocks are followed in different places by different unfossiliferous formations, variously dated as Ordovician (?) or older, Palæozoic (?), and pre-Mississippian.

North of the Yukon River at the Yukon-Alaska boundary the Tindir group, consisting of several thousand feet of quartzite, dolomite, phyllite, slate, and greenstone, is overlain unconformably by middle and upper Cambrian strata and has been assigned a Precambrian or early Cambrian age.

Elsewhere in Yukon and northern British Columbia the rocks referred to or correlated with the Yukon group represent the most highly metamorphosed and, presumably, oldest rocks in the particular districts. Since accumulating data show or suggest that in many places Palæozoic strata are included, the Yukon group is at present generally assigned to a Precambrian and Palæozoic age.

In the McDame area in northern British Columbia several thousand feet of strata of the Atan group lie in apparently unbroken succession below fossiliferous Lower Cambrian horizons. Highly metamorphosed rocks of the Horseranch group are considered to be in part equivalent to the Atan. Scattered occurrences of Lower Cambrian formations farther northwest suggest that Precambrian strata may outcrop in those areas also.

Palæozoic

Lower Palæozoic. Cambrian to Mississippian sedimentary rocks, with relatively minor volcanic rocks in restricted areas, underlie the greater part of the region northeast of the central geosynclinal trough. Unconformities have been noted at several horizons in various partial sections but in much of this vast, only partly explored territory, the stratigraphy is very incompletely known.

Along the Yukon-Alaska boundary north of the Yukon River, Middle and Upper Cambrian, Ordovician, Silurian, and Devonian strata are represented in a thick conformable succession that lies unconformably on the Cambrian or earlier Tindir group.

In the McDame area, southwest of Lower Post, the Atan group comprises some 14,000 feet of white and pink quartzite, limestone, and argillaceous rocks and carries Lower and Middle Cambrian fossils. Ordovician, Silurian, and Devonian horizons are represented in the Walker, Sandpile, and Hidden Valley groups, totalling more than 4,500 feet of calcareous and dolomitic, argillaceous, and quartzitic rocks, with chert fairly prominent in the Ordovician or early Silurian. The Sylvester group, post-middle Devonian, pre-Upper Mississippian in age, comprises some 18,000 feet of strata, including much intermediate lava, pyroclastic rocks, greywacke, and ribbon chert. This is overlain unconformably by the Nizi formation, Upper Mississippian and possibly later in age, which consists of about 2,000 feet of limestone, chert-conglomerate, and chert. Farther east the Sylvester volcanic rocks are absent, and strata equivalent to the Nizi unconformably overlie older rocks.

These strata extend northwest into the Wolf Lake area in Yukon Territory and similar Cambrian and Devonian strata occur in fault slices west of the main body of the Cassiar batholith. The greater part of the southwestern Wolf Lake and northeastern Teslin map-areas, however, is underlain by Mississippian limestone, argillite, quartzite, arkose, chert conglomerate, and chert, which lie with apparent structural conformity on a metamorphosed assemblage of schist, quartzite, gneiss, limestone, and greenstone, of uncertain but presumably greater age. Much of the greenstone is presumably equivalent to the Sylvester group. Fossils of probable Mississippian age have been found in a belt of relatively unmetamorphosed rocks that crosses the Canol road southeast of Ross River, and Lower Cambrian has been identified to the southeast within the Quiet Lake map-area. Mississippian limestone is associated with abundant chert-conglomerate and chert in the northeastern part of the Glenlyon area and these rocks extend into the southern part of the Mayo map-area.

On Upper Beaver River northeast of Keno Hill, Ordovician, Silurian, and Devonian sedimentary strata are believed to lie unconformably on an older assemblage that includes a conspicuous massive body of rusty weathering dolomite. Southeastward to the Logan Mountains the bedded rocks, as indicated by scattered exploratory traverses, are mainly of these Palæozoic ages. Silurian or Devonian strata unconformably overlie Cambrian or older beds near the upper part of Bonnet Plume River and succeeding rocks include algal limestone and a little iron-formation. On Upper Pelly and Ross Rivers, near the route of the Canol road, coarse grits and red and green slates are conspicuous below Ordovician black slate associated with a thick section of bedded varicoloured cherts. Chert-conglomerate that probably overlies this horizon is ferruginous and carries some thin limonite beds. A similar assemblage in Logan Mountains carries mid-Upper Cambrian and Lower Ordovician fauna, and Devonian strata occur to the southwest in the Hyland Plateau.

Southwest of the central trough the metamorphic rocks lying within the main belt of Coast Range intrusions are mostly of unknown age, but some in the Stikine, Taku Rivers, and southwest Atlin map-areas lie unconformably below Permian strata. In the Stikine area the pre-Permian assemblage carries probably Mississippian fossils in its upper part.

Southwest of Shakwak Valley (Figure 62) stratified rocks of Devonian and perhaps other ages are overlain, in places with definite unconformity, by Pennsylvanian or Permian strata. Devonian limestone and marble, associated with slate, schist, greywacke, and tuff, is widely exposed in the southwest Kluane and Kaskawulsh areas, and possibly occurs in the Dezadeash area. Both Silurian and Mississippian strata may also be present in the vicinity of Sheep Creek.

Upper Palæozoic. Permian and possibly Pennsylvanian strata form the upper part of an undifferentiated Palæozoic assemblage in some places but, in a significant number, they unconformably overlie rocks up to probably Mississippian in age.

Permian and possibly Pennsylvanian rocks occupy the mapped Palæozoic area between Teslin and Tagish Lakes and extend southeastward to the vicinity of Dease Lake, forming the core of the central geosynclinal trough. Their northwestern extension beneath Mesozoic strata is suggested by an isolated occurrence in northern Laberge map-area, but Mesozoic rocks are in contact with supposed pre-Permian rocks east of Teslin River and may overlap the Permian depositional boundary in that direction.

The assemblage of Permian and possibly Pennsylvanian rocks consists of a great but unknown thickness of limestone, bedded and "ribbon" chert, argillite, siltstone, sandstone, and quartzite, with greenstone prominent in some areas and greywacke, consisting largely of volcanic detritus, in others. The limestone is characteristically foraminiferal and the whole assemblage is very similar to the Cache Creek group of the southwestern Cordillera.

In the Tuya-Teslin area the Permian has been subdivided into the Kedahda and Teslin formations. In the Dease Lake area Permian limestone, associated with cherty quartzite and black slate, forms the top of the Dease series, otherwise undifferentiated.

In the Coast Mountains on Stikine River, 2,000 feet or more of Permian limestone unconformably overlie Mississippian strata. A thick limestone band in the Taku River area is correlated with this, and in the Atlin map-area a basal Permian or Pennsylvanian conglomerate contains detritus of quartz monzonite similar to nearby intrusions.

West of Shakwak Valley the upper Palæozoic is present in the White River, Kluane, Kaskawulsh, and Squaw Creek map-areas and probably is present in the Dezadeash map-area. In the Kluane area the Permian contains volcanic rocks and conglomerate in its lower part, with chert, limestone, and greywacke in its upper. The conglomerate contains boulders of gabbro at one locality and nearby, on Steele Creek, Permian strata lie unconformably on gabbro that intrudes Devonian rocks.

Thus an interval of widespread crustal disturbance, accompanied by local intrusive activity is indicated in pre-Permian, possibly late or post-Mississippian time. The apparent absence of Permian or Pennsylvanian strata east of Teslin Valley suggests that uplift of that area may have occurred during the same interval.

Mesozoic

Upper Triassic, Jurassic, and Lower Cretaceous sedimentary rocks, interbedded with volcanic rocks ranging in age from pre-Upper Triassic to post-Lower Cretaceous, make up a stratified sequence that is interrupted by several unconformities related to early phases of Mesozoic orogeny and intrusion. The marine geosynclinal conditions of the late Palæozoic persisted into Mesozoic time but apparently not continuously because, as in the southwestern Cordillera, specific Lower and Middle Triassic rocks are unknown. Furthermore, unconformable relations between known Permian and Upper Triassic in some areas suggest a major depositional break and probably crustal disturbance in this interval. An increasingly continental environment of sedimentation prevailed in Jurassic to Lower Cretaceous time. Mountain-building and granitic intrusion reached a climax in Middle or Upper Cretaceous time, and general uplift accompanying this event finally put an end to marine sedimentation within the region. Upper Cretaceous or Paleocene continental deposits are mainly undeformed, and overlie all older rocks, including the great Mesozoic intrusions, with major discordance.

Triassic. In the central geosynclinal trough the Triassic is represented in the Laberge and Whitehorse areas by the Lewes River group, which comprises more than 8,000 feet of volcanic and sedimentary rocks. Clastic sedimentary rocks include greywacke, siltstone, and argillite. Limestone occurs at several horizons and one band near the top of the section attains a thickness of 1,800 feet along the Lewis-Yukon River Valley. West of Whitehorse, interbedded andesite and basaltic lavas and pyroclastic rocks are abundant, and volcanic and clastic rocks in the Teslin area may be in large part contemporaneous. Farther southeast, in the Tuya-Teslin area, limestone is present in the Lower Mesozoic Nazcha formation. In the Dease Lake area, Upper Triassic limestone is associated with conglomerate and serpentine in the Thibert series.

East of the Coast Mountains in Lower Stikine and Taku Rivers, Triassic volcanic rocks lie unconformably on Permian and pre-Permian rocks and are overlain by clastic rocks and limestone. The limestone, in a band 1,000 feet or more thick, carries diagnostic Upper Triassic fossils. One or more unconformities are postulated within the system, which, in the Taku area, is subdivided into the King Salmon, Stuhini, and Honakta groups.

In the Kluane Lake area of Yukon, west of Shakwak Valley, an Upper Triassic sequence of limestone and limy argillite is infolded with Permian strata. Farther southeast the Mush Lake group of the Dezadeash map-area and an unnamed assemblage in the Squaw Creek area consist mainly of andesitic volcanic rocks with locally as much as 3,000 feet of limestone and argillite. They lie unconformably below lower Cretaceous beds and are thought to be at least partly of Triassic age.

Upper Triassic limestone and argillite occur in an infold or remnant near Upper Beaver River, northeast of Keno Hill, and may extend southeastward across Hess River. This, and possibly Triassic rocks in southwest Mayo area, suggest that late Triassic seas may have been rather extensive in that part of Yukon.

Jurassic. Jurassic clastic and associated volcanic rocks have been traced almost continuously from the northern part of the central trough to Taku River on the west and may be continuous with Jurassic strata in the Stikine and Lower Iskut River areas. On the east flank of the trough they occur intermittently at least as far south as Dease Lake and probably beyond.

In the Carmacks, Laberge, Whitehorse, Bennett, and Atlin areas clastic rocks form a thick section known as the Laberge group which contains Lower and early Middle Jurassic marine fossils. A nonmarine "upper part of the group" contains plant remains and coal seams in one locality in the Laberge area where it forms a continuous section with the Tantalus formation, chiefly continental, and of probably Lower Cretaceous age. No complete section is known; estimates of thickness range up to 10,000 feet.

The Laberge group consists chiefly of conglomerate, greywacke, arkose, sandstone, siltstone, and argillite. The conglomerate is especially coarse and abundant along the west flank of the Mesozoic trough, where it contains a large proportion of coarse granitic fragments. Conglomerate along the east flank in the Whitehorse and Teslin areas contains much fewer and finer granitic fragments and is characterized by black limestone in fragments ranging from large irregular blocks to sand-size grains, along with much greenstone and chert. The group overlies the Triassic Lewes River group conformably near the centre of the trough, but disconformably at its western and perhaps its eastern margin.

Volcanic rocks are abundantly and closely related to the Laberge group in many places. Some are thought to underlie, some to overlie the group, and some may be contemporaneous with it. They are chiefly andesite and dacite and have been given various names such as "Older Volcanics", and "Nordenskiöld".

In the Taku River area the Takwahoni group, containing upper Lower Jurassic fossils, appears to overlie the Upper Triassic Honakta group unconformably, and is unconformably overlain by the Sinwa and Yonakina formations of doubtfully Jurassic age. The Takwahoni consists of about 5,000 feet of conglomerate and finer clastic rocks with some limestone and dacite. The overlying Sinwa contains limestone and fine clastic rocks, and the succeeding Yonakina is composed chiefly of argillite, lava, and tuffs. The Lower Jurassic of the Lower Stikine area also consists of conglomerate and finer clastic and volcanic rocks unconformably overlying the upper Triassic. The overlying volcanic and sedimentary deposits include coaly beds and are of doubtful Jurassic age. Granitic fragments are common in the basal Lower Jurassic conglomerates of both areas.

In the Tuya-Teslin area, southeast of Teslin Lake, conglomerate of the Nazcha formation commonly contains limestone pebbles. That of the overlying Shonektaw formation, chiefly volcanic, carries altered diorite pebbles. Both formations are continuous with the McLeod series of the Dease Lake area, which is said to overlie the Upper Triassic limestone unconformably, and which consists largely of lavas and coarse clastic rocks.

West of Shakwak Valley, definitely Jurassic rocks are not known but part of the Mush Lake and other Mesozoic groups may be of this age, and upper Jurassic rocks may be present in Kluane Lake area.

Cretaceous. Lower Cretaceous nonmarine beds known as the Tantalus formation occur in scattered patches in the Carmacks, Laberge, and Whitehorse areas. They consist largely of chert-conglomerate with some sandstone, shale, and a few coal seams. They apparently overlie the upper part of the Laberge group conformably and are overlain with structural and erosional unconformity by Cretaceous volcanic rocks.

West of Shakwak Valley Lower Cretaceous strata, in part marine, are present in the Upper White River, Kaskawulsh, and Dezadeash map-areas, and also occur farther west in the high St. Elias Mountains. In the Dezadeash area they make up the Dezadeash group which overlies andesite of the Mush Lake group unconformably. The Dezadeash consists of about 12,000 feet of conglomerate and finer clastic rocks with some chert, tuff, and coal, and carries diagnostic marine Lower Cretaceous fauna.

Volcanic and clastic rocks of the Inklin group in the Taku River area are said to overlie the Jurassic Takwahoni group unconformably, and are of supposed Lower Cretaceous age.

Flat-lying or mildly-deformed volcanic rocks that overlie folded Jurassic and Lower Cretaceous strata with angular unconformity but are cut by major Mesozoic intrusions, make up the Hutshi and Mount Nansen groups of the Carmacks, Laberge, and Whitehorse areas. They are typically greenish, purplish, or black andesites, basalts, and pyroclastic rocks, commonly porphyritic. Massive and resistant to erosion, they form the upper parts of many high hills. Similar rocks that overlie lower Cretaceous strata make up part of the "Older Volcanics" of the Upper White River district, and rocks probably correlative with them are rather widely distributed in southern Yukon and adjacent areas of British Columbia. Although confined on the east to the general area of the central trough, they apparently overlap the older Mesozoic rocks and have a considerably broader distribution.

The late Cretaceous was a time of major igneous intrusion. Post-intrusive rocks of definitely Cretaceous age are rare, but in the Stikine River area coarse clastic and volcanic rocks overlain by the Helveker lavas contain fossils identified as Upper Cretaceous. Similar rocks in the Taku River area, and the Sloko volcanic-clastic group of the Atlin map-area may be of this age.

Cenozoic

Tertiary. Paleocene and Eocene continental sedimentary deposits occur in many parts of the region. These and early Tertiary volcanic rocks which are locally tilted but otherwise undeformed, overlie the major intrusions and all older rocks with pronounced angular unconformity, and are cut by a variety of minor intrusions. Younger volcanic rocks, chiefly basaltic lavas, overspread large areas in late Tertiary time and intermittent vulcanism has continued into recent times, especially in the St. Elias Mountains. Some superficial deposits, including placer gravels, may be of late Tertiary age.

The early Tertiary sedimentary deposits are composed chiefly of partly consolidated conglomerate, sandstone, shale, and tuff, with plant remains and seams of lignite. The larger areas of these rocks occur in the great valleys: the Tintina and Liard Valleys, the Rocky Mountain Trench, and the "Duke Depression", which lies between Kluane ranges and the main St. Elias Mountains. These valleys existed in Tertiary time and the rocks were apparently deposited in them and filled depressions elsewhere in a land surface whose relief was comparable to that of the present. Early fossil collections in the Tintina Valley and Upper White River areas were dated as Eocene; later collections from various areas have been classed as Paleocene. These beds are commonly overlain by early Tertiary lavas and, with them, are locally tilted and faulted and cut by minor intrusions. They occur prominently in the Sixtymile, Ogilvie, and Carmacks areas, and west of Shakwak Valley in the White River, Kluane, Dezadeash, and Squaw Creek areas. Coal seams of fairly substantial thickness are found in the Kluane area. Eocene flora have been reported from clastic beds associated with volcanic rocks in the Stikine area, and the Sloko group of the Atlin area may also be of early Tertiary age.

Paleocene to Miocene volcanic rocks are relatively widespread in southwest Yukon but are particularly abundant in a broad belt extending northwest from the vicinity of Carmacks to the Alaska boundary and are known as the "Carmacks Volcanics" and "Newer Volcanics". They are also prominent along the west of the Duke Depression, southwest of Shakwak Valley. In all areas they overlie early Tertiary clastic rocks conformably wherever these are present, and elsewhere lie directly on an erosion surface of still older rocks. They are locally tilted and faulted, cut by Tertiary intrusions, and truncated by the Miocene (?) upland erosion surface. The lavas are chiefly andesite and basalt but include trachyte, rhyolite, and interbeds of pyroclastic rocks. Their original thickness is unknown but locally as much as 5,000 feet of strata still remain. Equivalent volcanic rocks are called the Skukum group in the Whitehorse area, are present in the Lower Stikine area, and probably occur in the Bennett and Atlin areas of northern British Columbia.

Minor intrusions that in places cut early Tertiary sedimentary and volcanic rocks are widely distributed throughout southwestern Yukon and northwestern British Columbia. They are characteristically acid and include quartz and feldspar porphyries, drusy granites and syenites, and fine-grained rhyolitic rocks. In part they may be contemporaneous with acid lavas of the Carmacks group and "Newer Volcanics". In general they are likewise truncated by the old plateau surfaces but in places may have been extruded upon the present land surface.

Basalts and andesites that flowed down present valleys and old channels make up the Selkirk group of the Carmacks, Ogilvie, and McQueston areas. They overlie some old gravels. Some of the youngest flows and the vents from which they were extruded, such as Volcano Mountain north of Selkirk, are evidently very recent. The oldest flows, however, caused major diversions of the Yukon and Pelly Rivers, and valley lavas in places are glacier-scoured and overlain by till. Valley basalts also form Miles Canyon near Whitehorse, and occur in the Wolf Lake area. In northern British Columbia the Tuya formation, chiefly basalt, forms an extensive constructional surface of flat-lying volcanic rocks surmounted by volcanic cones. It is in large part preglacial but the youngest lavas and cones, like those of the Lower Stikine and Iskut Rivers farther south, are thought to be of very recent origin.

Surficial deposits possibly as old as late Tertiary include the auriferous "White Channel" gravels of the Klondike and some rusty pay gravels on deeply weathered bedrock in glaciated areas.

Quaternary. At one or more times during the Pleistocene most of the northwestern Cordillera was covered by ice and subject to erosion, but a large area in the Yukon Plateau was unglaciated. This condition permitted the general preservation of old gold-bearing stream deposits of the Klondike, such as the "White Channel" gravels. Some old gravels lie disconformably over White Channel gravels. Among other valley deposits of the unglaciated area is a black muck, composed chiefly of vegetable matter, and permanently frozen to within a few inches of the surface.

Large parts of the St. Elias and northern Coast Mountains are still covered by great snowfields and glaciers, but elsewhere alpine glaciers that slightly modified the upland surfaces have now mostly disappeared. Glacial deposits include boulder clay and till containing decomposed rock fragments. Fluvioglacial and alluvial silt, sand, and gravel floor most of the large valleys to great depths, and remnants of similar deposits occur high on upland surfaces.

Evidence of widespread recent vulcanism is found in the many little-modified cones, crater remnants, and scoria deposits of northern British Columbia and the Yukon Plateau. White volcanic ash that lies near the topsoil in many southwestern areas and reaches more than 100 feet in thickness in St. Elias Mountains is evidently the product of one of the latest great eruptions in that area.

Intrusive Rocks

As in the southwestern Cordillera, intrusive rocks are widespread and are believed to be mainly of late Mesozoic age, but there is evidence of intrusion also in Palæozoic, Permo-Triassic (?), pre-Jurassic, and Tertiary times.

Included in the "Palæozoic" classification are large bodies of granitic gneiss known as "Klondike Gneiss", and of sericite and chlorite schist and amphibolite of presumed igneous origin called "Klondike Schist". These cut the Yukon group, including those members of suspected Palæozoic age. Pre-Permian gabbro on Steele Creek west of Shakwak Valley cuts Devonian strata, and quartz-monzonite in the Atlin map-area is believed to have been a source of detritus contained in Pennsylvanian or Permian conglomerate. Large fresh feldspar crystals in arkose of probable Mississippian age in the Teslin area suggest the presence of exposed granitic bodies nearby at that time. Ultramafic rocks, described below, may be in part of Permian or Triassic age, but some are younger. Pre-Jurassic intrusions, probably in the area now occupied by the Coast Range Intrusions, supplied the abundant coarse granitic detritus of the western band of Laberge group conglomerate.

Most of the large granitic bodies of the region, including the Coast Range and Cassiar batholiths, are massive and only locally deformed, and, though heterogeneous, are very similar to one another in overall character. In many places along the flanks of the Coast Mountains, also west of Shakwak Valley and in interior areas, such rocks intrude strata up to early Cretaceous in age. In a few of those places they are overlain unconformably by deposits of early Tertiary age. These intrusions are therefore considered to be mainly of late Mesozoic age, although lithological variations in part represent successive phases of a prolonged period of batholithic invasion.

The northern Coast Range batholith lies mainly within the Alaska panhandle but extends into far northern British Columbia and southern Yukon northeast of Shakwak Valley. The Cassiar batholith farther east extends from British Columbia into Yukon. Intrusive rocks outcrop almost continuously to form a connecting link across far northern British Columbia. Between latitudes 60 and 61 degrees both batholiths lose their identities in breaking up into discrete bodies separated by large areas of bedded rocks. Elsewhere in Yukon only a few local names are applied to intrusive masses.

These Mesozoic intrusions, like those of the southwestern Cordillera, vary widely in composition. Granodiorite and quartz-monzonite are probably the most abundant types, grading into quartz-diorite, diorite, and locally gabbro on the one hand, and into granite and even syenite and other alkaline varieties on the other. Diorite and gabbro rarely form extensive bodies but occur commonly in small satellites and border zones of large batholithic masses. In such border zones they are generally cut by granite and other acid facies characteristic of the interior parts of these masses, and these basic intrusions are believed to be among the oldest products of Mesozoic igneous activity. In several areas they show evidence of derivation from assimilated basic volcanic rocks. In most areas granite forms less extensive and less homogeneous masses than granodiorite. It commonly shows both gradational and intrusive relationships with more basic phases. Smoky quartz is a characteristic constituent in much of southern Yukon. Some late granite, in both the Coast Range and Cassiar intrusions, is locally miariolitic. Fluorite occurs in drusy cavities, and quartz-tourmaline concentrations are present in some of the Cassiar granite. Syenite and allied rocks are especially prominent in the Carmacks and McQueston areas. They are commonly porphyritic, in places gneissic, and are both cut by, and grade into, granite.

Although mainly massive and undeformed, the Mesozoic intrusions, especially granodiorites, are gneissic in places near concordant contacts with stratified rocks in the Coast Mountains and elsewhere, and the northern Cassiar batholith is sheared for 4 miles from its western border.

The ultramafic rocks, peridotite, pyroxenite, dunite, and serpentine occur as tabular or lenticular bodies and small stocks scattered through a belt up to 100 miles wide that extends from Dawson City to beyond Dease Lake. Another much narrower belt lies mainly west of Shakwak Valley. Ultramafic rocks are especially abundant in northern British Columbia, and in adjoining areas of Yukon. In northern British Columbia some bodies are 40 miles or more in length and several miles wide. They intrude rocks of various types and ages. Most are closely associated with volcanic greenstones. Those of the Dease Lake area are thought to be genetically related to Triassic, and those of the Atlin area, to Permian greenstone. In the Teslin and Whitehorse areas, however, some ultramafic bodies apparently intrude Triassic and Jurassic rocks. In the Teslin area some of these are of fairly fresh and unsheared peridotite. Sheared peridotite intrudes Lower Cretaceous strata in the Dezadeash area. All varieties are cut by late Mesozoic granitic rocks in many places, and none is known to be younger. High grade chrysotile asbestos is being mined from ultramafic rocks in the McDame area but no other commercial deposits are yet in sight. Nickeliferous deposits occur in peridotite in the Kluane area. Some small chromite concentrations are known. Placer deposits near some bodies in the Dezadeash area contain a little platinum.

Dykes, stocks, and other minor intrusive bodies of more or less definite Tertiary age are widely distributed in Yukon from the Alaska boundary eastward to the Mayo area and southward to the Atlin area in British Columbia. As in the southwestern Cordillera they are mainly acid or alkaline rocks such as quartz-porphyry, granite porphyry, granite, syenite, granophyre, and rhyolite, but include gabbro and diabase. Porphyritic and felsitic textures are common, and in some places these intrusions are identified with Tertiary acid volcanic rocks. They cut Paleocene-Eocene beds and overlying volcanic groups such as the Carmacks in many areas, but are older than the late "valley" lavas such as the Selkirk group of the Ogilvie, McQueston, and Carmacks areas.

Structure

The general remarks contained in the first two paragraphs under the heading "Structure" in the southwestern Cordillera apply also to the northwestern.

The central late Palæozoic trough of Yukon and northern British Columbia (Figure 62) has the overall characteristics of a synclinorium in its relationships to older rocks on the flanks, but may be in fault contact with them along a lineament east of Teslin Valley. Although the outcrop pattern of upper Palæozoic and Mesozoic rocks in the southern part is that of a north-plunging anticlinorium, the major factor delimiting the upper Palæozoic rocks on the north may be a north-easterly striking transverse fault.

Major fold structures with various trends in Yukon group rocks have been delineated in the Mayo and McQueston areas and in Big Salmon Mountains. Elsewhere most of the folds trend northwesterly, both in Mesozoic and older rocks. A major anticline is postulated southwest of Shakwak Valley in the Dezadeash area.

Tintina Valley is a remarkably straight through-going lineament that extends about 400 miles southeast from the point where the Yukon River crosses the Alaska boundary. It is not in alignment with the Rocky Mountain Trench and is not physically connected with it. Major faults mark the course of the valley near Ross River Post and in the Glenlyon and southwest Mayo areas, and major geological boundaries coincide with it in other places. Early Tertiary beds, only gently warped, outcrop at intervals along the valley floor, proving its early development as a physiographic feature.

Shakwak Valley, another long straight lineament, extends from the Alaska boundary southeast through Kluane Lake almost to latitude 60 degrees. Through most of its length it forms a major geological boundary and is believed to mark a great fault zone. Evidence of recent movement is found in unconsolidated deposits along the valley floor. Southwest of Shakwak Valley in the Kluane area, a zone of overthrust faults is believed to form, with the Shakwak Valley fault, a graben structure enclosing upper Palæozoic to Tertiary rocks.

A zone of faulting and shearing marks the southwest limit of the northern Cassiar batholith, and is probably coextensive with a similar zone in the Teslin area.

A northeasterly striking fault in the Coast Range intrusive belt southwest of Whitehorse has been traced for more than 20 miles.

Eastern Cordillera

In the eastern Cordillera the rocks are almost entirely of sedimentary origin. All periods of geological time are represented in a nearly conformable sequence that ranges from Proterozoic to Tertiary (Table XXII, in pocket). Rocks of the Proterozoic, Cambrian, Devonian, Mississippian, and Cretaceous periods attain greatest thickness and widest distribution. Igneous rocks occur in limited areas as sills, flows, dykes, and stocks.

Proterozoic

Proterozoic rocks underlie much of the southern and southwestern Rocky Mountains, extend along the Rocky Mountain Trench, are known in the central and northern Rocky Mountains, and locally in other mountain ranges in the northeastern Cordillera.

Proterozoic rocks in the Lewis and Clark Ranges near the International Boundary are known as the Lewis series. This series is 11,100 feet thick and comprises eight formations described in ascending order as follows. The basal Waterton formation includes 617 feet of bedded red, green, and grey dolomite, banded limestone and dolomite, and argillite. The Altyn formation, about 1,000 feet thick, consists of laminated dolomite and overlying massive sandy and gritty dolomite, algal beds, and black argillite. The Appekunny formation consists of green and red argillite and quartzite. Quartzites at the base of this formation coarsen to the northeast and are accompanied in that direction by a thinning of the formation from 1,625 to 1,100 feet and an increase in the amount of red argillite. The Grinnell formation consists of red argillite, quartzite, and conglomerate, and is 1,000 feet thick. The Siyeh formation of interbedded limestone, dolomite, green and grey argillite, and algal beds, is about 3,000 feet thick, and is overlain by an amygdaloidal basalt flow, 200 feet thick, formerly termed the Purcell lava. The Sheppard formation comprises 600 feet of dolomite and argillite. The Kintla formation, at the top of the series, consists of 800 feet of red argillite, quartzite, and siliceous limestone, overlain by 500 feet of green argillite, 1,000 feet of thick-bedded red quartzite and red argillite, and 600 feet of green and grey argillite with oolitic limestone beds. The Kintla is unconformably overlain by Middle Cambrian beds. Chitinous plates and algal beds are common in the predominantly carbonate formations of the Lewis series, those in the Waterton being the oldest forms of life known in the Cordilleran region. Sun-cracks and salt-crystal impressions are notably present in the shallow water beds.

In the Galton Range, west of the Lewis Range, the Proterozoic rocks are termed the Galton series, which is 12,460 feet thick. The Galton series comprises nine formations, described in ascending order as follows. The Altyn formation consists of 650 feet of thinly bedded siliceous dolomite. The Hefty formation comprises 775 feet of massive bedded reddish sandstone and thin red shale. The MacDonald formation is composed of 2,350 feet of green argillite with rare red argillite and quartzite, the upper and lower parts weathering buff and the middle part grey. The Wigwam formation, 1,200 feet thick, is mainly red sandstone with partings of red argillite. The Siyeh formation comprises 4,000 feet of massive limestone and dolomite with interbedded grey, green, and red argillite at the top and base. The Siyeh is overlain by a lava flow about 310 feet thick of amygdaloidal and brecciated basalt. The Gateway formation consists of dolomite and argillite overlain by green argillite and quartzite; the formation totals 2,025 feet in thickness and the basal beds are similar to strata of the Sheppard formation of the Lewis series. The Phillips formation comprises 550 feet of alternating thin beds of purplish to brownish red argillite and quartzite. The succeeding Roosville formation, at the top of the series, is composed of 600 feet of green argillite and thin beds of quartzite.

Proterozoic rocks of the Purcell system occur mainly in the western Cordillera but extend into the eastern Cordillera near Cranbrook. The Purcell system is comparable to the Lewis and Galton series but is thicker, reaching an aggregate of 45,000 feet. The widespread lava flow in the Siyeh and the thick carbonate bodies of the Siyeh, Altyn, and Waterton formations serve as a means of correlation of these thick unfossiliferous, Proterozoic successions. The Purcell is unconformably overlain by the Windermere system, of which the basal, Toby formation is a conglomerate, and the overlying Horsethief Creek formation is mainly slate, grit, and conglomerate. The Lower Cambrian, Cranbrook formation lies on the Horsethief Creek in and south of Stanford Range, but lies on the Toby and Upper Purcell strata in the Hughes Range farther southeast.

Rocks of Precambrian age occur above some of the larger thrusts of the central Rocky Mountains near Lake Louise and Jasper, and in lesser known regions along the east side of the Rocky Mountain Trench near Tête Jaune. Those near Lake Louise comprise the Corral Creek formation, composed of 1,320 feet of quartzite, sandstone, and shale, and the overlying Hector formation of 4,590 feet of grey, green, and purple slates with interbedded conglomerate. The Hector is unconformably overlain by Lower Cambrian *Olenellus*-bearing beds. At Jasper, the Jasper series consists of several thousand feet of slate, argillite, breccia, and conglomerate. West of Mount Robson over 2,000 feet of massive grey sandstone, grit, arkose, and conglomerate, with interbedded siliceous shale, slate, and schist form the Miette series. The Jasper and Miette series are overlain by quartzites assigned to the Lower Cambrian.

In northeastern British Columbia, in the vicinity of Finlay Forks at the headwaters of Peace River, the Misinchinka schists are the oldest rocks. They consist of pale, silvery, finely laminated mica schists. Northwest of Finlay Forks rocks resembling the Misinchinka schists occur on both sides of the Rocky Mountain Trench. They are mainly quartz-mica schists, quartzite, gneiss, and minor limestone. Along the Alaska Highway and Toad River unnamed metamorphosed quartzite, argillite, slate, and marble intruded by dykes of diabase and gabbro are reported. The metamorphic rocks of northeastern British Columbia are tentatively assigned to the Precambrian and are overlain by beds provisionally referred to the Cambrian which are, in turn, overlain by fossiliferous Silurian strata.

In southern Franklin Mountains near Wrigley 375 feet of dark grey shale underlie beds placed in the Lower Cambrian. In northeastern Mackenzie Mountains near Norman Wells 800 feet of white quartzite overlain by 150 feet of black shale underlie the Cambrian (?) Katherine group. In Richardson Mountains chloritic and sericitic schists, quartzite, and black argillite are the oldest rocks known, and underlie the Upper Cambrian. Along the boundary between Yukon and Alaska in northern Ogilvie Mountains and the Keele Range, the Tindir group consists of varicoloured slate, phyllite, quartzite and dolomite about 5,000 feet thick. It is pre-Middle Cambrian and probably Proterozoic in age. Quartzite, slate, shale, and limestone possibly ranging from Proterozoic to Ordovician in age underlie Old Crow Range and parts of the British Mountains. At the head of Blow River in the Arctic Plateau, Proterozoic (?) black, red and green argillite, slate, quartzite, and phyllite are unconformably overlain by Carboniferous (?) limestone.

Palæozoic

Cambrian. Sedimentary rocks of Cambrian age are almost as extensive as the eastern Cordilleran region itself, but fluctuations of the sea caused wide variations in the type and thickness of the sediments. The Cambrian succession is thickest and most complete in the central Rocky Mountains. It is thin in the south and but little known in the northern part of the eastern Cordillera. In general, the basal Palæozoic beds rest on an erosion surface, but in many places there is no marked unconformity with underlying Proterozoic strata and, where differences in lithology are not marked, the dividing line may be difficult to place. The upper limit of the system is commonly not marked by a definite lithological break and Ordovician, Silurian, or Devonian strata may overlie the Cambrian with apparently conformable and transitional contact.

The Lower Cambrian sea was restricted in size in the eastern Cordillera, although it penetrated into the western Cordillera. In the Clark Range near the International Boundary, the Lower Cambrian is absent and Middle Cambrian beds lie unconformably on the Proterozoic. In the southwestern ranges, the Lower Cambrian consists of the basal Cranbrook formation composed of up to 950 feet of conglomerate and quartzite overlain by 900 feet of shale, quartzite, and limestone. In the Upper Bow Valley the Lower Cambrian is divided into three formations, which, however, are not recognizable throughout the valley. The Fort Mountain formation at the base comprises about 1,000 feet of massive, purplish quartzite, arenaceous shale, and basal conglomerate. It is overlain by the Lake Louise formation of 105 feet of grey shale, which is followed by the St. Piran formation of about 500 feet of grey and pink quartzite and shale. At Mount Robson, the Lower Cambrian consists of 400 feet of unnamed quartzite overlain by the Mural formation composed of 1,000 feet of arenaceous limestone and shale, which is succeeded by the Mahto formation of 1,200 feet of quartzitic sandstone and shale.

Middle Cambrian strata are the most widespread of the period. In the Clark Range they are represented by a basal thin quartzite and an overlying green shale, totalling about 200 feet in thickness. At Elko the Burton formation consists of 77 feet of green shale, and thin limestone overlying the Proterozoic. In the upper Bow Valley, the Middle Cambrian formations, in ascending order, are: the Mount Whyte, 350 feet of limestone and shale; the Cathedral, 1,000 feet of massive dolomite and limestone; the Stephen, 450 feet of calcareous shale; and the Eldon, 1,100 feet of massive reefoid dolomite which grades into shale, limestone, and dolomite. In the Field area, the Middle Cambrian is reported to exhibit a major facies change. The dominantly carbonate formations grade westward through interbedded limestone and shale into the dominantly argillaceous facies of the Chancellor group. The line of facies change lies close to a thrust of unknown magnitude. The Chancellor group consists of 4,500 feet of shale and argillite with thin beds of limestone and dolomite, and was formerly considered to be of Upper Cambrian age. Parts of the Middle Cambrian carbonate formations outcrop in the Front Ranges of the Rocky Mountains and have been penetrated in deep wells in the Foothills (the Front and other Ranges of the Rocky Mountains are shown in Figure 64). At Mount Robson, the Middle Cambrian formations total 4,900 feet in thickness and consist of massive to thinly bedded limestone with some shale and basal arenaceous beds.

Upper Cambrian rocks are of more restricted distribution than the Middle Cambrian in the southern and central Rocky Mountains. The basal formation in the Main Ranges is the Arctomys, comprising about 300 feet of varicoloured shale, limestone, and dolomite. The overlying Bosworth (Sullivan) formation is about 1,200 feet thick and consists of massive to thinly bedded arenaceous dolomite and limestone, with local beds of oolitic limestone termed the Paget and Sherbrooke formations. The succeeding Lyell formation consists of 1,100 feet of massive limestone. Probable equivalents of these carbonate formations are: the Ottertail formation of the western Main Ranges which consists of 2,000 feet of massive cherty dolomite and limestone; the Jubilee formation of the Western Ranges formed mainly of massive dolomite, 1,800 feet thick; and the Elko formation of the southwestern Rocky Mountains, 100 feet thick. The late Upper Cambrian is represented by the basal parts of the McKay group and the Goodsir and Mons formations which are mainly Ordovician and described under that heading. The Lynx formation of the Mount Robson district probably contains, in its 4,900 feet of thinly bedded limestone and shale, representatives of the more southerly Upper Cambrian formations.

In northeastern British Columbia the following unfossiliferous beds are provisionally assigned to the Cambrian: 3,500 feet of buff quartzite and pink calcareous shale on Peace River below Finlay Forks; white and grey, argillaceous, and arenaceous limestone east of Finlay River; 5,000 feet of coarse red conglomerate, sandstone, and limestone along the Alaska Highway west of Muncho Lake and in Toad River Valley.

In southwestern Mackenzie Mountains, on South Nahanni River above Flat River, 2,160 feet of unfossiliferous reddish quartzite, siltstone, maroon shale, and limestone underlie the Ordovician and are probably Cambrian. Between the headwaters of Flat River and the South Nahanni Forks, Upper Cambrian and Lower Ordovician beds, of the order of 3,000 feet in thickness, consist of buff to grey limestone, maroon and black shale, phyllite, and sandstone. In the vicinity of granitic intrusions they are metamorphosed to slate, sericitic limestone, and chloritic sandstone. In northeastern Mackenzie Mountains near Norman Wells, Cambrian and possibly older rocks comprise the Katherine and MacDougall groups. The Katherine group consists of about 200 feet of unfossiliferous black, brown and green shales with pink and white quartzites. It is overlain by the MacDougall group which consists of about 1,000 feet of grey limestone, green, brown and maroon shales and sandstones, gypsum-bearing in the upper part and containing sparse fossils of Middle or Upper Cambrian age. On Keele River between Natla and Twitya Rivers, 4,200 feet of unfossiliferous conglomerate, slate, and dolomite are overlain by 4,000 feet of dolomite, limestone, sandstone, and argillite of Middle or Upper Cambrian age. In southern Franklin Mountains near Wrigley, the Lower Cambrian Mount Clark formation overlies dark grey shales referred to the Precambrian, and consists of 600 feet of red shale, ferruginous sandstone, and conglomerate. It is succeeded by the Middle Cambrian Mount Cap formation, comprising 200 feet of grey and green shale and red sandstone. This is overlain by the Saline River formation of 500 feet of red and green shale with gypsum.

At the canyons of Peel River in southern Richardson Mountains, 3,500 feet of interbedded grey to brown sandstone, siltstone, and shale of Upper Cambrian age are overlain by 3,300 feet of thinly bedded, cherty, black limestone and argillite of Cambrian or Ordovician age. Along the boundary between Yukon and Alaska in northern Ogilvie Mountains and in the Keele Range, some 4,000 feet of massive to thinly bedded cherty grey dolomite and limestone range from Middle Cambrian to Middle Silurian in age. In northern Richardson Mountains mottled blue-grey limestone, quartzite, and chert are Lower and Middle Cambrian and possibly Ordovician.

Ordovician. Ordovician strata are well known in the central Rocky Mountains where they are closely associated with the Upper Cambrian in areal distribution, and are reported from northeastern British Columbia, Mackenzie Mountains, and southern Richardson Mountains.

In the Western and Main Ranges of the central Rocky Mountains, the basal parts of the Goodsir and McKay, as previously stated, are late Upper Cambrian and the upper and greater part are Lower Ordovician. The Goodsir formation consists of 5,000 feet of shale and argillaceous limestone. The McKay group, 4,500 feet thick, is less shaly and contains bedded limestone and intraformational conglomerate. In the southwest part of the Stanford Range only the Upper Cambrian part, termed the Sabine formation, is present, and is 700 feet thick. Equivalent to the upper part of the McKay, a black graptolitic shale of the Glenogle formation is developed in the eastern part of the Western Ranges. Its maximum thickness is 1,600 feet and it thins rapidly to the south and west, possibly due to unconformable relations with the overlying Wonah formation. The Wonah is a massive white quartzite, 1,500 feet in maximum thickness, that thins to zero in the south and west. It is succeeded by the Upper Ordovician Beaverfoot formation which unconformably overlies the Wonah, McKay, and Jubilee formations passing from east to west through the Stanford Range. The Beaverfoot is overlain by the Silurian Brisco formation but the two are inseparable, except faunally, and together constitute about 2,000 feet of massive to thinly bedded dolomite and limestone.

Ordovician strata of the eastern Main Ranges and western Front Ranges of the central Rocky Mountains are included in the Mons and Sarbach formations. The Mons consists of 1,000 feet of shale and thinly bedded argillaceous and siliceous limestone. The lower 400 feet of shaly beds are Upper Cambrian. The overlying Sarbach comprises 850 feet of massive, resistant limestone and dolomite. The Sarbach is overlain by the Mount Wilson formation, or unconformably by the Devonian. The Mount Wilson, at the headwaters of the North Saskatchewan River, is a massive quartzite, 550 feet thick. It thins to zero a short distance to the north and also to the south in the Sawback Range of Bow Valley. The Mount Wilson may be equivalent to the Wonah formation, and is overlain by 150 feet of *Halysites*-bearing beds, faunally equivalent to the Beaverfoot, and succeeded, in turn, by the Devonian. The Cushina formation of the Mount Robson district is equivalent to the Ordovician part of the Mons. It is 1,500 feet thick and consists of shale and thinly bedded limestone. Overlying massive arenaceous limestones, 1,500 feet thick, forming the peak of Mount Robson, are termed the Robson formation.

In the eastern Front Ranges of the central Rocky Mountains, the Ordovician is apparently absent, the Devonian lying on the Middle Cambrian with only the thin, undated, Ghost River formation intervening. In the southern Rocky Mountains the Ordovician is absent.

In northeastern British Columbia, on Halfway River, limestones and dolomites carrying Upper Ordovician fossils are reported. In the Mackenzie Mountains below the confluence of the Keele and Twitya Rivers, 4,000 feet of argillite, dolomite, and limestone are overlain by 1,500 feet of sandstones and a diabase sill, and are reported to be Ordovician. On South Nahanni River above Flat River, the Middle Ordovician Sunblood formation consists of 2,500 feet of dark grey limestone. Towards the headwaters very thick Lower (?) Ordovician black and green slates are overlain by about 1,500 feet of unfossiliferous limestone. These occurrences are overlain by Silurian beds. At the south end of Richardson Mountains on the canyons of the Peel River, 2,000 to 6,000 feet of thinly bedded black, cherty limestone, argillite, and shale carry Lower Ordovician graptolites.

Silurian. Rocks of Silurian age are known in the western central Rocky Mountains and the northeastern Cordillera.

In the Western Ranges of the central Rocky Mountains the Silurian is represented by the Brisco formation, as previously noted. It consists of about 1,000 feet of interbedded limestone and dolomite with black shale about the middle and carries Middle Silurian faunas. In Clark Range some 600 feet of gritty massive limestone that overlie the Middle Cambrian may be Silurian. These beds are absent a short distance to the north.

In the Franklin and Mackenzie Mountains the Silurian is referred to as the Ronning group and Bear Rock formation. The Ronning group includes the Lower Silurian Franklin Mountain formation of 800 feet of dolomite, cherty limestone, and shale, and the Middle Silurian Mount Kindle formation which consists of 450 feet of massive dolomite and porous limestone. The Ronning is overlain disconformably by the unfossiliferous Bear Rock formation of 200 to 500 feet of brecciated dolomite, and limestone and gypsum. It may possibly be of Devonian age and is succeeded by Middle Devonian strata. In southern Mackenzie Mountains 500 to 1,200 feet of bedded dolomite and limestone are termed the Lone Mountain formation. On upper South Nahanni River in southwestern Mackenzie Mountains, the Silurian is represented by black, cherty, and shaly limestone, 500 to 750 feet thick.

In northeastern British Columbia along the Alaska Highway, massive, coral-bearing limestone and dolomite, and shale, 1,200 feet thick, are correlated with the Ronning group of the Mackenzie Valley region.

At the canyons of Peel River in southern Richardson Mountains 3,000 feet of black shale, limestone, breccia, and chert are of early Middle Silurian age. They are unconformably overlain by the Devonian. On Wind River to the south, 1,000 feet of Middle Silurian porous dolomite underlies the Devonian.

Devonian. Prior to the deposition of the Devonian there was a general withdrawal of the seas from the eastern Cordillera. No Lower Devonian strata have been recognized and Middle and Upper Devonian beds lie unconformably on the older systems. The Middle Devonian is known only in the Western Ranges of the central Rocky Mountains and in the northeastern Cordillera. The Upper Devonian is widespread throughout the Front Ranges of the Rocky Mountains and in the northeastern Cordillera but is absent in the western Rocky Mountains.

In the western Rocky Mountains the Middle Devonian Harrogate formation consists of limestone and quartzite at the top and of unfossiliferous varicoloured dolomite and shale at the base. The latter beds are apparently underlain by the Burnais formation which consists almost entirely of finely laminated, primary gypsum about 750 feet thick. The lower Harrogate and Burnais overlie the Middle Silurian Brisco formation and may, accordingly, be Silurian or Devonian in age.

In the Mackenzie and Franklin Mountains and along lower Mackenzie River, the Middle Devonian is represented by the Ramparts formation. The Ramparts consists of 1,300 feet of limestone, commonly divided into a lower and an upper part by a median shale; locally, an organic reef limestone occurs at the top. The formation thins to the north through bevelling prior to the deposition of the Upper Devonian. In southern Richardson and northwestern Mackenzie Mountains the Ramparts consists of 400 to 700 feet of thinly bedded black limestone and shale, locally with massive porous biostromal limestone at the top. In western Porcupine Plateau the Ramparts consists of 900 feet of evenly bedded limestone overlain by 1,300 feet of massive porous biostromal limestone. Middle Devonian limestone, locally termed the Salmontrout formation, unconformably overlies the Silurian in the Keele Range and northern Ogilvie Mountains. It consists of 500 feet of massive, porous, coarsely crystalline, petroliferous limestone with a discontinuous, thin, basal quartzite.

On lower Liard River, at the mouth of the South Nahanni River, 450 feet of limestone and dolomite are termed the Nahanni formation of probable Middle Devonian age. In northeastern British Columbia along upper Liard River 1,000 feet of limestone and coral-reef limestone are correlated with the Ramparts formation. There, other possible equivalents of the Ramparts comprise 500 feet of unfossiliferous siltstone and silty limestone which are underlain by 600 feet of unfossiliferous silty and shaly limestones of the Muncho formation. The Muncho is disconformably underlain by the McConnell formation, which consists of 680 feet of limestone with some shale and lies disconformably on the Silurian. Middle Devonian limestones are reported from upper Peace River and Pine River Valleys, and are 2,000 feet thick at the latter locality.

In southwestern Mackenzie Mountains, northeast of South Nahanni River above Flat River, 2,200 feet of massive grey to white and porous limestones are considered lithologically equivalent to the Ramparts formation. They are underlain disconformably by 1,150 feet of black nodular limestone of Devonian age, and, in turn, by 1,000 feet of unfossiliferous black shale and thinly bedded limestone which overlie Silurian beds. Between the South Nahanni River and the headwaters of Redstone River more than 4,000 feet of massive grey and buff limestone and dolomite with minor sandstone, grit, and pebble conglomerate are included in the Middle Devonian.

The Upper Devonian of the eastern Rocky Mountains is represented by the Fairholme group and overlying Alexo and Palliser formations. The Fairholme group embraces the Cairn and Southesk formations which consist principally of organic and reef carbonates, commonly termed the carbonate sequence, and the Flume, Perdrix, and Mount Hawk formations which consist of bedded carbonates and shale, termed the clastic or off-reef sequence. These two sequences grade laterally into one another at several localities along the Front Ranges of the central Rocky Mountains. The carbonate sequence lies principally south of the North Saskatchewan River and occurs as structurally isolated masses at Sunwapta Pass in the Main Ranges, in the Bighorn Range, at the confluence of Southesk and Cairn Rivers, and at the headwaters of Snake, Indian and Smoky Rivers.

The Cairn formation consists of about 600 feet of dark grey, massive, vuggy dolomite, with dense and cherty dolomite at the base. The Southesk comprises about 600 feet of light grey, massive, vuggy dolomite. The Flume formation is commonly about 200 feet thick, and comprises argillaceous and organic limestones and bedded dolomites, cherty at the base. The Perdrix consists of 300 to 500 feet of black, calcareous shale and argillaceous limestone which grade upwards into the overlying Mount Hawk comprising 200 to 500 feet of argillaceous limestone and dolomite. In the vicinity of the North Saskatchewan River the lower part of the Mount Hawk formation consists of up to 600 feet of greenish grey, dolomitic shale.

The Alexo formation varies in thickness from 200 to 600 feet and is thinnest where it overlies the carbonate sequence. It consists of silty and laminated dolomites and, locally, sandstone and breccia. The overlying Palliser formation, 800 feet thick, is a massive, cliff-forming limestone, mottled with dolomite and forms many of the more spectacular peaks of the eastern Rocky Mountains and Foothills. In the Brazeau Range it is formed of porous and vuggy dolomite. It is overlain by the Exshaw formation of Devonian or Mississippian age.

In the easternmost Front Ranges and Foothills, the unfossiliferous Ghost River formation grades into underlying Middle and Upper Cambrian strata and into overlying Upper Devonian, and may be Middle Devonian in age. The formation consists of 150 to 200 feet of variegated dolomite and shale, and sandy dolomite. In the more westerly ranges of the eastern Rocky Mountains the Ghost River formation is not recognized and the Upper Devonian lies unconformably on various horizons of the Ordovician and possibly on the Upper Cambrian.

In the Clark Range, Devonian and possibly older strata are unnamed. They overlie the Middle Cambrian and consist of 1,450 feet of limestone and dolomite and with three intervening beds of shale. Fossils of Upper or Middle Devonian age have been found in beds near the middle.

In northeastern Mackenzie and Franklin Mountains the Fort Creek and Imperial formations compose the Upper Devonian. The Fort Creek is made of 1,500 feet of dark grey, locally bituminous, shale with lenses and reefs of limestone, one of which forms the reservoir rocks of the Norman Wells oil field. The formation grades into the overlying Imperial formation which consists of 2,000 feet of interbedded green marine sandstone and shale and grey limestone, overlain unconformably by Cretaceous strata. On Peel River in Richardson Mountains the Fort Creek is about 1,000 feet thick and consists of black shale and thin beds of siltstone. It is thin or absent on the western Porcupine Plateau. The overlying Imperial formation is 2,000 to 4,000 feet thick and consists of interbedded shale, mudstone, siltstone, and sandstone; it carries plants and is in part of nonmarine origin. On lower Arctic Red and Mackenzie Rivers similar unfossiliferous nonmarine (?) beds are assigned to the Imperial formation. On lower North Nahanni River, the Upper Devonian consists mainly of grey and green shales, rarely red, with zones of thinly bedded limestones, and totals 3,500 feet in thickness. On lower South Nahanni River about 1,200 feet of unfossiliferous dark grey shales lie between the Middle Devonian and the Mississippian. Along the Alaska Highway and upper Liard River, 800 feet of soft, black, fissile shales are correlated with the Fort Creek formation.

Carboniferous and Permian. Carboniferous strata were laid down with apparent conformity on the Upper Devonian throughout the eastern Rocky Mountains, Foothills, and southern Mackenzie Mountains.

In the Rocky Mountains and Foothills, Carboniferous and Permian strata embrace, in ascending order, the Exshaw and Banff formations, the Rundle group, and the Rocky Mountain formation. The Exshaw is Mississippian or Devonian in age and consists of a thin but persistent black shale, usually about 10 feet thick but increasing to over 100 feet in the west and absent in the region north of Athabasca River. It lies with sharp and locally erosional contact on the Upper Devonian. The Banff formation of Kinderhookian age consists mainly of basal dark grey shale which grades upwards into dense, argillaceous limestone and cherty or crinoidal limestone. It is 1,450 feet thick at Banff and thins eastward to 600 feet in the central Foothills.

The Rundle group overlies the Banff and is commonly transitional into it. The group is divided into three formations. The basal formation, the Livingstone, of Osagian age, characteristically contains massive beds of crinoidal limestone with interbedded argillaceous and cherty limestone and silty dolomite. Its upper beds, in the southern Foothills, are partly of porous dolomite and form the reservoir rocks of the oil and gas fields of that region. The overlying Mount Head formation of Meramecan age, consists of arenaceous dolomite and limestone, dense dolomite and limestone, in part brecciated and anhydritic, crinoidal limestone, and grey and green shale. The Chesterian, Etherington formation consists of basal green shale, dense and crinoidal limestone and dolomite, and arenaceous beds. The Rundle group is, in general, thickest in the more westerly ranges of the eastern Rocky Mountains and thins eastward and northward mainly through convergence and loss of beds through erosion at the top. It is 2,000 feet thick at Banff, 1,100 feet at Jasper, attains a maximum of 3,900 feet at Crowsnest Pass, and thins to 450 feet in the central Foothills.

The Rundle group is overlain with apparent conformity by the Rocky Mountain formation. At Banff this formation consists of 290 feet of quartzite and sandy dolomite of possible Pennsylvanian age, overlain by 240 feet of sandy dolomite, chert, and phosphatic beds of Permian age. The formation thickens to the south and thins rapidly to the southeast, east, and north, in part through pre-Triassic and pre-Jurassic erosion.

In the Hughes Range of the southwestern Rocky Mountains, 1,300 feet of strata, lithologically similar to the Banff formation, are overlain by 300 feet of crinoidal limestone carrying a fauna of Kinderhook and Osage affinities. They are underlain by a covered interval and the Middle Devonian (?) Burnais formation.

The Carboniferous and Permian are but little known in the northern Rocky Mountains. Mississippian limestone and 400 feet of Permian sandstone are reported from the Peace River Valley and some 900 feet of crinoidal and dense Mississippian limestone, from the Sikanni Chief Valley. Carboniferous and Permian strata along the Alaska Highway comprise the Kindle formation which is formed of several hundred feet of dense argillaceous and arenaceous limestones, overlain, possibly disconformably, by 200 feet of black chert.

In the southern Mackenzie Mountains near the mouth of South Nahanni River, Mississippian strata consist of 450 to 1,100 feet of dark grey shale with overlying dark grey limestone, partly cherty and crinoidal. These beds are succeeded by 1,000 feet of late Mississippian or early Pennsylvanian quartzitic sandstone and dark grey shale capped by chert and conglomerate, apparently overlain by Lower Cretaceous beds. On Beaver River to the west 1,600 feet of sandstone, shale, and limestone are overlain by 150 feet of chert and sandstone. The upper part is Permian and the remainder is probably Permian or Pennsylvanian.

Late Palæozoic strata are absent in the Franklin Mountains and more northerly parts of the Mackenzie Mountains, where the Lower Cretaceous overlies the Upper Devonian. Mississippian bituminous shale and shaly limestone, 2,500 feet thick, occur on upper Peel River and on the west side of Richardson Mountains but are absent in southern Richardson Mountains. They are overlain by 3,500 feet of Pennsylvanian marine shale and siltstone with basal conglomerate, very similar in appearance to the overlying Cretaceous or underlying Devonian Imperial formation. Locally 1,600 feet of unfossiliferous coarse ferruginous sandstone and angular conglomerate, possibly of Pennsylvanian or Permian age, unconformably overlies the Mississippian or Devonian. In the Keele Range and northern Ogilvie Mountains the Mississippian Racquet group consists of 1,500 feet of bedded limestone and chert with minor shale and conglomerate. It is overlain by the Pennsylvanian Nation River formation of conglomerate, sandstone, shale, and rare limestone, up to 4,800 feet thick. On Firth River in the northern British Mountains massive grey limestone and marble of possible Mississippian age are overlain by 1,000 feet of grey to red sandstone, shale, and conglomerate of possible Pennsylvanian to Triassic age, and these are overlain by Jurassic shale. At the head of Blow River on the Arctic Plateau thick-bedded blue-grey limestone, cherty limestone, and chert is referred to the Carboniferous. In northeastern Richardson Mountains about 800 feet of conglomerate and shale of Pennsylvanian or Permian age are overlain by 400 feet of Permian (?) sandstone.

Mesozoic

Triassic. Marine strata of Triassic age are distributed throughout the Front Ranges of the Rocky Mountains and parts of their bordering Foothills. The Triassic rests on Permian in more westerly and northern ranges, but lies disconformably on Pennsylvanian (?) and Mississippian strata in the eastern and southern Foothills. It is absent in the northeastern Cordillera.

In the Banff region the Spray River formation is divisible into a lower Sulphur Mountain member composed of laminated, calcareous shale, siltstone, and argillaceous limestone of Lower Triassic age, and an upper Whitehorse member of grey limestone with shaly and sandy beds. The formation is about 1,650 feet thick. South of Banff the Whitehorse member is absent or thin, but is present in unknown thickness in the Crowsnest basin of southeastern British Columbia and in the Flathead Valley. It is absent in the Foothills to the east.

The two members are also present between the Banff and Jasper regions, being thickest in the mountains and thin or absent in the Foothills. The Sulphur Mountain member is lithologically similar to that at Banff, but the Whitehorse member contains much dolomite. In the Jasper region the Whitehorse includes gypsum and other evaporites, overlain by the Jurassic. On Mowitch Creek, north of Athabasca River, the gypsum is overlain by some 480 feet of light grey limestone, followed by the Jurassic.

In the Foothills south of Smoky River the Sulphur Mountain member is probably represented by 1,000 feet of unfossiliferous sandstone and siltstone and is overlain by 150 feet of limestone and dolomite of Middle Triassic age termed the Whitehorse formation (Figure 63). North of Smoky River the Triassic is 1,900 feet thick and divisible into three parts. The lower part is 276 feet thick and consists mainly of dark grey shale and siltstone carrying a Lower Triassic fauna. The middle part comprises 604 feet of interbedded sandstone and siliceous dolomite with an early Middle Triassic fauna. The upper part is 1,034 feet thick and consists of massive to shaly limestone containing an early Upper Triassic fauna in the uppermost beds. The latter beds probably represent the southernmost extent of Upper Triassic strata in the eastern Cordillera.

In the Peace River Foothills the Triassic is exceptionally fossiliferous, is more than 2,500 feet thick, and consists of three main lithological units. The basal, Dark Siltstones, consist of 75 to 450 feet of dark calcareous shale, siltstone, and limestone of probable Ladinian, late Middle Triassic age. The overlying Grey beds are massive, calcareous sandstones and grey limestones about 2,000 feet thick. They are late Middle to early Upper Triassic. At the top of the succession the Upper Triassic Pardonet beds of Karnian and Norian age consist of dark calcareous shale and siltstone varying in thickness from 250 to 2,000 feet, being thickest in more westerly sections.

North of Peace River the Pardonet beds extend north of Sikanni Chief River, but are unknown in the Tetsa and Liard River Valleys. The lower part of the Triassic section, which is concealed in the Peace River Foothills, appears in the valleys of the Halfway and Sikanni Chief Rivers. The Dark Siltstones are underlain by 300 feet of grey, flaggy, calcareous siltstones termed the Flagstones. These beds carry a late Middle Triassic, Ladinian fauna, and are underlain by the Toad formation.

In the Liard and Tetsa Valleys the early Lower Triassic Grayling formation comprises 600 to 1,000 feet of soft grey shale with thin sandstone bands. It rests, possibly disconformably, on the Permian and is overlain by the Toad formation of late Lower and early Middle Triassic age. The Toad consists of 800 to 1,800 feet of dark calcareous siltstone, shale, and limestone. The overlying Liard formation

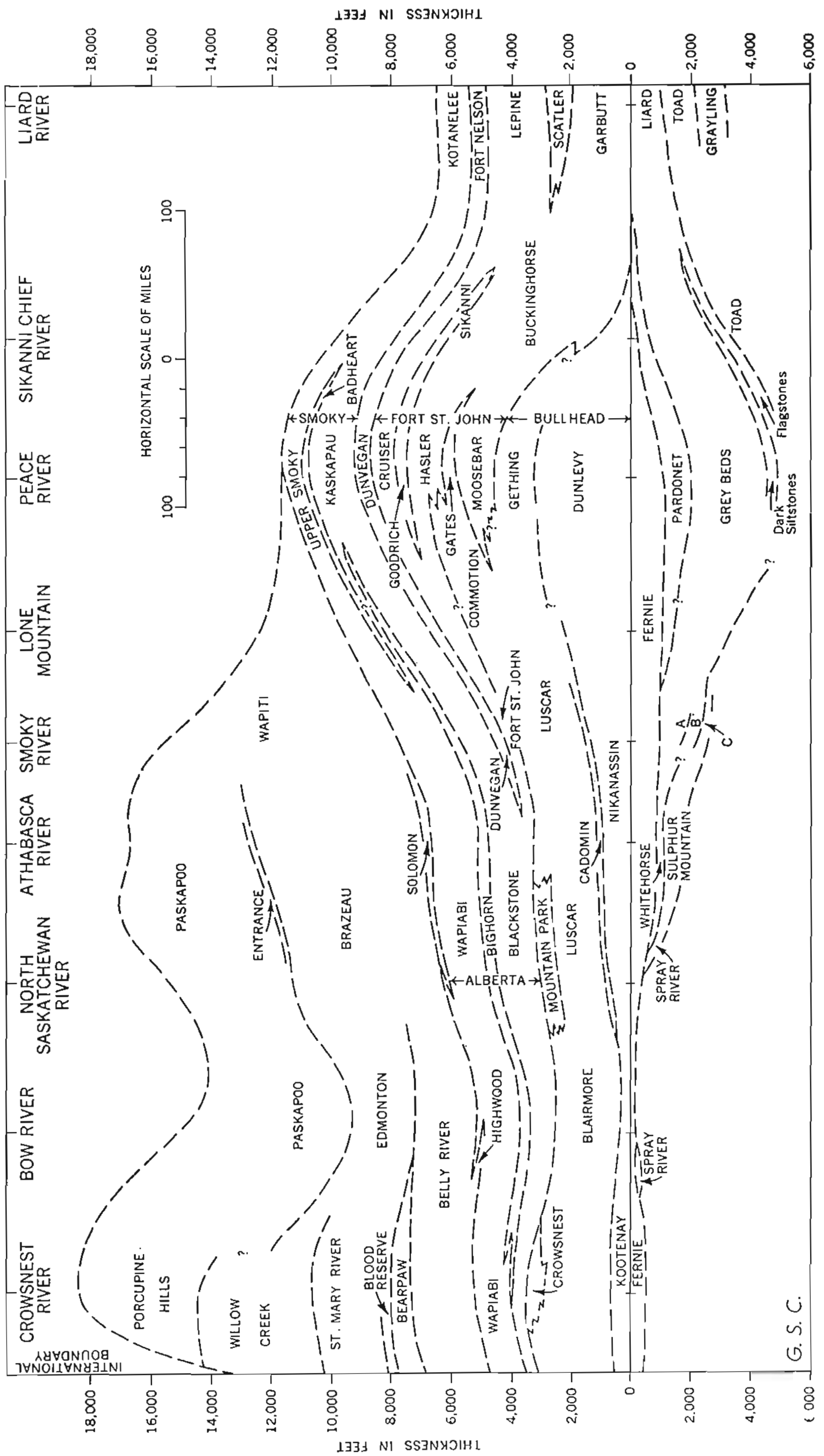


FIGURE 63. Sketch showing approximate stratigraphic relationships and thickness of Mesozoic and Tertiary formations from south to north along the Foothills belt, Alberta and British Columbia.

includes equivalents of the Flagstones, Dark Siltstones, and lower Grey beds of the region to the south. It is 600 feet thick, overlain by the Lower Cretaceous, and disappears east of Crusty Creek, a tributary to the Liard. The Triassic is absent or very thin on the lower Liard and Petitot Rivers, and none has been recognized in the eastern Cordillera to the north.

Jurassic. Marine Jurassic sedimentary rocks can be traced continuously along the Front Ranges of the Rocky Mountains and along the Foothills from the International Boundary to beyond Peace River. Jurassic strata are also reported from the Richardson Mountains, but are absent in the northern part of the Rocky and Mackenzie Mountains.

In the Front Ranges and Foothills the Jurassic is represented by the Fernie group and some parts of overlying formations (Figure 63). In the vicinity of Blairmore, in the Crowsnest Pass, the Fernie is about 700 feet thick, thinning to 200 feet in the east and thickening slightly westward. It has been subdivided into lower, middle, and upper parts, equivalent to the Lower, Middle, and Upper Jurassic. The lower part, 80 to 200 feet thick, consists mainly of dark grey shales of Sinemurian and Toarcian age which transgressively overlap eastward and unconformably overlie older formations. Locally the Sinemurian is absent. The Toarcian shales grade eastward into thinly bedded sandstone with basal conglomerate. The middle part of the Fernie group is 100 feet thick and is divided into a lower Rock Creek member of mid-Bajocian age characterized by sandy beds and many belemnoids, ammonoids, and pelecypods, and an upper, unfossiliferous shale. The upper part of the Fernie consists of 200 feet of grey shale of early Callovian age overlain by up to 50 feet of glauconitic sandstone termed the Green beds of Oxfordian age. The succeeding Passage beds, Oxfordian to early Portlandian, consist of 150 to 190 feet of interbedded shale and sandstone which grade upwards into the basal sandstone of the Kootenay formation. The basal Kootenay sandstone in the Crowsnest basin contains a late Portlandian ammonite.

North of Crowsnest Pass many of the subdivisions of the Fernie group are lithologically similar to those farther south. Some, however, are different: in the central Foothills the lower part of the group includes up to 150 feet of black phosphatic beds of Sinemurian age termed the Nordegg member, the Rock Creek may consist mainly of sandstone, and the Oxfordian may be represented by concretionary shale. The group as a whole is about 350 feet thick.

In the vicinity of Athabasca River the Fernie thickens to about 900 feet, of which over half is equivalent to the Passage beds. The remainder is mainly shale with the Nordegg member at the base. In the central and northern Foothills of Alberta, the Fernie group is overlain transitionally by the Nikanassin formation, part of which may be of Jurassic age.

In northeastern British Columbia the Jurassic is represented by beds assigned to the Fernie group, and possibly by a lower part of the Bullhead group. The Fernie is little known in this region, but consists mainly of dark grey shale with some interbedded sandstone towards the top. Fossils recorded are of Lower Jurassic age. North of Peace River the Fernie thins and, just north of Sikanni Chief River only 18 feet remain.

Jurassic rocks are unknown in the Franklin and Mackenzie Mountains. In northeastern Richardson Mountains the Permian (?) is overlain disconformably by about 500 feet of sandstones containing Lias, Bathonian, and Callovian faunas. They are gradationally overlain by Upper Jurassic to early Lower Cretaceous marine shales about 800 feet thick. On upper Blow River on the Arctic Plateau black concretionary shale of possible Upper Jurassic age is overlain by buff sandstone of early Lower Cretaceous age. On Firth River in the northern British Mountains 100 feet of grey fissile shale and thin beds of sandstone carry a Callovian fauna.

Lower Cretaceous. The Lower Cretaceous of the eastern Cordillera is represented by nonmarine strata from the International Boundary to and beyond Peace River. North of Athabasca River marine beds make their appearance above the nonmarine beds, at Peace River the whole upper half of the section is marine, and at Liard River and northward to the Arctic all of the Lower Cretaceous is mainly marine. In early and mid-Jurassic times the clastic sediments were derived from the east, whereas, in late Jurassic and throughout the Lower Cretaceous and succeeding epochs sand, shale, and conglomerate coarsen in texture westward, and were derived from a land thought to lie along the sites of the present Selkirk, Purcell, and other eastern ranges of the western Cordillera.

In the Foothills at Crowsnest Pass, the Lower Cretaceous is represented by the Kootenay formation, Blairmore group, and Crowsnest formation (Table XXII and Figure 63). The Kootenay transitionally overlies the Fernie group and the basal sandstone, at least, is Jurassic. Succeeding strata are composed of sandstone and shale with several coal seams, two of which are mined. The formation is about 550 feet thick and thins to nearly zero along the eastern margin of the Foothills. The overlying Blairmore group decreases in thickness from 2,500 feet in the west to 1,300 feet in the east. It consists of a basal conglomerate with chert and quartzite pebbles overlain by black shale, thin limestone beds, and quartzose sandstone, succeeded by green arkosic sandstone, green and red shale, and a conglomeratic sandstone, the pebbles of which are quartzite, chert, and igneous rocks. The pebbles of igneous rock suggest that an intrusive mass had been unroofed in the source region before the close of the Lower Cretaceous. The Blairmore is overlain transitionally by acid tuff and agglomerate of the Crowsnest formation. The agglomerate contains fragments of a sanidine and analcite porphyry. The volcanic rocks thin rapidly to the north and east, where they become interbedded with upper Blairmore strata. Dykes of similar material have been found cutting Mesozoic strata at Coleman and Palæozoic strata of the mountains to the west. The Crowsnest is disconformably overlain by the Upper Cretaceous Blackstone formation.

In the Crowsnest Basin near Fernie, the Kootenay attains a thickness of 2,100 feet. It is overlain by the Elk formation, which comprises 1,700 feet of conglomerate, sandstone, shale, and minor coal. It contains a flora similar to that of the

Kootenay and may represent a conglomeratic facies of the upper Kootenay of more easterly regions, or it may have been removed by pre-Blairmore erosion. The Elk is succeeded by about 600 feet of the Blairmore group, the youngest beds preserved, composed of conglomerate, sandstone, and varicoloured shale.

The Kootenay and Blairmore maintain comparable lithological characteristics to a point north of Bow River. Their thicknesses increase, and the textures of the sandstones and conglomerates become coarser, from east to west. The Kootenay contains all the commercial coal seams in this region.

In the central Foothills between the North Saskatchewan and Athabasca Rivers, the Lower Cretaceous has been divided into four formations, the Nikanassin, Cadomin, Luscar, and Mountain Park. The Nikanassin is largely equivalent to the Kootenay and the other three, to the Blairmore (Figure 63). Commercial coal, however, is found not in the Kootenay equivalent but in the Luscar formation. The Nikanassin varies in thickness from 200 feet in the east to about 1,200 feet in the west. It consists of quartzose sandstone, black fissile shale, and thin coal seams and may be, in part, Jurassic. It is overlain by the Cadomin, a thin conglomerate equivalent to the basal conglomerate of the Blairmore group to the south and extends northward beyond Peace River, a distance of over 600 miles. The Luscar varies from 900 to 2,000 feet thick and is thickest in the west. The lower part is similar to the Nikanassin and the upper part consists of green arkosic sandstone and shale with coal seams. It is transitionally overlain by the Mountain Park, 300 to 1,000 feet thick, composed of massive, ridge-forming sandstone, locally conglomeratic, and green shale. North of Athabasca River the Mountain Park loses its ridge-forming character and, if present, has not been separated from the underlying Luscar. In the vicinity of Smoky River the Luscar and Mountain Park equivalents total about 2,000 feet in thickness and the Nikanassin reaches over 4,000 feet.

In the Peace River region the Lower Cretaceous is represented by the Bullhead group and overlying Fort St. John group. In the eastern Foothills the Bullhead is divided into the Dunlevy and Gething formations. The Dunlevy gradationally overlies the Jurassic and may be, in part, of that age. It contains in its lower 2,400 feet thick-bedded, fine-grained, quartzitic sandstones and dark carbonaceous shales of marine origin. Its upper part is nonmarine and consists of about 500 feet of massive, coarse-grained, conglomeratic sandstone, grit, and interbedded thin shales and coal seams. The Gething formation overlies the Dunlevy conformably. It is 1,400 feet thick, and consists of nonmarine siltstone, sandstone, shale, and coal seams, some of which are mined.

In the western Peace River Foothills, in the vicinity of Carbon Creek, the Bullhead group is divided into four formations, the lower three of which are marine. The basal Monteith consists of 1,000 to 1,750 feet of arkosic sandstone and shale conformably overlying the Jurassic. It is overlain by the Beattie Peaks formation, comprising 600 to 1,200 feet of shale with minor sandstone. The succeeding Monach formation is composed of 350 feet of massive, coarse-grained sandstone and minor shale. The uppermost formation, unnamed, is referred to as the "Coal

Measures" or "Non-marine Bullhead" and consists of over 4,000 feet of sandstone, shale, conglomerate, and coal seams. These beds are approximately equivalent to the Gething and to the upper, nonmarine, part of the Dunlevy to the east. North of Peace River the Bullhead thins rapidly and loses its identity about midway between Peace and Prophet Rivers (Figure 63).

The Fort St. John group of the Peace River Valley has been divided into five formations, the Moosebar, Gates, Hasler, Goodrich, and Cruiser. The Moosebar, Hasler, and Cruiser are mainly marine shales, each about 1,000 feet thick. The Gates consists of marine sandstone and shale and grades laterally northward into shale. It is about 300 feet thick and thickens southward. The Goodrich consists of 500 feet of marine sandstone and shale.

On Pine River 1,300 feet of marine and nonmarine sandstone, conglomerate, and shale, called the Commotion formation, includes equivalents of the Gates and lower part of the Hasler. South of Peace River in the Lone Mountain area along Monkman road nonmarine sandstones and conglomerates are correlated with the Commotion formation. Overlying beds are mainly shale and are equivalent to the Hasler, Goodrich, and Cruiser formations farther north and indicate that the Cruiser grades southward into shale. Between Smoky and Athabasca Rivers, dark grey shales, about 400 feet thick, contain the *Neogastrolpites* fauna found in the Goodrich formation of the Peace River region. This shale, which is tentatively termed the "Fort St. John" group, is gradationally overlain by the Upper Cretaceous, Dunvegan formation, and is underlain with sharp contact commonly marked by a thin conglomerate, by the undivided Luscar and Mountain Park formations.

North of Peace River in the valleys of Halfway and Buckinghorse Rivers the Fort St. John group consists of the Buckinghorse and Sikanni formations. The Buckinghorse consists of 3,500 feet of marine shale and minor sandstone. It overlies the Bullhead group with a thick transition zone of shale and sandstone, suggesting that the upper part of the Bullhead may grade northward into the Fort St. John. The Sikanni formation comprises 980 feet of marine sandstone and shale. On Liard River the Fort St. John group disconformably overlies Triassic rocks. It is composed of: the unfossiliferous Garbutt formation, 2,000 feet of marine shale; the Scatter formation, 750 feet of marine sandstone; and the Lépine formation, 2,000 feet of marine shale.

In the Mackenzie River Valley between Franklin and Mackenzie Mountains the Lower Cretaceous Sans Sault group disconformably overlies the Middle and Upper Devonian. It consists of 3,850 feet of sandy shale and fine-grained sandstone, and is overlain gradationally by the Slater River formation of Upper or Lower Cretaceous age. Rocks of Cretaceous age, possibly mainly Lower Cretaceous, underlie much of the plains and plateau regions of northern Yukon and lower Mackenzie River Valley. The Lower Cretaceous rocks of southern Porcupine Plateau and western Peel Plateau range up to 1,600 feet in thickness and consist of soft black shales of Albian age with local basal glauconitic sandstones from 100 to 600 feet thick. In the Aklavik Range of northeastern Richardson Mountains

800 feet of marine shales are of latest Jurassic and earliest Lower Cretaceous ages. They are overlain by 500 feet of sandstone with coal beds at the top, followed by 1,100 feet of marine concretionary shale, which grades upwards into 600 feet of sandstone. This entire section is early Lower Cretaceous in age and older than the Lower Cretaceous rocks of areas to the southeast.

Upper Cretaceous. Upper Cretaceous rocks extend through the Foothills of the Rocky Mountains and eastern ranges of the Mackenzie and Franklin Mountains. The lower formations are marine, and are succeeded by thick, nonmarine beds which are difficult to separate from those of the Tertiary.

In the central Foothills between Athabasca and North Saskatchewan Rivers the marine formations are termed the Blackstone, Bighorn, and Wapiabi. The basal Blackstone formation overlies the Mountain Park with sharp and locally erosional contact. It consists of about 1,500 feet of shale and siltstone, from which the oldest known fossils are of Cenomanian, earliest Upper Cretaceous age. The Bighorn consists of about 300 feet of sandstone, shale, and local conglomerate. Sandstone beds included in the top and base of the formation in more westerly parts grade laterally eastward into shales included in the overlying and underlying formations. The Wapiabi comprises about 1,800 feet of shale and siltstone, the uppermost beds of which intertongue with the basal sandstones of the Brazeau formation.

In the southern Foothills these three formations constitute the Alberta group and differ little in lithological characteristics from those in the north. However, the Bighorn, which is here commonly called the Cardium formation, thins to a few feet of sandstone and pebble conglomerate. The Blackstone overlaps the Blairmore group and Crowsnest formations, and fossils from its basal beds in the Crowsnest Pass region are of Turonian age.

North of Athabasca River, sandstones appear in the lower part of the Blackstone and are correlative with the Dunvegan formation of the Peace River region. They carry a Cenomanian fauna, thicken northward, and overlie shales of the "Fort St. John" group (Figure 63). The sandstones are overlain by 1,800 feet of shales which are tentatively placed in the Blackstone. These are succeeded by the Bighorn and Wapiabi formations, 600 and 1,500 feet thick, respectively.

In the southern Foothills the Alberta group is overlain by the Belly River formation of about 2,000 feet of nonmarine green sandstone and shale with coal at the top, followed by the Bearpaw formation of about 800 feet of marine shale. This is succeeded by the St. Mary River formation of about 2,500 feet of nonmarine green sandstone and shale, the basal sandstone of which may be marine and is locally mapped as the Blood Reserve formation. The St. Mary River is overlain by the Willow Creek formation which attains a maximum thickness of 4,000 feet. The lower beds are grey sandstone with interbedded green, grey, maroon, and variegated shales which grade upwards into massive bedded, buff weathering sandstone and shale, rarely red. The lower part is Upper Cretaceous and the upper part is Paleocene. Between Oldman and Highwood Rivers, the

Willow Creek loses its identity. The lower part together with the equivalent of the underlying St. Mary River formation is included in the Edmonton formation.

In the eastern Foothills north of the Bow River the marine Bearpaw formation is very thin or absent. North of Clearwater River its equivalents together with the underlying and overlying formations are termed the Brazeau formation. The Brazeau consists of about 5,000 feet of nonmarine sandstone, conglomerate, and shale, with some tuff towards the top. The basal sandstone in the central Foothills and north of Athabasca River is marine, and is termed the Solomon sandstone. The Solomon grades eastward into siltstone and shale of the Wapiabi formation.

In the Peace River region the Upper Cretaceous is represented by the Dunvegan formation and overlying Smoky group and Wapiti formation. The Dunvegan consists of 1,100 feet of interbedded sandstone and shale of marine and nonmarine origin. The Smoky group contains the basal Kaskapau formation, 1,550 feet of marine shale, the Badheart formation, 100 feet of sandstone and shale, and, at the top, an unnamed marine shale, 650 feet thick. The overlying Wapiti formation is approximately equivalent to the Brazeau, but may contain Tertiary beds in its upper part.

Farther north, on Liard River, the Dunvegan has graded into the Fort Nelson formation of nonmarine conglomerate and sandstone, 560 feet thick. The Fort Nelson is overlain by the Kotanelee formation of 500 to 1,000 feet of marine sandstone and shale, and these beds are succeeded by the basal part of the Wapiti.

In the Mackenzie River Valley between the Franklin and Mackenzie Mountains, the Upper Cretaceous has been divided into the Slater River, Little Bear, and East Fort formations. The Slater River transitionally overlies the Lower Cretaceous Sans Sault group and may possibly be of that age. It consists of 1,000 feet of concretionary marine shale with basal bentonite bands. The Little Bear consists of 700 feet of nonmarine sandstone, shale, and lignite. The East Fork consists essentially of grey marine shale up to 850 feet thick. The Upper Cretaceous generally forms the youngest rocks of the region but is locally unconformably overlain by the Tertiary.

Cenozoic

Tertiary. Nonmarine sandstone and shale of Paleocene age are known along the eastern margin of the Foothills, rarely within it, and form the western margin of the Plains south of the Peace River region. These strata range up to 5,000 feet in thickness, their top surface being the present erosion surface. In the southern Foothills the highest beds are termed the Porcupine Hills formation which overlies, locally unconformably, the Willow Creek formation the upper part of which, previously described, is also of Paleocene age. The contact is gradational in the south, but northward is unconformable. From Turner Valley to a point north of Athabasca River, the Paleocene strata are termed the Paskapoo formation. The basal sandstone is locally conglomeratic south of North Saskatchewan River, but to the north consists of up to 50 feet of chert and quartzite-pebble conglomerate called the Entrance conglomerate. The lower 2,000 feet contain several coal seams in the central Foothills, some of which are mined. The upper part of the Wapiti formation, south of Peace River, may contain Paleocene strata.

Strata in an intermontane basin in the Flathead Valley of southeastern British Columbia are called the Kishenehn formation and have yielded mammalian remains dated as very late Eocene or very early Oligocene (late Duschenean). The formation is of nonmarine origin and comprises some 1,500 feet of soft sand and shale with thin limestone beds, coal seams and conglomerate. The conglomerate contains pebbles of Proterozoic rocks now exposed in adjacent ranges. The strata dip about 30 degrees northeast and lie unconformably on folded and faulted Lower Mesozoic beds.

In the Rocky Mountain Trench along Finlay River and through Sifton Pass coarse conglomerate, sandstone, and shale of the Sifton formation are of Upper Cretaceous or early Tertiary age. In places these beds are tilted up to 40 degrees, showing that they have been affected by mountain-building movements.

On Petitot River, a tributary to the Liard, sand, shale and conglomerate, unconformably lying on the Upper Cretaceous, are probably Paleocene in age.

In the vicinity of Fort Norman on Mackenzie River soft sandstone, conglomerate and shale with lignite seams are of Paleocene or early Eocene age. They lie unconformably in Upper Cretaceous beds and vary in thickness, reaching 1,600 feet on Little Bear River. In the Bonnet Plume Basin on upper Peel River in southern Richardson Mountains, Tertiary gravel, sand, and shale with lignite are 1,000 feet thick. They are gently folded and lie with high angular unconformity on steeply folded older formations. To the northwest on Porcupine River light coloured beds of clay, sand, and conglomerate rest unconformably on Cretaceous and older strata and are thought to be Tertiary.

Igneous Rocks

In southeastern Cordillera porphyritic diorite forms sills and dykes intrusive into the Proterozoic Purcell system and the Galton and Lewis series. They occur in nearly all formations of the Lewis series, even the youngest, but are unknown in Cambrian or younger beds.

Small stocks and dykes of sodic syenite are common in the Western Ranges of the Rocky Mountains east of Cranbrook. They are heavily altered to chlorite, talc, and epidote. It has been suggested that they are early Tertiary in age.

Agglomerates, tuffs and rare flows of the Lower Cretaceous Crowsnest formation are widespread in the eastern Crowsnest Pass region. The rocks are essentially sodic trachytes, some containing considerable analcite and sanidine. Small dykes of this composition intrude Lower Cretaceous rocks at Coleman and cut Palæozoic strata of the easternmost range of the Rocky Mountains.

The largest intrusive bodies known in the Rocky Mountains are those of the Ice River complex near Field. The rocks range from nepheline syenite to alkali

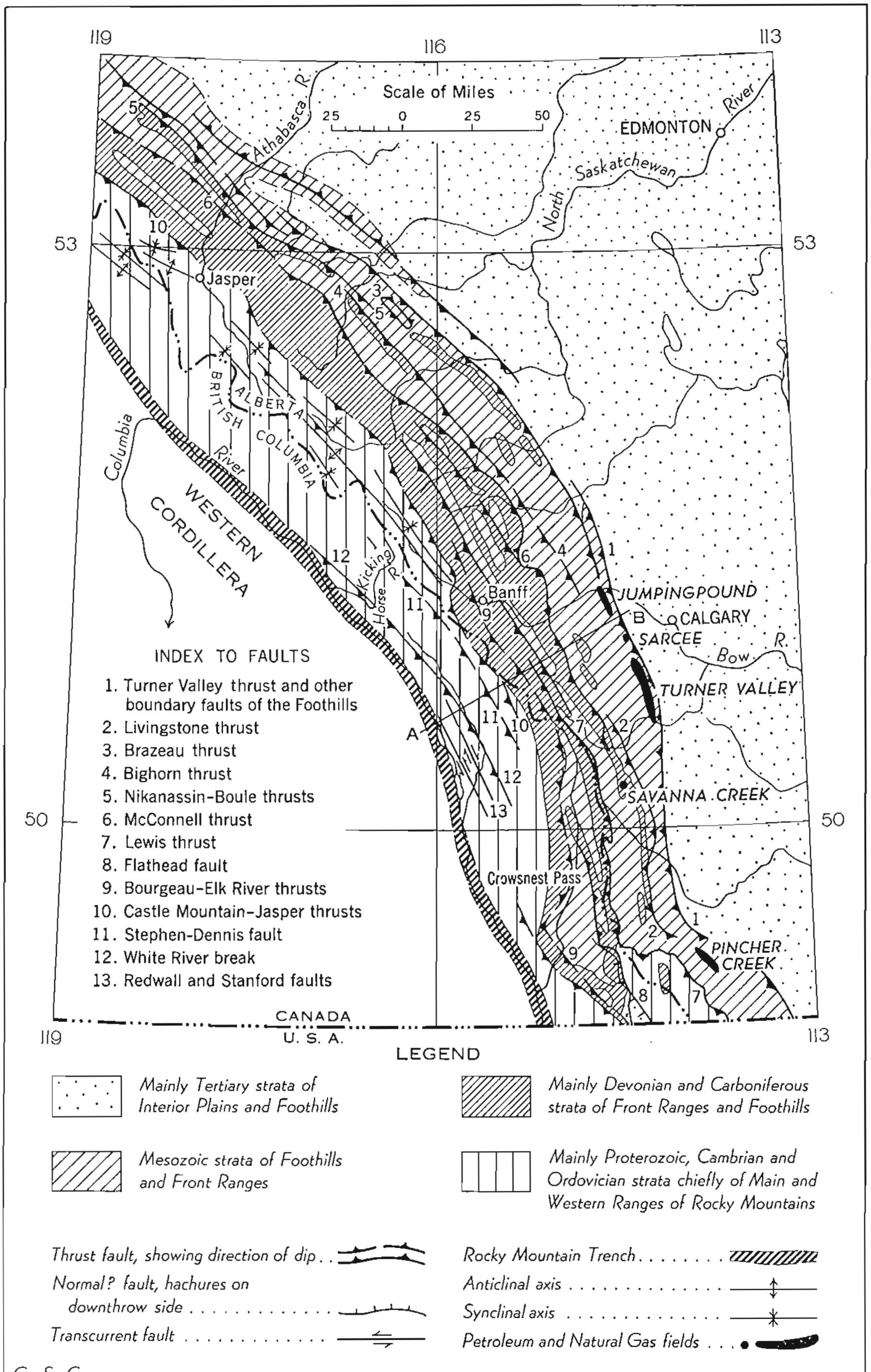


FIGURE 64. Major structural features of the southern and central Rocky Mountain area. (*See* Figure 65 for Structure-section along line A-B.)

pyroxenite. The two laccolithic bodies together cover about 12 square miles and cut rocks as young as the Goodsir formation of Cambrian and Ordovician age. The intrusions are post-tectonic and are presumed late or post-Cretaceous in age. To the southeast on Cross River a small body of diorite is intrusive into gently dipping, possibly Goodsir strata.

In southwestern Mackenzie Mountains, Cambrian and Ordovician strata southwest of upper South Nahanni River, and Middle Devonian strata northeast of the river, are intruded by granitic stocks, presumably related to large igneous bodies in the Selwyn Mountains to the west. Light grey to buff, coarse-grained granodiorite is most common. Some fine-grained syenite, diorite porphyry, and tourmaline-bearing granite with well developed contact zones are present.

In southern British Mountains and in the Old Crow Range along the boundary between Alaska and Yukon stocks of massive porphyritic granite intrude early Palæozoic and Proterozoic sedimentary rocks and have metamorphosed them to schist, phyllite, and slate. On Porcupine River south of the Old Crow Range, rocks of the Tindir group are intruded by dykes and sills of diabase.

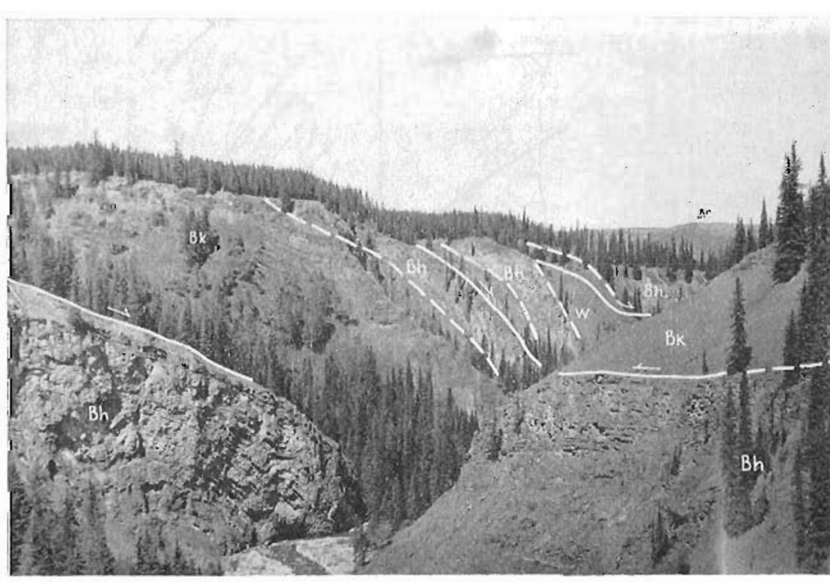
Structure

The eastern Cordillera falls, structurally, into three main parts: the Rocky Mountain area, the Mackenzie-Franklin Mountain area, and the northern Yukon area (Figure 61).

The Rocky Mountain Area. The Rocky Mountain area may be divided into four units which from east to west are: the Foothills, the Front Ranges, the Main Ranges, and the Western Ranges (Figure 64). In general, the youngest rocks outcrop in the Foothills and progressively older formations are exposed towards the west. Thus, the Foothills are underlain mainly by Mesozoic strata, the Front

Plate XXXIII

Looking northeast at northeast-dipping parts of three folded faults which repeat northeast-dipping Alberta group strata on Canyon Creek in central Foothills of Alberta. These faults are folded so that behind the observer and beneath the hill in the background they dip southwest. Formations shown as follows: Bk, Blackstone; Bh, Bighorn; W, Wapiabi.



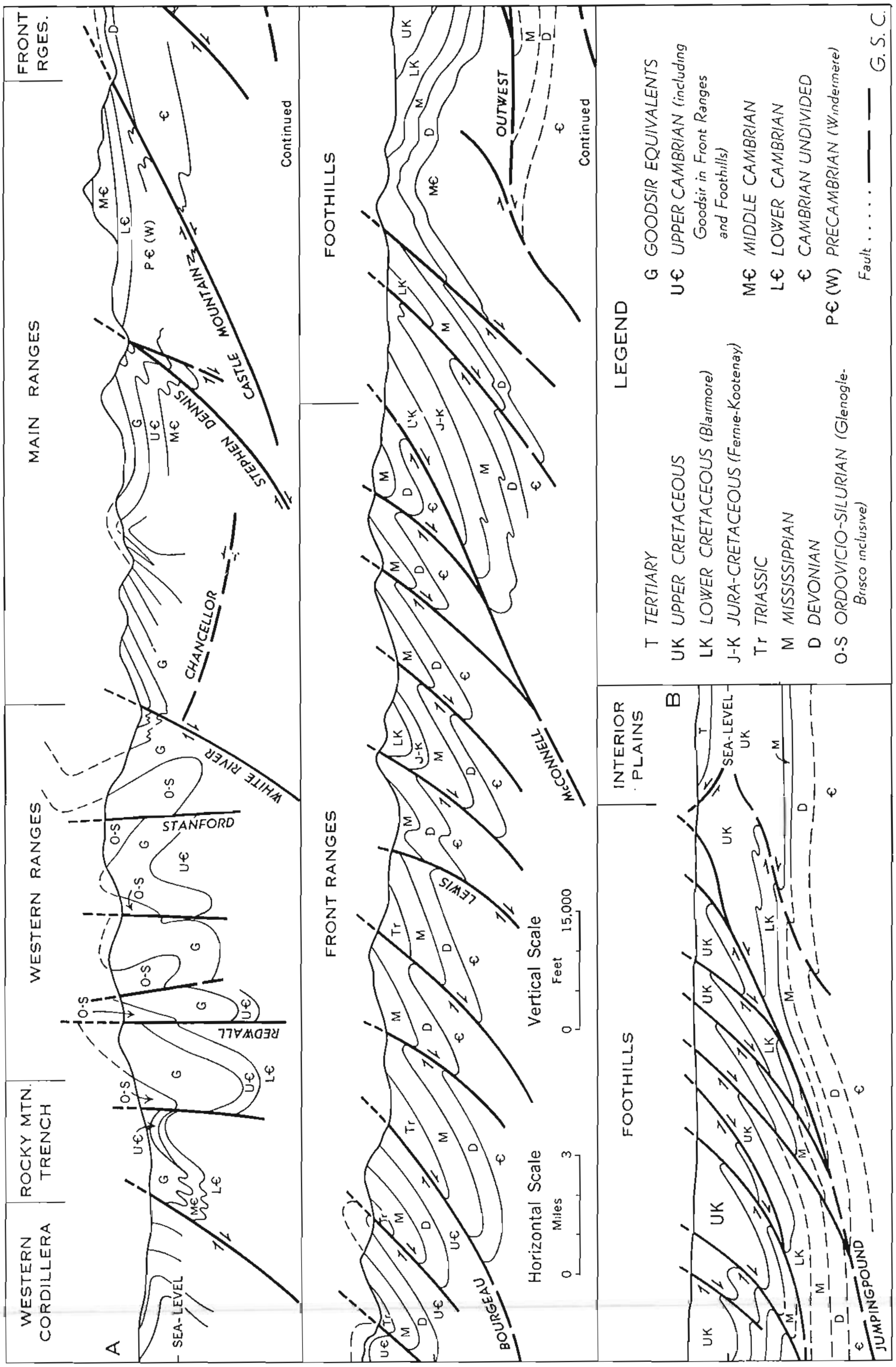


FIGURE 65. Structure-section along line A-B of Figure 64. (After F. K. North and G. G. L. Henderson.)

Ranges are characteristically formed of Devonian and Carboniferous strata, the Main Ranges are mainly of Proterozoic, Cambrian and Ordovician formations, and the Western Ranges embrace strata ranging from Proterozoic to Mississippian.

The Foothills, particularly of southern and central Alberta, are characterized by subparallel thrust faults. Most of the faults dip westerly as do the strata they displace. Some faults are folded, either individually or in groups (Plate XXXIII), with closure across the strike ranging to over a mile. The faults are commonly closely spaced and steeply inclined within late Mesozoic strata and several merge within the early Mesozoic so that Palæozoic strata are displaced on fewer, more widely spaced thrusts of large displacement (Figure 65). The thrusts vary in locale of greatest displacement and, at their extremities where displacements are small, commonly lie as subsidiary faults within adjoining thrust sheets. Culminations within the various thrust sheets bring Palæozoic rocks to the surface. Some of these form ranges that merge with the Front Ranges and present an *en échelon* pattern with right hand offset between Crowsnest Pass and Athabasca River and with left hand offset thence northward to Peace River. Similarly, the eastern margin of the Foothills is bounded by a series of *en échelon* faults. Locally, the easternmost structures of the Foothills are east- or northeast-dipping thrust faults. In the northern Foothills of Alberta the Mesozoic strata lie above widely spaced thrusts and are closely folded. Some of these folds appear to have formed with *décollement* above the thrusts. Between Peace and Liard Rivers in northeastern British Columbia, Foothills structures are broad folds, locally faulted, in which Triassic and Lower Cretaceous rocks are exposed.

In the Front Ranges of the Rocky Mountains, structures are exposed such as are present beneath the Mesozoic cover of much of the Foothills. South of Crowsnest Pass, the Front Ranges are represented by two main thrust sheets which contain Proterozoic and Palæozoic rocks, the eastern of which is underlain by the Lewis thrust (Plate XXXIV). In Flathead Valley normal faults and east-dipping thrusts may be present. Between Crowsnest and Athabasca Rivers, the Front Ranges are composed of two to five main thrust sheets in which the exposed rocks are mainly Devonian and Carboniferous, in small part Cambrian and early Mesozoic. The thrusts extend for the order of 100 to 300 miles, about the same as the major thrusts of the Foothills. The massive carbonate rocks which lie above them form linear ranges, mainly with simple, westerly dipping, homoclinal structure, but locally folded and broken by small faults. In the vicinity of Athabasca River the Devonian and Carboniferous strata loose their competency and the structure within the main thrust sheets is complex. Close folding, overturning of strata westward as well as eastward, and minor faults are evident. North of Athabasca River the Front Ranges are reduced to a single range. North of Peace River the Rocky Mountains broaden to their greatest width, but the structure is unknown.

The structure of the Main Ranges of the Rocky Mountains is largely unknown. In the Bow Valley the eastern margin of the Main Ranges is marked by the Castle Mountain thrust which brings a thick, synclinally folded succession of Proterozoic

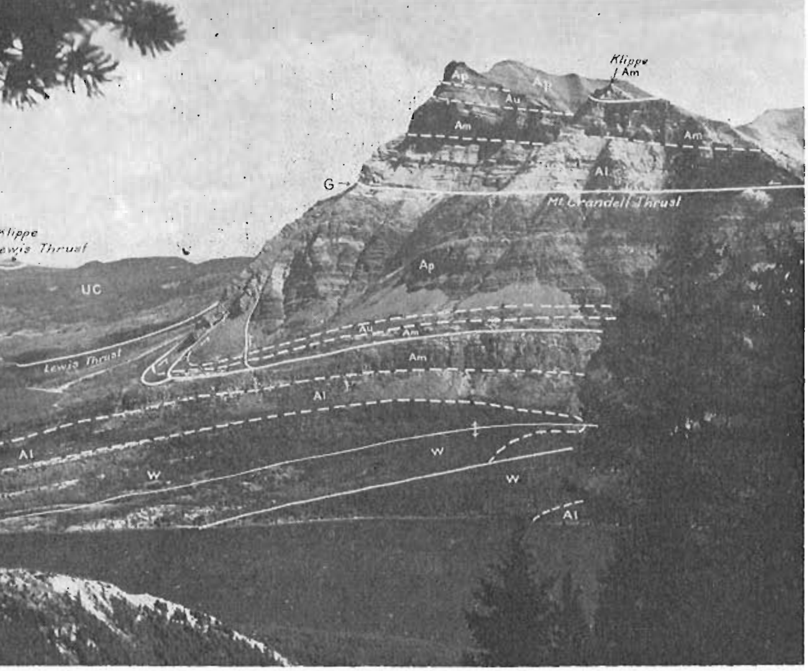


Plate XXXIV | *Structures in the Lewis series above the Lewis thrust, looking east towards Front Ranges (foreground) and Foothills (left background). Formations shown as follows: W, Waterton; Al, Am, Au, lower, middle, and upper Altyn; Ap, Appekunny; G, Grinnell; UC, Upper Cretaceous. Vimy Peak, Waterton National Park, Alberta.*

and Cambrian rocks over late Palæozoic strata. Beyond an anticline to the west Cambrian and Ordovician strata, mainly west-dipping, are broken by one or more large thrusts, and minor folds within them are overturned to the east. East-dipping thrusts are present along Kicking Horse River. It has been suggested that the western part of the Main Ranges is underlain by a major east-dipping thrust on which displacement of overlying rocks was directed westward, and that this fault was subsequently overridden by the White River break. The White River break marks the boundary between the Main and Western Ranges and brings rocks of different facies of the Cambro-Ordovician formations into juxtaposition. In the Athabasca Valley Proterozoic and Cambrian strata extend from the Jasper thrust in the east to the Rocky Mountain Trench in the west. The Cambrian lies mainly in the trough of a syncline which passes through the Mount Robson district. North of Athabasca River the Main Ranges narrow, and at Peace River the Proterozoic and Cambrian (?) form a belt scarcely 20 miles wide.

The Western Ranges exhibit structures not found elsewhere in the eastern Cordillera and which may be genetically allied to structures in the Rocky Mountain Trench to the west. Several high-angle, strike-slip faults are marked by broad zones of breccia. They trend northwest and converge in that direction with the Rocky Mountain Trench. Within the eastern fault blocks, the strata are closely folded and strongly overturned to the west. In the more westerly fault blocks, northeast-striking faults occur between the strike-slip faults. Apparent displacement is reverse on some which dip northward and is normal on some others which dip nearly vertically.

Mackenzie-Franklin Mountain Area. This area embraces the Mackenzie and Franklin Mountains, the intervening Mackenzie Plain, and the Liard and Peel Plateaux (Figure 61). The area is bounded on the west by the Selwyn Mountains and on the east by the Interior Plains.

The Mackenzie Mountains are broadly convex to the northeast, the strike of the structures changing from east of north in the south to east in the north. The western or Backbone Ranges constitute a rugged compact mass underlain in large part by gently dipping, broadly folded Palæozoic strata. At the headwaters of the Redstone and South Nahanni Rivers the broad folds trend northwest. Minor folds are asymmetric eastward, and locally have irregularly trending axes. Early Palæozoic to Middle Devonian strata are intruded by small, cross-cutting granitic stocks. Folding is broad and open in the eastern or Canyon Ranges but locally may be close, particularly along the mountain front. Faulting is minor. In the Liard Plateau south of the Mackenzie Mountains, Palæozoic and Mesozoic strata are involved in broad open folds.

The Franklin Mountains, together with the Mackenzie Plain, constitute a belt marginal to the Mackenzie Mountains not unlike that of the Foothills to the Rocky Mountains. The Franklin Mountains parallel the curvature of the Mackenzie Mountains. In the south they consist of subparallel ranges of Middle Devonian and older strata, either folded into anticlines or occurring as sheets bounded by westerly dipping thrust faults, possibly of small displacement. Locally the strata are closely folded and faulted. At the north end of the mountains the strata are mainly anticlinally folded, broken by north and south-dipping faults, and plunge westward beneath Cretaceous rocks of the Peel Plateau.

The Mackenzie Plain is underlain by soft Upper Devonian, Cretaceous and Tertiary strata. They are bent mainly into gentle, discontinuous folds with irregular trends.

Northern Yukon Area. The Northern Yukon area embraces the Richardson and British Mountains, the Arctic Plateau and Coastal Plain, the Porcupine Plain and Plateau, and the northern part of the Ogilvie Mountains (Figure 61).

The northern Ogilvie Mountains are on a continuation of the westerly trend of the northwestern Mackenzie Mountains. On upper Peel River the trend changes abruptly to the north.

The Richardson Mountains trend north and are a continuation of northerly trends in the extreme northern elements of the Mackenzie and Ogilvie Mountains. The southern Richardson Mountains are bounded on the east by north-striking faults and on the west by north-striking thrust and normal faults. They are essentially an anticlinorium with a core of lower Palæozoic and Proterozoic rocks and flanks of upper Palæozoic strata. The northern Richardson Mountains are characterized by numerous, rather close folds in Cretaceous and upper Palæozoic strata, mainly trending northerly. Some elements trend southwest into the Porcupine Plateau.

The Porcupine Plain is, in part, underlain by gently folded Cretaceous rocks trending north. The Porcupine Plateau which forms a narrow belt nearly surrounding the Porcupine Plain, also contains the Keele and Old Crow Ranges. Structures in the former trend northeast and join the southwest trends of the Richardson Mountains and northerly trends in the Ogilvie Mountains. The Old Crow Range is underlain by lower Palæozoic and Proterozoic rocks intruded by granite. It forms a projection into Yukon Territory of the southern Brooks Range of Alaska.

The British Mountains are the eastern extension of the northern Brooks Range. The southern part of the British Mountains contains granitic intrusions. The northern part is underlain by upper Palæozoic sedimentary rocks that strike southeast and are reported to be closely folded and faulted.

Age of the Rocky Mountain Deformation. The age of the orogenic movements that produced the eastern Cordillera is Laramide (early Tertiary). Although Tertiary strata are lacking over deformed beds through much of the system and some, particularly in the north, are not yet accurately dated, the age of the deformation of the southern ranges of the Rocky Mountains and Foothills can be ascertained within fairly close limits. Three regions yield pertinent data.

Along the eastern margin of the Foothills from the International Boundary to a point near Peace River, Paleocene strata of the Porcupine Hills, Willow Creek, and Paskapoo formations are strongly upturned or involved in the easternmost fold and fault structures. These easternmost and, presumably, youngest structures of the Rocky Mountains were therefore developed in post-Paleocene time.

In the Flathead Valley, west of Clark Range, the Kishenehn formation of very late Eocene or very early Oligocene (Upper Duschenean) age unconformably overlies early Mesozoic strata which are involved in the structures of the southern Rocky Mountains. The strata are gently folded, dipping mainly about 30 degrees northeast. These observations indicate two phases of deformation, the first, pre-Kishenehn and post-early Mesozoic, probably post-Paleocene in age, during which the main orogenic movements took place, and the second, post-Kishenehn in age, during which the Kishenehn beds were tilted. Conglomerates of the Kishenehn carry pebbles of Proterozoic rocks indicating that these rocks were exposed in adjacent ranges following the first phase of the deformation.

Further evidence on the age of the uplifts associated with the orogenic movements in the southern Rocky Mountains is found in conglomerates on the Plains of southern Saskatchewan. The products of erosion from the uplift of the southern Rocky Mountains during two phases of the deformation are thought to be represented by gravels in the Cypress Hills region which carry pebbles of the distinctive Proterozoic rocks and bracket in age the time of deposition of the Kishenehn formation. Mammalian fossils in the Swift Current Creek beds are Uintan (late Eocene) and those in the Cypress Hills formation are of Chadronian (early Oligocene) age. In summary, the first and main deformation in the southern Rocky Mountains took place in the interval between the Paleocene and the late Eocene. Uplift and erosion occurred in the late Eocene (Uintan), followed by relative quiescence during the deposition of the Kishenehn beds (Duschenean). Moderate deformation and renewed uplift took place in early Oligocene (Chadronian) time.

In the Mackenzie River Valley, Tertiary strata in the vicinity of Fort Norman are tentatively considered to be early Eocene in age. A short distance northwest, at Bear Rock, these beds have been faulted and it may therefore be presumed that this and possibly other structures of this region were formed in post-early Eocene time. In the Bonnet Plume Basin of upper Peel River between Richardson and Mackenzie Mountains, Tertiary strata rest with high angular unconformity on formations ranging from Cambrian to Upper Devonian in age. They are, themselves, gently folded. More accurate dating of the orogenic and epirogenic movements in the northeastern Cordillera should follow accurate dating of the Tertiary beds and study of the extensive high level erosion surfaces of the Mackenzie Mountains.

Economic Geology

The economic minerals of the Cordillera comprise metallic minerals, industrial minerals, coal, petroleum, and natural gas. The production of major mineral commodities for 1955, and the cumulative totals, are tabulated by provinces in the introductory chapter of this volume (Table III). Metallic mineral production ranks first in value and is almost all from the western Cordillera. Production of petroleum and natural gas is confined to the eastern Cordilleran region. Coal and some industrial minerals are produced in both regions.

Metalliferous Deposits

The most important metals of the Cordillera are lead, zinc, copper, gold, and silver. Up to 1955 more than 90 per cent of the lead, more than half the zinc, nearly half the silver, and more than a sixth of the copper and gold produced in Canada came from the Cordilleran region. It also contributed all the mercury and tin, nearly all the tungsten and antimony, and most of the cadmium and bismuth, besides some iron and a few metals of minor economic significance.

With the exception of a small area near Field, B.C., essentially all known metalliferous occurrences are in the western Cordilleran region. Metal mines and prospects are particularly numerous in an area that skirts the Coast batholith and projects eastward at two places: one projection includes the many stocks and smaller batholiths that extend along Skeena and Bulkley Valleys towards Pinchi Lake; the other includes the major intrusions that extend from lower Fraser River, through Nelson nearly to the Rocky Mountains. However, scattered prospects and a few productive mines occur throughout much of the remainder of the western Cordilleran region, except in those areas covered by late Tertiary lavas. Some, as at Field and in the Barkerville Gold Belt, are many miles from the nearest exposed large intrusions.

The deposits, with few exceptions, are believed to be genetically related to these Mesozoic, and perhaps Tertiary, intrusions. The intrusions comprise a number of phases injected at various times during this general period; how much and what kind of metallization, if any, accompanied each phase is not known. A region-wide zoning is apparent, with the known large copper deposits lying in the western and central parts, and most lead-zinc-silver deposits concentrated in an eastern belt, near or beyond the eastern margin of the main zone of large intrusions.

The deposits are mostly tabular bodies, formed in fault fissures or in sheared and brecciated zones in which replacement of the country rock was extensive. Some, however, such as the Sullivan, are closely controlled by bedding structures and others, especially copper and iron deposits, are irregular replacements in limestone close to intrusive contacts. The deposits range from high-temperature contact metamorphic or skarn types to low-temperature types apparently deposited far from their source, such as the Pinchi Lake mercury ores. Some deposits, such as the silver-lead orebodies of the Slocan, do not appear to extend to great depths. Others, such as the gold-quartz veins of Bridge River camp, persist through a vertical range of several thousand feet without significant changes in mineralogy or precious metal content. With some exceptions the orebodies are of primary origin; much of the upper parts of mineral bodies, which may have been oxidized and enriched by downward percolating waters in pre-Pleistocene time, have been removed by ice action.

Placer deposits are mainly of value for their gold content, but some platinum, tungsten minerals, mercury, and cassiterite have been recovered locally. Some valuable placers are in recent alluvium, such as the bars of Quesnel and Fraser Rivers, but the greatest and richest are in, or reconcentrated directly from, old gravels accumulated in stream channels during the long Tertiary erosion interval. Most have been to some extent dissipated, disturbed or reworked by ice action during the Pleistocene, but the great Klondike field of the Yukon is in an unglaciated area, and its rich deposits remained undisturbed.

History of Mining

The mineral resources of the Cordilleran region attracted little notice until 1855 when placer gold was found in British Columbia on Pend d'Oreille River by miners spreading north from the waning gold fields of California. By 1857 others had located gold in the gravels of lower Fraser River. The ensuing rush was followed by other thousands of gold seekers who headed for the Cariboo district following the discovery there in 1861 of the rich placer deposits of Williams and Lightning Creeks. Other important placer camps were found between 1860 and 1865 at various places in southern British Columbia. Placer production in the province reached its peak between 1863 and 1867 when gold valued at $16,283,592 was recovered. In 1873 work began in the Manson Creek area and farther to the northwest the productive gold-bearing gravels of the Dease Lake region were staked for the first time. By 1880 the latter had contributed gold to the value of nearly $4 million and along with those of the older placer camps of the province, was well past peak production. The next and last outstanding placer discovery in the province was made in 1898 when miners on their way to the Yukon discovered gold in the Atlin district. This proved to be the most productive field in the province, next to the Cariboo.

Placer gold was found on Yukon River in Yukon Territory, as early as 1869, and by 1890 prospecting had spread to tributary streams where coarse gold was recovered. The discovery of the Sixtymile field in 1892 was eclipsed in 1896 by the report of fabulously rich placers on Klondike River and its tributaries. In 1897 and 1898 there followed an unparalleled rush of gold hunters from all parts of the world, and in 1900 gold production of the Yukon, mainly from the Klondike district, reached its peak value of $22,275,000.

Active lode prospecting in British Columbia started between 1880 and 1890 and eventually resulted in an annual and aggregate production of gold and base metals far in excess of that of the more spectacular placer fields. As in the case of placers, the search started in the southern part of the province, and in the 10 years commencing in 1882 spread throughout the Kootenay, Slocan, Boundary, and Rossland districts, and through areas tributary to the Canadian Pacific Railway, which reached Vancouver in 1885. By the end of the century mining was a thriving industry in the southern part of the province, and a dozen or more smelters had been built to treat various ores. All of these have since been abandoned, but the Trail Smelter, built soon after to treat the Rossland copper ores and later converted to treat the Sullivan lead-zinc ores, is now the largest metallurgical plant in Western Canada. The Rossland gold-copper camp attained maximum production in about 1902, and was practically abandoned about 20 years later. In the meantime copper mining at Phoenix in the Boundary district, had reached peak proportions in 1913, and continued until the closing of the smelter at Grand Forks in 1919. Four other outstanding properties were found in the south between 1892 and 1898: the lead-zinc deposits of the Sullivan mine near Kimberley; the copper deposits of Copper Mountain near Princeton; the copper ores of Britannia mine on Howe Sound; and the gold ores of the Nickel Plate mine near Hedley. Mining began at the Nickel Plate property in 1903. Metallurgical difficulties were encountered at the other three properties, but the Britannia and Sullivan mines entered continuous large-scale production in 1923, and intermittent but important production at Copper Mountain commenced in 1926.

In northern British Columbia the Portland Canal area had been prospected for metalliferous deposits since 1898, and by 1910 wide areas were staked. In 1914 the first copper ore from the Hidden Creek mine was smelted by the Grandby Company at Anyox, where operations continued until 1935. The Premier mine near the head of Portland Canal has contributed important quantities of gold and silver since 1918.

Only two lode camps in Yukon maintained steady production for more than 5 years. The mines of the Whitehorse copper belt, discovered in 1897, reached a peak production of 2,807,096 pounds of copper in 1916 but were virtually abandoned in 1920. High-grade silver-lead veins were found by placer miners in the Mayo area in 1906 and, in 1924, a 150-ton concentrator was erected at Wernecke to treat the ores. Production from Keno and Galena Hills has continued intermittently since that time.

The rise in the price of gold in 1933 and 1934 profoundly affected the lode and placer gold industry in both Yukon and British Columbia; many old properties were reopened or expanded, and the search for new deposits went on apace. During the early thirties production from the Pioneer and Bralorne deposits in the Bridge River area expanded very greatly to make this camp the largest gold producer in the province. Many other gold mines were revived or brought into initial production between 1933 and 1939 in the Cariboo, Hedley, Nelson and other areas. The Zeballos camp, on the west coast of Vancouver Island, became an important producer in 1938.

Marked readjustments in the mining industry came with the Second World War, including a greatly increased production of base metals and a decided curtailment in gold mining, during which a host of small gold mines were closed. A demand for so-called "strategic metals" resulted in the production of large amounts of mercury from the recently discovered deposit at Pinchi Lake north of Fort St. James, the recovery of tin from the complex ore of the Sullivan mine, the production of scheelite concentrates from the Red Rose mine near Hazelton, and the discovery and development of the tungsten ore of the Emerald mine in the Nelson district.

Since the war rising costs have seriously handicapped the gold mining industry. In 1956 only Bridge River and Cariboo, of the primarily lode-gold camps, maintained substantial production. Base-metal mining has continued to thrive. Exploration and development in 1955 and 1956 were directed mainly to copper, especially in Unuk River area (Granduc), Kamloops vicinity, and Vancouver Island. Tungsten production at the Emerald mine was resumed in 1951 and the mill capacity has been steadily increased. Considerable tonnages of iron ore have been mined, and prospecting for iron, uranium, and a few miscellaneous metals has been active.

Gold

Gold produced in the Cordilleran region up to the end of 1955 was valued at $751,492,459, more than one-sixth of the national total. Production in 1955 was valued at $11,225,214, far less than that of zinc, lead or copper, which it formerly greatly exceeded in value. Nearly half the cumulative gold production was derived from placer operations, and more than two-thirds of this was from Yukon Territory. The remainder came from lode gold and base metal mines in British Columbia.

Placer Mining

Placer mining, which provided the first great impetus to exploration in the western Cordillera, has remained an important industry in several districts, although the current production is greatly exceeded in value by that of lode metals.

The Klondike district (1)* near Dawson, Yukon, was discovered in 1896 and ranked as one of the greatest placer fields in mining history. Most of Yukon's gold production, estimated at 10.4 million ounces to the end of 1955 and valued at about $237 million, came from this field. Even in the present unfavourable

*Reference number indicates locality shown in Figure 66.

INDEX TO SYMBOLS AND PROPERTIES							
Lode Gold	Lead-Zinc-Silver	Copper	Placer Gold	Silver	Mercury	Tungsten	Iron
●	▲	■	o	△	♦	×	◊
4	2	3	1	8	11	9	9
5	30	8	4	9	12	32	16
7	32	9	6	26	21		17
13	33	18	10	31	23		20
14	34	19	14				
15	35	24	22				
17	36	27	24				
22	37						
25	38						
26	39						
28							
29							
31							
32							

FIGURE 66. Some metalliferous mines and mining camps of the Cordilleran region. (Reference to numbers is made in Table XXIII and in descriptive text.)

economic condition for gold mining, annual production valued at between 2 and 3 million dollars has been maintained.

Three features of the district are thought to be of greatest significance in accounting for the presence and richness of the placer deposits (1) The ancient schists that underlie the area are cut in places by numerous quartz veins and stringers carrying small amounts of gold; (2) The plateau-like character of the upland surface, now deeply dissected by stream valleys, points to a long history of undisturbed erosion during which gold could accumulate in old stream channels; (3) The area was not overridden by glaciers, hence accumulated gold was not swept away or scattered by ice, or buried by or mixed with glacial deposits.

The auriferous gravels are in the present valley bottoms and on rock terraces along their sides. The terrace deposits, often referred to as "high level benches", contain the initial high-grade placer concentrations. These form the "paystreak", a zone generally a few feet thick that occurs in the base of the gravels and in fractures in the underlying bedrock. At the valley heads the terraces are nearly level with present stream course, but downstream the new courses are entrenched and near Yukon River they are 300 feet or more below the top of the terrace.

The gravel of the high level benches consists largely of vein quartz and leached material, accumulated in old stream channels, and is known as the "White Channel" gravel. Some of the richest placers occur in the present stream channels where these have cut and reconcentrated the paystreak of the White Channel. The pay channels of the main creeks head in a few limited areas and the gold appears to have come from restricted areas of the bedrock.

The ground in the area is permanently frozen to depths ranging to more than 200 feet, and must be thawed before it can be worked. The permafrost permitted early drift mining without the necessity of supporting the workings or of pumping out water. Most of the gold in recent years has been won by dredging on river and creek flats and to a lesser extent by hydraulicking.

Although the great bulk of the gold produced has come from the creeks of the Klondike where Bonanza Creek and its tributary, Eldorado, are credited with a yield of more than $65 million many other streams in the Yukon have yielded considerable amounts. Notable among these are Miller Creek, Sixtymile River, Henderson, Clear, Highet, and Livingstone Creeks, each of which is believed to have yielded $1 million or more.

The Atlin district (4), of northwestern British Columbia became known as a placer gold camp in 1898. Recorded production to the end of 1954 amounted to 719,709 ounces valued at $16,931,588.

The area is a deeply eroded plateau region lying east of the Coast Range. The principal gold-bearing creeks traverse an area on the east side of Atlin Lake which is underlain chiefly by schists and serpentine containing gold-bearing quartz veins and mineralized zones. This area was perhaps less affected by glacial erosion than the surrounding region, and yellow decomposed gravels, commonly buried beneath glacial drift, are found in the valleys of Pine, Spruce, and other creeks. Most gold is found in the top few feet of bedrock and in immediately overlying gravel but some, concentrated from overlying gravel and drift deposits, lies on a hardpan of boulder clay. Drift mining and hydraulicking methods are used.

The Cariboo district (14), including Quesnel River and Barkerville areas, from 1858 to 1954 produced placer gold estimated at 2,585,186 ounces and valued at $53,449,489. Among the most productive streams are Quesnel River, Lightning, Lowhee, Williams Keithley, and Cedar Creeks.

The Barkerville area is a plateau-like upland now deeply dissected by the stream valleys. Bedrock consists mainly of old partly schistose sedimentary rocks traversed by a zone in which are many gold-bearing quartz veins. Coarse placer gold is believed to be derived from originally fine gold in the veins, by solution and reprecipitation. The district was glaciated but remnants of preglacial gravels remain, and especially where reworked by later stream action formed the most important paystreaks. In these the gold is mainly on and in bedrock and in immediately overlying gravel. Some paystreaks occur on bedrock benches and old channels above the present creek levels, and others in interglacial gravels between layers of glacial drift. Some gold is found in glacial gravel and drift deposits, and fine gold occurs on bars in the wide lower parts of streams. Hydraulicking, deep-lead, and dredging methods have been used.

Other placer fields of former major importance are those of Stikine area, near Dease Lake (6); Omineca, west of Finlay Forks, (10); Lillooet, where production was largely from the Fraser River (22); and Tulameen, near Princeton (24). The Tulameen field is especially interesting in that a substantial amount of platinum, derived from nearby ultramafic intrusions, has been recovered along with gold.

Lode Gold

Lode gold deposits occur throughout the western Cordillera but only a few minor occurrences are known east of Kootenay and Upper Arrow Lakes. They are found in a great variety of rocks, sedimentary, volcanic, and intrusive. Much of the gold produced has come from replacement lodes and irregular bodies commonly associated with copper, but the most typical gold orebodies are quartz-filled fissure veins. In these, pyrite and arsenopyrite are the most common sulphides and copper may be subordinate to lead and zinc. The lode gold deposits are believed to be related to Mesozoic or early Tertiary granitic intrusions.

The Engineer mine (4)* about 20 miles west of Atlin was well known for its spectacular but pockety gold showings but was never an important producer. The country rocks are Mesozoic argillite and greywacke cut by a stock and dykes of granodiorite. A shear zone about 4,000 feet long contains quartz, much pyrite, and a little gold. The principal gold-bearing veins lie on either side of the zone and trend towards it at various angles. Most are filled with quartz but one has a calcite-mariposite filling. Native gold, gold tellurides, and mariposite occurred in rich pockets.

*Reference number indicates locality shown in Figure 66 and production in Table XXIII.

TABLE XXIII

Main Lode-Metal Producers of the Cordillera (approximate production to 1953)

No. (Note 1)	Property	Camp or Area	Location (Note 2)	Years (Note 3)	Ore Million tons	Gold Thousand oz.	Silver Million oz.	Copper Million lb.	Lead Million lb.	Zinc Million lb.	Other Metals Million lb.
	GOLD										
4	Engineer	Atlin	59°–134° SE	1913–1952	0.017	18.1	—	—	—	—	
5	Polaris-Taku (Whitewater)	Taku River	58°–133° NW	1937–1942	0.753	231.6	0.0	0.2	—	—	
5	Big Bull, Tulsequah Chief	Taku River	58°–133° NW	1951–1953	0.293	23.8	0.8	6.5	7.3	32.5	Cd.
7	Premier (Silbak-Premier)	Portland Canal	56°–130° SE	1918–1953	4.636	1,783.3	40.3	4.2	58.0	15.2	Cd.
7	Big Missouri	Portland Canal	56°–130° SE	1927–1942	0.848	58.4	0.05	—	0.0	0.0	
13	Surf Inlet	Princess Royal Island	53°–128° SW	1902–1943	1.012	388.9	0.2	6.2	—	—	
22	Bralorne	Bridge River	50°–122° NW	1900–1953	3.175	1,550.1	0.4	—	—	—	W
22	Pioneer	Bridge River	50°–122° NW	1908–1953	1.876	1,012.0	0.2	—	—	—	
15	Privateer	Zeballos (V.I.)	50°–126° SW	1934–1953	0.311	170.4	0.1	0.0	0.0	—	
15	Mount Zeballos	Zeballos (V.I.)	50°–126° SW	1939–1944	0.082	56.8	0.0	0.0	0.0	0.0	
15	Spud Valley	Zeballos (V.I.)	50°–126° SW	1936–1951	0.210	54.1	0.0	0.0	0.0	—	
15	Central Zeballos	Zeballos (V.I.)	50°–126° SW	1938–1947	0.058	41.7	0.0	0.0	0.0	0.2	
17	Marble Bay	Texada Island	49°–124° NW	1899–1929	0.314	50.0	0.4	15.0	—	—	
25	Nickel Plate	Hedley (Princeton)	49°–120° SE	1904–1953	3.099	1,272.2	0.1	2.2	—	—	
25	Hedley Mascot	Hedley (Princeton)	49°–120° SE	1936–1949	0.682	223.0	0.05	1.9	—	—	
26	Cariboo-McKinney	Greenwood Mining Div.	49°–119° SE	1894–1946	0.126	69.6	0.0	—	0.0	0.0	
27	Snowshoe	Greenwood Mining Div.	49°–118° SW	1900–1911	0.601	41.3	0.2	13.9	—	—	
28	Union Franklin Camp	Greenwood Mining Div.	49°–118° NE	1913–1946	0.189	55.1	1.4	0.0	0.3	0.7	
29	Le Roi, Centre Star, War Eagle, etc.	Rossland	49°–117° SW	1918–1942	5.937	2,674.1	3.3	118.3	—	—	
32	Sheep Creek (Queen)	Sheep Creek, Salmo	49°–117° SE	1902-1952	0.719	303.8	0.1	—	0.0	0.0	
32	Reno	Sheep Creek, Salmo	49°–117° SE	1929–1948	0.318	168.1	0.1	—	0.1	0.1	
32	Kootenay Belle	Sheep Creek, Salmo	49°–117° SE	1904–1950	0.293	109.9	0.0	—	0.0	0.0	
32	Gold Belt	Sheep Creek, Salmo	49°–117° SE	1934–1951	0.257	80.0	0.0	—	—	—	
31	Ymir	Ymir (Nelson)	49°–117° SE	1899–1950	0.367	109.6	0.5	—	10.5	1.8	
31	Yankee Girl	Ymir (Nelson)	49°–117° SE	1907–1951	0.408	123.8	0.7	—	13.7	14.2	Cd.
31	Second Relief	Erie (Nelson)	49°–117° SE	1902–1948	0.228	98.7	0.0	0.0	0.0	0.0	
31	Granite Poorman	Nelson	49°–117° SE	1890–1953	0.198	64.6	0.0	0.0	0.05	0.0	
31	Arlington	Erie (Nelson)	49°–117° SE	1900–1953	0.033	49.2	0.1	—	0.8	0.5	
14	Cariboo Gold Quartz	Barkerville, Cariboo	53°–121° SW	1933–1953	1.407	520.2	0.04	—	—	—	
14	Island Mountain	Barkerville, Cariboo	53°–121° SW	1934–1953	0.741	320.8	0.0	—	—	—	
	SILVER										
26	Bell, Highland Lass, Sally, Rob Roy	Beaverdell (Greenwood)	49°–119° SE	1913–1953	11.605	4.0	27.5	—	10.0	12.0	Cd.
8	Torbrit (Toric)	Portland Canal	55°–129° NW	1928–1953	0.559	0.1	9.3	—	3.7	0.6	
9	Silver Standard	Hazelton	55°–127° SW	1913–1953	0.144	9.6	4.6	0.1	8.8	16.5	Cd.
9	Henderson (Duthie)	Smithers	54°–127° NE	1923–1953	0.065	2.7	1.65	0.0	6.0	4.9	
8	Dolly Varden	Portland Canal	55°–129° NW	1919–1940	0.037	—	1.4	0.0	0.0	—	
31	Silver King	Nelson	49°–117° SE	1889–1948	0.222	0.3	4.4	14.9	0.0	0.0	

	COPPER										
3	Whitehorse Copper Belt	Whitehorse, Yukon	60°–135° NW	1897–1930	—	—	—	13.1	—	—	
8	Hidden Creek	Portland Canal	55°–129° SW	1914–1936	23.948	121.3	6.6	708.9	—	—	
8	Bonanza	Portland Canal	55°–129° SW	1928–1935	0.724	2.8	0.3	31.5	—	—	
19	Britannia	Vancouver	49°–123° NE	1905–1953	41.330	388.5	4.5	869.2	27.0	144.6	Cd.
24	Copper Mountain	Princeton	49°–120° SW	1917–1953	28.436	163.0	3.9	540.3	—	—	
27	Granby, Phoenix, Knob Hill, Ironsides	Greenwood	49°–118° SW	1900–1942	13.725	642.7	3.8	315.0	—	—	
27	Mother Lode	Greenwood	49°–118° SW	1900–1920	3.773	159.3	0.6	70.1	—	—	
18	Tyee	Mount Sicker, Victoria	48°–123° NW	1901–1951	0.221	26.6	0.5	13.7	0.4	4.2	Cd.
9	Rocher de Boule	Hazelton	55°–127° SW	1915–1952	0.053	4.5	0.1	6.2	0.0	0.0	
	LEAD-ZINC-SILVER										
2	Keno and Galena Hills	Mayo, Yukon	63°–135° NE	1913–1953	—	—	66.1	—	181.6	41.1	Cd.
34	Sullivan	Kimberley	49°–115° NW	1900–1953	63.091	0.1	171.4	—	10,102.7	8,102.8	Cd., Tin 8.8
34	North Star	Kimberley	49°–115° NW	1895–1929	0.068	—	1.3	—	47.9	0.0	
33	St. Eugene	Cranbrook	49°–115° SW	1899–1929	1.062	2.5	5.9	—	249.2	31.9	
38	Monarch and Kicking Horse	Field	51°–116° SE	1888–1953	0.813	—	0.8	—	101.9	157.1	Cd.
37	Giant (Silver Giant)	Golden (Spillimacheen)	50°–116° NE	1908–1953	0.310	0.0	0.2	0.0	23.8	2.0	Sb.
35	Paradise	Golden (Invermere)	50°–116° SE	1901–1952	0.071	0.0	0.7	—	16.0	8.0	Cd.
39	Estella	Fort Steele	49°–115° NW	1951–1953	0.067	0.0	0.9	—	6.4	12.3	Cd.
30	Lucky Jim	Slocan	50°–117° SE	1893–1953	1.174	0.1	0.6	—	8.0	175.8	Cd.
30	Whitewater	Slocan	50°–117° SE	1892–1953	0.501	1.8	3.5	—	30.7	50.9	Cd.
30	Standard	Slocan	49°–117° NE	1905–1953	0.775	0.5	8.2	—	81.0	103.9	Cd.
30	Silversmith and Slocan Star	Slocan	49°–117° NE	1893–1953	0.383	1.2	7.2	—	70.9	22.2	Cd.
30	Payne	Slocan	50°–117° SE	1893–1939	0.122	—	3.7	—	38.3	2.3	
30	Rambler Cariboo	Slocan	50°–117° SE	1895–1951	0.209	0.0	3.5	0.0	23.7	5.9	Cd.
30	Van Roi	Slocan	49°–117° NE	1893–1953	0.297	0.3	2.6	—	16.5	14.9	Cd.
30	Ruth-Hope	Slocan	49°–117° NE	1895–1951	0.065	0.2	2.4	—	22.2	3.3	
30	Cork Province	Slocan	49°–117° NE	1900–1953	0.169	0.05	0.5	—	11.3	15.0	Cd.
30	Victor (Violamac)	Slocan	49°–117° NE	1923–1953	0.052	0.8	1.6	—	18.7	9.2	Cd.
30	Bosun	Slocan	49°–117° NE	1898–1952	0.070	0.1	1.9	—	10.8	6.9	Cd.
30	Queen Bess	Slocan	49°–117° NE	1893–1937	0.018	0.0	1.4	—	18.8	0.0	
30	Highland	Ainsworth, Kootenay Lake	49°–116° NW	1890–1953	0.098	—	0.3	—	20.6	0.8	Cd.
30	Yale (Highlander, etc.)	Ainsworth, Kootenay Lake	49°–116° NW	1889–1953	0.145	0.1	0.3	—	14.6	4.4	Cd., Sb.
30	Florence	Ainsworth, Kootenay Lake	49°–116° NW	1912–1953	0.127	0.1	0.2	—	13.7	2.8	Cd.
30	Number One	Ainsworth, Kootenay Lake	49°–116° NW	1889–1929	0.040	0.2	2.0	—	0.3	—	
30	Blue Bell	Riondel, Kootenay Lake	49°–116°NW	1895–1953	0.895	—	1.3	0.4	90.0	48.2	Cd.
32	Jersey (Emerald)	Salmo (Nelson)	49°–117° SE	1906–1953	1.319	—	0.1	—	65.0	121.9	Cd.
32	Reeves — MacDonald	Salmo (Nelson)	49°–117° SE	1949–1953	1.058	—	0.1	—	19.4	72.1	Cd.
	TUNGSTEN										
32	Emerald	Salmo (Nelson)	49°–117° SE	1944–1953	0.331	—	—	—	—	—	WO_3, 5.3
9	Red Rose	Hazelton	55°–117° SW	1942–1953	0.088	0.3	0.0	0.0	—	—	WO_3, 1.7

Note 1 — *See* Figure 66 for location of numbered properties.
Note 2 — Latitude and longitude of southeast corner of one-degree quadrangle and quarter of quadrangle in which property is situated.
Note 3 — Years of earliest and latest recorded production.

The Polaris-Taku mine (5) lies near the east flank of the Coast Range batholith, about 40 miles northeast of Juneau, Alaska. The vein zones occur in a greenstone complex consisting of folded tuffaceous rocks cut by altered basic intrusions. They are widest and most continuous in bedded, blocky members, and are generally narrow and less continuous in schistose and serpentinized members. Vein matter consists of quartz, carbonate, and wall-rock fragments which are partly replaced by pyrite and arsenopyrite. Gold is very fine and is associated with arsenopyrite and in some places, stibnite.

The Silbak-Premier mine (7) near the head of Portland Canal is noteworthy for its high productions of silver in proportion to gold. The property lies close to the eastern edge of the Coast Range batholithic area. The country rock at the mine is feldspar porphyry holding many large inclusions of sheared volcanic rocks altered to greenstone and chloritic schist. The porphyry forms a stock about 3 miles long. The orebodies occupied fracture or shear zones, and most of the ore occurred where these zones cut brittle porphyry rather than where they crossed the more easily sheared volcanic rocks. The orebodies were, however, mainly in porphyry that is capped by such impervious rocks, and few occurred in those porphyry bodies that have large surface exposures. Most ore shoots are in northeasterly striking shear zones; only a few are in northwesterly striking zones. The main ore zone extends for a total length of 6,700 feet, swinging from northwest to northeast, but the stopes average only about 260 feet in depth, and rarely more than 30 feet in width. The ore at depth is primary, consisting of pyrite, galena, and sphalerite, with some chalcopyrite. The upper 300 to 600 feet contained secondary ore minerals and was greatly enriched in gold and silver.

The Surf Inlet mines (13) on Princess Royal Island were the most important of several operating in the northern coastal areas south of Portland Canal. The orebodies are quartz-pyrite veins in a complex fault zone that traverses gneissic quartz diorite of the Coast Range intrusions and also cuts a large inclusion of chlorite schist. Two main veins at the surface join at depth to form a single vein 40 feet wide in places. Auriferous pyrite composed up to 25 per cent of the vein material. Chalcopyrite, native silver, hematite, and molybdenite were also present. Quartz and ankerite were the principal gangue minerals.

The Zeballos camp (15) is on the west coast of Vancouver Island. The main properties are grouped within an area of about 2 by 3 miles at the nose of a quartz diorite intrusion that extends several miles to the southeast. The invaded rocks are andesite, tuff, limestone, and granodiorite of presumed metasomatic origin.

The orebodies are quartz veins that occupy fault fissures in the quartz diorite and adjacent rocks. The fissures occur in several sets and are believed to mark complementary shears and tension fractures. They are rarely more than a foot wide and maintain a fairly uniform strike and dip. The walls are commonly marked by a film of gouge. The veins are banded and consist of quartz and sulphides. Coarse, crystalline visible gold is fairly common. The amount of gold is proportional to the sulphide content and generally depends on the presence of sphalerite and galena.

The Bridge River camp (22) lies near the east flank of the Coast Range intrusive belt and includes the important Bralorne and Pioneer mines. The Bralorne has, of late years, been the leading gold producer of the province. These two properties adjoin each other along a northwesterly trending belt of rocks bordered on the northeast by a thrust fault and on the southwest by a shear zone of serpentine (Figure 67).

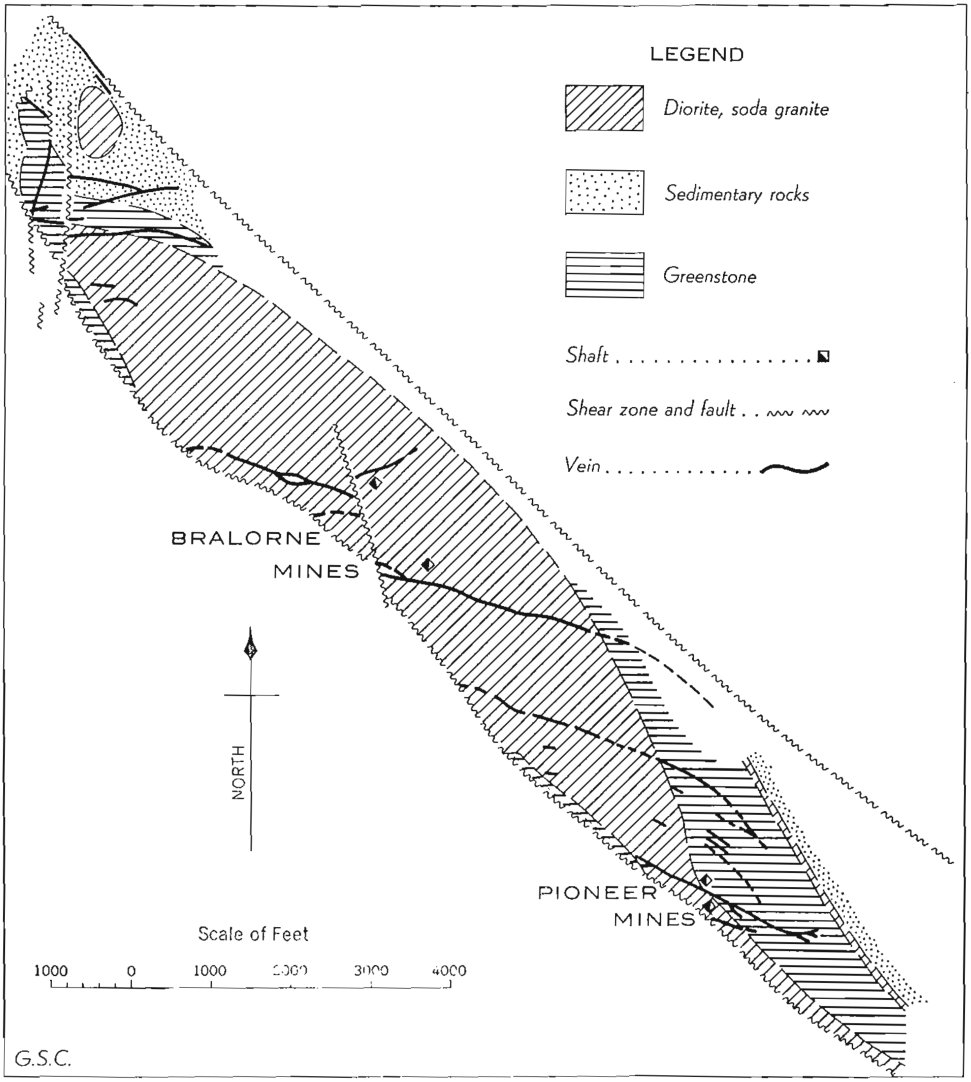


FIGURE 67. Bralorne and Pioneer mines, British Columbia, plan at elevation of 3,200 feet. (Generalized after Franc R. Joubin.) Permission of the Canadian Institute of Mining and Metallurgy.

The principal vein-bearing fissures occur in and near a long, narrow body of augite diorite and soda granite that intrudes greenstone and sedimentary rocks. The veins strike west-northwesterly, angling obliquely across the belt, and dip steeply. Some are remarkably persistent, one vein having a known length of 7,800 feet and depth of 4,250 feet. The lower part of this vein contains the biggest ore shoot in the camp, which now provides most of the ore at the Bralorne mine. A pronounced ribbon structure is a common feature of the veins, which range up to about 20 feet in thickness.

Metallic minerals are chiefly pyrite and arsenopyrite, with some sphalerite, galena, and other sulphides. Gold occurs native and as the telluride, with arsenopyrite and other sulphides, disseminated through massive vein quartz. Gangue minerals also include much calcite and important amounts of scheelite. The altered wall-rocks contain abundant carbonates, with pyrite, mariposite, quartz, and albite.

Vein widths do not alter materially with depth. Economic veins appear to be fewer but individual ore shoots are larger, ranging up to 800 feet in length and carrying up to 0.69 ounce a ton. The sulphide mineralization becomes less varied at depth, consisting chiefly of arsenopyrite and pyrite, with minor amounts of sphalerite. Sphalerite continues, as at upper levels, to serve as a useful indicator for high gold content.

The Hedley district (25) includes the Nickel Plate mine, once Canada's largest gold producer, the Sunnyside, and Hedley Mascot mines.

Rocks of the productive upper part of Nickel Plate Mountain comprise Triassic limestone, quartzite, and argillite, and sills and stocks of gabbro and diorite. The youngest rock is granodiorite which forms the base of the mountain. The strata dip gently west but are traversed by several northwesterly trending minor folds. Low-angle, west-dipping thrust faults divide the rocks into several superimposed slices, separated by breccias.

The orebodies occur within the beds of the Nickel Plate formation between the gently dipping surface of the granodiorite and the breccia of the lowest thrust, known as the Climax breccia. Within this wedge the sills and sedimentary rocks have been intensely metamorphosed. Close to the basic intrusions the calcareous strata have been converted to a pyroxene-garnet skarn. All known ore shoots occur in the skarn not more than 250 feet from the "Marble Line" that separates skarn from relatively unaltered limestone. Further deformation and fracturing, together with the damming effect of intrusive sheets, still further localized the deposition of metallic minerals. The last and most detailed control is formed by the intersection of sills and dykes, ore shoots often occurring in the crotches between the two, and also in small drags or crumples.

Arsenopyrite is the chief metallic mineral. Gold occurs as the native metal in minute specks in the arsenopyrite and, to a lesser extent, in pyrrhotite. It appears that the gold is in two generations: one early, accompanying the arsenopyrite, and one later than most of the sulphides and accompanying calcite.

The Rossland properties (29) inactive except for minor leasing operations since 1928, still greatly surpass all other lode mining camps in Western Canada in recorded gold production. Ninety-eight per cent of the tonnage came from an area about 4,000 by 2,000 feet, worked by four interconnected mines: the LeRoi, Centre Star, War Eagle, and Josie.

The country rocks consist of augite porphyry flows and sills, interbedded with slates of the Mount Roberts formation. These are intruded by an elongate stock of monzonite, by diorite porphyry tongues, and at depth by granodiorite of the Nelson batholith. Lamprophyric dykes also played an important role in ore control.

An irregular horseshoe, formed by the west end of the monzonite stock, enclosed the main area of mineralization (Figure 68). The ore occurs chiefly in augite porphyry near two monzonite prongs, and commonly along the contacts of diorite porphyry tongues. The lamprophyre dykes occupy a north-trending set of

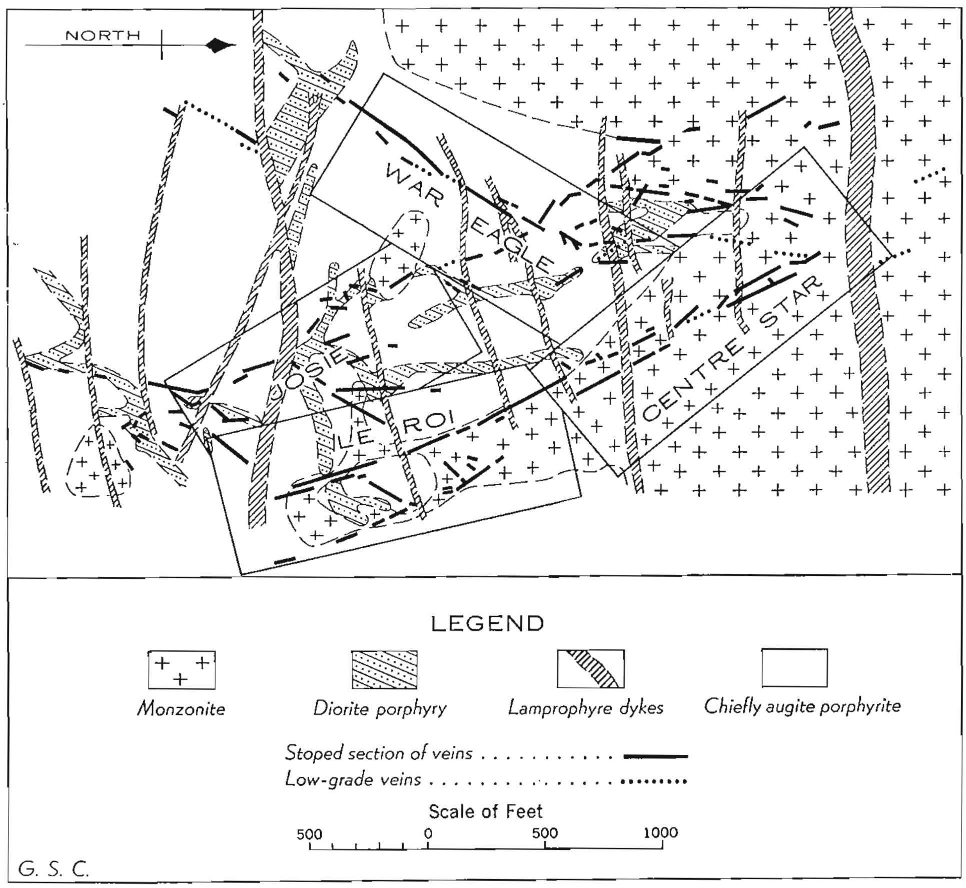


FIGURE 68. Generalized plan of the central area of the Rossland camp, British Columbia, at an elevation of approximately 3,500 feet. (After Geoffrey Gilbert.) Permission of the Canadian Institute of Mining and Metallurgy.

fractures and the veins fill two sets, one trending northeast and the other northwest. The veins are chopped into short lengths by the dykes, which were incompetent under fracture and acted to some extent as barriers to the ore-bearing solutions. These and other cross structures in part determine the location of ore shoots which occur more or less *en échelon* in strike and dip along the veins.

The orebodies are replacement lodes along fissure veins. The ore is composed chiefly of pyrrhotite, chalcopyrite, and pyrite, in a gangue of altered wall-rock, quartz, and calcite. It ranges from massive sulphide to sparse disseminations. Neither gold nor copper bears much relation to the total sulphur, and the gold-copper ratio is extremely variable.

The Sheep Creek camp (32) lies in a belt of lower Palæozoic rocks, about 25 miles south-southeast of Nelson. Up to 1952, when operations were suspended, it ranked as the sixth in British Columbia in terms of gold produced.

The country rocks, mainly quartzite, argillaceous quartzite, and some limestone are closely folded along northerly trending axes and dip steeply to the east. Several granitic stocks occur nearby and a narrow belt of aplite dykes, parallel in strike and dip with the bedded rocks, passes through the central part of the productive belt. The productive belt extends northward about 3½ miles from the vicinity of Sheep Creek and is less than a mile wide.

The gold-bearing quartz veins occupy fault fissures that strike north of east, diagonally across the bedded rocks, and generally dip steeply. The fissures are tight and poorly mineralized where they cross argillite and limestone but commonly contain quartz veins and ore where they cross certain quartzite beds. In any one vein the profitable ore shoots have been found within a vertical range of not more than 1,600 feet. This depth zone slopes regularly downward from the northern to the southern end of the camp. Veins as mined range from a few inches to about 5 feet in thickness. Patches of high-grade ore occur at random and rarely exceed a few hundred square feet in area within the plane of the vein.

The main metallic sulphides are pyrite, pyrrhotite, chalcopyrite, galena, and sphalerite. Gold occurs with the sulphides, especially galena and sphalerite, and also within the quartz. Other gangue minerals include calcite, scheelite, and wolframite. The sulphide content of veins decreases at depth in several mines. Oxidation of sulphide minerals extends to depths of more than 1,000 feet in some veins.

Cariboo Gold Quartz (14), which also operates the former Island Mountain mine, near Barkerville, is the important lode gold producer of the Cariboo district. The mines are in the northern part of a northwesterly trending belt that lies along the line of the richest gold placers. The belt coincides with the outcrop of certain quartzitic members of the tightly folded Cariboo sedimentary group. The lodes are auriferous pyritic bodies comprising quartz veins and bedded replacements in limestone.

The veins are systematically related to faults and are transverse or diagonal to the strike of bedding (Figure 69). They occupy fractures whose spacing largely

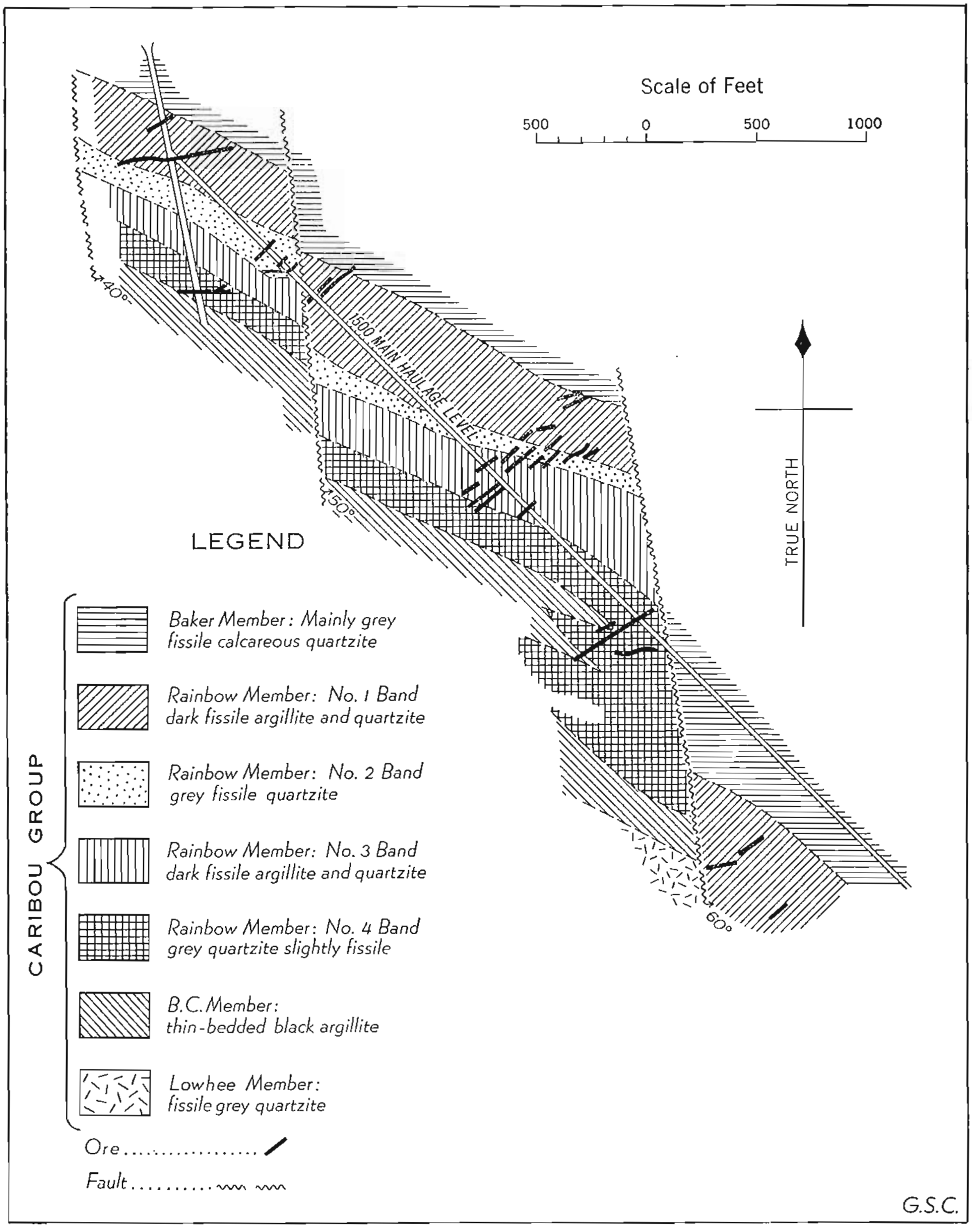


FIGURE 69. Plan of 1,500-foot level Cariboo Gold Quartz mine, British Columbia. (After F. Richards.) Permission of the Canadian Institute of Mining and Metallurgy.

determines the tenor of ore. The vein filling is fractured and the mineralization may post-date the original fracturing. Metallic minerals include pyrite, arsenopyrite, galena, sphalerite, and scheelite; also bismuth-lead sulphides which occur in nests commonly accompanied by free gold. Gangue minerals are mainly quartz and ankerite.

Replacement deposits in limestone occur in pencil-shaped bodies at the crests and troughs of folds or in tabular bodies on the limbs, and are commonly associated with transverse veins. Massive pyrite bodies of this type are especially rich in gold.

Copper

Copper produced in the Cordilleran region up to the end of 1955 was valued at $448,157,000, more than one-sixth of the national total, and came mainly from the Britannia, Copper Mountain, and Hidden Creek mines, and the Greenwood (Phoenix) and Rossland camps. All the known important copper deposits are in the central and western parts of the western Cordilleran region, notably along the coast and islands, and in the southern interior west of Nelson. For the most part they lie close to large intrusive bodies, such as the Coast Range and Nelson batholiths, and are to some extent replacement bodies in sheared greenstone or limestone. Gold is the most valuable associated metal and many smaller copper-bearing deposits were worked originally or primarily for their gold content.

The Whitehorse Copper belt (3) just west of Whitehorse, Yukon, was discovered in 1897 and worked intermittently until 1920 when it was virtually abandoned. The deposits occur in skarn at the contacts of granite with limestone and are scattered through a belt about 12 miles long. The chief ore minerals are bornite and chalcopyrite, commonly associated with abundant magnetite and some specular hematite.

The Hidden Creek mine (8) at Anyox has been inactive since 1936, but is second only to Britannia in recorded copper production. The country rocks are metamorphosed argillite and amphibolite that form a remnant about 20 miles long in granitic rocks of the Coast Range batholith. They are closely folded, broken by faults, and cut by post-ore dykes. The ore deposits occurred in the amphibolite, at and near the contact with argillite. The ore ran from 1.2 to 2.3 per cent copper, with some gold and silver. Ore minerals are chalcopyrite, sphalerite, and galena, associated with pyrrhotite, pyrite, magnetite, and arsenopyrite.

The Britannia property (19) of Britannia Mining and Smelting Company Limited, on Howe Sound has been the principal copper producer of Western Canada. The country rocks are steeply dipping slaty tuffs and greenstones, part of a roof-pendant about 7 miles long in granodiorite of the Coast Range intrusions. Movements on a fault zone near the contact between the slaty tuffs and relatively competent greenstones have resulted in a zone of shearing about 5 miles long, accompanied by a number of drag-folds that plunge northwest (Figure 70). Adjacent to these folds the greenstones were silicified, repeatedly brecciated and fissured, and partly replaced by pyrite, chalcopyrite, sphalerite, galena, tetrahedrite,

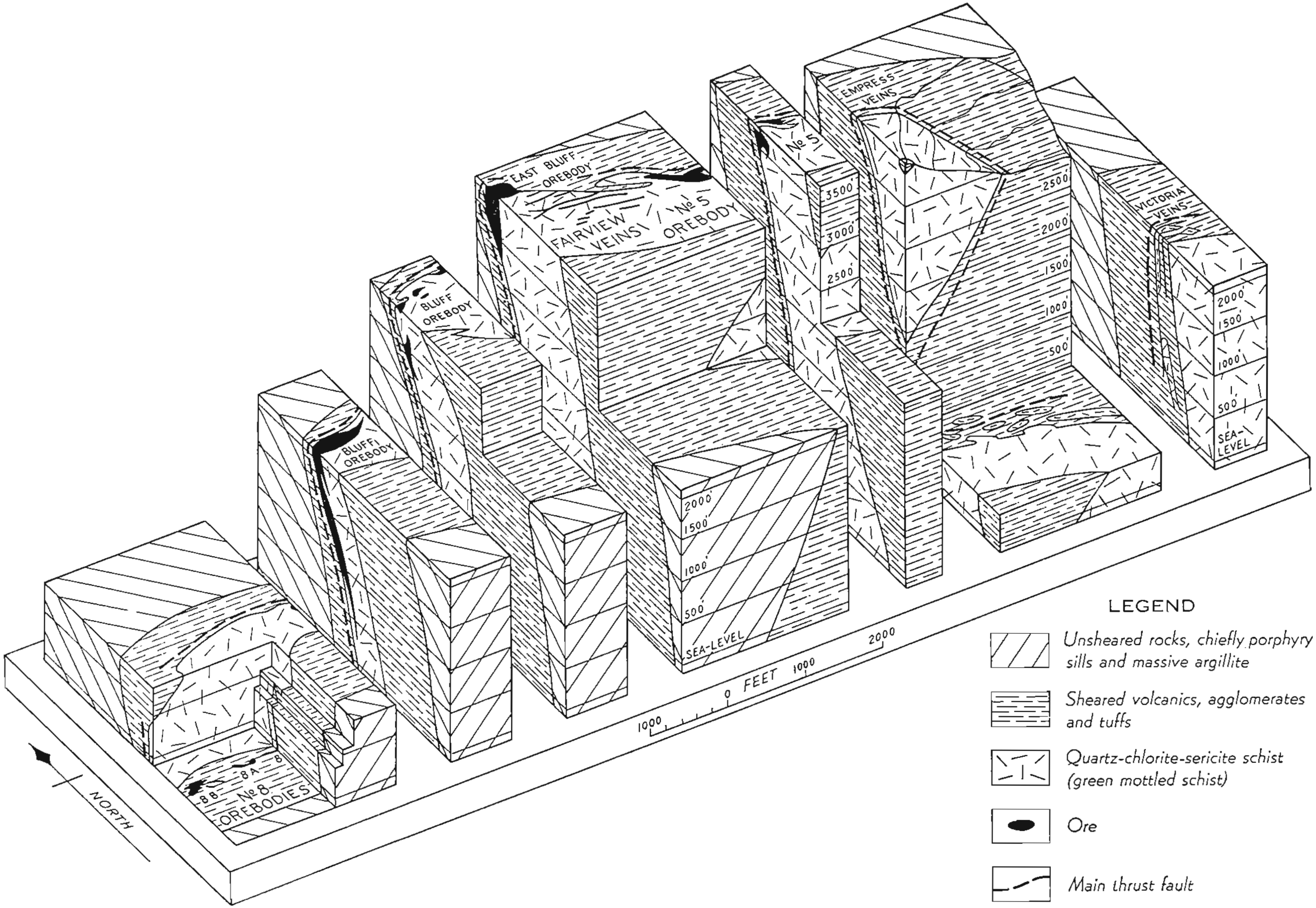


FIGURE 70. Block diagram showing the various Britannia orebodies. (After W. T. Irvine.) Permission of the Canadian Institute of Mining and Metallurgy.

barite, and anhydrite. The resultant orebodies, worked at the Bluff, Fairview, Empress, and Victoria mines, occur at intervals along about 1½ miles of the shear zone.

The Copper Mountain mine (24) of Granby Consolidated Mining, Smelting and Power Company Limited, is about 12 miles south of Princeton. The orebodies are in volcanic rocks of the Nicola group, adjacent to the northeast edge of an elliptical stock about 5 miles long. The stock varies in composition from gabbro at its outer margin to copper-bearing pegmatitic syenite at its centre (Figure 71). All phases are quartz-free. Fragmental rocks adjacent to the stock strike parallel to the long axis and are cut by a set of "ore-fractures". These fractures extend at right angles to the contact but do not penetrate beyond the outer margin of the breccias, where they adjoin massive non-fragmental rocks. The ore occurs as vein fillings in the fractures and as disseminated particles in sheared rock between them. The spacing of the fractures determines the tenor of the ore. The chief ore minerals are bornite, chalcopyrite, and chalcocite. Common vein minerals, quartz and pyrite, are conspicuously rare or absent.

The Granby Phoenix (27) properties of Granby Consolidated at Phoenix, and the Mother Lode mine at Deadwood, both near Greenwood, were the major copper producers of the Boundary district in the past. In this district, formerly an important contributor to the Province's output of copper, several old mines were reopened in 1956. The orebodies are of the skarn type, consisting of chalcopyrite, pyrite, magnetite, and specularite, disseminated through a gangue made up largely of garnet, epidote, calcite and quartz. They were formed by replacement of limestone, and are presumably related to granodiorite intrusions, although no large plutonic bodies outcrop at Phoenix. The skarn deposits at Phoenix are irregular lens-like bodies lying along a jasperoid foot-wall and mainly limited to about 200 feet in thickness. The ore mined averaged 1 to 1½ per cent copper, with some gold and silver. At the Mother Lode gold recovered was valued at more than half that of copper.

Other Properties. The Rossland camp ranked next to the Granby Phoenix in copper production but was primarily a gold camp. Other well known old producers are on Vancouver Island and in the Hazelton and Kamloops districts. Important contributions have come lately from the Tulsequah (Taku River) area, and new developments in the Unuk River area, where Granduc Mines Limited is preparing a copper property for production, indicate large tonnages of copper ore. A copper occurrence on Evans Mountain, west of Kimberley, is a rare example of deposits believed related to pre-Mesozoic intrusions, in this case the Precambrian (?) Purcell intrusions.

Silver

Silver production from the Cordillera to the end of 1955 valued at $281,084,000 came mostly from the lead-zinc-silver ores of the Sullivan mine, the silver-rich lead-zinc ores of the Keno Hill, Slocan and Ainsworth camps, and the Premier gold mine but a few properties are primarily silver mines.

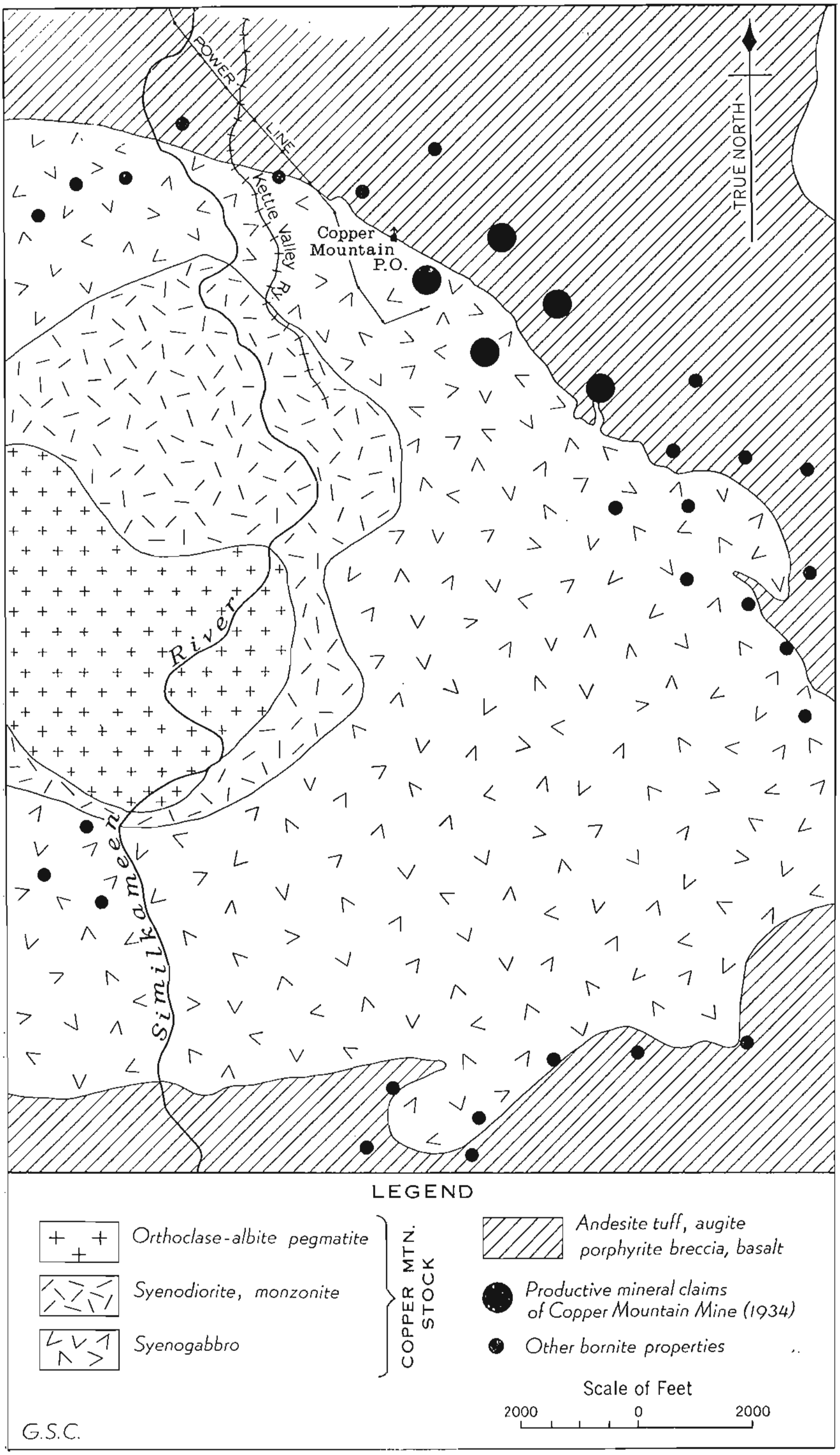


FIGURE 71. Copper Mountain area, British Columbia.

The Beaverdell camp (26) is on West Kettle River, about 25 miles east-southeast of Penticton. The high-grade silver deposits, now operated as the Highland Bell mine, occupy an area on Wallace Mountain about 1½ miles long and ½ mile wide.

The deposits are mineralized shear zones in quartz diorite of the West Kettle batholith. They change progressively in strike from an east to a northeast direction, dip southerly, and vary up to 15 feet in width. The vein matter includes pyrite, sphalerite, and galena with some arsenopyrite and chalcopyrite, in a gangue of quartz, calcite, fluorite, and sericitic remnants of wall-rock. The vein walls are sheared and brecciated, with much clayey gouge. Ore shoots contain visible amounts of tetrahedrite, pyrargyrite, polybasite, argentite, and native silver. The orebodies are cut by numerous north and northeasterly trending faults, and the productive belt has been downfaulted progressively towards the east.

Other Properties. A few other properties listed as silver producers have geological features of special interest. The Torbrit (Toric) deposits near Alice Arm, B.C. are replacements in sheared fragmental greenstone, and consist mainly of hematite, barite, quartz, jasper, and carbonates with a small proportion of pyrite, galena, and other sulphides. Silver is present only as the native metal, in thin flakes. The Silver King mine near Nelson was one of the first discoveries in southeastern British Columbia. It is unique in that silver is present mainly as stromeyerite, and copper is the most abundant base metal.

Lead-Zinc-Silver

Lead valued at $820,275,700, zinc at $684,492,100, and silver at $281,084,000, produced in the Cordilleran region up to the end of 1955 amounted to more than 90 per cent, more than half, and nearly half, respectively, of the national totals for these metals. Cadmium to the value of $26,657,770, about 84 per cent of the national total, was also derived from zinc-rich ores of the Cordillera in that period.

In contrast with copper deposits, most lead-zinc-silver deposits lie within a northwesterly trending eastern belt, near and beyond the eastern margin of the main zone of large intrusions such as the Nelson batholith. This belt includes numerous deposits of southeastern British Columbia, including the only important metal mine in the eastern Cordillera, and also those of Keno and Galena Hills and several promising discoveries farther southeast in Yukon Territory. In every important case, the country rocks are mainly sedimentary, and the deposits appear to be, or to have some of the characteristics of, moderate to low temperature types. Copper, where present, is usually in the form of complex copper-silver-lead minerals and the presence of such minerals is a characteristic feature of those deposits that are richest in silver.

Keno and Galena Hills (2) from which most of Yukon's production has come, form the central part of an easterly trending mineralized zone about 20 miles long. The rocks are gently dipping, but intricately folded, ancient quartzite and schist with some limestone, and sheared greenstone of probably igneous origin. The ore occurs as fillings along mainly northeasterly trending left-hand faults. Most productive veins occur in quartzite and many lie near contacts with schist. Others are at or near contacts between schist and greenstone. Right-hand cross-faults offset the veins and some post-mineral shears are parallel with them.

The principal ore minerals are galena (commonly carrying 100 to 200 ounces of silver a ton), grey copper (generally richer in silver than the galena), and sphalerite. The gangue consists of manganiferous siderite and quartz. Secondary minerals are locally important and include cerrusite and ruby silver. The value of the ore is counted mainly in ounces of silver.

The Sullivan mine (34) at Kimberley is the largest lead-zinc-silver mine in Canada. Although known since 1892, it was not until new metallurgical processes for treatment of the complex sulphide ores were applied in 1923 that successful exploitation became possible. Metals now recovered include lead, zinc, silver, cadmium, tin, antimony, bismuth, copper, and gold.

The country rocks are quartzite, argillaceous quartzite, and siltstone of the Aldridge formation of Proterozoic age. Quartzite and slate of the overlying Creston formation outcrop north of the Kimberley fault. Sheet-like bodies of diorite and granophyric rock identified with the Purcell intrusions outcrop east and west of the mineralized area and similar dykes are encountered in the mine workings.

The regional dip of the bedded rocks is about 30 degrees east, and the orebody lies at the crest and on the east limb of a broad anticlinal nose (Figure 72). Minor folds on the limb, locally sharp, trend about north. A large east-trending fault, the Kimberley, crosses the workings towards the northern limit. A well defined set of faults of the "Sullivan" type, striking east of north, offsets the orebody successively downward to the west.

The foot-wall of the orebody consists of conglomerate and a tourmalinized cherty rock. The ore horizon is mainly thin-bedded argillaceous siltstone and the hanging-wall is massive quartzite, in large part chloritized and albitized. The orebody pinches and swells, attaining a maximum thickness in excess of 200 feet. Much of the ore is well banded, in layers ranging down to a fraction of an inch in thickness and consisting of alternate laminae of galena, marmatite (iron-rich sphalerite), and pyrrhotite. The laminae are commonly contorted and evidently reflect original sedimentary bedding. Pyrite, chalcopyrite, and arsenopyrite are occasionally present, and fibrous boulangerite, a lead-antimony mineral, is prominent locally in open fractures. Typical high-temperature minerals are present in small amount and include garnet, magnetite, and cassiterite. A central oval-shaped zone about 800 feet long consists chiefly of pyrrhotite. The outer part of this zone is relatively rich in tin and the ratio of lead to zinc is especially high around the outer edge. Tin is locally concentrated also in some parts of the foot-wall zone that are impregnated with pyrrhotite.

The main factors in the localization of the orebody are believed to be favourable lithology for replacement and overall permeability of the ore horizon.

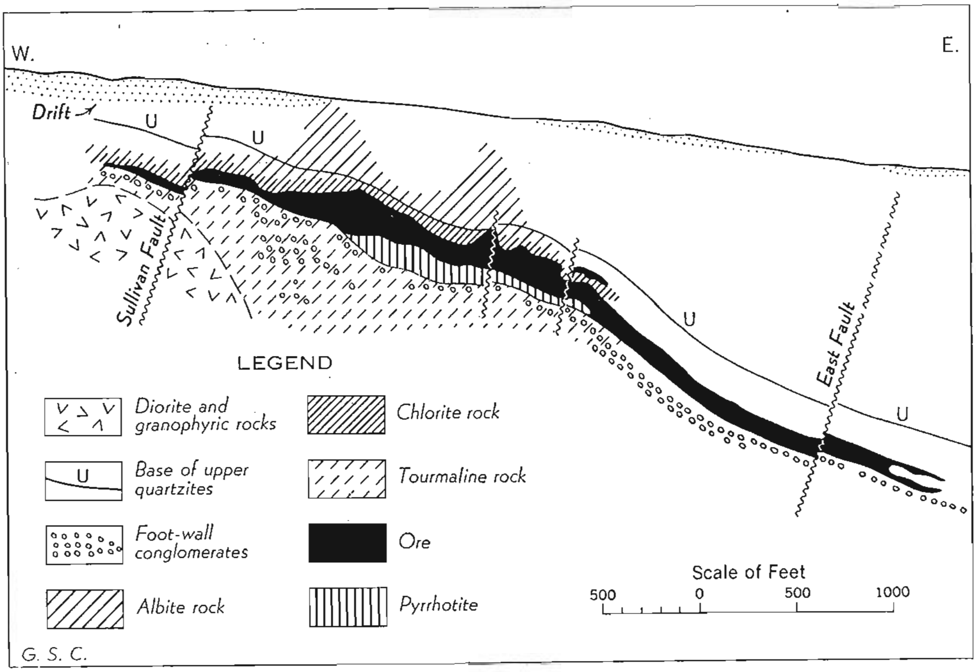


FIGURE 72. Vertical east-west section of the Sullivan Mine, British Columbia. (After C. O. Swanson and H. C. Gunning.) Permission of the Canadian Institute of Mining and Metallurgy.

Permeability may be related to the presence of the foot-wall conglomerate and to the competency of the hanging-wall quartzites, as a result of which deformation would be concentrated in the less competent strata that make up the ore horizon. The mineralization has most commonly been attributed to the main, late Mesozoic, period of regional batholithic intrusion, but the older Purcell intrusions are not excluded as the possible source.

The Monarch and Kicking Horse mines (38) at Field, inactive since late in 1952, were the only important mines lying within the Palæozoic belt of the eastern Cordillera. They lie on opposite sides of Kicking Horse River on the slopes of Mount Stephen and Mount Field and are probably remnants of one original orebody.

The ore deposits occur in gently dipping Middle Cambrian, dolomitic limestone of the Cathedral formation. They are at or near the base of a prominent dolomitic alteration zone, which is partly brecciated and is at the top of a band of dark grey to black dolomitic limestone. The ore is further localized in part by fracturing, but many ore margins have no visible localizing factor. The alteration zone, in which bedding is obliterated, is of major size, being 4,000 to 4,500 feet long, as measured on the mountain faces, and up to 400 feet thick. Brecciation throughout the lower part is said to be related to minor structures in the underlying thin-bedded rock. The alteration-breccia zone may be related to drag-folds, shattered and now obliterated, on the eastern flank of a broad northerly trending anticline. The orebodies occur in the breccia, but the reasons for their exact position are in doubt.

The two principal orebodies at the Monarch mine are long narrow flat bodies striking about north and lying about 660 feet apart. The west one was 1,760 feet long, 158 feet wide at the cliff, and averaged 19 feet in thickness. The east body has been explored for more than 2,300 feet. The orebodies so far developed at the Kicking Horse are smaller, and less regular. The ore has replaced breccia fragments and white dolomitic matrix, and consists of sphalerite, galena, pyrite, and minor chalcopyrite, quartz, barite, and silver. The west Monarch orebody averaged 1.7 ounces of silver, 10.5 per cent lead and 12.5 per cent zinc. The mineralization is thought to be related to an igneous body of which the Ice River alkaline intrusive complex, 15 miles to the south, is the only visible part.

The United Estella mine (39) in the Fort Steele Mining Division, a lead-zinc-silver property, and several other metallic mineral deposits lie east of the Rocky Mountain Trench opposite Cranbrook. They are in Proterozoic rocks of the Purcell system and, though east of the trench, belong to the western Cordilleran geological province.

The St. Eugene mine (33) is at Moyie, 15 miles south of Cranbrook. Inactive since 1923, except for retreatment of old tailings for zinc, it was at one time the largest lead producer in Canada.

Two main fissures in argillaceous quartzite of the Purcell series are joined by a system of connecting fissures that usually meet the main fissures at small angles. The orebodies occurred as replacements, mainly at or near such junctions. The ore consisted of galena, with sphalerite, pyrite, pyrrhotite, magnetite, and chalcopyrite. Garnet, actinolite, and quartz are prominent in the gangue and wall-rocks.

The Slocan camp (30) lies about 15 miles west-northwest of Kaslo, a town on Kootenay Lake. It is noted for the tremendous number and richness of its silver-lead-zinc deposits, and, less favourably, for their discontinuity, unpredictability, and apparent limited persistence in depth.

Most of the deposits occur in argillite, quartzite, and limestone of the Slocan series of probable Triassic age, but important orebodies have been found in the adjacent Nelson granite and related minor intrusions. The former include most of the "wet ores", in which galena and sphalerite are of greater value, and which have accounted for most of the production. The latter exemplify the "dry-ores", carrying much silver, and in places some gold, in quartz veins relatively free of base metals. Ores high in silver usually contain a high proportion of galena to sphalerite, the silver occurring chiefly in small blebs of freibergite within the galena. Ruby silver, stephanite, argentite, and native silver are also present in some ores. Marginal parts of orebodies are relatively richer in zinc than in lead and some orebodies grade downward into pyritic zinc bodies.

The main structure in the Slocan series is a huge northwesterly striking, complex, recumbent fold. A broad cross-warp extends through the main productive belt of the camp. The lodes are in cross-cutting faults, and orebodies are related to zones of fracture in competent beds. Significant replacement deposits occur where, as at the Lucky Jim, vein-bearing fissures cross limestone beds.

The Spider (Sunshine-Lardeau) (36) *and the Mineral King* (35) have lately come into important production. The Spider mine is 30 miles southeast of Revelstoke, and the Mineral King about 25 miles southwest of Invermere.

Tungsten

Tungsten produced in the Cordilleran region to the end of 1955 was valued at more than $25 million, about 95 per cent of the national total.

The Emerald, Dodger and Feeney mines (32) of Canadian Exploration Limited are the largest producers of tungsten in Canada. They are about 25 miles south of Nelson and adjoin the Jersey lead-zinc mine.

Easterly dipping argillite and limestone, probably on the west limb of an overturned fold, are cut off at depth by a granite stock. Scheelite-bearing skarn occurs in limestone immediately above the argillite and along the limestone-granite contact, thus forming a trough-shaped structure. Though modifications occur, such trough structures are essential for the formation of persistent, commercial tungsten ore zones. Several sets of strike-faults complicate the structure. The orebodies are generally lenticular in cross-section with a maximum thickness of about 30 feet at the low point of the trough. The Emerald and Dodger ore zones have each been tested over a length of 4,000 feet. The host rocks include garnet-diopside-amphibole skarn, with quartz, calcite and pyrrhotite. The granite is strongly altered near the contact where quartz-tourmaline veins and pegmatite dykes are prominent. Biotite is also conspicuous in the ore zones.

The Red Rose mine (9) about 8 miles south of Hazelton, was originally staked as a gold property but was developed into an important tungsten producer during the war.

A northwesterly striking shear zone, exposed for about 1,000 feet, cuts a diorite stock that intrudes hornfels, argillite, and quartzite of the Hazelton group. Biotite is plentiful in the invaded rocks. A scheelite-bearing quartz vein is confined mainly to that part of the zone that cuts the diorite stock. Wolframite, ferberite, and chalcopyrite are also present. Where the vein cuts sedimentary rocks, it carries pyrite, pyrrhotite, arsenopyrite, chalcopyrite, and some gold, but no tungsten. Ore shoots in the diorite are separated by barren zones, one of which coincides with a curved section of the vein. Presumably pre-mineral horizontal fault movement here tightened up the vein, preventing ore deposition. A large mass of granodiorite lies to the east of the property and in it, about 2 miles to northwest, lie the Rocher de Boule and Victoria mines.

Cariboo and Bridge River districts. Many tungsten occurrences, both placer and lode, are known in various parts of British Columbia, notably in the Cariboo and Bridge River districts. Many gold-quartz veins and some other metallic mineral deposits contain appreciable amounts of scheelite and small recoveries have been made from a few. Producers up to 1953 include the Columbia Tungsten (Hardscrabble) mine in the Cariboo district and the Tungsten Queen and Bralorne properties in the Bridge River district. Production from these properties has amounted to a little more than 60,000 pounds of WO_3.

Mercury

The Pinchi Lake mercury belt (12, 11) near Fort St. James includes the Pinchi Lake and Bralorne Takla mines and a number of other occurrences. The mines were operated during the Second World War, when they accounted for practically all the Canadian production of about 4.2 million pounds valued at $10,409,359.

The belt lies along a northwesterly trending fault zone at least 150 miles long. The zone marks the contact between Permian rocks on the southwest and Mesozoic rocks on the northeast, and appears to represent a major thrust from the southwest. Most orebodies are in sheared and brecciated Permian limestone, a few in carbonatized serpentine. Cinnabar in veinlets, blebs and grains fills pre-existing openings such as fissures, solution cavities, and interstices between grains and breccia fragments. Permeability was a major factor in controlling ore deposition, and replacement of limestone is of little importance. In places impervious cap rocks and fault gouge have acted as traps to mineralizing solutions. The source of the solutions is unknown. The deposits are probably Tertiary in age since they are later than the faulting, and some fault movements are post-Paleocene.

Near Kamloops (23) mercury deposits occur in carbonatized volcanic rocks mainly north of Kamloops Lake. The Copper Creek Cinnabar property has produced 11,168 pounds and the Hardie at Tunkwa Lake, 199 pounds.

In Tyaughton Creek (21) and vicinity, cinnabar and some native mercury occur in placer deposits and in sheared dolomitized greenstones riddled with porphyry dykes of probable Tertiary age. Stibnite is a common associate. The Empire Mercury property has produced 1,196 pounds of mercury and the Red Eagle, 512 pounds.

Iron

Known iron ore deposits in British Columbia are small compared with the main commercial sources in North America but are becoming increasingly significant in view of rapid growth and industrial development of Western Canada and recent advances in technology. Production on an important scale began in 1951 and to the end of 1955 was valued at $21,672,172.

The Iron Hill (Argonaut) (16) *and the Prescott* (17) deposits have yielded most of this ore. The Iron Hill deposit, owned by Utah Company of the Americas, is in the Campbell River area, Vancouver Island, and the Prescott, owned by Texada Mines Limited, is on Texada Island. Both are well situated with respect to transportation, coal deposits, and important industrial centres. These exemplify a contact metamorphic type of magnetite deposit, of which many are known along the Pacific coast and islands and in southern British Columbia. Such deposits occur commonly in limestone at or near contacts with granitic intrusions. Silicates such as garnet, epidote, pyroxene, and hornblende, normally accompany the magnetite and are in such quantity that concentration is usually necessary to produce a marketable product. Sulphides are commonly present, but in some the sulphur content is quite low. Phosphorus and titanium are low, so that they are of Bessemer quality. Some magnetite-bearing bodies that are high in sulphur contain commercial copper ore. A few replacement deposits, as at Chromium Creek, consist of relatively pure hematite.

Bog iron deposits, some of considerable size, are known in several localities, particularly along the east flank of the Coast Mountains. On Zymoetz River (9) east of Terrace a sheet of soft earthy limonite estimated to contain more than 500,000 tons lies on a steep side-hill. The underlying rock is a green porphyry containing pyrite, and on the slope above the deposit are many pyritic quartz veins. Surface water, charged with iron sulphates from the decomposition of the pyrite, is constantly flowing down the hillside and has gradually built up the deposit by the transformation to limonite of successive layers of moss and other vegetation. Deposition is still in progress.

Similar deposits at the head of Taseko River (20), 65 miles northwest of Lillooet, are estimated to contain 670,000 tons of limonite material with a probable iron content of nearly 50 per cent. The maximum thickness of the sheets is probably about 15 feet.

Miscellaneous Metals

Antimony, valued at $6,380,274, and bismuth at $6,743,874, produced in the Cordilleran region to the end of 1955 amounted to about 93 and 91 per cent, respectively, of the national totals for these metals. Most of this output is recovered at the refineries at Trail, B.C. and is derived from Sullivan ores and custom concentrates. Production of antimony is reported separately from the Snowbird (Stuart Lake Antimony) and a few other properties in the Golden, Slocan, and Bridge River districts.

All the tin produced in Canada, valued at $7,005,866, came from the Sullivan lead-zinc orebody.

Molybdenum occurs in many scattered localities and a small production has been recorded from several properties. Of these, the Molly, a few miles south of the Emerald mine has shipped the equivalent of 25,058 pounds MoS_2.

The only nickel produced was from the British Columbia Nickel Mine, near Hope, and amounted to 281,453 pounds in 1936 and 1937. Other nickel occurrences are known along the Fraser Valley and near Kluane Lake, Yukon Territory.

Colbalt occurs in two localities and, at the Victoria mine near the Red Rose tungsten mine, 1,730 pounds have been recovered, along with some molybdenite, arsenic, and gold. Uranium mineralization accompanies cobalt at both localities and is reported from half a dozen others. Near Kamloops, niobium is associated with uranium at two properties, but no economic deposits of these metals are known.

The only appreciable chromium production was 670 tons of 38.5 per cent Cr_2O_3 from the Mammoth property in the Greenwood area, in 1918. Chromite occurrences in the vicinity of the Cassiar Asbestos deposit have recently been reported. A little manganese ore has been shipped from the Victoria and Slocan areas.

Industrial Minerals

Asbestos

Cassiar Asbestos Corporation property is about 60 miles southwest of Lower Post, in northern British Columbia. Opening of a mill at the property in 1953 marked the establishment of the first important asbestos mining operation in Western Canada. Production to the end of 1955 amounted to 28,907 tons, valued at $8,198,438.

The asbestos occurs in a lenticular body of serpentinite which is intrusive into Devonian argillaceous quartzite and greenstone on the southwest limb of a broad synclinorium. The ultramafic body is at least 1,700 feet long, up to 350 feet thick, and is mainly concordant with the bedding. A low-grade to barren zone forms an envelope around the commercial asbestos deposit. The asbestos veins, chiefly of the cross-fibre and split-fibre varieties, are controlled by joints which were apparently initiated during the folding of the synclinorium. Fibres are commonly ½ to 1 inch, and exceptionally as much as 3½ inches long, and the quality is high. Separation of veinlets from enclosing rock by frost action has produced a large area of asbestos fluff in the vicinity of the deposit and this material contributes to current production.

Gypsum and Barite

Gypsum is quarried at Falkland, 40 miles east of Kamloops; at Mayook, 16 miles east of Cranbrook; and near Windermere, B.C. Total recorded production to the end of 1955 amounted to 1,525,499 tons, valued at $7,038,408. At Falkland the deposits are lens-shaped masses in a fault zone traversing Cache Creek greenstone. In the Windermere area they are finely laminated bedded deposits in the Burnais formation of the western Rocky Mountains. The other known deposits are non-commercial.

To the end of 1954 barite valued at $417,135 came from deposits in Columbia Valley south of Golden.

Fluorite

The largest known deposits of fluorspar in British Columbia are at the Rock Candy mine, 15 miles north of Grand Forks, and near Birch Island Station, 81 miles north of Kamloops. Other occurrences are near Nelson, in Slocan and Ainsworth areas, near Liard Hot Springs, and west of Okanagan Lake. Production, all from the Rock Candy mine, amounted to 40,165 tons of ore between 1918 and 1929, and had a value of $783,578. This deposit is a stockwork of closely spaced veins in syenite. The veins are characteristically vuggy, and contain fluorspar, barite, chert, quartz, calcite, and pyrite. At Birch Island, fluorite is accompanied by celestite, and at Liard Hot Springs, by witherite.

Hydromagnesite and Magnesite

Earthy hydromagnesite deposits occur in the Clinton area and the largest of these is at Meadow Lake. They form horizontal deposits in parts of a shallow depression about 15 miles long. The upper, purer, white layers are as much as 2,000 feet long and 3 feet deep. Other similar deposits of considerable size also occur in the Cariboo, Atlin, and Kamloops areas. Some have been worked on a small scale, but there has been no production for many years.

Rock magnesite makes up a thin bed in the Cambrian Cranbrook formation north of Cranbrook. The deposit is large and, in part, remarkably pure but has not been exploited. Other deposits are known in the Bridge River and Clinton areas.

Saline Deposits

Small, undrained lakes containing concentrated solutions or crystalline deposits of sodium and magnesium salts are found in the Clinton, Chilcotin, Ashcroft, Kamloops, and Okanagan areas in the rather arid interior of British Columbia. A few have been commercially exploited on a small scale. The salts include sodium carbonate, sodium sulphate, and magnesium sulphate.

The soda lakes contain only minor amounts of other salts and one, Last Chance Lake, about 16 miles north of Clinton, contains a permanent deposit of crystalline material as bowl-shaped masses separated by mud. These crystal masses are partly composed of sodium carbonate and range from 4 to 70 feet in diameter and from 1 foot to 10 feet deep.

The sulphate lakes all contain both sodium and magnesium sulphate, but sodium sulphate is the major constituent in some of those of the Kamloops area. One of these lakes may hold 150,000 tons of impure hydrous sodium sulphate as a permanently crystalline deposit containing some 60,000 tons of sodium sulphate.

Lakes containing mainly magnesium sulphate are more widespread. The Basque deposits, 12 miles from Ashcroft, occur in four mud-filled ponds 500 to 750 feet in length. Sodium and magnesium salts, principally bloedite and epsomite, form bowl-shaped masses set in the mud. They are up to 60 feet in diameter and some exceed 10 feet in depth.

Miscellaneous Deposits

Mica to the value of about $165,000 has been produced from properties in Tête Jaune Cache, Armstrong, and other areas.

Talc was produced for several years from a deposit at Anderson Lake, west of Lillooet. Several other deposits have potential value, and small shipments have been made.

Limestone is quarried in several areas and is used in lime and cement manufacture, pulp mills, and as a flux. Lime of a high degree of purity is calcined from Middle Cambrian limestone near Kananaskis station in Bow River Valley, Alberta. A cement plant at Bamberton on the east coast of Vancouver Island uses, as raw material, crystalline limestone of the Vancouver group and nearby tuffaceous argillite. Another cement plant at Exshaw, Alberta, uses limestone of the Palliser formation mixed with shale from the Wapiabi formation.

Stones that have been quarried for building and ornamental purposes include those of the Spray River formation in the Rocky Mountains, sandstone of the Nanaimo series from Vancouver Island and nearby channel islands, granodiorite from Jervis Inlet and a few other localities, and marble from Texada Island and from Marblehead, north of Kootenay Lake.

Clay deposits near Vancouver and Victoria are used in the manufacture of building products, ceramics, and refractories. Other products of minor commercial importance include bentonite, diatomite, and perlite.

Rock phosphate deposits are widespread in the Rocky Mountains but are not of commercial grade at present. Near Banff, Jasper, and Crowsnest Pass they are in beds which lie at or near disconformable or erosional contacts, mainly near the top and base of the Rocky Mountain formation, more rarely within it, and at the base and middle of the Fernie group. At Crowsnest Pass phosphate occurs near the base of the Banff formation.

Fuels

Coal, oil, and gas are the principal mineral products of the eastern Cordillera and coal is of considerable importance in the western Cordillera. Large reserves of bituminous coal and some of Canada's large oil and gas fields are present in the Foothills and Front Ranges of the Rocky Mountains and in Mackenzie River Valley.

Coal

Coal deposits are widely distributed in the Cordilleran region (Figure 73), the largest being in the Foothills and southern Rocky Mountains. Most of the coal mined comes from beds of Lower Cretaceous and Upper Cretaceous age and the remainder from Tertiary strata. Coal production reached an all time high of 7,019,452 tons in 1949 and has since gradually declined until, in 1955, production was 3,575,993 tons. Of the latter, 2,115,072 tons were mined in the Alberta Foothills, 1,446,921 tons in British Columbia and 7,040 tons in the Yukon. Coal production in the Cordilleran region in 1955 accounted for 24 per cent of the total Canadian output of 14,819,000 tons.

Rocky Mountains and Foothills. In the southern Rocky Mountains and Foothills the coal deposits occur mainly in the Kootenay formation of Lower Cretaceous age. The Kootenay is coal-bearing from the International Boundary to a point north of Bow Valley. The coal is mainly of bituminous rank and locally is semi-anthracite. Much of the coal is sheared as the strata may be highly inclined, closely folded, and repeated by thrust faults. Some is hard and blocky where the seams are less disturbed. Coking coal is present locally.

In southeastern British Columbia, Crowsnest coalfield comprises three areas, namely: the undeveloped Upper Elk River area to the north; the central Crowsnest area in which there is large production at Fernie and Michel; and the undeveloped

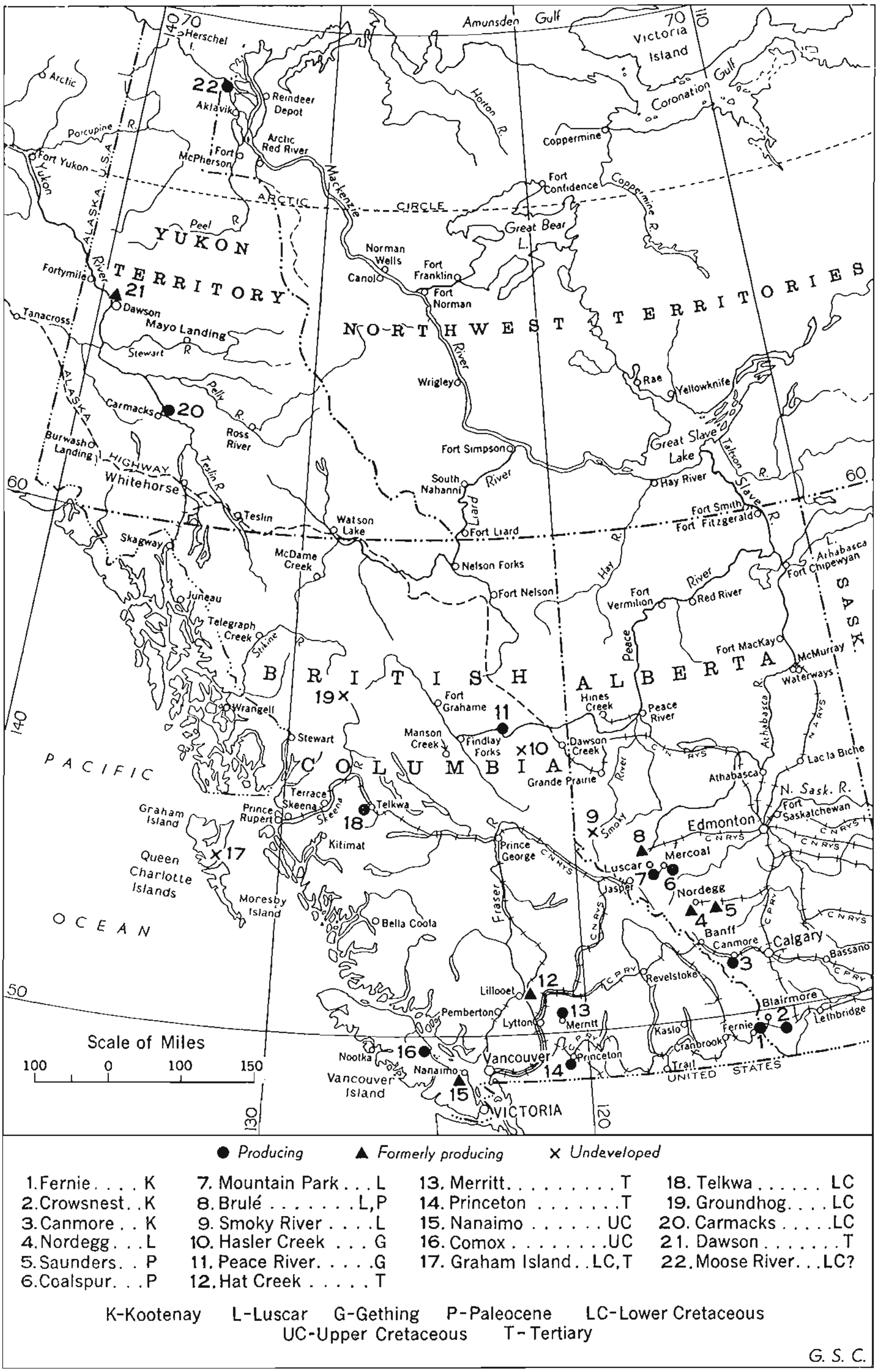


FIGURE 73. Principal coalfields of the Cordilleran region.

Plate XXXV

Tent Mountain strip mine, Crowsnest basin, Alberta and British Columbia. Note remaining coal face in centre.

Flathead River area to the south. In the Crowsnest area the Kootenay is about 3,500 feet thick and contains 22 seams with an aggregate thickness of 150 feet. Some four seams are mined at Fernie where the strata are gently inclined. At Michel to the north, and at Corbin and Tent Mountain (Plate XXXV) to the east, the strata have been folded and faulted and the coal has been squeezed from the limbs into pockets on the crests and troughs of the folds where it is several times thicker than normal. Large volumes of relatively low-grade coal are recovered by strip mining methods at low cost and this, when blended with the superior product from underground mining, produces a larger volume of acceptable coal. In 1955 the Crowsnest area produced 1,164,438 tons and the total production to the end of that year was 50,426,570 tons. The coal is of medium volatile bituminous rank and has excellent coking qualities. The probable recoverable reserves of the Crowsnest coalfield are estimated at 5,167,194,000 tons.

In the Crowsnest coal area of Alberta, coal is mined from the Kootenay formation at Coleman, Blairmore, and Bellevue. The formation has decreased in thickness to 800 feet at Coleman, where five seams aggregate 47 feet in thickness, and to 430 feet at Bellevue, farther east, where three seams total 37 feet. Only two seams are mined at any one locality. The coal is obtained from underground and strip mines. As in the Crowsnest basin, much of the coal recovered in the strip mines lies in pockets. This is well shown at the Grassy Mountain strip mine (Plate XXXVI) where the No. 2 seam, normally about 15 feet thick, has been thickened to 90 feet in a syncline and to 60 feet in an anticline. The coal is of medium and low volatile bituminous rank. It is used as industrial and railway fuel and to a minor extent for domestic purposes. Some is briquetted. Production in 1955 totalled 1,156,119 tons. Probable recoverable reserves are 3,062,640,000 tons.

Along Bow River Valley in the vicinity of Canmore, Kootenay coal has been mined continuously since 1888. The coal measures are about 1,000 feet thick, dip steeply west, and lie within the Palæozoic strata of the Front Ranges. Three seams

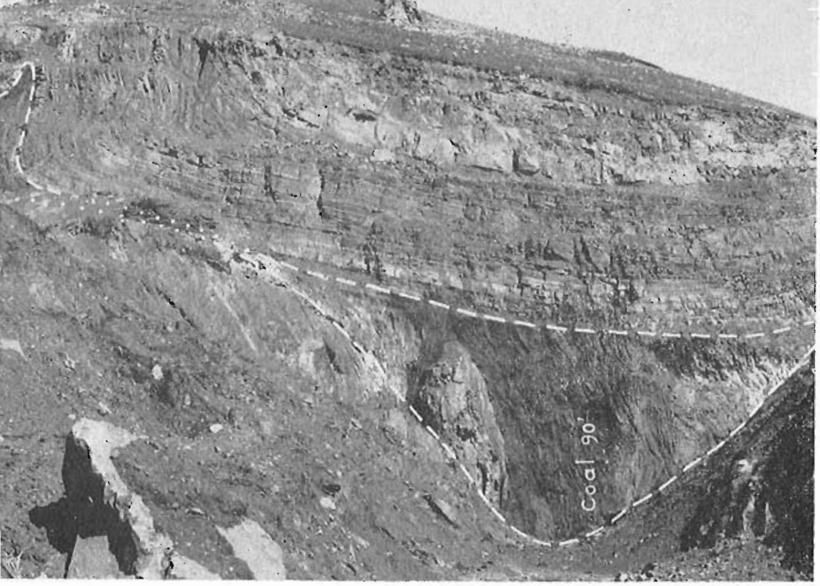


Plate XXXVI

Grassy Mountain strip mine near Blairmore, Alberta showing thickening of coal seam on syncline and anticline and discordance in structure at the roof and floor.

6, 8, and 10 feet thick, are mined. The coal is of low volatile, bituminous rank with small pockets of semi-anthracite. It is briquetted and used mainly as steam coal. Production in 1955 was 201,513 tons; probable recoverable reserves are 1,114,400,000 tons. Between Canmore and Crowsnest Pass much coal is known, principally along Kananaskis, Sheep, Highwood, and Oldman Rivers, and forms a large reserve estimated to be 3,286,640,000 tons. Some small operations were carried out in the past but as the area is not reached by rail, its development has not been carried much beyond the prospecting stage.

At Luscar in the central Foothills of Alberta west of Edmonton, coal is mined from the Luscar formation of Lower Cretaceous age, occurring somewhat higher stratigraphically than the seams in the Kootenay formation. The Luscar formation is about 1,000 feet thick and contains several seams. In its upper part two seams, 6 and 40 feet in thickness, are mined. The coal is of low and medium volatile bituminous rank. All of the 178,335 tons mined in 1955 was from strip mines. Probable recoverable reserves are 3,855,600,000 tons. The coal-bearing Luscar formation extends within the Foothills belt southward to the North Saskatchewan River and northward at least as far as the Kakwa River. Until recently coal was mined at Mountain Park, Cadomin, Brûlé, and Nordegg. In much of the remaining part of the region prospecting has indicated a considerable reserve of bituminous coal.

At Mercoal and Sterco, east of Luscar, coal is obtained from basal beds of the Tertiary, Paskapoo formation. It occurs in four seams, two of which are mined. The seams lie on the flanks of broad folds or are contorted and thickened by minor folds and faults into large masses of sheared coal. The coal is of high volatile bituminous rank. Some is hard and makes a good domestic fuel, or blended with higher rank coal is used as steam coal by the railways. Production in 1955 was 405,104 tons. Coal from the Paskapoo formation was formerly mined at Coalspur, Hinton, and Saunders, and the coal-bearing strata are known to extend some distances north and south of these towns. Probable reserves of recoverable coal are 2,426,490,000 tons.

Coal seams of Upper Cretaceous age extend along the eastern edge of the Foothills belt from the International Boundary to the North Saskatchewan River. The seams occur in the Belly River, St. Mary River, and Edmonton formations. They are not utilized and reserves are small.

In the Peace River area, coal deposits are found in the Gething formation of the Bullhead group. This formation is correlated with the Luscar and it is possible that much of the region between the Kakwa and Peace Rivers is underlain by coal-bearing strata. Coal is mined at Peace River Canyon where 3,650 tons were produced in 1955. Considerable reserves are known nearby in the Carbon Creek basin and on Hasler Creek. The Gething formation extends northward to a point about half-way between Peace and Liard Rivers.

Along Liard River at the south end of the Mackenzie Mountains, and in the Mackenzie River Valley, coal seams of Cretaceous and Tertiary ages occur but are undeveloped. At Moose River, at the north end of Richardson Mountains, about 200 tons are produced annually from a seam 7 feet thick and are used at the town of Aklavik.

Western Cordillera. On Vancouver Island the coal-bearing strata belong to the Nanaimo group of Upper Cretaceous age. The Nanaimo is about 7,000 feet thick, nonmarine in its upper part and partly marine in the lower coal-bearing part. The coal is of high volatile bituminous rank. The strata were deposited in basins on a deeply eroded, uneven surface of Mesozoic sedimentary, volcanic, and plutonic rocks. The seams are floored by sandstone which rarely contains the roots of vegetation from which the coal was derived. Accordingly, it has been suggested that the larger part of the coal was derived from driftwood which was deposited in lagoons. Most of the present production comes from the Tsable River field where 204,369 tons were mined in 1955, and from the Nanaimo field where 5,415 tons were produced. Mining commenced in the Nanaimo and Comox fields in 1852, and about 50 million and 29 million tons, respectively, were produced from these fields to the end of 1954. Coal deposits of the same age occur farther north at Suquash and on Graham Island, the most northerly of the Queen Charlotte Islands. Lignitic coal of Tertiary age is also found on Graham Island.

Coal seams of Upper Jurassic or Lower Cretaceous age occur in rocks included with the Hazelton group in Bulkley River Valley and in Kispiox area north of Hazelton. The coal-bearing strata are cut by minor igneous intrusions and in places lie near younger volcanic rocks. As a result, the coal ranges from low-grade bituminous to low-grade anthracite, depending on the proximity to igneous rocks. Seams range up to 14 feet in thickness, but have been folded and crushed. In 1955 production from the Telkwa coalfield near Telkwa amounted to 31,460 tons. The strata of the remotely situated Groundhog coalfield, at the headwaters of the Skeena River, are presumably of the same age. The seams are closely folded and faulted. The coal is sheared, semi-anthracite in rank, but very high in ash.

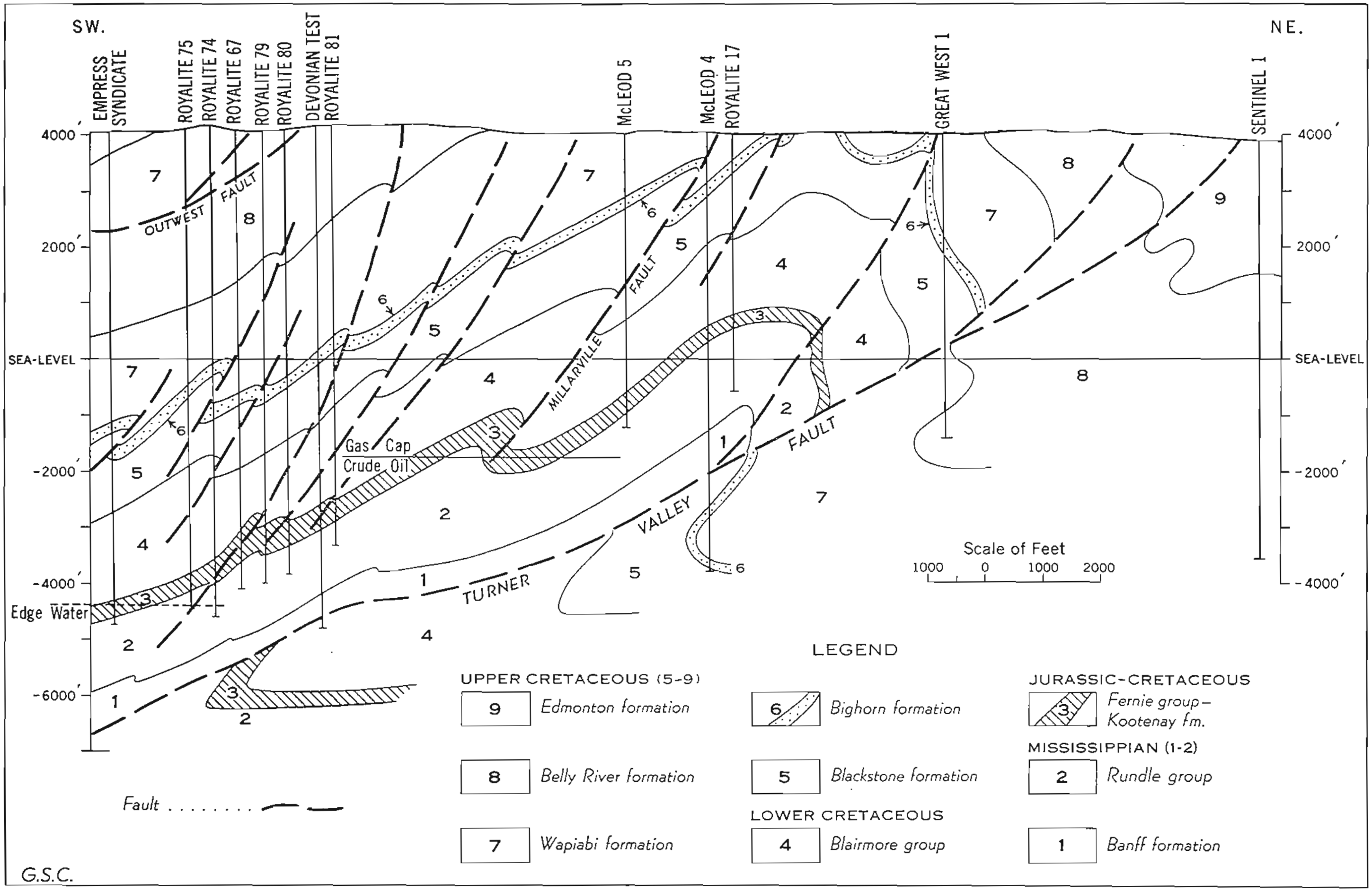


FIGURE 74. Structure-section through the central part of the Turner Valley oil and gas field. (Modified after W. B. Gallup.)

The principal coal mining area in Yukon is at Carmacks where 7,040 tons were mined in 1955. Production is from a seam 9 feet thick in the Tantalus formation of early Lower Cretaceous age. This formation occurs in several small, isolated areas between Carmacks and Whitehorse. A little Tertiary coal is mined from a locality about 40 miles north of Dawson.

Coals of Tertiary age are widely distributed over the western Cordillera, but the principal producing areas are in the south near Princeton and Merritt. There, production of subbituminous and high-volatile bituminous coal amounted to 74,734 tons in 1955. At Hat Creek the seams are exceptionally thick, totalling 466 feet. The coal is very dirty but may be, in part, recoverable by stripping.

Petroleum and Natural Gas

Petroleum and natural gas are found in four major fields in the eastern Cordillera. Three of these, Turner Valley, Jumpingpound, and Pincher Creek, lie in the southern Foothills of Alberta (Figure 64). The fourth, the Norman Wells field, lies in Mackenzie River Valley between the Franklin and Mackenzie Mountains, in the Northwest Territories. Oil is produced from the Norman Wells field, oil and gas comes from the Turner Valley field, and natural gas and condensate are obtained from the Jumpingpound and Pincher Creek fields. In 1954 natural gas was discovered at Savanna Creek and at Sarcee (Figure 64).

The Turner Valley Field is the largest oil field in the eastern Cordillera and for several years it was by far the largest in Canada. In 1942, its peak year, it produced 9,701,719 barrels of oil and 42,260,390 cubic feet of gas. In 1955 it produced 2,056,439 barrels of oil and 31,211,757 cubic feet of gas. The total production up to the end of 1955 was 110,470,464 barrels of oil and 1.7 trillion cubic feet of gas. The oil is of high gravity, ranging from 38 to 42 degrees A.P.I. Part of it is refined in the vicinity of the field and the remainder is transported by pipeline for treatment in Calgary. The gas is utilized there and in many towns of Alberta. Royalite Oil Company's plant, constructed at Turner Valley in 1952, extracts hydrogen sulphide from the gas and recovers elemental sulphur.

The field lies within the easternmost thrust sheet of the Foothills which is underlain by the Turner Valley thrust. The oil and gas occur mainly in the Mississippian Rundle group beneath Jurassic and Cretaceous strata. In the south and central parts of the field the formations have been folded into an anticline which is broken by small faults subsidiary to the Turner Valley thrust (Figure 74). In the northern part of the field the anticline is overriden by the Millarville fault and other splays (Figure 75). Oil obtained from the Rundle strata of some of these fault slices is from elevations lower than the oil-water interface of the west flank of the field, suggesting that movement took place on the faults after the oil and gas had accumulated. The wells range in depth from about 4,000 feet on the gas cap to more than 9,000 feet on the lower part of the crude oil zone.

The field was discovered in 1913 when gas and oil were obtained from sands in the Lower Cretaceous Blairmore group. In 1924 the porous beds of the Rundle group were tapped on the gas cap of the present field. In 1936 the first well reached

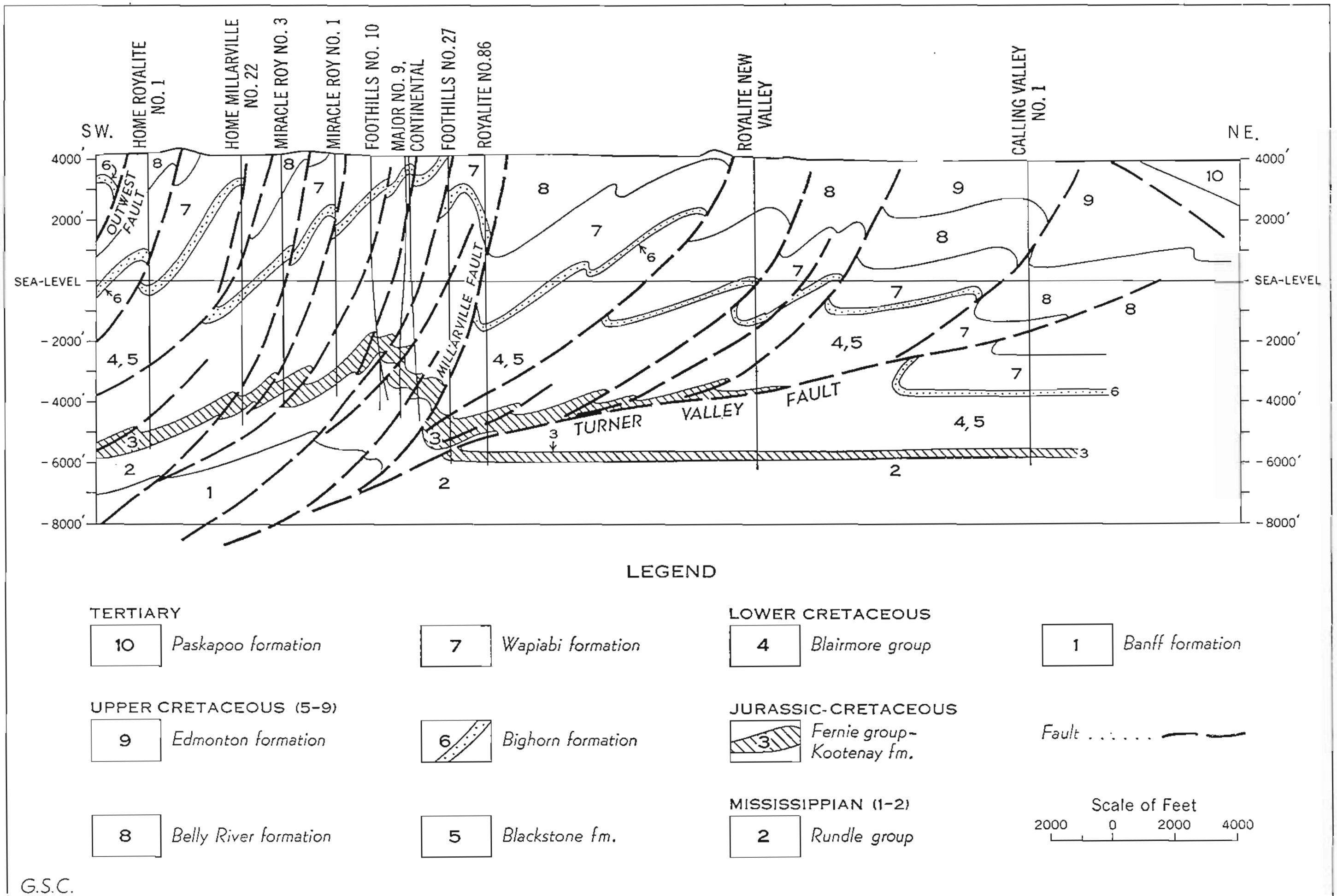


FIGURE 75. Structure-section through the northern part of the Turner Valley oil and gas field. (Modified after W. B. Gallup.)

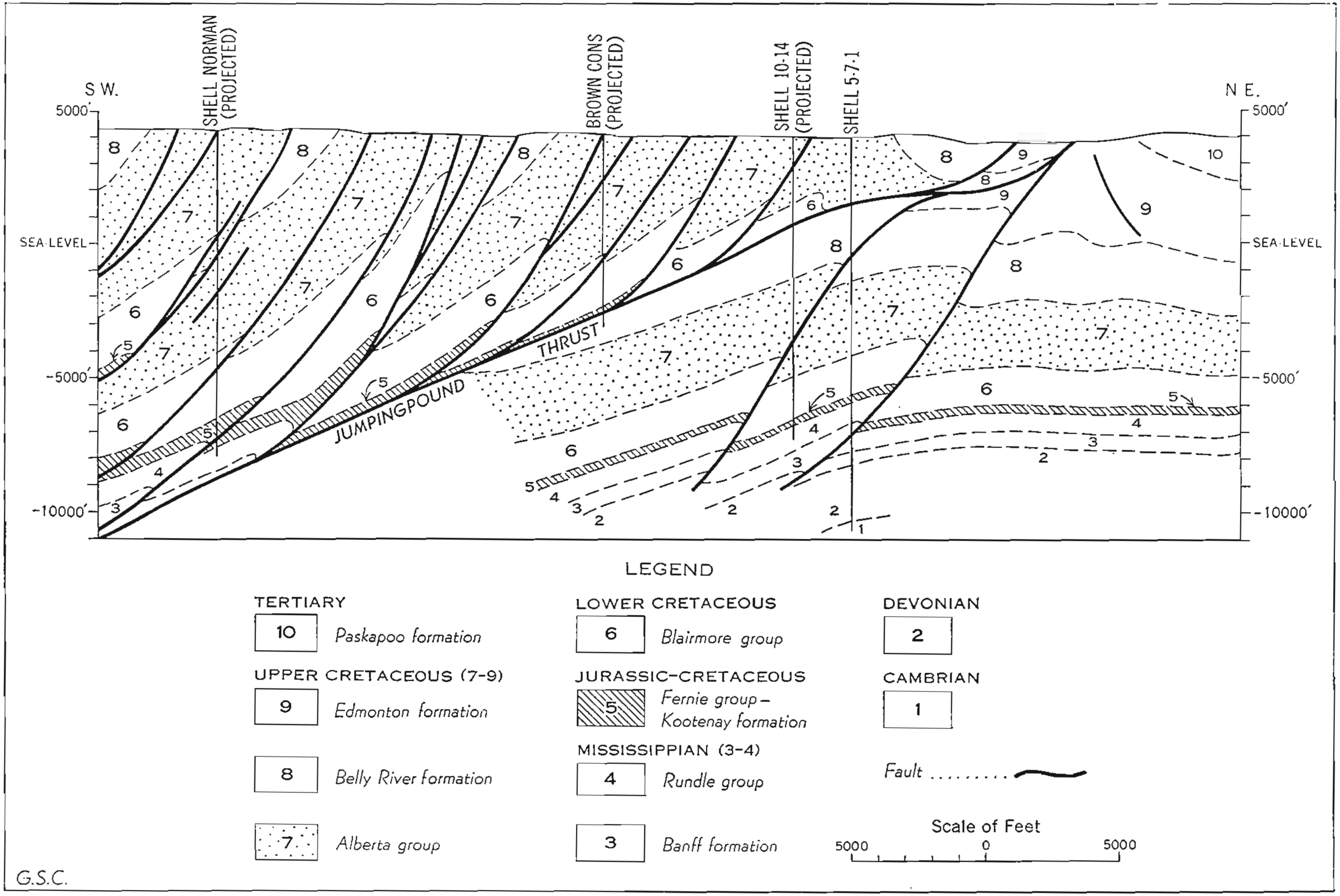


FIGURE 76. Structure-section through the Jumpingpound gas field, Alberta.

the crude oil zone. The field is 22 miles long and 2½ miles wide. At the end of 1954 gas reserves were estimated at 380 billion cubic feet and oil reserves at 20 million barrels.

The Jumpingpound field lies along the eastern margin of the Foothills 21 miles west of Calgary. Earlier wells probing the surface anticline encountered a shallow thrust fault without penetrating the Rundle above it. In 1943 a deep well was drilled to test the Rundle above this thrust, but the well was unproductive. The field was discovered in 1944 when natural gas and condensate were encountered in the porous beds of the Rundle group at a depth of 9,618 feet (Figure 76). Between 1944 and 1947 two wells were drilled which indicated the absence of an oil column on the west flank. A third well, one of the deepest in Canada, was drilled in 1947. Below the productive zones it penetrated a lower barren fault slice of Rundle strata and was continued into the Cambrian to a total depth of 14,443 feet. The field was shut in, as no market was available, until 1951 when a pipeline was built to Calgary and another up Bow Valley to Banff and nearby cement and lime plants. Fourteen wells have been drilled, of which 10 are productive. To the end of 1955 the field produced, 50,226,831M cubic feet of gas and 591,677 barrels of 51 to 57 degrees A.P.I. gravity oil and condensate. Production in 1955 was 14,076,988M cubic feet of gas and 221,036 barrels of oil and condensate. In 1952 a sulphur extraction plant was built by Shell Oil Company of Canada at Jumpingpound which produced 44,432 tons of elemental sulphur to the end of 1955. The field is 12 miles long and its limits are not entirely established. Productive closure is about 1,000 feet at the south end. Estimated gas reserves at end of 1954 were 550 billion cubic feet.

The Pincher Creek field is in the southern Foothills of Alberta close to the International Boundary. It was discovered in 1947 and to the end of 1955 eight wells had been drilled, of which five are productive with estimated open flows of 45,000 to 168,000M cubic feet per day. The field is shut in pending construction of the Trans-Canada pipeline which will make the gas available to eastern markets. Reserves in 1955 were estimated at between 2 and 3 trillion cubic feet, one of the largest gas fields in Canada. The gas occurs in fractured porous dolomite of the Mississippian Rundle group, as in the Turner Valley and Jumpingpound fields. The wells are drilled through several small faults and two thrusts of large displacement, which repeat beds of Lower and Upper Cretaceous, and eventually penetrate a gently west-dipping fault slice of the Rundle at a depth of about 12,000 feet (Figure 77). The field is 8 miles long with productive closure estimated at 1,000 feet. The limits have not been determined.

The Norman Wells field lies along Mackenzie River 90 miles south of the Arctic Circle. The field was discovered in 1920 and for many years supplied oil to a local refinery that served the requirements of the district. In 1942 development was accelerated by the Canol Project, an enterprise designed to supply motor fuel to military forces defending the North Pacific region during the war with Japan. The project had three main objectives all of which were accomplished (1) to develop the Norman Wells oil field and drill sufficient wells to maintain a supply

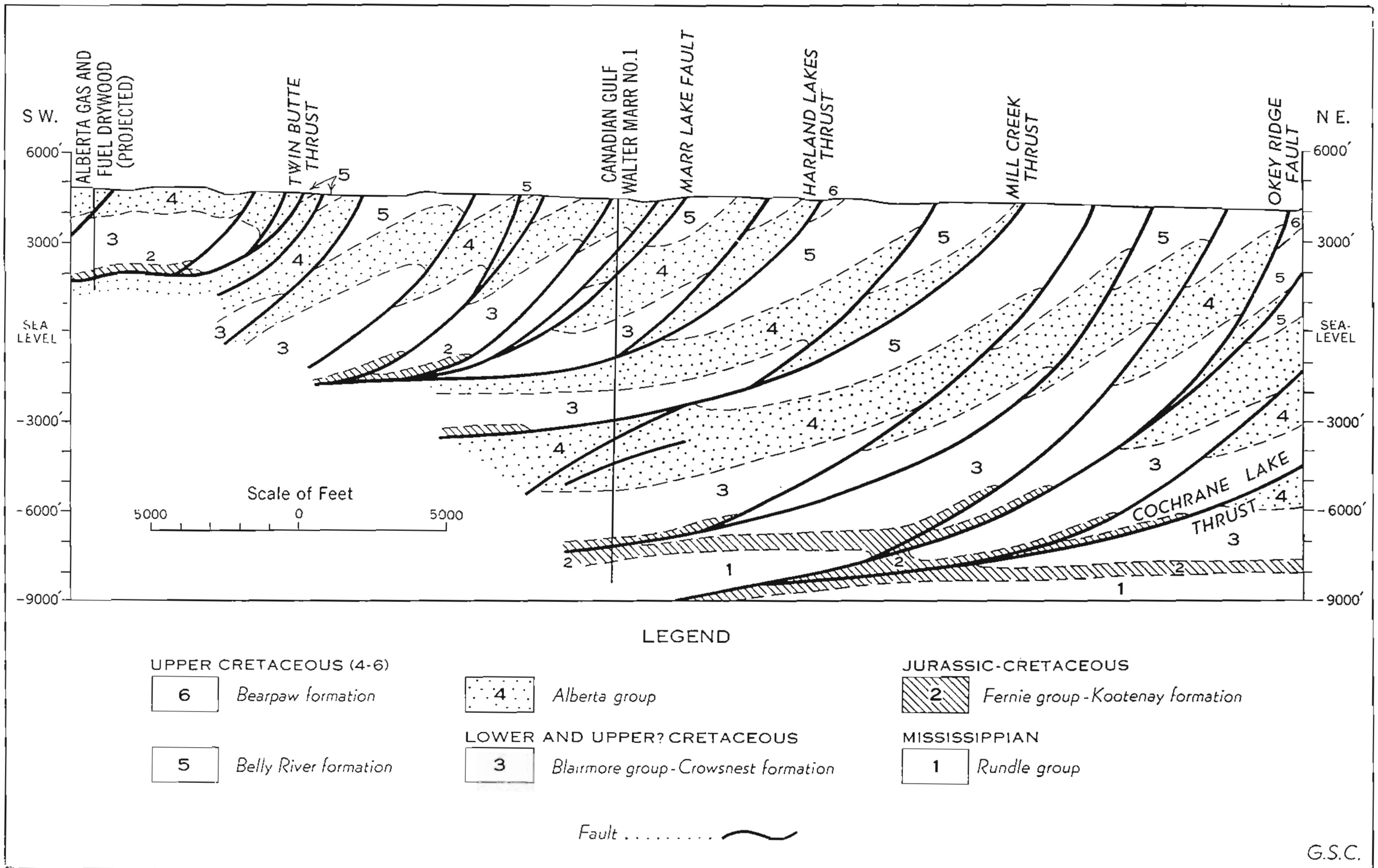


FIGURE 77. Structure-section through the Pincher Creek gas field, Alberta. (By R. J. W. Douglas.)

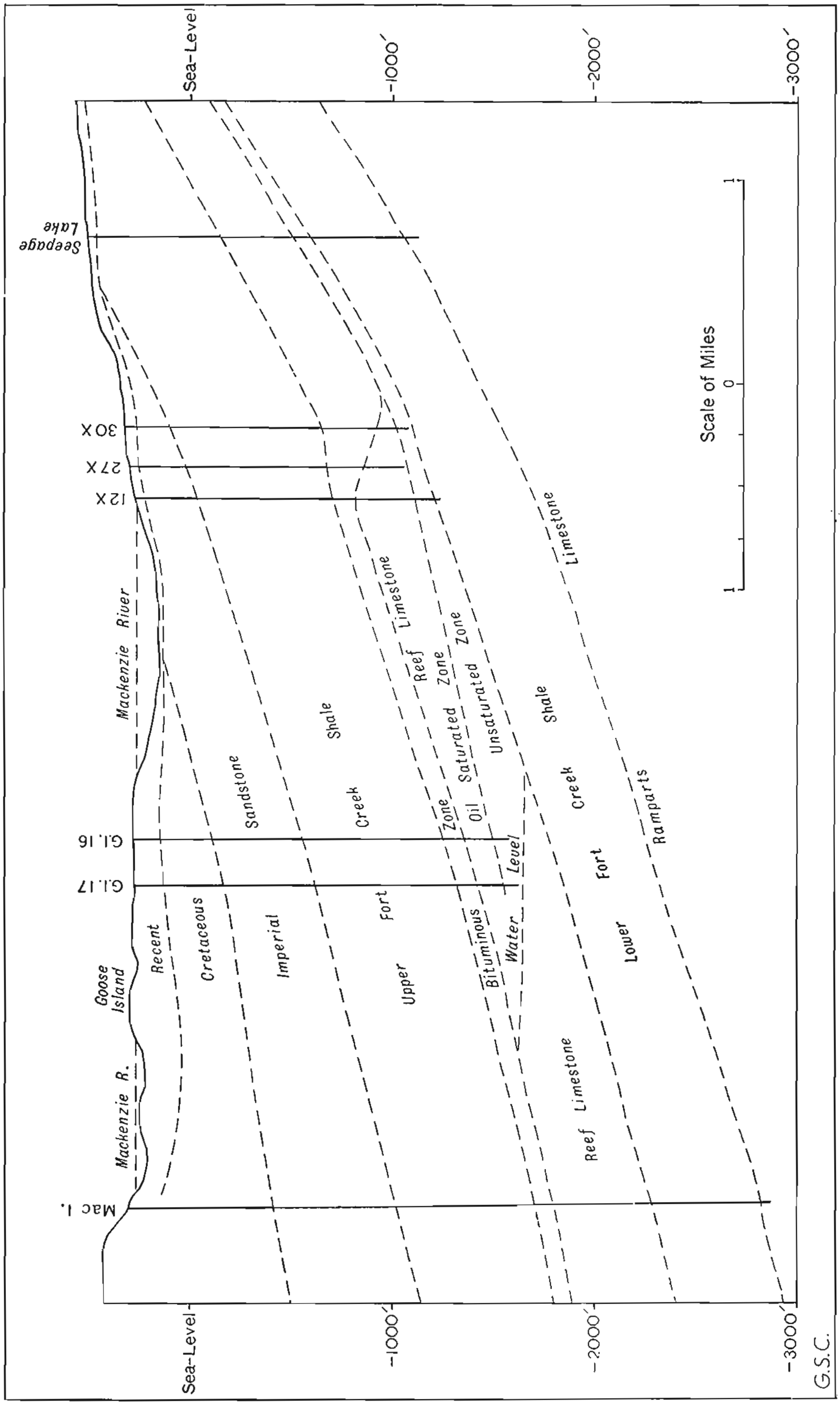


FIGURE 78. Vertical section northwest across Norman Wells oil field, Northwest Territories.

of 3,000 barrels of crude oil a day, over and above that required for local use; (2) to build a 4-inch pipeline from Norman Wells to Whitehorse, Yukon, a distance of 600 miles, with booster pumps capable of delivering at least 3,000 barrels a day at Whitehorse; and (3) to build a refinery at Whitehorse to process the crude oil. Drilling commenced in 1942 and by 1945 sixty productive wells had been drilled. After the war the pipeline was abandoned and removed. In 1947 the refinery at Whitehorse was dismantled and rebuilt at Edmonton to process oil from the newly discovered Leduc field in the Interior Plains.

The Norman Wells field is on the southwest flank of the Norman Range of Franklin Mountains in which rocks of Cambrian to Devonian ages are exposed. The strata in the field dip west at about 5 degrees. The oil occurs in an Upper Devonian reef limestone that reaches a maximum thickness of 400 feet (Figure 78). The reef limestone had grown on a barren basal limestone about 100 feet thick and extends over a wide area beyond the limits of the productive oil field. Closure on the oil-saturated section is formed by pinching out of the reef up the dip. Oil saturation of the reef is irregular both horizontally and vertically. The depth of the wells to the top of the reef/limestone varies from 1,050 feet on the up-dip side, on the northeast bank of the river, to about 1,900 feet on Bear Island on the down-dip side. Latest estimates of the area covered by the productive section of the reef give 4,335 acres, of which 2,020 acres lie beneath Mackenzie River. The oil is 38.4 degrees A.P.I. During the last 6 months of the life of the Canol Project, the field produced at a rate of more than 4,000 barrels a day. Since 1945 when the Canol Project was abandoned, the field has served local requirements of gasoline and fuel oil. The output in 1955 was 404,219 barrels and the total output to the end of that year was 5,196,630 barrels. Recoverable reserves at the end of 1955 were estimated at 53,707,000 barrels.

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CHAPTER VII

THE ARCTIC ARCHIPELAGO

(Y. O. Fortier)

The Arctic Archipelago, or Arctic Islands, lies north of the Canadian mainland and, together with Boothia and Melville Peninsulas, is within the administrative district of Franklin in the Northwest Territories.

The land area of this region exceeds half a million square miles, almost one-seventh of the land area of Canada. The islands extend from longitude 61 degrees to 126 degrees, a distance of 1,200 miles at the latitude of Bellot Strait, and from latitude 61 degrees to 83 degrees, a distance of 1,600 miles. Canada's middle parallel of latitude crosses southern Baffin Island, and most of the islands are north of the Arctic Circle.

The islands lie far north of the 50 degrees Fahrenheit mean temperature isotherm for the month of July, a line which coincides closely with the northern limit of trees on the mainland and which is used as the southern limit of the Arctic region. The ground is permanently frozen except for a few inches from the surface in the summer. Although the region is covered with snow, apart from the short summer season, the annual precipitation is low, exceeding 15 inches only in the southeast part of the Archipelago, and seldom more than 5 inches in the northernmost islands. Ice-caps, snowfields, and glaciers are common in the east where the land surface is high, and a few small ice-caps are found in the west. The sea among the islands is covered with ice in the winter, except for the eastern parts of Hudson Strait and Lancaster Sound and, elsewhere, in local channels where currents are strong. In summer the sea ice remains in the northwest and in M'Clintock Channel in the south, but disappears in the other southern regions. In other parts the extent of open water and drifting ice varies from summer to summer.

Permanent settlements are few and widely scattered in the southern islands, although there are none on Somerset and Prince of Wales Islands. Frobisher Bay, the largest settlement, has military installation and administrative services. Among the northern islands only Cornwallis, Ellesmere, Ellef Ringnes and Prince Patrick Islands have permanent settlements; the largest military and government outpost is at Resolute on Cornwallis Island.

Rocks of almost every age from Precambrian to Cenozoic occur in the region. Except for coal extracted for local needs at Pond Inlet there has been no sustained mineral exploitation. This is not due to unfavourable geological terrains but mainly to difficulty of access.

Exploration and Development

Eskimos of different cultures, and presumedly at different periods of time, were the first men to penetrate the Arctic Islands. It is not known whether refuge from human turmoils, the search for more rewarding hunting grounds, or an ingrained desire to push on, caused those emigrants either to travel through or to settle permanently among the islands centuries or milleniums ago. At any rate, their life economy was wholly within the geographic confines of the treeless Arctic. Eskimos knew where to find flint to shape into tools, soapstone to carve into lamps, and in the southwest part of the Archipelago, copper to shape into other implements, but they did not know coal as a source of fuel.

Norsemen are believed by some to have reached the easternmost Archipelago in the tenth and eleventh centuries either from their colony on Greenland or on their way to Greenland from Iceland. Presumedly both innate adventurous spirits and more pragmatic desires motivated such landings, perhaps too short for the visitors to make permanent use of the minerals of the rocky eastern coasts.

Five centuries passed before further exploration in the Archipelago was recorded. In 1576 a period of exploration began with the prime purpose of finding a northwest passage as a trading route between Europe and the Orient and, from the very first, some interest was created in new Arctic discoveries. In that year Martin Frobisher, on his way west, discovered Baffin Island and within it, Frobisher Bay, where he was led to believe that he had uncovered gold. This resulted in an unsuccessful mining episode. Following Frobisher, major exploratory voyages were made in the eastern Arctic, from Hudson Bay, through Hudson Strait, Davis Strait, and Baffin Bay to Smith Bay and Jones Sound by Davis, Hudson, Button, Bylot, Baffin, Foxe, James, and Middleton.

In 1818 such famous men as Edward Parry, John Franklin, John Ross, and George Back appeared on the scene and the stage was set to push Arctic exploration westward. In 1819 Parry practically discovered a passage through the Archipelago by penetrating from Lancaster Sound to Melville Island and sighting Banks Island. In the reports of Parry's discoveries the first information regarding the geology of the Archipelago is presented, including the mention of coal measures and petroliferous strata. Other observations made by Parry and Ross induced whalers, who for two centuries had confined their operations to the eastern side of Davis Strait, to go to the western or Canadian side. Almost all expeditions that followed Parry's included natural scientists and their observations are still the only source of information on the geology of parts of the Archipelago. This period of Arctic penetration ended in tragedy with the loss of Sir John Franklin's expedition in the region of King William Island in 1847-48.

The search for Franklin marked a period of concentrated activities and resulted in the charting of the southwestern part of the Archipelago and of the islands lying on both sides of the Lancaster Sound-M'Clure Strait line. The organized search, which lasted until 1859 when F. L. M'Clintock found evidence of the tragedy, produced much information on the geology of the Archipelago. Samuel

Haughton compiled the first geological map of the Archipelago. J. W. Salter also made original stratigraphic interpretations. More coal was located and further indication was found by Edward Belcher of petroliferous strata; P. C. Sutherland, describing the crystalline rocks of Baffin Island, wrote about abundant graphite in Cumberland Sound and about whalers using the coal of Padloping.

Although the Northwest Passage remains to this day a matter of practical interest to Canada for development of the Archipelago, the period of Arctic exploration following the search for Franklin was mainly oriented northward towards the Pole. It was initiated by I. I. Hayes in 1860 and reached its acme when Peary, in 1909, left the north coast of Ellesmere Island for the North Pole. Until the attempts to reach the Pole began, exploration in the Archipelago had been carried out almost entirely by the British, but after that time substantial American and Norwegian expeditions entered the field. Major geographical discoveries were made on Ellesmere Island and in the Sverdrup Islands.

During this period the Canadian Government sent its first expeditions to the Archipelago. Great activity in whaling led to the establishment of small settlements on Cumberland Sound. Some whalers traded with natives and it was in connection with the whaling activities that mica and graphite were mined in Cumberland Sound and at Lake Harbour. These were the first minerals exported, following the worthless rocks carried by Frobisher's ships. Coal was mined at Fort Conger on Ellis Island for local use by the expeditions of G. S. Nares, A. W. Creely, and R. E. Peary, and at Pond Inlet by J. E. Bernier.

The period saw a major advance in the study of Arctic geology. H. W. Feilden made geological observations on eastern and northern Ellesmere Island and C. D. DeRance helped in their interpretation. Per Schei, geologist of the 'Fram' expedition to Ellesmere and the Sverdrup Islands, made a most substantial reconnaissance of the geology of those parts of the Archipelago. Reports by specialists on the material he collected fill many publications. J. G. McMillan was the first geologist to visit Melville Island. Robert Bell, in 1884, was the first member of the Geological Survey of Canada to visit the Arctic Islands and was the first geologist to do systematic geological mapping on Baffin Island. Another member of the Geological Survey of Canada, A. P. Low, led, in 1903-04, a Canadian Government expedition over widespread parts of the eastern Archipelago and made an extensive report on the geology.

The next period of activity in the Archipelago extended from 1909 to 1942, and marked the first stage of permanent development. It witnessed the establishment of trading posts, missions, and Royal Canadian Mounted Police detachments. A yearly Eastern Arctic Patrol was established by the Canadian Government, whereby governmental administrators and scientists visited eastern settlements each summer. Graphite was mined during the First World War at Lake Harbour and in Cumberland Sound, Baffin Island. During this period new lands were still sought, and major discoveries included Borden, Brock, and Meighen Islands, but the time had come for investigation of the natural sciences of the Archipelago by expeditions organized specifically for that purpose. Notable regional geological contributions of the period were made by the Fifth Thule Expedition in the west part of Foxe Basin and in northern Baffin Island, by the Putnam Expedition to southwestern Baffin Island, by L. J. Weeks in Cumberland Sound, by A. L. Washburn on Victoria and King William Islands, and by J. C. Troelsen on Ellesmere Island. The second and third decades of this century saw the first aircraft over the Archipelago, heralders of a new period of activities.

A great change has taken place in the Archipelago since 1942. Although new islands were put on the map as late as 1950, utilization rather than exploration is now the order of the day. Military interest in the area has provided a great impetus, and the use of aircraft is the greatest single factor in this new approach. It started during the Second World War when permanent airfields were constructed on southern Baffin and Southampton Islands. Following the war the value of polar air routes for commercial as well as for military use became apparent and developments towards this end are still in progress. Their strategic value is reflected in the number of military installations recently constructed in the Canadian Arctic.

The need for accurate meteorological data from the vast sector lying north of the populated area of North America has resulted in the erection of many permanent weather stations. Five of these are on islands north of the Lancaster Sound-M'Clure Strait channel, a region recently designated as the Queen Elizabeth Islands. Ships have penetrated nearly all the southern parts of the Archipelago, with the exception of M'Clintock Channel and Committee Bay, and have reached northeast Ellesmere Island, Nansen and Eureka Sounds, and the eastern part of Norwegian Bay; only the extreme northern and western parts of the Queen Elizabeth Islands have yet to be reached by sea. Float-equipped aircraft have made landings on the sea as far north as Prince Patrick Island, Bathurst Island, and northeastern Ellesmere Island; landings have been made on lakes as far north as central eastern Axel Heiberg Island. Ski-equipped aircraft have landed on the sea ice in the vicinity of almost every island, and in addition, heavy transport aircraft can land on wheel on seasonal strips at the northernmost weather stations in the Queen Elizabeth Islands. An all-weather landing strip and a Royal Canadian Air Force detachment are located at Resolute, on Cornwallis Island. Helicopters operating from ships or from pre-established fuel caches, have landed on all the major islands with the exception of Meighen Island, the Borden-Mackenzie King group, and possibly Prince Patrick Island.

The entire Archipelago has been photographed from the air and modern, accurate maps are being prepared. In many areas these new maps are the first to appear since the British Admiralty Charts were prepared, some as long ago as the middle of the last century. Airborne systematic geodetic, geophysical, and geological surveys have been conducted over large parts of the Arctic Islands. During every year since 1947, several geological parties have mapped some parts of the Archipelago. In the spring and summer of 1955, a thirty-man party of the Geological Survey of Canada, including eleven geologists, and employing two large helicopters, explored the geology within some 120,000 square miles of land within the larger part of the Queen Elizabeth Islands and parts of Baffin, Somerset, and

Prince of Wales Islands. Geologists have now visited all major islands with the exception of Meighen Island and the Mackenzie King-Borden Islands group.

Physiography

The land surface of the Arctic Archipelago includes mountains, uplands, plateaux, lowlands, and plains. Although in some places one type of topography may pass gradually into another and at some localities information is lacking, the region, nevertheless, may be provisionally divided into those categories (Figure 79). In general, the land surface is high in the east where mountain systems possibly reach over 10,000 feet in elevation. From there the land slopes down through uplands and plateaux to lowlands and plains in the central part of the region. The low areas, however, are not continuous but occur as basins surrounded by higher ground or are interrupted by tongues or belts of uplands. The land rises again in the west, where plateaux reach 3,600 feet in elevation, and finally drops off to a low coastal plain along the western limit of the region. In general, the physiography of each island is related to that of adjacent islands and this, together with the bedrock geology, indicates that the Archipelago was formerly a continuous landmass which is now partly submerged.

Aside from the regional changes in level due to broad crustal warping, the main physiographic units are generally an expression of the bedrock and of its structure. Thus, the mountains and uplands are either on resistant Precambrian rocks, or on folded formations of various ages where ridges and valleys, or escarpments, reflect the bedrock structure; the plateaux are on unfolded strata mainly of Palæozoic limestone; the lowlands and plains cover areas of flat-lying Palæozoic, Mesozoic, and Cenozoic strata.

To facilitate description, the main physiographic divisions are given local names as shown on Figure 79. This should be studied in conjunction with Map 1045A (in pocket) which gives many of the geographic names mentioned in the following descriptions.

Mountains

The Baffin-Ellesmere mountains of crystalline rocks extend along the east coasts from southeastern Baffin Island northward through Bylot and Devon Islands to about half-way along Ellesmere Island. They are a part of Canada's high eastern seaboard that extends from the coast of Labrador to northern Ellesmere Island. As in Labrador, they are formed of Precambrian crystalline rocks. South of Cumberland Sound mountains are restricted almost solely to the coast and rise to some 3,000 feet south of Frobisher Bay and to about 3,500 feet on the south coast of Cumberland Sound. North of the sound the mountains are more extensive and higher. Their maximum elevation, perhaps over 8,000 feet, is in the Penny Highlands which lie a short distance north of Cumberland Sound. Thence to its north end on Ellesmere Island, the mountain system's greatest elevations vary from 5,000 to 6,000 feet. Except locally where bounded by plains or lowlands in small coastal areas at Clyde River, Eclipse Sound (Plate XXXVII), and western and northern Bylot Island, the mountains are rugged to the very coast. The system includes

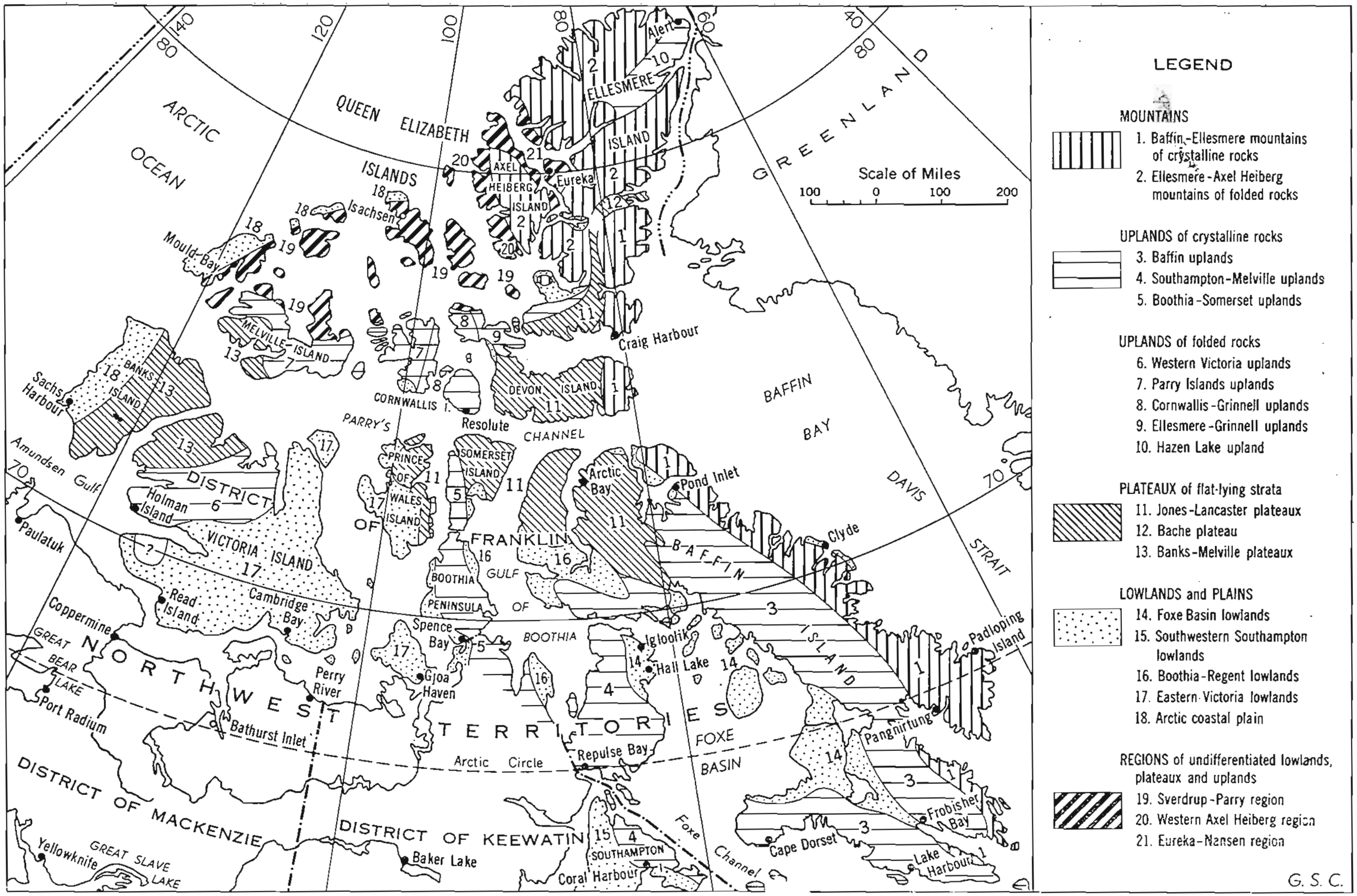

FIGURE 79. Provisional physiographic divisions of the Arctic Archipelago.

Plate XXXVII

Baffin-Ellesmere mountains bounded by a small coastal lowland (centre background) and passing into the Baffin uplands (left background); looking north toward Eclipse Sound.

decussate surfaces, sharp-edged ridges, arêtes, isolated horns and isolated tablelands. Glaciers have obviously contributed towards the development of local high relief. A notable feature is the presence of numerous long fiords; these penetrate deeply into the mountain system, and the longer ones cut across it. The continuity of the mountain belt is broken by Lancaster, Jones, and Eclipse Sounds and by Frobisher Bay, Cumberland Sound, and Makinson Inlet with lowlands and valleys at their heads. Glaciers, snowfields and ice-caps, though rare south of Cumberland Sound, are widespread throughout the major part of the system and some reach the sea. The mountains appear, in many parts, to be the product of erosion of the seaward side of an extensive series of uplands and plateaux that slope inland. Westward, the mountains grow more massive, gently rolling summits become more extensive, and the system passes gradually into uplands (Plate XXXVII).

The Ellesmere-Axel Heiberg mountains of folded rocks lie over much of Ellesmere and the larger part of Axel Heiberg Islands. The system is almost divided into two areas by the Hazen Lake upland and cut by the lowlands and uplands of Nansen Strait and Eureka Sound. It contains extensive ice-caps, snowfields, and glaciers, and any map showing land-ice distribution clearly indicates, pictorially, the quasi-duality of the mountain system. The western area has the higher elevations, possibly reaching 10,000 feet in the northern part of Ellesmere Island and above 7,000 feet in the central part of Axel Heiberg Island. Both areas are underlain by folded strata of Precambrian to Cenozoic age. Parallel ridges and valleys

Plate XXXVIII

Ellesmere - Axel Heiberg mountains reflecting folds in steeply dipping strata (foreground); piercement domes of gypsum stand above coastal lowland (left background). Axel Heiberg Island, looking towards west coast.

reflect the structure of the bedrock. The eastern area appears to be finely dissected because crested ridges are closely spaced. In the western area, especially on Axel Heiberg Island, the major ridges and valleys are broad and correspond, respectively, to broad crests and troughs of folds. Long, narrow, crested ridges are carved out of folded limbs that locally dip steeply (Plate XXXVIII). In areas of gentle folds, escarpments bound the upper reaches of broad dip-slopes on resistant formations. The coasts are indented by many fiords, bays, and inlets, most of which cut across the folds.

Uplands

Uplands of Crystalline Rocks

The Baffin uplands lie on Baffin Island and are, in major part, adjacent to the mountains to the east. The uplands are underlain by Precambrian crystalline rocks and their western boundary is, for the most part, arbitrarily placed at the edge of exposures of such rocks. In most areas the uplands slope southwesterly: from the Cumberland Peninsula towards Nettilling Lake and the head of Cumberland Sound; from the south coast of Cumberland Sound towards Amadjuak Lake and Frobisher Bay; and from the south coast of Frobisher Bay to Hudson Strait. This suggests that the three segments were fault blocks tilted southwesterly. In the southeastern part of Foxe Basin the Precambrian terrain is near sea-level and becomes part of the Foxe Basin lowlands. On northern Baffin Island the uplands pass westward into the Jones-Lancaster plateaux. In the lower parts, the Baffin uplands contain many lakes. There are some ice-caps on the uplands, the larger one by far being the Barnes Ice-cap.

The Southampton-Melville and the Boothia-Somerset uplands are also underlain by Precambrian crystalline rocks. Their higher elevations vary from 1,000 to 2,000 feet. In many places these uplands rise abruptly above adjacent lowlands but the rugged upland of Somerset Island is, in part at least, continuous with the adjacent plateau of Palæozoic rocks. This upland, in contrast with the plateau, is characterized by many lakes.

Uplands of Folded Rocks

The western Victoria uplands are underlain by gently folded Proterozoic rocks. It is a region of ridge topography with cuestas, escarpments, dip-slopes, rugged hills, and deep valleys. Many parts are about 2,000 feet above the sea. The region of Hadley Bay is rugged, much dissected, and has many cliffs. The upland on southwest Victoria Island rises westward from the Eastern Victoria lowlands and reaches 1,700 feet in the Colville Mountains on Wollaston Peninsula. It is possible that the upland on this peninsula is partly a plateau underlain by flat-lying Palæozoic strata.

The Parry Islands uplands trend easterly across much of Melville and Bathurst Islands and include Byam Martin and other small islands. The uplands are underlain by Palæozoic rocks and the topography is characterized by subdued ridges and valleys trending easterly along the folds in the bedrock (Plate XXXIX). Elevations

Plate XXXIX

Parry Islands uplands and Parry Islands Fold Belt, showing subdued ridges and valleys trending easterly along folds in the bedrock. Bathurst Island, looking towards east coast.

are possibly in excess of 1,600 feet in the central part of Bathurst Island whence they decrease southwesterly to some 500 feet on Byam Martin Island, and vary between 300 and 600 feet in the southeastern part of Melville Island. On the northern side of the uplands elevations do not appear to exceed 1,000 feet. Towards the west part of Melville Island the uplands narrow and rise to perhaps more than 1,800 feet near the west coast.

The Cornwallis-Grinnell uplands extend over Cornwallis Island, western Grinnell Peninsula, and the eastern fringe of Bathurst Island. They include plateaux and lowlands. In some parts the surface is rolling, but other places present ridges that trend north to northeasterly and follow the structure of the underlying, folded, Palæozoic rocks. Elevations are up to 1,300 feet in southeastern Cornwallis Island and reach about 1,500 feet in Grinnell Peninsula.

The Ellesmere-Grinnell uplands of folded rocks include a part of southwestern Ellesmere Island, Kent Island, Colin Archer Peninsula, eastern Grinnell Peninsula, and adjacent part of northwestern Devon Island. Eastward and southward it merges with the Jones-Lancaster plateaux; westward, its westerly trending broad ridges contrast with the northerly grain of the Cornwallis-Grinnell uplands; northeastward, its ridges, curving to the northeast, are more subdued and of lower elevation than those of the Ellesmere-Axel Heiberg mountains. On the south coast of Baumann Fiord, the uplands slope down to lowlands. The uplands in part are deeply dissected, and their maximum elevation is perhaps over 2,500 feet. They contain ice-caps at their boundary with the Jones-Lancaster plateaux and as far west as Colin Archer Peninsula.

The Hazen Lake upland of folded rocks cleaves the northeastern part of the Ellesmere-Axel Heiberg mountains into two segments. The relative uniformity of its surface, up to some 3,000 feet above sea-level, contrasts with the ridges of the bounding mountains which, at least to the northwest, rise rather abruptly above the upland. The latter has a northeasterly grain in conformity with the structures of the underlying rocks, apparently slightly metamorphosed Palæozoic and possibly Proterozoic strata.

Plateaux

The Jones-Lancaster plateaux lie west of the Baffin uplands and the Baffin-Ellesmere mountains. Generally these surfaces merge into that of adjacent physiographic divisions and their boundaries, especially the northern ones, are difficult to locate at present. In the main, the plateau surfaces slope away from their higher and easternmost elevations on northeastern Baffin Island, eastern Devon Island, and central southern Ellesmere Island. For example, on Borden Peninsula, many areas are above 2,000 feet and in part exceed 3,000 feet, whereas, the plateau surfaces have maximum elevations of 1,800 feet on Brodeur Peninsula, 1,300 feet on Somerset Island, and somewhat lower than 1,000 feet on northeastern Prince of Wales Island. The surface also lowers towards the Gulf of Boothia and Creswell Bay. On Devon Island the plateau is over 2,000 feet high just west of the Baffin-Ellesmere mountains, slopes to less than 1,000 feet at the southwest coast, and to

Plate XL

Part of the Jones-Lancaster plateaux underlain by flat-lying Palæozoic strata which (in left foreground) lie unconformably on Precambrian gneiss, South coast of Devon Island.

a low plain in the northern part of the west coast of Wellington Channel. The plateau surface of southern Ellesmere Island has an ice-cap over 5,000 feet above sea-level but elevations there are generally 3,500 feet or less. From that locality the surface lowers northerly towards Baumann Fiord and southwesterly towards the southwestern part of the island where it is up to 2,500 feet or so. The plateaux are underlain chiefly by flat-lying Palæozoic strata. There is little relief inland but the coastal areas are characterized by high cliffs, steep-walled inlets, bays, fiords, and canyons (Plate XL). Local low plains are found on some narrow coastal strips and on a few estuaries. A noteworthy feature is the lack of widespread drumlins, eskers, and morainal ridges. Except on Devon Island, lakes are rare or non-existent. Ice-caps are found as far west as Brodeur Peninsula.

The Bache plateau occurs on a narrow band of flat-lying strata approximately half-way along the east coast of Ellesmere Island, separating the Baffin-Ellesmere and the Ellesmere-Axel Heiberg mountain systems. Its surface probably rises above 2,000 feet. It is not known whether such a surface follows a possible narrow strip of unfolded strata westward and inland towards the head of Bay Fiord, thence southward and east of Vendome Fiord to link up with the Jones-Lancaster plateaux.

The Banks-Melville plateaux include much of Banks Island, the northwest part of Victoria Island, and the southwest part of Melville Island. In southernmost Banks Island, a plateau of limited extent is underlain by gently inclined Proterozoic strata. On the south coast it drops to the sea in cliffs 500 to 1,000 feet high.

Inland it reaches some 2,400 feet and the surface generally slopes northward towards Masiks Pass. This pass separates the high plateau from a lower plateau that occupies much of the central part of Banks Island. The lower plateau is of rolling hills and its larger part does not exceed an altitude of 1,000 feet, although it may reach 1,500 feet in the north. Its surface slopes generally down towards the west. The plateau terminates abruptly on the north coast of Banks Island in bold cliffs up to 800 feet high and is composed, partly at least, of gently warped Devonian strata. Inland from the coast the plateau is cut by deep canyons. The divide on this plateau is near Prince of Wales Strait the shores of which are, in part, lowlands. On the northwest part of Victoria Island the land generally slopes northwesterly from the western Victoria uplands down to Prince of Wales Strait. The slope is in harmony with the gentle regional dip of underlying Palæozoic strata. This is a region of rolling hills, all probably below 1,000 feet in elevation. In southwestern Melville Island a plateau reaches a maximum height of about 3,500 feet and contains a few small snowfields. It has high sea-cliffs and short, steep-walled estuaries and canyons. It is underlain by flat-lying to gently warped strata most probably all of Devonian age.

Lowlands and Plains

The Foxe Basin, southwestern Southampton, and Boothia-Regent lowlands are generally less than 300 feet in elevation. They are almost everywhere underlain by flat-lying Palæozoic limestone. A notable exception is found in the southeast part of the Foxe Basin lowland where the low ground extends over Precambrian rocks. In the region of Nettilling Lake, for example, it is only a few hundred feet above sea-level and, though rugged in detail, is without high relief. The lowlands are poorly drained and much of the terrain contains many lakes.

The eastern Victoria lowlands extend from the western fringe of Boothia Peninsula and the southwestern part of Prince of Wales Island, through King William Island, to eastern and southern Victoria Island, and to Stefansson Island. They are underlain mainly by flat-lying, Palæozoic strata. The region is of low relief and rarely reaches 300 feet above sea-level. One exception is Mount Pelly, near Cambridge Bay, which is 600 feet high. The lowlands are poorly drained and dotted with numerous lakes. The coasts are shelving. Raised beaches are widespread and the plains are crossed by eskers and a great many drumlins, forming belts of fluted moraines.

The Arctic coastal plain lies along the western and part of the northwestern limit of the Archipelago. From the plateau on central Banks Island the surface slopes westerly to the sea. This is a region of rolling hills and in places, the sea is cutting low cliffs into the soft strata of the coast. It is drained by a profusion of dendritic streams flowing westerly. On Prince Patrick Island a tilted plain slopes gently northwestward to the sea from a height of land some 800 feet high near the east coast. It is covered by a multitude of subparallel streams flowing on unconsolidated strata. This surface apparently extends along the shores of the polar sea to at least the northwestern parts of Brock, Borden, and Ellef Ringnes Islands.

Other Regions

The Sverdrup-Parry physiographic region comprises the Ringnes Island, Graham Island, the northern parts of Cameron and Melville Islands, the eastern parts of Prince Patrick, Brock, and Borden Islands, and other islands within that periphery, probably including Meighen Island. This region is in larger part made of gently sloping lowlands, less than 600 feet above sea-level, traversed in many areas by long, low, meandering escarpments, but includes local hills, plateaux, and uplands. It is mainly underlain by gently folded to almost flat-lying strata, generally poorly consolidated, and the larger streams are braided. Local hills or uplands rise sharply to some 400 feet above the surrounding lowlands and are typically associated with piercement domes of gypsum (Plate XLI). Internally these domes are finely dissected and have a high relief which contrasts with the smoother profile of the lowlands. Some small uplands contain many gabbro sills and dykes in flat-lying or gently folded strata. Mount Nikolay, at about 1,300 feet, is the high point of such an upland on Cornwall Island, and probably is the highest elevation of the Sverdrup-Parry region. Low plateaux are formed by strata that are inclined very gently, or are almost flat over relatively large areas. Graham Island, for instance, is mainly a gently undulating surface, about 900 feet in maximum elevation, that in many parts dips steeply to a coastal plain that encircles it. Meighen Island, which is little known and reportedly up to 500 feet in elevation, has a snowfield in its central part, the only one known in the Sverdrup-Parry physiographic region.

Plate XLI

Piercement dome on Ellef Ringnes Island; the core, mainly of gypsum, forms a hill above surrounding upturned strata.

Western Axel Heiberg is a region of intermediate elevation and relief between the Sverdrup-Parry region to the west and the mountains to the east. Elevations vary from that of lowlands, a few hundred feet to near sea-level, to that of plateaux and uplands, at a maximum of approximately 3,700 feet. Lowlands are more extensive in the southern part than in the northern. The higher parts comprise plateaux and uplands. The plateaux are underlain by gently inclined to almost flat-lying strata. The uplands are less extensive and are underlain by moderately to highly deformed strata and by a few domes of gypsum. Isolated mesas and a few buttes of flat-lying strata capped by gabbro sills rise abruptly above surrounding lowlands. A few ice-caps and glaciers are present.

The regions of Nansen Sound and upper Eureka Sound contain lowlands, plateaux, and uplands. Rolling lowlands interspaced with ridges, escarpments, and hills of folded strata are found north of Stör Island, on easternmost Axel Heiberg Island, on Fosheim Peninsula, and on Ellesmere Island between the mountains on Axel Heiberg and those on Ellesmere. The north coast of Nansen Sound rises abruptly to a high plateau or upland and the underlying strata are gently inclined to highly folded, and are traversed by many dykes and sills. The mountains on the central part of Axel Heiberg Island slope down to uplands and, in most parts, to coastal lowlands on the shores of upper Eureka and Nansen Sounds. North of the mountains, where strata are almost flat lying to moderately inclined over wide areas, high plateaux and uplands are in many parts dissected into broad mesas and hills which are separated by, or lie in, valleys and larger lowlands. Scattered small ice-caps occur on the north coast of the island where there are steep cliffs.

Geology

Geological Regions and Structure

The Archipelago is, geologically and physiographically, the northward extension of the North American continent. The exposed formations in general are successively younger from southeast to northwest. As in other parts of the continent, the Archipelago is divided into a stable region, a relatively mobile region, and a coastal plain. The stable region has undergone no major deformation since the onset of the Palæozoic and underlies the southeastern and major part of the Archipelago. The stable region is underlain in part by Precambrian rocks in extension of the Canadian Shield of the mainland, and in part by mainly flat-lying to gently inclined Palæozoic strata which mantle the Precambrian basement and form the Arctic Lowlands and Plateaux (Figure 80).

Like the Interior Plains and the St. Lawrence Lowlands, the Arctic Lowlands and Plateaux separate the Shield from an unstable region. This is the Innuitian Region which has been tectonically active from the Palæozoic to some time in the Tertiary. There, troughs and basins, deepening on the failing basement, have received thick columns of sediments and, in major part, have been deformed by many orogenies into belts of folded rocks. The Innuitian Region includes rocks of all eras, mainly Palæozoic and Mesozoic, and covers a large part of the Queen Elizabeth Islands. Both the Innuitian Region and the Arctic Lowlands and

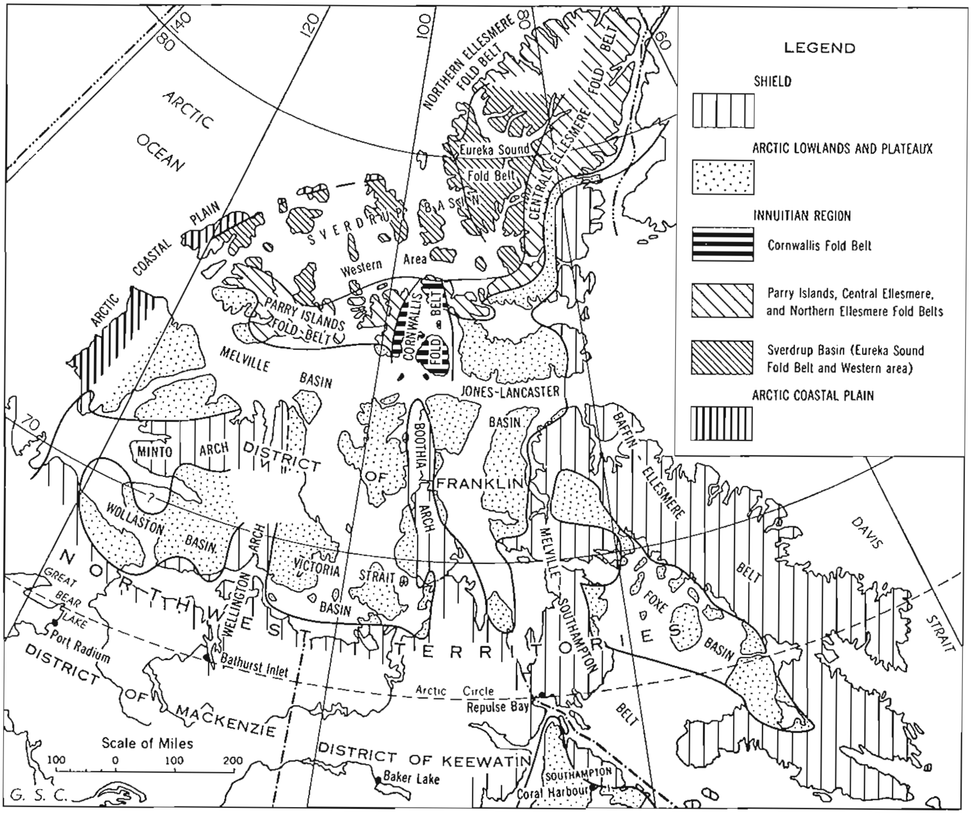

FIGURE 80. Geological regions and subdivisions of the Arctic Archipelago.

Plateaux are bounded on the west by the Arctic Coastal Plain, which forms the western and narrow margin of the Archipelago. It is poorly known and is provisionally defined to include, in the north, undeformed Cenozoic strata mantling gently deformed Mesozoic formations, and, in the south, Cenozoic and Mesozoic strata apparently mantling Palæozoic formations.

The geological regions are subdivided into several units as outlined in Figure 80 and tabulated below.

- Shield Areas
  - Baffin-Ellesmere Belt
  - Melville-Southampton Belt
  - Boothia Arch
  - Wellington Arch
  - Minto Arch
- Arctic Lowlands and Plateaux
  - Foxe Basin
  - Victoria Strait Basin

Wollaston Basin
Jones-Lancaster Basin
Melville Basin

Innuitian Region

Cornwallis Fold Belt
Parry Islands Fold Belt
Central Ellesmere Fold Belt
Northern Ellesmere Fold Belt
Sverdrup Basin: Eureka Sound Fold Belt; western area

Arctic Coastal Plain

Areas of the Shield

Rocks of the Shield areas are divided into two main groups. The one includes chiefly gneisses, granitic rocks, and smaller amounts of sedimentary material that is metamorphosed and commonly much deformed. The other group consists of less deformed and less metamorphosed strata cut by basic intrusions. Both are Precambrian in age. At some localities the rocks of the first group are seen to be overlain unconformably by strata of the second. Although absolute ages are unknown, the younger rocks are probably Proterozoic and the older, which lie beneath the unconformity, are tentatively considered to be Archæan but may be Proterozoic. Correlation from one region to another is uncertain. In areas where relative age cannot be determined, formations are provisionally assigned, for the sake of convenience in description, to either the Proterozoic or the Archæan on the basis of lithology and degree of deformation and metamorphism.

Three areas of the Shield, namely, the Baffin-Ellesmere Belt, the Melville-Southampton Belt, and the Boothia Arch, are underlain by Archæan rocks and smaller amounts of Proterozoic rocks. The other two areas, the Wellington and Minto Arches, are underlain by Proterozoic formations.

The Baffin-Ellesmere Belt is the largest and most easterly of the Precambrian areas. It occupies the larger part of Baffin and Bylot Islands, the eastern part of Devon Island, and stretches about half-way along the east coast of Ellesmere Island. The belt is composed chiefly of Archæan gneisses and granitic rocks. The structures of the gneisses are complex but a northwesterly trend is prevalent in southern Baffin Island. Proterozoic strata are found in northern Baffin Island and are gently flexed along northwesterly to northerly trending axes. Flat-lying or gently inclined Proterozoic strata also occur at the north end of the belt on Ellesmere Island.

The Melville-Southampton Belt underlies almost all of Melville Peninsula and eastern Southampton Island, continues across Fury and Hecla Strait, and obviously connects with the Baffin-Ellesmere Belt. Little is known about the geology of this area, but it is apparently underlain mainly by Archæan rocks with Proterozoic strata along and north of the strait.

The Boothia Arch occupies most of Boothia Peninsula, the western part of Somerset Island, and fringes the southern part of the western shores of Peel Sound.

It appears to be made mainly of granitic rocks and gneisses, much folded along a northerly to northeasterly regional trend. In the northern part it is flanked by apparently Proterozoic strata which appear to form the outer limbs of a geanticline. This northerly structure may have been in part the effect of a late Silurian orogeny which has affected lower Palæozoic strata adjacent to the Precambrian formations. Basic dykes similar to the so-called diabase dykes so widespread on the mainland Canadian Shield, referred to here as the 'Diabase Series' and described later, occur throughout the Precambrian of Baffin, Devon, southern Ellesmere, Somerset, and Prescott Islands, and of Boothia Peninsula. They are the youngest Precambrian rocks and their predominant orientation is northwesterly.

The Wellington Arch, in southern Victoria Island, is apparently made exclusively of Proterozoic rocks in obvious extension of the Proterozoic strata of Kent Peninsula and of Bathurst Inlet on the mainland. It trends northerly through Washburn Lake and possibly joins the Minto Arch.

The Minto Arch is much more extensive. It stretches from southern Banks Island, across the northern part of Amundsen Gulf, to the west coast of Victoria Island, between the west half of the north shore of Prince Albert Sound and the north shore of Walker Bay. Thence it crosses Victoria Island to its northeastern part, where it probably stretches from Richard Collinson Inlet to the west part of Goldsmith Channel, from which it trends southerly, being possibly within 40 miles of the east coast at Greely Haven. Magnetic data suggest that the Precambrian extends, at shallow depth beneath a thin cover of Palæozoic strata, from the latter locality to the Precambrian of eastern Prince of Wales Island. The rocks of the Minto Arch appear to be entirely Proterozoic and include sedimentary strata in part intercalated with lava and sills. The strata trend northeasterly to northerly and, over most of the belt, form undulatory folds with gentle dips, although in some areas the beds are practically flat lying. In the south half of Wollaston Peninsula unmapped rocks of reddish colour, as observed from aircraft, form many ridges of uniform elevation and oriented east to northeast. Possibly these are Proterozoic formations similar to those of the Minto Arch.

Arctic Lowlands and Plateaux

The second geological region, the Arctic Lowlands and Plateaux, includes, in its southern part, the Foxe, Victoria Strait, and Wollaston Basins. These abut the mainland Canadian Shield and are partly or entirely surrounded by Precambrian rocks. They are made mainly of limestone, dolomite, and shaly limestone of Ordovician and Silurian ages. It has not been established whether the basins originated before or after the deposition of the lower Palæozoic rocks.

The Arctic Lowlands and Plateaux include, in their northern part, the Jones-Lancaster Basin and the Melville Basin. These basins are almost completely separated by the Boothia Arch. They extend from Banks Island to Bache Peninsula, midway along the east coast of Ellesmere Island and, accordingly, lie mainly between the outer areas of the Shield and the Innuitian Region. Most of the strata of the Jones-Lancaster Basin range in age from Cambrian to Devonian but may include rocks of Tertiary age. Although normal faults and a few folds are present the strata throughout most of the basin dip gently away from the Shield areas and towards the Innuitian Region. Thus, in the northern part of the basin on Ellesmere Island, the regional dip is northerly, farther south it is westerly, and near the south coast of the island it is northwesterly. On Devon Island the dip is westerly and on Brodeur Peninsula of Baffin Island it is northwesterly. Near the Innuitian Region, however, at least some of the beds are flexed into folds which are probably related to the orogenies that affected that region, but are on a smaller scale. Such folds are found, for instance, on Somerset Island. In the northwestern and south-central parts of Somerset Island and in the northeastern part of Prince of Wales Island, that is, on each side of the Boothia Arch, a late Silurian or early Devonian conglomerate is made of detritus derived from the Precambrian rocks of the arch. However, the arch is presently separated from the conglomerate by a wide exposure of earlier Palæozoic strata, the gentle flexure of which, at least in the east, may have been contemporaneous with the uplift and denudation of the arch and with the deposition of the conglomerate. Little is known of the Melville Basin, except for the above conglomerate, but Silurian strata are apparently widespread in its eastern part and Devonian strata occur in its western part. North of the Minto Arch, the strata on northwestern Victoria Island regionally dip gently to the northwest; on northern Banks Island they are flexed in gentle, southerly trending folds; and on southwestern Melville Island they are flat lying to gently flexed.

Innuitian Region

The unfolded or in part gently flexed strata of the Arctic Lowlands and Plateaux pass northward and westward into folded structures of the Innuitian Region. These structures were produced during many periods of orogeny. Some of the structures of the Northern Ellesmere Fold Belt may date from the Precambrian. A Caledonian (late Silurian-early Devonian) orogeny, so far recognized only in the Cornwallis Fold Belt, was of mild intensity and its resulting folded structures are of limited areal extent. A Variscan (post-Devonian and pre-middle Pennsylvanian) orogeny was widespread. It caused the folding in the Parry Islands Fold Belt (Plate XXXIX), produced extensive deformation in the Central Ellesmere Fold Belt and apparently in the Northern Ellesmere Fold Belt. An Alpian orogeny (possibly ranging from late Mesozoic to some time in the Tertiary) was also widespread. Its effects have been determined in the Northern Ellesmere belt and in the Central Ellesmere belt. It has differentially deformed the Sverdrup Basin producing, in its eastern part, the Eureka Sound Fold Belt (Plate XXXVIII) but, in the western part generally more gentle folds and broad open flexures of varied trends.

Cornwallis Fold Belt. The Cornwallis Fold Belt occupies all of Cornwallis Island, the western and central parts of Grinnell Peninsula, a fringe along the east coast of Bathurst Island, and small islands south of Cornwallis Island. This belt separates the Parry Islands belt from the Central Ellesmere belt and trends northerly at right angles to them. Folds in the belt trend northerly to northwesterly but are locally flexed so as to trend east. Synclines are broad. Most anticlines are also broad but a few are narrow and some are separated by large areas of very gently dipping to almost horizontal strata. The deformed strata range in age from Ordovician to late Silurian or early Devonian. They are overlain by flat-lying to gently dipping beds of latest Silurian or earliest Devonian and of Pennsylvanian ages, indicating that the folding occurred during a Caledonian orogeny.

Parry Islands Fold Belt. The Parry Islands Fold Belt occupies much of Melville and Bathurst Islands. Its south edge cuts diagonally across southwestern Melville Island but includes the eastern part of the south coast. It lies south of Byam Martin Island and about a third way up from the south coast of Bathurst Island. Its north boundary lies at the southern limit of an unconformable cover of Pennsylvanian, Permian, and Mesozoic strata along a line passing through Helen and Cameron Islands, and, on northern Melville Island, across Weatherall Bay to Marie Bay just north of the Raglan Range. The belt is underlain by Ordovician, Silurian and Devonian strata that are folded generally into symmetrical folds trending east. The synclines have broad troughs and the anticlines have narrow crests with the more steeply dipping strata close to the crests. Individual folds generally extend for long distances along strike. No regional overturning has been detected. At the east end of the belt, most folds plunge westerly and away from the Cornwallis belt. The folding of the belt is assigned to a Variscan orogeny because the folded Devonian strata are overlain unconformably by Pennsylvanian strata. Definite folds of the belt extend as far as the west coast of Melville Island from Marie Bay southward but it has not been established whether gentle folds in Devonian strata on Prince Patrick Island, which are unconformably overlain by Mesozoic beds, are to be included in the orogenic belt.

Central Ellesmere Fold Belt. The Central Ellesmere Fold Belt extends from the eastern part of Grinnell Peninsula to the northeastern coast of Ellesmere Island. The southeast boundary of the belt passes south of Colin Archer Peninsula and, by a marked curve, passes east of Vendome Fiord, thence northerly to the head of Bay Fiord, and, by another marked curve, it reaches the east coast of Ellesmere Island near Dobbin Bay. The western boundary is placed along a line extending from northeastern Grinnell Peninsula, through the southern neck of Bjorne Peninsula, to the east shore of Baumann Fiord, along Trold Fiord, thence across the east side of Canyon Fiord, and from there to a point near Dana Bay on northeastern Ellesmere Island. At the last locality the boundary between the Central and Northern Ellesmere belts is placed at the first outliers of Permo-Carboniferous strata. Rocks of the belt include Proterozoic, Cambrian, Silurian, Devonian, and Tertiary strata. In general, the rocks are more intensely deformed than those of the Parry Islands belt. They are crossed by thrust faults and high angle faults. The folds are either symmetrical or asymmetrical and some are overturned. Individual folds extend for long distances without detected plunges but some folds are closed. On Grinnell Peninsula, at the west end of the belt, the folds plunge easterly. Northward within the belt, deformation becomes more severe and metamorphism increases. East of southern Trold Fiord, Ordovician carbonate strata are well indurated and veined. Slate, phyllite, micaceous sandstone, and fine-grained schists of Ordovician, Silurian, and possibly Devonian age occur at Canyon Fiord. In the north part of the belt rocks are cleaved and few fossils are known. In the central-eastern part of the belt Proterozoic strata underlie unmetamorphosed lower Palæozoic beds. Along much of the west boundary of the belt the rocks are overlain unconformably by Pennsylvanian and Permian strata of the Sverdrup Basin and have therefore been involved, like those of the Parry Islands belt, in a Variscan orogeny. They have been affected also by an Alpian orogeny because lower Palæozoic strata are overlain by folded Cenozoic strata.

Northern Ellesmere Fold Belt. The Northern Ellesmere Fold Belt underlies the northern coastal area of Ellesmere Island and apparently extends to northwestern Axel Heiberg Island. The rocks comprise sedimentary and volcanic material possibly ranging from the Precambrian to the Tertiary. A part of the belt includes gneisses and intrusions that vary from granitic to ultrabasic. These are undated but it is probable that they are Precambrian in age and were deformed during that time. Some volcanic rocks are pre-Permo-Carboniferous, either Silurian or Devonian, and are adjoined by greywackes. These rocks and Ordovician beds are mildly metamorphosed but have complex structures that probably resulted from the Variscan orogeny. Widespread outliers of mildly folded Permo-Carboniferous strata unconformably overlie older rocks of more complex structures and indicate that the Alpian deformation extended to those parts.

Sverdrup Basin. The Sverdrup Basin occupies a large part of the northwest Queen Elizabeth Islands. It underlies all of Axel Heiberg, Amund Ringnes, Cornwall, and Graham Islands and extends to the boundaries of the Parry Islands, Central and Northern Ellesmere belts. To the northwest it is in part bounded by the Arctic Coastal Plain. The basin is underlain by an essentially conformable sequence of marine and nonmarine late Palæozoic beds, marine, nonmarine and minor volcanic Mesozoic rocks, and nonmarine Tertiary strata. In the eastern margin of the basin, especially in the southwest, some of the younger formations overlap older formations of the basin. On southeastern Prince Patrick Island, Jurassic and Cretaceous formations unconformably overlie Devonian beds, and these overlaps must indicate the margin of the basin. The boundary between the Northern Ellesmere belt and the northeast part of the Sverdrup Basin is difficult to locate at present. This is because a continuous cover of Permo-Carboniferous strata of the basin has not been differentiated from mere outliers of such strata within older rocks of the Northern Ellesmere belt. Sills and dykes of gabbro, at least as young as Cretaceous, occur throughout much of the basin and extend to some adjoining parts of surrounding fold belts. They outcrop abundantly on Ellef and Amund Ringnes, Cornwall, and Axel Heiberg Islands and the parts of Ellesmere Island adjoining Eureka and Nansen Sounds. The long axis of the exposed basin extends from the north part of Sabine Peninsula on Melville Island, northeasterly across Ellef and Amund Ringnes Islands, to central-eastern Axel Heiberg Island, thence northerly along the east part of that island and across eastern Nansen Sound to Ellesmere Island. The axis of the basin thus described has stratigraphic and structural implications. It trends remarkably parallel to the Variscan folds of the

Parry Islands and Central Ellesmere belts. It coincides with a zone of some forty piercement domes (Plate XLI) and diapir folds which contain cores of gypsum and the oldest fossils found in the central part of the basin. The axis may well be the keel of the basin and may lie along a depression initially formed by the Variscan orogeny and later filled with evaporite. It is the zone of greater deformation within both the Eureka Sound belt and the western area of the basin. The strata of the eastern part of the Sverdrup Basin have been deformed into the Eureka Sound Fold Belt. This belt extends from the eastern boundary of the basin to western Axel Heiberg Island and reaches its west coast only in the northwest part. Folds trend northerly to northwesterly. Synclines have broad troughs and the larger anticlines have rounded crests, but narrow zones on many limbs dip steeply to vertically.

On the Ellesmere coasts of Greely Fiord and eastern Nansen Sound, and on northern Axel Heiberg Island the folds are mainly broad and relatively gentle although beds dip steeply at the locus of faults. On northeasternmost Axel Heiberg Island and on westernmost Ellesmere Island the strata form an extensive, easterly to southeasterly dipping monocline. Raanes Peninsula, west of Trold Fiord, apparently is mainly a west-dipping monocline. Central Axel Heiberg Island appears to be a regional structural low between the tectonically higher parts of Nansen Sound and Bjorne Peninsula. Late Mesozoic and possibly early Tertiary strata outcrop in the structural low and contain many small, doubly plunging folds of complex pattern, locally departing from the regional northerly trend. These small folds are centred by gypsum. Strata of the western part of the Sverdrup Basin have generally been deformed into large open folds and broad flexures. Beds dip gently and over large tracts of land are almost flat lying. Strata dip most steeply around the piercement domes and the latter occur at the crests of regional folds. Axes of folds trend in various directions except near the Eureka belt where they trend northwesterly almost parallel with those of that belt.

Arctic Coastal Plain

The Arctic Coastal Plain covers the western part of Banks Island, the western and northwestern parts of Prince Patrick Island and probably extends to the northwestern parts of Brock, Borden, and Ellef Ringnes Islands. The rocks include Cenozoic beds unconformably covering Mesozoic strata and, south of the Sverdrup Basin, comprise Cretaceous and possibly Jurassic formations apparently overlapping Devonian strata.

Archæan

Much the greater part of the Precambrian mapped on Baffin Island consists of gneisses, prevailingly granitic, heterogeneous, banded, and complexly folded (Table XXIV, in pocket). Areas of homogeneous, massive granitic rocks are much more restricted. Limestone, quartzite, and mafic schists, partly of possible volcanic origin, occur in belts and single bands bedded with gneisses.

The gneisses of Baffin Island south of the Arctic Circle have features not observed in the northern part of the island. In the south, besides prevailingly granitic gneisses, are widely distributed gneisses, granulites, and granitoid massive rocks of felsic to mafic composition and containing hypersthene with or without hornblende. In the southwestern and western parts of Cumberland Sound such rocks are regionally arranged in zones that vary successively from massive charnockite to hypersthene gneiss and granulite, to pyroxene-hornblende gneiss, to hornblende gneiss, to epidote-hornblende gneiss, and farthest away from the charnockite, to epidote-biotite gneiss. Common to both northern and southern Baffin Island are fine- to medium-grained granitic gneisses that are, in many parts, interbanded with biotite granitic gneiss and, less commonly although locally extensively, with biotite-garnet granitic gneiss. In the Cumberland Peninsula the bulk of the exposures are of gneissic granite, in part epidotized, and of biotite paragneiss. Also present are occasional, conformable dark bands of amphibolite and biotite paraschist, partly rusty weathering. The rocks are folded largely along northwesterly axes and the intensity of folding increases southwestward. Granites apparently separate the gneisses of Cumberland Peninsula from those of the River Clyde region. In the fiord belt of the River Clyde region, broadly homogeneous granitic gneisses, with biotite or less commonly hornblende, are associated with widespread bands, lenses, and patches of amphibolite, presumed to be metamorphic derivatives of dykes and sills. The rocks belong to the amphibolite metamorphic facies. A noteworthy feature of the structure throughout this area is the regional near-horizontal attitude of the foliation. Recumbent folds have been outlined locally, and very low-dipping thrusts and high-angle faults have dislocated the rocks. The gneiss terrains of Eclipse Sound and Admiralty Inlet regions are apparently similar to those of the River Clyde.

Crystalline limestone and metamorphic derivatives, graphite, biotite, garnet, and sillimanite gneisses and schists, amphibole schist and gneiss, quartzite, and quartz-mica schist are bedded with the granitic gneisses and mixed with granitic rocks of southern Baffin Island. These meta-sedimentary strata occur singly or more commonly as groups in bands a few feet to thousands of feet wide. Limestone occurs mainly in widespread bands not exceeding a few hundred feet in width. Quartzite in substantial amount has been mapped in the western part of southern Baffin Island. In the area of Schooner Harbour and of Alareak it is associated with belts of amphibole schists and gneisses possibly of volcanic origin. East of Schooner Harbour, the quartzite, with minor amounts of presumed arkose and metacrystic mica schist, is gently folded and may be thousands of feet thick. It is traversed by fresh looking granite and an extensive network of granite pegmatite dykes. Magnetite in various concentrations lies in banded gneisses on islands and on the mainland east of Chorkbak Inlet. Some meta-sedimentary rocks also occur in small areas of Cumberland Sound. The inland gneisses of the River Clyde region, which are similar to the fiord gneisses, contain a belt with limestone and metamorphic derivatives with a little quartzite, and a belt of quartzite with lesser carbonates and with meta-argillaceous strata and a stratum of banded quartz-magnetite rock probably derived from an iron-formation. Granite, paragneiss, schist, and granitic gneiss in part with garnet are found on the little-explored eastern shore of Foxe Basin. In the same region, specimens of greywacke, argillite, and greenstone have been collected at localities from Clarke Sound to Harbour Bay and form an assemblage not found elsewhere on Baffin Island.

Little is known of the northern part of the Baffin-Ellesmere belt. Granite, granitic and layered garnetiferous gneisses, and gneissoid quartzites are found on eastern Devon Island. Granite and augen-gneiss are exposed on southern Ellesmere Island. On the central part of the eastern coast of Ellesmere Island, among para-gneisses and granites, are acid and basic rocks with hypersthene and other features such as are found in the granulitic and charnockitic rocks of southern Baffin Island.

Precambrian granitic rocks, gneisses, and schists of northeastern Southampton Island, of Melville and Boothia Peninsulas, and of western Somerset Island have not been differentiated. Minerals collected on Melville Peninsula indicate the presence of ultrabasic rocks. Crystalline limestone and metamorphic derivatives, and argillite, quartzite, slate, garnet-mica schist and paragneiss lie in northeasterly trending folds midway up the eastern part of the peninsula.

Proterozoic

Flat-lying to gently folded Proterozoic rocks occur in the west and north parts of the Baffin-Ellesmere Belt. No granite intrusion has been found in them, but they are crossed, except in the Bache Peninsula region of Ellesmere Island, by dykes of the 'Diabase Series'. They rest with an angular unconformity on Archæan granitic rocks and on highly folded banded gneisses. They do not form a continuous belt between the Archæan terrains to the east and the Palæozoic strata to the west but are broken, as, for instance, on southern Devon Island, where Lower Cambrian strata lie directly on the gneisses.

Two groups of Proterozoic rocks have been mapped in the region Admiralty Inlet, on northern Baffin Island. The Eqalulik group, which rests unconformably on gneisses, has a Lower Quartzite member varying in thickness from 10 to 100 feet. This unit is overlain by a volcanic member made of some 1,000 feet of pillowed basaltic flows, massive and amygdaloidal basalts, andesites, and thin tuffaceous beds. The volcanic member grades into an overlying Upper Quartzite member, 1,000 feet thick. In most parts this member is essentially a uniform succession of quartzites, but it contains rare beds of conglomerate. The quartzite is commonly crossbedded and grain-graded, and shows local ripple-marks. Laterally it changes into a succession of purple shale, chloritic shale, chlorite-bearing quartz-ite, and pure quartzite. The Eqalulik group is block faulted and gently warped. Beds strike northwest and, in most places, dip northeasterly; dips do not exceed 20 degrees and are generally less than 10 degrees. The contact between the Eqalulik group and the overlying Uluksan group has not been observed. The latter contains five formations. The lowest of these, the Arctic Bay formation, is composed of approximately 500 feet of black shale. It is overlain by the Society Cliffs formation made of 900 feet of dolomite above which are beds of the Victor Bay formation, 600 feet thick. These are dolomites commonly with flecks of chert, with edgewise conglomerate, and with minor limestone and mudstone. Topmost silty flagstones and mudstones of the Victor Bay formation are transitional into the Strathcona Sound formation of mudstones and siltstones with an exposed thickness of 2,500 feet. The youngest unit of the Uluksan group is the Elwin formation which contains apparently more than 2,500 feet of alternating thick bands of orange-coloured sandstone and red siltstone and shale. A regional shallow north to northwest dip is modified by some broad flexures with axes oriented north or northeast. The belt of Proterozoic strata of Admiralty Inlet extends southeasterly across Borden Peninsula to at least Paquet Bay, south of Eclipse Sound. The strata of this region are flexed into gentle folds oriented southeasterly. They have not been mapped as separate formations. They include quartzite, sandstone, shale, and carbonate rocks. Undifferentiated from these and lying mainly to the west of Milne Inlet are substantial areas of limestone which may be Palæozoic.

Sandstones and quartzites of various colours, shale, and limestone, apparently of gentle dips, lie on the shores and in some islands of Fury and Hecla Strait between Melville Peninsula and Baffin Island. Most likely those are Proterozoic. Flat-lying sandstone immediately above Precambrian gneisses in the area of Fram Fiord, on the south coast of Ellesmere Island, in all probability represents an area of Proterozoic rocks. The Proterozoic rocks of the Admiralty Inlet-Paquet Bay area and those of probably this age at Fury and Hecla Strait and at Fram Fiord are cut by dykes of the 'Diabase Series'.

At Bache Peninsula the Proterozoic Thule group lies unconformably over Precambrian gneisses and has been divided into three formations with a total thickness of less than 630 feet. These are: the Rensselaer sandstone with purple and red yellowish quartzite and *Cryptozoon*?; the Cape Leiper, of grey and yellowish dolomite; and the Cape Ingersoll dolomite, weathering rusty red. The top of the Cape Ingersoll dolomite is possibly an erosion surface beneath the Lower Cambrian strata.

South of Aston Bay, on western Somerset Island, and on the east side of gneisses and granite of the Boothia Arch, the Proterozoic is possibly represented by a lower unit of 7,000 feet of grey and red quartzite, minor amounts of siltstone, slate, shale, and conglomerate, a limestone stratum with *Protozoans*?; and about 1,400 feet of gabbro sills. Conformably above, is an upper unit of 2,250 feet of dolomite. The lower unit and, to a much lesser extent, the upper unit are traversed by dykes of the 'Diabase Series', but there is no record of granite intruding the strata. The contact with fossiliferous, lower Palæozoic strata has not been observed. The Middle Ordovician to Middle Silurian Allen Bay formation is the nearest Palæozoic unit observed and it lies a few miles east of the Proterozoic exposures. On Prescott Island, in Peel Sound, some pink quartzite traversed by basic dykes outcrops immediately west of a granite exposure. Farther west on the island is some dolomite which may belong either to the Proterozoic sequence or to the Allen Bay formation. On the strike of and south of Prescott Island, near the east coast of Prince of Wales Island, southerly striking band of bedded and tilted sandstone or quartzite lies west of exposures of granitic rocks. It is most likely that at least the quartzitic rocks are Proterozoic and that they belong to the lower unit of the sequence on Somerset Island.

The Minto arch is mainly a sequence of interlayered Proterozoic sedimentary strata and undifferentiated gabbro sills, amygdaloidal basalt and basalt flows. At

Nelson Head, on the south coast of Banks Island, crossbedded white and pink quartzites, arkose, dark shale, and slate are overlain by sheets of basic igneous rocks, and one such sheet occurs within the strata at lower levels. The sedimentary sequence is predominantly siliceous. In contrast with these predominantly siliceous rocks is a succession of calcareous rocks that extend from the west end of the north shore of Prince Albert Sound to a point half-way along the south shore of Minto Inlet. These include limestone, crystalline limestone, marble, shale, and lesser dolomite which are intercalated with basic igneous sheets. In the vicinity of Holman Island, the limestone is partly stromatolitic and has biohermal lenses. In the region of Walker Bay the igneous sheets are also intercalated with carbonate strata. North of the east end of Prince Albert Sound sedimentary strata alternate with basic igneous sheets for some 8 miles across strike, to the north of which thick basic sills intrude limestones with some red gypsiferous shales. There is no other lithological information on this Precambrian area. Its rocks are thought to be Proterozoic because of similarities with formations of the Bathurst Inlet-Coppermine River region. Stromatolites found both at Holman Island and at Coppermine may have value in supporting the suggested correlation.

Proterozoic rocks of the Wellington Arch appear to be extensions of Proterozoic formations on the mainland across Coronation Gulf and Dease Strait. The rocks in the Richardson Island area consist of diabase, dolomite, sandstone, and quartzite of various colours and in part crossbedded. At Wellington Bay and Washburn Lake crossbedded quartzite of various colours and quartzitic conglomerate are associated with basalt, some of which forms sills.

In the mountainous east edge of the Innuitian Region, at Copes Bay, north of Bache Peninsula, folded Middle Cambrian beds are apparently conformably underlain by 3,750 feet of unfossiliferous strata, in part similar to the Proterozoic Thule group of Bache Peninsula. The bottom of the sequence is separated from underlying Silurian strata by a major thrust fault. Above the fault the unfossiliferous strata comprise 340 feet of dolomite, followed by 340 feet of conglomerate and 1,090 feet of sandstone in the lower 500 feet of which the sandstone alternates with conglomerate. This is followed upward by 295 feet of alternating black shale, sandstone, and dolomite, topped by 1,500 feet of dolomite with a few beds of sandstone. Many of these strata are red. They apparently extend northeasterly from Copes Bay to Dobbins Bay on the east coast, thence northward past Scoresby Bay along or near the coast to latitude 80°45′.

The 'Diabase Series' consists of unaltered basic dykes (Plate XLII), partly with a diabasic texture. It occurs from the south coast of Baffin Island to the southern part of Ellesmere Island, and from the east coast of Baffin Island to Boothia Peninsula and Peel Sound. In almost all the areas of this vast region the dykes are oriented northwesterly; the granitic rocks and gently deformed Proterozoic formations of Somerset Island, however, are crossed by a large plexus of diversely oriented dykes and sills. A belt of many dykes extends southeasterly from the area of Arctic Bay to south of Eclipse Sound; and a few dykes in the area of Arctic Bay deviate from the northwesterly trend. Elsewhere the dykes occur singly

Plate XLII

Dykes of the "Diabase Series" cutting gently inclined Proterozoic formations of the Jones-Lancaster plateaux east of Admiralty Inlet.

or in groups of a few units. The dykes lie beneath the surface of erosion over which the Lower Cambrian strata of southern Devon Island have been laid. In the area of Arctic Bay, the gently deformed Proterozoic formations are crossed by the dykes which are truncated by a conformable sequence of formations, the younger of which contain Palæozoic fossils. Nowhere are the dykes known to cut fossiliferous strata but they cut all gently to highly deformed formations lying unconformably beneath fossiliferous sequences. They probably marked a period of plateau intrusion at the end of Precambrian time during a hiatus in sedimentation.

Palæozoic

Cambrian

Exposures of the Cambrian system are, as far as known, limited to Lower and Middle Cambrian series in the Jones-Lancaster Basin, which fringes to the west the Baffin-Ellesmere belt, and to a Middle Cambrian formation within the Innuitian Region on Ellesmere Island. In the basin the strata are bounded by disconformities and diastems indicating instability that resulted in transgressions and regressions of the shallow seas in which the sediments were deposited. Upper Cambrian or Lower Ordovician fossils have been found in float south of Victoria Island and an Upper Cambrian fossil, also in float, has been collected on the northeast coast of Victoria Island. The strata from which these originated have not been located.

On Bache Peninsula, in the narrow tract of unfolded Palæozoic rocks between the Precambrian and the folds of the Innuitian Region, Cambrian rocks lie with structural conformity on the possibly eroded surface of the Proterozoic Cape Ingersoll dolomite, which is the uppermost formation of the Thule group. The Cambrian Strata have been divided into three formations. At the base is the Lower Cambrian Police Post limestone. It is made of some 12 feet of limestone, mainly impure or even slightly arenaceous, with thin layers of conglomerate containing rare quartz pebbles. On the eroded surface of the Police Post limestone rests 48 feet of grey or violet, partly oolitic limestone referred to the Cape Kent limestone of Lower and/or Middle Cambrian age. Disconformably over the Cape Kent limestone is the Middle Cambrian Cape Wood formation with 120 feet of limestone and dolomite overlain disconformably by 15 feet of limestone with very thin layers of sandstone and limestone conglomerate.

Fossils collected among lower Palæozoic limestone and limestone conglomerate of the south coast of Ellesmere Island indicate that at least Middle Cambrian strata lie between Proterozoic and Ordovician beds.

Lower and Middle Cambrian rocks outcrop at Dundas Harbour, in the eastern part of the south coast of Devon Island, and have been divided into three formations. The lowest is the Lower Cambrian Rabbit Point sandstone, 86 feet thick. It rests unconformably on Precambrian gneiss and granite and on dykes of the 'Diabase Series'. It corresponds to part of the Cape Kent limestone. Above are 786 feet of the Middle Cambrian Bear Point limestone with numerous limestone conglomerate beds, some of which correspond to part of the Cape Kent limestone and others to the Cape Wood formation. Next is the Middle Cambrian Ooyahgah formation comprising 555 feet of dolomitic limestone alternating with calcareous sandstone and shale, limestone conglomerate, and a 2-foot stratum with gypsum. Nearby at Cuming Inlet 50 to 100 feet of red and purple arenaceous shale and thin beds of sandstone are possibly Cambrian in age. They rest unconformably over Precambrian gneisses and are conformably overlain by carbonate strata.

Within the Innuitian Region, at the head of Copes Bay, north of Bache Peninsula, are 870 feet of Middle Cambrian limestone and minor shale in structural conformity over Proterozoic strata.

Cambrian or Ordovician

In the upper part of Admiralty Inlet, on northwest Baffin Island, rocks that may be Cambrian or Lower Ordovician in age are divided into the Gallery and Turner Cliffs formations. The Gallery formation rests with slight angular unconformity on the Proterozoic Elwin formation and on dykes of the 'Diabase Series'. It varies in thickness in accordance with undulations on the underlying surface of erosion and comprises a maximum of 600 feet of crossbedded sandstone. It is overlain conformably by the Turner Cliffs formation of about 350 feet of sandstone, siltstone, mudstone, and shale, which contain non-diagnostic fossils. These rocks are regarded as Cambrian or Ordovician because they are overlain conformably by the Ship Point formation of Middle and/or Upper Ordovician age.

In the western part of the Parry Islands belt is the Canrobert formation containing at least 600 feet of silty dolomite and edgewise conglomerate. It is the oldest formation of western Melville Island and underlies, in apparent conformity, the lowest beds of the graptolitic Ibbutt Bay formation which ranges in age from Lower Ordovician to Upper Silurian. The Canrobert rocks resemble the Cambrian and Lower Ordovician formations of eastern Devon Island and of Bache Peninsula.

Lower Ordovician

Lower Ordovician strata are known on Devon and Ellesmere Islands in the Jones-Lancaster Basin, where disconformities and diastems resulted from oscillatory subsidence, and are also found in the eastern part of the Central Ellesmere belt and on western Melville Island at the west end of the Parry Islands belt.

At Dundas Harbour, on Devon Island, Lower Ordovician strata are divided into two formations, the Mingo River limestone and the Nadlo Point limestone. The Mingo River lies on the eroded surface of the Middle Cambrian Ooyahgah formation, is 260 feet thick, and consists of interbedded limestone and limestone conglomerate overlain by massive limestone. It is disconformably overlain by the Nadlo Point limestone which is 590 feet thick and comprises limestone with a little dolomite, a few beds of sandstone and limestone conglomerate, and 47 feet of sandstone at the base. Many beds are reddish brown. Farther west, at Burnett Inlet, some 1,260 feet of reddish brown limestone and dolomitic limestone of Ordovician age, at least in its upper part, possibly belong to the Nadlo Point formation although they are associated with a larger amount of sandstone. They lie unconformably over Precambrian gneisses (Plate XL) and dykes of the 'Diabase Series'. On the north coast of the island, in the eastern part of Bear Bay, 1,200 feet of alternating beds of limestone, dolomitic limestone, sandstone, and shale, commonly with limestone conglomerate, lie unconformably over Precambrian gneisses. The top 100 feet of massive dolomitic limestone are possibly of Lower Ordovician age and the middle part of the formation is certainly Ordovician. These rocks may contain strata correlative with the Nadlo Point.

West of South Cape, on southern Ellesmere Island, unconformably over an upfaulted block of Precambrian gneiss, are rocks lithologically somewhat similar to the beds at Bear Bay, and apparently older than the Middle Ordovician Eleanor River formation. They comprise 1,200 feet of unfossiliferous, thin to massive beds of limestone and dolomitic limestone, commonly with pebbly limestone conglomerate in the lower 700 feet.

Among the gently north-dipping formations on Bache Peninsula, four are correlated in variable degree of assurance, with the lower Ordovician Cass Fiord, Cape Clay, Nunatami, and Cape Weber formations of Greenland. Interbedded limestone and limestone conglomerate that are separated by talus from the Middle Cambrian Cape Wood formation are correlated with the Cass Fiord. These rocks are apparently overlain by mottled limestone referred to the Cape Clay and this, in turn, by beds with fossils correlated with those in the Nunatami and Cape Weber formations. Correlatives of the Nunatami and Cape Weber limestones have been found in the inner part of the Princess Marie Bay and the equivalents of the Cass

Fiord formation apparently occur half-way between Bay and Flager Fiords, on Ellesmere Island.

In the Central Ellesmere belt limestone beds, correlative with the Lower Ordovician Nunatami and Cape Weber formations, occur on the west coast of Kane Basin, between Hayes Point and Cape Frazer, and the Cape Weber limestone is found on the north and northwest coast of Scoresby Inlet. Not far west, at Copes Bay, the Lower Ordovician is possibly represented within 4,800 feet of unfossiliferous limestone and impure limestone with gypsiferous beds separating a Middle Cambrian formation from a Middle Ordovician formation.

Ordovician and Silurian

Middle and Upper Ordovician and Silurian strata are widespread in the Arctic Lowlands and Plateaux and in the belts of folded Palæozoic rocks of the Innuitian Region. Middle and Upper Ordovician and Silurian beds were laid down in the south in apparently shallow seas transgressive over a large part of the Shield areas. In widespread parts of the southern basins of the Arctic Lowlands and Plateaux, the Middle and Upper Ordovician beds lie directly on Precambrian terrains whereas to the north, at least in the eastern parts of Jones-Lancaster Basin, such beds are separated from the Precambrian basement by Cambrian and older Ordovician formations. The Ordovician and Silurian sequences apparently thicken towards the Innuitian Region. Ordovician and Silurian beds include widespread shelly faunæ. Within these is a well known and characteristic 'Arctic Ordovician fauna' of Middle and possibly early Upper Ordovician age. It extends from northwest Greenland to southern Manitoba. Included in the Silurian shelly faunæ is a well known and characteristic Arctic fauna which ranges in age from Middle to Upper Silurian and possibly later. It is the *Atrypella scheii* fauna, formerly referred to as the *Lyssatrypa phoca* fauna. Beds containing this fauna are called *Atrypella* beds. It is found on King William Island and the west coast of Boothia Peninsula, in the Victoria Strait Basin, to at least Scoresby Bay, near the eastern margin of the Central Ellesmere belt. The Ordovician and Silurian strata of the Arctic Lowlands and Plateaux have a shelly fauna and are mainly carbonate rocks. Some Ordovician formations of the Innuitian Region contain a shelly fauna and they include mainly carbonate beds, and some Silurian formations of the same region have a shelly fauna either in carbonate or sandy rocks. However, within the Innuitian Region, the shelly strata change partly or entirely to a graptolitic facies. This change was initiated in Lower Ordovician time in the western part of the Parry Islands belt and in late Middle Ordovician time in the Cornwallis and Central Ellesmere belts. The graptolite formations range well up into the Silurian and are in part correlative with the shelly Silurian formations. They are essentially restricted to folded belts and are found from the west coast of Melville Island to at least Canyon Fiord on Ellesmere Island. The graptolitic fauna occur chiefly in impure carbonate rocks and shales, but are found also in sandy Upper Silurian strata. A thick sequence of gypsiferous beds were deposited in Middle Ordovician time and these beds straddle the boundaries between the Jones-Lancaster Basin and the Cornwallis and Central Ellesmere belts.

The Middle and Upper Ordovician and the Silurian rocks are divided into several formations, some of which overlap the boundary between the two periods. The most useful reference column has been erected on Cornwallis Island. There the Eleanor River formation is overlain by the Cornwallis formation, both of Middle Ordovician age. In the south this is followed by the Middle Ordovician to Middle Silurian Allen Bay formation and by the Read Bay formation of Middle and Upper Silurian age and contains *Atrypella* beds. All those formations belong to the shelly facies. In the north part of the island the Cornwallis is overlain by the Middle Ordovician to Upper Silurian Cape Phillips formation of the graptolitic facies.

All these formations, or their correlatives which have been given other names, have been traced beyond the limits of Cornwallis Island.

Eleanor River Formation. The Eleanor River formation is the oldest unit on Cornwallis Island where it contains some 500 feet of unfossiliferous limestone. The lower contact has not been recognized here or elsewhere.

In the Jones-Lancaster Basin the formation has been found on southern Ellesmere and southern Devon Islands. At Sydkap Fiord the exposed section, above a talus, comprises 350 feet of limestone, with chert nodules in the upper 150 feet. At Burnett Inlet the limestone is 650 feet thick with chert nodules in the upper 200 feet, contains Middle or Upper Ordovician fossils, and is conformably overlain by the Middle Ordovician Cornwallis formation. A fault separates it from beds that possibly belong to the Lower Ordovician Nadlo Point formation.

The Eleanor River formation also occurs in folded rocks of the Central Ellesmere belt. In the Druro Range of northwestern Devon Island at least 100 feet of the formation occur between a fault and younger formation. Beds that are probably correlative with it occur in a 3,300-foot section of limestone with some dolomite beneath the Cornwallis formation east of southern Trold Fiord and in the upper part of 4,800 feet of unfossiliferous strata below the Cornwallis at Copes Bay.

Cornwallis and Equivalent Formations. On Cornwallis Island the Cornwallis formation, of Middle Ordovician age, lies with apparent conformity on the Eleanor River and is in sharp contact with the overlying Allen Bay formation. It contains 5,000 feet of varied but predominantly carbonate strata. The basal 800 feet are made of siltstone and shale alternating with fewer strata of limestone, gypsum or anhydrite, and gypsiferous shale. These are overlain by 1,700 feet of alternating beds of limestone and impure limestone with a few interbeds of siltstone. The uppermost strata comprise about 60 feet of limestone overlain by 28 to 40 feet of shale, are exceptionally fossiliferous and contain a prolific representation of the 'Arctic Ordovician fauna'. Noteworthy features of the formation there and elsewhere are the thick and widespread evaporate sequence in its lower part and the shelly 'Arctic Ordovician fauna' in its upper part.

The formation is also exposed elsewhere in the Cornwallis belt. Near the east coast of Bathurst Island a section contains 2,275 feet of dolomite, limestone, and sandstone, with a prolific fauna at the top. The formation apparently outcrops extensively on Grinnell Peninsula. Inland from Cape Ogle on the north coast, some 500 feet of Ordovician strata probably belong to the Cornwallis formation.

The Cornwallis formation or its equivalent occurs at widespread localities within the Central Ellesmere belt. A thickness of 2,200 feet, including evaporites, outcrops in the Druro Range. As much as 4,400 feet, with up to 800 feet of evaporite beds in the bottom part, are exposed in folded terrains from Vendome to Trold Fiords. At the head of Trold Fiord 1,900 feet of Cornwallis limestone are exposed. On the east side of Canyon Fiord, talus associated with a thick sequence of calcite-veined and indurated limestone contains forms of the 'Arctic Ordovician fauna' and is possibly correlative with the Cornwallis. Beds equivalent to the Cornwallis outcrop at the head of Bay Fiord. Farther north, at Copes Bay, the formation is represented by 4,400 feet of limestone and impure limestone including at the base about 850 feet of gypsum. On the eastern side of Kane Basin, between Dobbin Bay and Cape Norton Shaw, carbonate strata have been correlated with the Gonioceras Bay and Cape Calhoun formation of northwestern Greenland and are most probably correlative with the Cornwallis formation. Possibly equivalent also to the Cornwallis formation is the black bituminous shaly Cape Baird limestone at the north end of Judge Daly Promontory.

The Cornwallis formation is also widespread in the Jones-Lancaster Basin, where it is found on Ellesmere and Devon Islands and possibly on northern Baffin Island. South of a thrust fault that separates the Central Ellesmere belt from the basin at Copes Bay, the Middle Ordovician evaporites are widespread and extend to the western part of Bache Peninsula. At Sydkap Fiord the formation comprises 700 feet of evaporite beds with lesser limestone and shale overlain by 950 feet of limestone. It occupies a large part of central Devon Island where it occurs in the area between Maxwell Bay, Bear Bay, and Burnett Inlet, and possibly extends to Dundas Harbour. At Burnett Inlet 530 feet of interbedded limestone and gypsum are overlain by 510 feet of richly fossiliferous limestone below the plateau surface. At Dundas Harbour this surface is on the Croker Bay limestone comprising 1,100 feet of limestone overlying 290 feet of limestone, impure limestone, and limestone conglomerate. This formation lies conformably over the Lower Ordovician Nadlo Point limestone and possibly includes beds correlative with the Cornwallis and/or the Eleanor River formation. South of the western part of Bear Bay, the Cornwallis evaporite sequence is exposed in a large piercement dome including and surrounded by complex structures in the overlying carbonate strata of the formation. In Admiralty Inlet the Ordovician Ship Point formation is composed of 920 feet of commonly silty dolomite, overlies conformably the undated Turner Cliffs formation, and conformably underlies the Ordovician Baillargé formation which forms the plateau surface. The Baillargé has a minimum of 460 feet of limestone, including a 30-foot gypsum stratum in the upper part. It may represent the lower part of the Cornwallis formation, but it is not possible at present to correlate the Ship Point formation with the Eleanor River. The younger strata of the region progressively overlap southward the older formations until they rest directly on the Precambrian gneisses, and the Foxe Basin appears to be made exclusively of Middle Ordovician and younger beds. On the islands and on the coasts of the basin, as well as on western Southampton Island the Ordovician strata, especially at Igloolik, contain elements of the 'Arctic Ordovician fauna'. The strata at Silliman Fossil Mount, on southeastern Baffin Island, and the lower part of Ordovician limestone strata on Akpatok Island, in Hudson Strait, have been specifically correlated with the topmost 500 feet of Cornwallis formation on Cornwallis Island. The 'Arctic Ordovician fauna' is well represented at Coral Harbour, on southern Southampton Island, in the 700 feet of limestone and impure limestone of the Putnam Highland, and in limestone debris which is widely distributed in the region of Nettilling and Amadjuak Lakes on Baffin Island. The Ordovician beds rest on the Precambrian at many localities of southern Baffin Island. In the Victoria Strait Basin beds probably correlative with the Cornwallis formation occur on southern King William Island.

A group of rocks known as the Challenger group occurs among the metamorphic terrains of the Northern Ellesmere belt. It includes limestone with Ordovician fossils like those found in the Cornwallis, Gonioceras Bay, and Cape Calhoun formations.

Allen Bay and Equivalent Formations. The Middle Ordovician to Middle Silurian Allen Bay formation overlies the Cornwallis formation on southern Cornwallis Island. It is 5,000 feet thick and consists mainly of dolomite.

The formation also occurs above the Cornwallis in the southern and eastern parts of the Central Ellesmere belt. A thickness of 3,700 feet of mainly dolomite outcrops in the Druro Range. A poorly exposed interval between outcrops of the Cornwallis and Upper Silurian beds in the region of Vendome Fiord probably contains beds correlative with the Allen Bay. At Copes Bay 1,620 feet of Allen Bay dolomite and limestone are exposed and similar dolomite is found in Scoresby Bay.

The Allen Bay formation is also found in the Jones-Lancaster Basin. It outcrops down the regional westerly dip along a large tract of land on western Devon Island where it may be seen between Cape William Herschell and Radstock Bay on the south coast, and west of Bear Bay on the north coast. At Boat Point at least 1,700 feet of dolomite are exposed. On southern Ellesmere Island at least 850 feet of Allen Bay dolomite occur along Goose Fiord, and at least 1,760 feet of dolomite are exposed along Sydkap Fiord. The formation occurs along the flanks of the Boothia-Somerset Arch, as on the west side of Peel Sound and on western Somerset Island where older Palæozoic beds possibly separate it from Proterozoic rocks. On Somerset Island it forms an easterly dipping homocline extending from the region of Aston Bay southward apparently to a point just east of Fort Ross and possibly to the northeast coast of Boothia Peninsula at least as far as Cape Farraud.

In the Wollaston Basin, Upper Ordovician and Silurian dolomitic strata occur on southwestern Victoria Island and on small islands off the south coast, and are possibly correlative with the Allen Bay formation.

Read Bay and Other Atrypella Beds. In the southern part of Cornwallis Island the Read Bay formation overlies the Allen Bay formation conformably and grades into it. The Read Bay is Middle and Upper Silurian in age. It is 8,500 feet thick and is made in large part of limestone and argillaceous limestone with some shale and dolomite and minor amounts of sandstone and siltstone. It includes *Atrypella* beds. An upper Silurian graptolitic shale member, 100 feet thick, forms a tongue within the shelly facies. The formation extends to parts of the Arctic Lowlands and Plateaux adjacent to the Cornwallis belt.

At Goose Fiord, near the northwestern margin of the Jones-Lancaster Basin, the Allen Bay is overlain by a formation in part containing 1,300 feet of dolomite and limestone, in the upper part of which are layers with *Atrypella.* It is substantially represented on the west coast of Devon Island and occupies the greater part of the surface of the synclinal area between the Precambrian of Somerset Island and of Admiralty Inlet. Along Prince Regent Inlet the formation includes thin beds of gypsum. On Brodeur Peninsula an unmapped strip separates Read Bay beds from the Ordovician formations of Admiralty Inlet. The Read Bay formation lies on Prince of Wales Island west of the Allen Bay occurrences, and dolomitic limestone at Greely Haven on the northeast coast of Victoria Island may correspond to either of these formations. *Atrypella* beds occur on the west coast of Boothia Peninsula. Undifferentiated Silurian carbonate beds are found on southwestern and northern Southampton Island and a Middle Silurian dolomitic limestone outcrops on islands of northern Foxe Basin.

Beds containing *Atrypella* are widespread in the southern and eastern parts of the Central Ellesmere belt. In the Druro Range 1,300 feet of limestone, argillaceous limestone, and lesser shale, with *Atrypella,* conformably overlie the Allen Bay formation. In the region of Vendome Fiord at least 1,450 feet of limestone, silty limestone, dolomite, and cherty limestone are included in the *Atrypella* beds. At Copes Bay 900 feet of limestone and shale overlie the Allen Bay formation and are included in the *Atrypella* beds which are also reported on shores of Scoresby Inlet.

Cape Phillips and Other Graptolitic Formations. On northern Cornwallis Island the Cape Phillips formation lies conformably above the Cornwallis formation. It is Middle Ordovician to Upper Silurian in age, represents a graptolitic facies and is correlative with the Allen Bay and most of the Read Bay shelly formations. The Cape Phillips comprises 8,500 feet of impure carbonate rocks, shales, and cherty carbonates. The upper part of the formation is beneath an unconformable contact with the overlying Disappointment Bay formation which is described later. The top of the formation is exposed at Driftwood Bay, near the central east coast of Bathurst Island, where 1,600 feet of the formation lie conformably under a younger Silurian formation.

The Cape Phillips also occurs in the Parry Islands belt. On central Bathurst Island 1,865 feet of the formation are exposed and consist of calcareous and dolomitic mudstone and shale, which are silty in the upper part. These beds are overlain conformably by another Silurian graptolitic formation which comprises 3,000 feet of argillaceous and calcareous, fine-grained sandstone.

On the west coast of Melville Island, Lower Ordovician to Upper Silurian graptolitic strata have been called the Ibbutt Bay formation. Stratigraphically it does not reach as high as the Cape Phillips but reaches lower and includes beds correlative with the Cornwallis, Eleanor River, and older formations. The exposed section contains 3,500 feet of black shale and argillite. The main graptolitic facies has not been mapped between Cornwallis Island and Baumann Fiord in the Central Ellesmere belt. However, 480 feet of Upper Silurian graptolitic shale overlie the *Atrypella* beds of Goose Fiord. Those, like the 100-foot shale member within the Read Bay formation on Cornwallis Island, are graptolitic tongues within the shelly facies. In the bay east of southern Trold Fiord a formation has been in part at least correlated with the Cape Phillips. Its lower 850 feet consist of graptolite-bearing fissile, limy argillite and shale. They are overlain by 1,230 feet of limestone, shale, limy shale, and argillite with sericite along bedding planes. These beds grade into 1,300 feet of calcareous shale, siltstone and sandstone with sericite and poorly preserved fossils. Farther north at the head of Trold Fiord 2,300 feet of Ordovician and Silurian graptolitic shale, micaceous in the upper part, overlie the Cornwallis formation. On the east side of Canyon Fiord, in an area of metamorphosed strata, approximately 120 feet of shale with Silurian graptolites overlie a thick limestone formation which is probably the Cornwallis. In the eastern part of Bay Fiord, an Ordovician black argillaceous limestone, called the Thorup Fiord limestone, and a black calcareous Silurian shale belong to the graptolitic facies.

Silurian and Devonian

Numerous strata lying above Upper Silurian graptolitic beds or above *Atrypella* beds and, in some parts, below Middle Devonian formations, are dated or regionally correlated with difficulty. For the most part they were deposited at some time during the span of the Upper Silurian to Middle Devonian.

In the Arctic Lowlands and Plateaux of Somerset and Prince of Wales Islands, Upper Silurian or Lower Devonian formations occur in proximity to the Boothia Arch. They contain red conglomerate, sandstone, and siltstone. The conglomerate contains debris derived from the Precambrian rocks of the Arch. It overlies the Read Bay formation conformably and grades into it.

On the east coast of Cornwallis Island, in the Cornwallis belt, the Snowblind Bay formation likewise conformably overlies and grades into the Read Bay formation. The Snowblind Bay is either Upper Silurian or Lower Devonian in age and is made of 800 feet of limestone breccia, limestone conglomerate, red sandstone, and siltstone. On the north coast of Cornwallis Island, the Disappointment Bay formation overlies the Cape Phillips with angular unconformity and is also either Upper Silurian or Lower Devonian in age. It consists of at least 280 feet of dolomite, sandstone, and limestone conglomerate. On the other hand, the Cape Phillips at Driftwood Bay, on the central part of the east coast of Bathurst Island, is overlain conformably by 520 feet of limestone, limestone conglomerate, dolomite, and sandstone. These rocks are overlain unconformably by 200 feet of basal conglomerate and overlying sandstone which is followed conformably by a Middle Devonian formation.

In central Bathurst Island, in the Parry Islands belt, a conformable sequence of 1,270 feet of calcareous and argillaceous sandstone and of 860 feet of calcareous shale are Lower and possibly Middle Devonian in age and overlie the uppermost graptolitic Silurian formation. In the area of Weatherall Bay of northeastern Melville Island 700 feet of limestone and minor dolomite are geographically located between the graptolitic Silurian beds of central Bathurst and those of western Melville Islands. They contain a shelly Silurian fauna without known equivalent in the region. They are the oldest beds found in the area and are overlain disconformably by Pennsylvanian strata.

Near the boundary between the Jones-Lancaster Basin and the Central Ellesmere belt, strata of Upper Silurian and/or Lower Devonian age are exposed in the Druro Range and at Goose Fiord. At both localities these rocks lie conformably above Upper Silurian graptolitic shale and are overlain by Middle Devonian marine strata. In the Druro Range they comprise 500 feet of dolomitic beds and 310 feet of unfossiliferous sandstone. At Goose Fiord they consist of 310 feet of limestone followed, possibly disconformably, by 1,000 feet of unfossiliferous dolomitic siltstone, in part sandy. The Cape Phillips formation in the bay east of southern Trold Fiord is conformably overlain by some 4,200 feet of limestone and silty limestone with poorly preserved fossils of Upper Silurian or Devonian age. At the head of Trold Fiord, more than 2,500 feet of siltstone, fine sandstone, and shale are at least younger than Cape Phillips beds which they overlie conformably; they are overlain unconformably by Pennsylvanian strata. Strata exposed east of Canyon Fiord are also pre-Pennsylvanian and younger than Silurian graptolitic shale. These include an estimated 3,000 feet of sandstone, sandy shale, and slate, without known fossils and, though separated by a covered interval, include also an apparently younger and conformable sequence of beds with rare and poorly preserved fossils. These beds, though apparently younger, are more metamorphosed and comprise quartzite, fine-grained quartz-sericite schist, phyllite, basal slate with faint cleavage, bedded chert, and conglomerate with chert pebbles. A few miles east of Alert on northeastern Ellesmere Island a 2,000-square foot exposure of fresh-looking limestone with Middle Silurian fossil shells is partly surrounded by slightly metamorphosed rocks and may overlie them.

In the Northern Ellesmere belt the presence of Silurian rocks is indicated in a mixed collection from Ward Island that includes shells of Silurian age, and in Lower Silurian fossils in rock fragments embedded in volcanic rocks on northernmost Axel Heiberg Island.

Devonian

Devonian strata are known in the Central Ellesmere, Cornwallis and Parry Islands belts of the Innuitian Region and in nearby parts of Prince Patrick, Banks, and Victoria Islands, and in southwestern Ellesmere Island. Middle Devonian formations on southern Ellesmere and eastern Bathurst Islands are mainly marine, whereas those on western Melville Island are chiefly nonmarine. Upper Devonian formations are chiefly nonmarine although some marine beds occur on Cameron and Prince Patrick Islands and apparently on northwestern Cornwallis Island. On Banks and northwest Victoria Islands some beds of limestone, possibly of Middle and/or Upper Devonian age, are marine and on Banks Island are associated with sandstone.

In the Central Ellesmere belt a Lower or Middle Devonian formation, probably including well over 1,000 feet of marine calcareous shale and siltstone, underlies the country of Eids Fiord and eastward. A thick sequence of Middle and Upper Devonian formations overlies that unit, and also the sandstone of Druro Range and the dolomitic siltstone of Goose Fiord, both of which were described in the previous section. It also overlies an unfossiliferous sandstone of Colin Archer Peninsula. The sequence lies within a large syncline, which is, in those parts, the first major fold including strata passing from the Jones-Lancaster Basin into the Central Ellesmere Fold Belt. It has a maximum thickness of over 16,000 feet. Its lower formations are thicker north of the syncline than to the south. The lowest formation of the sequence comprises 1,900 to 3,800 feet of marine Middle Devonian limestone, dolomite, and calcareous shale, in part with coral biostromes and bioherms. The overlying formation consists of 1,700 to 2,900 feet of marine Middle Devonian limestone, sandy limestone, sandy shale, and sandstone. The third and topmost formation of the conformable sequence is over 10,000 feet thick beneath the eroded plateau surface. It is Upper Devonian and is largely made of nonmarine sandstone and shale with thin seams of bituminous coal. The large syncline with Devonian beds extends to the east coast of Grinnell Peninsula. Possibly correlative with the Upper Devonian beds are at least 5,700 feet of unfossiliferous, nonmarine sandstone and minor coal that constitute the youngest structurally conformable beds above the Ordovician-Silurian strata of Vendome Fiord.

On Central Bathurst Island the previously described Lower and possibly Middle Devonian strata are overlain by Middle Devonian limestone and interbedded shale followed by sandstone and sandy mudstone. These are overlain conformably by nonmarine sandstone that most likely corresponds to part of the thick, nonmarine, Upper Devonian formation of southwestern Ellesmere Island. On Cameron Island, off northwest Bathurst Island, nonmarine Upper Devonian clastic strata with coal seams are conformably overlain by at least 1,000 feet of partly marine, Upper Devonian siltstone and shale with some layers of coal. To the west, in the area of Weatherall Bay, on northwestern Melville Island, are at least 300 feet of Devonian sandstone with coal beds. On western Melville Island the Melville Island formation lies conformably over the Ibbutt Bay formation and contains a minimum of 11,000 feet principally of nonmarine sandstone, with shale, siltstone, and coal. It ranges in age from Middle to Upper Devonian. The lower 6,500 feet are thin bedded and include some thin layers of marine, impure limestone of Middle Devonian age. About 7,500 feet of strata included in the Melville

Island formation are exposed on Prince Patrick Island, where the lower 1,800 feet are thin bedded and include marine strata of Upper and possibly Middle Devonian age. Extensive areas of sandstone with beds, lenses, and fragments of coal and with plants occur on the southern part of Melville, on Byam Martin, on western Bathurst, and on the northeast coast of Banks Islands. It is most probable that these contain beds correlative with the Melville Island formation or with the non-marine Upper Devonian strata of central Bathurst and southwestern Ellesmere Islands. On northern Banks Island and on its east coast, and on the northwest coast of Victoria Island, along Prince of Wales Strait are limestones possibly of Middle and/or Upper Devonian age.

Near the east coast of Bathurst Island, at the latitude of Driftwood Bay, the 200 feet of sandstone and basal conglomerate, described in the previous section, are overlain by 850 feet of Middle Devonian limestone, calcareous shale and sandstone, and bioclastic limestone, above which occur conformably some 3,800 feet of sandstone. Farther south on eastern Bathurst Island are outcrops of marine Middle Devonian bioclastic limestone. Limestone debris covering many acres on northwest Cornwallis Island contains marine fossils of Upper and probably Middle Devonian age.

Pre-Pennsylvanian

The Northern Ellesmere and north part of the Central Ellesmere belts contain many undated, or poorly dated, mainly metamorphic rock units, most of which are unconformably overlain by Permo-Carboniferous strata.

The Cape Columbia group is the most extensive known unit of the Northern Ellesmere belt. It is made of a variety of generally banded gneisses and of schists, quartzite, and crystalline limestone. These metamorphic terrains are complexly folded and have been intruded by granite, norite, peridotite, and syenite, which, as far as known, cut only this group. The group is more intensely folded and markedly more metamorphosed than other pre-Permo-Carboniferous formations. It is unconformably overlain by Permo-Carboniferous strata. Rocks similar to it occur as pebbles in an Upper Ordovician conglomerate of the Challenger group and in a conglomerate possibly near the base of the M'Clintock group. The Cape Columbia complex may be as old as Precambrian.

The Challenger group occurs in the M'Clintock Bay area in the Northern Ellesmere belt. It includes fossiliferous Ordovician beds, reddish sandstones in large amount, red limestone and mudstone, minor altered basic volcanic rocks, and conglomerate. Some of these may be younger and others older than Ordovician. In the same region, that is, on Ward Hunt Island, have been found Silurian fossils of unknown source.

Also in this region is the M'Clintock group of volcanic flows, breccia and tuff, associated tuffaceous greywacke, slate, sandstone, chert, limestone, and a layer of gypsum up to 400 feet thick. It is undated but is unconformably overlain by Permo-Carboniferous limestone, and occurs adjacent to and possibly underlies strata of the Challenger group; similar rocks occur as pebbles in an Ordovician conglomerate.

The Cape Rawson, Mount Disraeli, Sail Harbour, and View Creek groups of northeastern Ellesmere Island are undated, differentially but slightly metamorphosed, much folded, and of unknown stratigraphic relations to one another. The Cape Rawson beds are known to be unconformably overlain by Permo-Carboniferous strata, and the other three groups are thought to be older than the Permo-Carboniferous because they are more metamorphosed and generally more severely folded.

The Mount Disraeli group occurs west of Clements Markham Inlet and contains an assemblage of calcareous black slate and phyllite alternating with an assemblage of limestone and shaly limestone in part marbleized. The Sail Harbour group lies east of the inlet and includes black shale, slate, and argillaceous limestone, with veins of carbonate and quartz, and unidentified fossils. It possibly is underlying the Permo-Carboniferous Guide Hill formation. The View Creek group covers a small area in the southeast part of Feilden Peninsula. It contains a great diversity of prevailingly clastic rocks, including sandstone with numerous interbeds of granule and pebble conglomerate, red sandstone and conglomerate, black and green slate and phyllite, quartzite, limestone, and greywacke. Quartz veins cross many beds.

The Cape Rawson beds were originally defined as strongly disturbed jet-black slate and impure limestone between Scoresby Bay and latitude 82°33′ on the east coast of Ellesmere, and thence north to Dana Bay, as a vast series of quartzites and grits. Subsequently, the term has been extended to include unfossiliferous strata, of low metamorphic grade, that spread across the northern part of the Central Ellesmere belt. These rocks are composed of slate, phyllite, sandstone, limestone, and black chert and some of them have slaty cleavage.

Within the area originally described as underlain by the Cape Rawson beds, clastic beds on the east shore of Kennedy Channel are now thought to be an extension of similar Proterozoic strata at Copes Bay, Ordovician beds have been located on the north shore of Scoresby Bay, the Ordovician Cape Baird limestone has been described at the north end of Judge Daly Promontory, and a Silurian limestone has been found near Alert. In the extended area of occurrence of Cape Rawson beds, some metamorphosed strata may be as young as Devonian. It therefore seems that, apart from the fact that some are overlain unconformably by Permo-Carboniferous strata, the Cape Rawson beds have no stratigraphic status.

Permo-Carboniferous

Permo-Carboniferous strata occur along the southern, eastern and northern periphery of the Sverdrup Basin, where they lie unconformably above upper Devonian and older strata. They are found in widespread outliers unconformable above the metamorphic terrains of the Northern Ellesmere belt. They are exposed within the gypsum cores of piercement domes and diapir folds of the Sverdrup Basin. Finally they comprise nonmarine beds that lie unconformably over lower

Palæozoic strata in the Cornwallis Belt. A small angular unconformity separates Pennsylvanian and Permian beds on Trold Fiord. Units of limestone, units of sandstone with layers of conglomerate, and lesser units of shale generally occur together. Limestone, commonly with chert, is the most widespread type, but in the western part of the Parry Islands belt sandstone occurs almost to the exclusion of limestone. The sandstone is locally glauconitic. Some of the sandstone and conglomerate is red and, in some localities, the limestone and shale have vivid colours.

Evaporites, mainly gypsum, form the cores of the series of piercement domes and diapir folds extending from Sabine Peninsula on northern Melville Island, through the Ringnes and western Axel Heiberg Islands, north to Ellesmere Island. Narrow bands and blocks of limestone within the evaporites, which are commonly bedded, contain Permo-Carboniferous fossils and it is probable that the evaporites themselves are of this age or older. Nevertheless, the evaporites have been intruded into much younger rocks and their injection was accompanied by deformation of strata of Triassic, Jurassic, Cretaceous, and possibly Tertiary age.

At Weatherall Bay, on northeastern Melville Island, 2,500 feet of Pennsylvanian red weathering sandstone, conglomerate containing chert pebbles with graptolites, and minor shale unconformably overlie nonmarine Devonian strata. They are overlain in apparent conformity by Permian strata including 1,300 feet of sandstone and 2,500 feet of sandstone with bands of crossbedded sandstone, and with conglomerate and shale. Nearby, on Cameron Island, a Permian sandstone with glauconite lies unconformably over Upper Devonian marine beds. A colourful sequence at least 800 feet thick of richly fossiliferous Permo-Carboniferous limestone conglomerate, shale, sandy clay, and sandstone unconformably overlie Middle Ordovician strata on the north coast of Grinnell Peninsula.

At Eids Fiord, on Ellesmere Island, Pennsylvanian strata unconformably overlie Middle Devonian beds. They include conglomerate, shale, sandstone, and limestone. Northward, on Bjorne Peninsula, these strata are overlain by Permian limestone and chert that extend from Great Bear Cape eastward. The Pennsylvanian rocks possibly belong to the Canyon Fiord formation described below. In the northern part of Bjorne Peninsula, the Permian strata occur at the crest of a large anticline and include 550 feet of limestone, cherty limestone, chert, and glauconitic sandstone. On the Raanes Peninsula, in the region of Trold Fiord, the Pennsylvanian Canyon Fiord formation comprises over 1,700 feet of sandstone, limestone, and conglomerate. These strata lie with a large angular unconformity over Ordovician, Silurian, and possibly younger beds. With a small angular unconformity over the Canyon Fiord formation are about 70 feet of glauconitic beds with Permian fossil overlain by 1,200 feet of unfossiliferous sandstone of unknown age. At Blind Fiord the Permian section comprises about 2,000 feet of limestone, chert, and shale. The top of this section is marked by the boundary with Triassic strata but the base of the Permian formation is not exposed. The east coast of Bjorne Peninsula and, to a lesser extent, the opposite east shore of Baumann Fiord contain dusky red strata possibly similar to the Permo-Carboniferous beds north of Eids Fiord. On the east shore of Canyon Fiord, farther north on Ellesmere Island, 474 feet of colourful conglomerate, sandstone, and limestone are included in the Pennsylvanian Canyon Fiord formation. These lie unconformably over graptolitic Silurian beds and younger, metamorphosed strata.

Farther north on Canyon Fiord, in the eastern part of Greely Fiord, and in the Sawtooth Range, west of Canyon Fiord, the Permian strata of the Greely Fiord group are at least 2,000 feet thick, possibly much more, and include limestones in part with chert, sandstone, and some conglomerate. The sandstone includes cross-bedded, red, and glauconitic varieties. The presence of chlorite in strata of the Sawtooth Range suggests that the sediments were partly derived from volcanic rocks.

In the region of Feilden Peninsula on northeastern Ellesmere Island, the Permian Dana Bay and Feilden formations are made of limestone, in part with chert nodules, argillaceous limestone, sandstone, and conglomerate. Apparently conformable under the Feilden is the Permo-Carboniferous Guide Hill formation composed of a sequence of red sandstone and conglomerate with numerous diastems, and black and purple shale. Both the Guide Hill and the Feilden lie unconformably above Cape Rawson beds. Farther west, on the north coast of Ellesmere Island, are widespread Permo-Carboniferous limestone, conglomerate, and cherty limestone. Unfossiliferous sandstones have been grouped with them. Those rocks are similar, in part at least, to the Feilden and Guide Hill formations. Such strata unconformably overlie the apparently pre-Middle Ordovician Cape Columbia group of metamorphic rocks and the M'Clintock formation of volcanic and sedimentary strata.

Permo-Carboniferous strata form a substantial exposure on northern and northwestern Axel Heiberg Island and on northwestern Ellesmere Island. Folded, cherty limestone of Permian age occurs on Axel Heiberg Island at Li Fiord, at Bunde Fiord and east, and along the southwest shore of Nansen Sound. At Bunde Fiord, about 5,500 feet of limestone conformably overlie an estimated 5,000 feet of basalt flows, and at least locally some 500 feet of sandstone and conglomerate are at the top of the volcanic sequence. East of the fiord and a few miles from Nansen Sound, Permian cherty limestone is overlain by some 150 feet of lava.

A volcanic sequence also occurs within Permian cherty limestone at Cape Stallworthy. At least 2,000 feet of basic lavas, in part porphyritic, and with blocks of Lower Silurian limestone, of agglomerates and tuffs are present. Apparently some 160 feet of sandstone, partly carbonaceous and with coal seams, are at the top of the volcanic measures. The latter apparently extend to Land's Lokk on westernmost Ellesmere Island, where volcanic rocks have been called the Bourne group. This comprises basic flows with many gabbroic intrusions and lesser black slate, phyllite, and tuff. Such rocks are also in pebbles within a nearby Permo-Carboniferous conglomerate and therefore have been thought to be pre-Permo-Carboniferous. The Imina group lies to the north of the Bourne volcanic group. It is a uniform sequence of subgreywacke, greywacke, and argillaceous greywacke with some graded bedding. These are represented in pebbles in a Permo-Carboniferous conglomerate. Permo-Carboniferous strata, mainly limestone, apparently overlie unconformably the Imina group. The relation of this group to the Bourne group is not known. Eastward on the north shore of Nansen Sound, to east of Otto Fiord, Permian limestone is with calcareous shale and siltstone. On Ellef Ringnes Island, where a Lower Cretaceous bed contains derived lower Palæozoic fossils, blocks of basic pillow lava and breccia occur in the gypsum core of a piercement dome. In another such dome on Amund Ringnes Island similar blocks are exposed at the core of anticlinally folded gypsum.

The Pennsylvanian nonmarine Intrepid Bay formation occurs on Cornwallis Island unconformably on the Ordovician-Silurian Allen Bay formation where it has escaped erosion along the down-faulted side of a northwest-trending fault. It is composed of 2,000 feet of alternating sand, clay, and coal seams.

Mesozoic

Strata of Mesozoic age are largely confined to the Sverdrup Basin and belong mainly to a conformable sequence that started at least in Permian time and extended to Upper Cretaceous and probably to Tertiary time.

Triassic

Known Triassic occurrences are limited to the Sverdrup Basin. In the Eureka Sound belt of the basin, the exposures are abundant and the strata are thick. In the western part of the basin few occurrences are known.

The Blaa Mountain formation, of Middle, Upper, and probable Lower Triassic age occurs on western Ellesmere Island, from Bjorne Peninsula to north of Greely Fiord and Nansen Sound, and on the eastern and northern parts of Axel Heiberg Island. Its thickest known occurrence is on central-eastern Axel Heiberg, where the formation consists of over 4,000 feet of siltstone with lesser shale and silty shale overlain by 10,000 feet mainly of shale with siltstone, sandstone, and sills of gabbro. At least 8,400 feet of shale, calcareous sandstone, sandstone, and argillaceous limestone have been measured on northeastern Axel Heiberg Island and, farther west, the formation is estimated to be some 10,000 feet thick. There, the formation is locally divisible into lower non-calcareous shale and sandstone, overlain successively by calcareous black shale with minor sandstone and limestone, by shale, and, at the top, by sandy shale and sandstone. North of Nansen Sound and Greely Fiord, the Blaa Mountain formation is estimated to be at least 5,000 feet thick, of which 3,000 feet of sandstone, siltstone, shale, and limestone have been measured. The formation is widespread on Raanes Peninsula, and extends to western Stör Island, to Hat Island, and to southeastern Axel Heiberg Island. Northwest of Blind Fiord the formation is composed of 3,700 feet of siltstone overlain by at least 1,500 feet of shale, siltstone, and calcareous siltstone. It is apparently structurally conformable over Permian beds. On Bjorne Peninsula the formation is also apparently conformable over Permian strata, and contains 1,750 feet of sandstone overlain by 800 feet of calcareous siltstone and shale. On Cameron Island an Upper Triassic limestone and an underlying calcareous sandstone of Middle or Upper Triassic age are at least 60 feet thick. These strata are in apparent structural conformity with Permian beds.

Triassic and Jurassic

A sandy formation is widespread in the Sverdrup Basin. It is marine and Upper Triassic in its lower part and is nonmarine and possibly ranges into the Lower Jurassic in its upper part. At Wolf Fiord, on southeastern Axel Heiberg Island, it is 5,600 feet thick with sandstone, shale, siltstone, and carbonaceous films in the upper part. West of Mökka Fiord it comprises 5,300 feet of similar beds with coal seams in the upper part. It has also been located on the central-western and northern parts of Axel Heiberg Island. On Cornwall Island, the formation is exposed in the crestal part of a large, gentle anticline and contains at least 1,500 feet of sand and sandstone, with coal seams in the upper beds. Sand, pebble beds, and coal on Cameron Island possibly belong to this formation. On Bjorne Peninsula of western Ellesmere Island, the formation conformably overlies the Blaa Mountain and includes 1,500 feet of sandstone overlain by at least 1,000 feet of sandstone with coal. On eastern Stör Island 800 feet of undated sandstone with coal and plants possibly belong to the upper part of the formation. These are conformably overlain by 2,600 feet of sandstone, also undated. The Cape With formation of Triassic and/or Jurassic age occurs on the coasts of Canyon Fiord and, nearby, on the north coast of Greely Fiord. On Fosheim Peninsula it overlies disconformably the Permian Greely Fiord formation and contains at least 2,360 feet of sandstone and minor shale.

Jurassic

Beds of known and possible Jurassic age extend from the Fosheim Peninsula of western Ellesmere Island to Prince Patrick Island. On Axel Heiberg Island, the sandy formation of Upper Triassic and possibly Lower Jurassic age that has been described above, is conformably overlain by a Jurassic marine shale. Across the central part of the island the shale thickens from 300 feet in the east to 900 feet in the west and is some 1,100 feet thick in the southeast. Above the marine shale is a mainly nonmarine sandstone interbedded with lesser shale, mainly of marine origin and of Upper Jurassic age. It varies in thickness across central Axel Heiberg Island from 1,000 feet in the east to 600 and 1,300 feet in the middle part and to 250 feet in the west, whereas, farther south, it is over 1,200 feet thick at Wolf Fiord, and over 800 feet at Good Friday Bay. A sandstone in the northwestern part of the island possibly belongs to the Upper Jurassic.

The sandy Upper Triassic and possibly Lower Jurassic formation of Cornwall Island is overlain by over 1,000 feet of sandstone, sand, glauconitic sandstone, and, in part, carries carbonaceous material. These strata range in age from Lower to Upper Jurassic and are overlain by at least 1,650 feet of undated sand and sandy shale, with minor coal, conglomerate, and dolomite. A sandstone with phosphatic nodules on Cameron Island contains Middle Jurassic fossils. The Wilkie Point formation of Prince Patrick Island contains at least 500 feet of Lower to Upper Jurassic sand and sandstone with phosphatic nodules. It unconformably overlaps Devonian strata.

Jurassic and Cretaceous

The Deer Bay formation, of latest Jurassic and earliest Cretaceous age, has been recognized from Ellef Ringnes Island to eastern Axel Heiberg Island and beds possibly correlative with it occur beyond that area. The formation is mainly shale with minor sandstone, siltstone, and some ironstone concretions. It includes a maximum of 600 feet of the oldest beds exposed on Ellef Ringnes Island. On central western Axel Heiberg Island it is as much as 2,500 feet thick, whereas at its easternmost occurrence on the island it is 850 feet thick. On Fosheim Peninsula of Ellesmere Island approximately 500 feet of shale and clay, overlying some sandstone and shale, all of Lower Cretaceous age, possibly belong to the Deer Bay formation. The Mould Bay formation of Prince Patrick Island overlaps both Devonian and Jurassic strata. It is made of sandstone and shale of Upper Jurassic and/or Lower Cretaceous age and is of marine origin in its lower part, but contains coal and is nonmarine in its upper part. The lower part may contain beds correlative with the Deer Bay formation.

Cretaceous

During Cretaceous time there was alternation of marine and nonmarine deposition. Minor volcanic activity occurred in the Lower Cretaceous and at some time between late Lower Cretaceous and middle Upper Cretaceous.

A Lower Cretaceous formation, called the Isachsen formation, conformably overlies the Jurassic-Cretaceous Deer Bay formation. It is widely exposed on the Ringnes and western Axel Heiberg Islands and is mainly nonmarine and made of sandstone, in part gritty, with shale, siltstone, minor limestone, coal, plants and, locally, lithified wood. On Amund and Ellef Ringnes, it is, respectively, as much as 3,250 and 3,000 feet thick. On Ellef Ringnes the formation includes an agglomerate bed a few inches thick. On western Axel Heiberg exposed sections of the Isachsen vary from 2,000 to 4,500 feet and the formation includes, near the central part of the island, a 200-foot stratum of volcanic breccia. At Li Fiord, in the northern part of western Axel Heiberg, at least 1,300 feet of exposed beds, such as found in the Isachsen formation, are capped by at least 160 feet of conglomerate mainly with fragments of dolerite and of rare black shale and plants.

In most parts the Isachsen formation is conformably overlain by the Lower Cretaceous Christopher formation containing mainly shale and locally minor sandstone, siltstone, conglomerate, limestone, and ironstone concretions. Largest known thickness on each of the Ringnes islands is some 1,500 feet but on Axel Heiberg Island it reaches some 3,000 feet. Possibly contemporaneous with the Christopher formation is the undated Landing Lake formation. It is exposed on Prince Patrick Island and includes at least 150 feet of marine clay, shale, and limestone. It appears to lie conformably on the Mould Bay formation, although the relationship is uncertain because the contact is not exposed. Undifferentiated Mesozoic beds lie north of the Parry Islands belt on Melville Island and possibly include both Jurassic and Cretaceous strata. Undifferentiated Lower Cretaceous beds, mainly clastic, occur on northern and southern Banks Island.

Semi-consolidated beds of sandstone with included shale and seams of coal occur in the area of Durban Harbour and on the nearby Padloping Island, on and off the east coast of Baffin Island. They are Jurassic and/or Lower Cretaceous in age. Sandstone, shale, and coal seams of Eclipse Sound, both west of Pond Inlet and on southwestern Bylot Island, may contain beds contemporaneous with those of the Durban Harbour region.

Cretaceous basalt flows up to 600 feet thick occur on central and western Axel Heiberg Island. They are separated from the Christopher formation by up to 750 feet of conformably sandstone and shale, at least partly nonmarine. They are conformably overlain by 800 to 1,200 feet of middle Upper Cretaceous shale with rare beds of probable bentonitic shale. The shale is conformably overlain by a sequence at least 8,000 feet thick of siltstone, sandstone, silty shale with coal, and plants. This sequence possibly extends from the Upper Cretaceous into the Miocene and contains the youngest known folded beds of Axel Heiberg Island. On Ellef Ringnes Island the Christopher formation is conformably overlain by more than 1,800 feet of sandstone, siltstone, minor shale and limestone known as the Hassel formation. Conformably over this are approximately 650 feet of middle Upper Cretaceous shale with minor silty shale and some ironstone concretions, which are correlative with the shale of western Axel Heiberg Island. These grade upward into some 200 feet of Upper Cretaceous or Lower Tertiary sandstone and siltstone, with silty shale and conglomerate containing pebbles of basalt. Above these are unconsolidated sands with conspicuous logs of partly carbonized wood and thin lignite partings. On Graham Island over 1,000 feet of shale with a few bands of apparently bentonitic clay-shale, probably of early Upper Cretaceous age, conformably overlie undated, nonmarine sand and sandstone at least 500 feet thick.

Sills and dykes of diabasic gabbro, with or without olivine, are widespread and common from northwestern Ellef Ringnes to eastern Axel Heiberg Islands, on almost all of western Ellesmere Island as far south as Baumann Fiord, and in many areas of the north coast of this island. Their southwesternmost known occurrence is in the area of Weatherall Bay, on northeastern Melville Island. At Weatherall Bay they cut Pennsylvanian and Permian beds. West of Baumann Fiord they intrude beds of Permian, Triassic, and possibly Lower Jurassic age. Northeast of this fiord they transect lower Palæozoic strata. On northeasternmost Ellesmere Island, dykes have intruded Permo-Carboniferous and younger strata. The youngest rocks known to be intruded by sills or dykes lie immediately above latest Lower Cretaceous strata and no intrusion is known in nonmarine Tertiary beds.

Cenozoic

Nonmarine strata in the region of Banks and Prince Patrick Islands, in the eastern Queen Elizabeth Islands and in the regions of Eclipse Sound and Durban Harbour of Baffin Island, have been loosely referred to the Tertiary, in large part because of associated soft coal, 'lignite', and wood, either lithified and carbonized or unlithified and uncarbonized. However, plants included in some of the strata that had been specifically referred to Cenozoic epochs are now known to occur also in the Cretaceous. Moreover, soft coal and wood occur in many Jurassic and

Cretaceous as well as in Cenozoic formations, and deposits such as those of Durban Harbour are now known to be older than Upper Cretaceous. Yet Tertiary deposits have been substantiated and apparently are widespread.

Deposits including mainly nonmarine and poorly consolidated sandstone and shale, commonly with lignite, are widespread in the eastern Queen Elizabeth Islands. They are pre-Pleistocene and younger than the latest marine Cretaceous beds. Perhaps up to 7,000 feet of openly folded sandstone, shale with apparently Paleocene or Eocene plants, and lignite with under-clay, occur on the Fosheim Peninsula within the Eureka Sound belt. Part of the sequence of such strata indicates cyclic deposition. Carbonized logs and stumps stand upright in some strata and a field of such stumps projecting above ground has been located in the area. Contact relations with older formations are not known. On southeastern Bjorne Peninsula a soft shale occurs as small, flat-lying and apparently unconformable erosional remnants deep down in local catchment basins eroded in gently dipping Permo-Carboniferous strata. Approximately half-way between Hazen Lake and Alert, in a region of folded Cape Rawson beds, flat-lying sand, grit, boulder beds, and lignite seams contain plants not older than Miocene age and possibly more recent. At Alert Point, on the north coast of Ellesmere Island, deposits of poorly consolidated but well stratified mudstone, sandstone, shale, and conglomerate contain undated petrified wood and carbonaceous plant remains. The strata are flat lying, except for local contortions. Nearby, at Yelverton Bay, an apparently flat-lying soft conglomerate is made wholly of basalt material. A conglomerate derived mainly from basic igneous rocks lies north of Whitsunday Bay and next to a piercement mass of gypsum on Axel Heiberg Island. It is at least 1,000 feet thick and dips steeply. Rare sandy beds contain plants of probable Tertiary age and there are a few seams of coal.

In the Central Ellesmere belt, in the region of Vendome Fiord, exposures up to 210 feet thick include shale, mudstone, sand, grit, conglomerate, sandstone, limestone, nodular limestone, seams of impure peaty and lignitic coal, sandstone with carbonized plant fragments, and lithified tree stems not older than Upper Cretaceous. The strata are folded and appear to have been laid in catchment basins on the eroded surface of lower Palæozoic beds. Petrified tree trunks and impressions of leaves and twigs at Cape Baird may be correlative with the Fosheim Peninsula and Vendome Fiord occurrences. North of the cape, at Discovery Bay, undisturbed beds of sandstone and shale with seams of lignite lie in a valley in folded Cape Rawson beds.

On southern Viks Fiord, on western Devon Island, are at least 600 feet of bedded sand and clay-shale containing fragments of coal, seams of coal, and a hard bed of sandstone with fragments of lithified and carbonized wood. The beds are down-faulted and tilted against flat-lying lower Palæozoic strata. They are undated but are similar to Tertiary occurrences on Ellesmere Island.

The Eureka Sound group has been defined to include, on Ellesmere and Axel Heiberg Islands, all deposits of sandstone, shale, and lignite younger than the last orogeny. All deposits described above would lithologically fall into the Eureka Sound group, but the deformation of some prevents such inclusion. The stratigraphic range of the Eureka Sound group, as defined, is not known, nor was any accurately dated occurrence originally included in the group. Exact dating on the last, Alpian, orogeny is wanting. It apparently commenced not earlier than Upper Cretaceous time possibly as late as Miocene, and may have ended before the close of the Miocene or more recently. It is not known whether it was restricted to one epoch or whether it extended to many, possibly occurring in various phases in different areas. Many occurrences referred to the Eureka Sound group are in local areas of low relief, such as in valleys and terraces. Such occurrences may locally appear to be undeformed where they lie in broad synclinal troughs of folded sequences.

The Beaufort formation occurs over much of Prince Patrick Island. The greatest local thickness observed is over 250 feet. The formation contains unconsolidated, bedded, and crossbedded quartz sands with thin seams of gravel and a large amount of rounded fragments of unlithified and uncarbonized fossil wood, and some large logs. The formation unconformably overlies Palæozoic and Mesozoic formations, and is apparently as old as 'early Wisconsin' and may be much older. It most likely includes similar occurrences with wood on the south and north coasts of Prince Patrick Island and at many points of the west coast of Banks Island; a formerly assigned Miocene age for these beds cannot be confirmed.

Flat-lying volcanic rocks, exceeding 2,500 feet in thickness, extend as erosional remnants on a hilly surface of Precambrian metamorphic rocks between Cape Dyer and Padloping Island on and off eastern Baffin Island. They are basalt flows underlain by crossbedded agglomerate bands alternating with flat-lying tuff beds. These volcanic rocks are undated but are possibly contemporaneous with Tertiary volcanic measures in the region of Disco Island which lies across Davis Strait on the west coast of Greenland.

Economic Geology

Exploitation of minerals for export from the Arctic Archipelago may be said to have started as early as 1577, although the products that Martin Frobisher brought to England were worthless. Since then there has been no substantial and sustained mineral exploitation in the islands. Very little prospecting was done in the Archipelago prior to the Second World War, but at present there is some organized prospecting, at least on southern Baffin Island, and interest has been increasing in the potential oil and natural gas resources of the large areas of fossiliferous sedimentary rocks of the islands, although no exploration has occurred as yet. Difficulty of economical transportation has hampered mineral development despite the diversity of geological terrains.

Iron. A zone of banded crystalline quartz and magnetite, probably derived from an iron-formation, is reported to be extensive and exposed for about a mile in the Clyde district on Baffin Island. On southern Baffin Island magnetite commonly is in disseminated grains in gneisses, and west of Amadjuak it occurs in some concentration in banded gneisses which can be traced for many miles along the strike.

Native Copper. Specimens of native copper have been collected on western Victoria Island and Eskimos reportedly have located outcrops of the metal at the head of Minto Inlet. The mode of occurrence of the mineral is not known but the region is in part underlain by rocks similar to those of the Coppermine district of the mainland.

Chromium. Chromite has been identified among specimens collected on Melville Peninsula by early travellers and this indicates the possible occurrence of ultrabasic rocks on that peninsula.

Sulphides and Associated Metals. Disseminated or slightly concentrated chalcopyrite, pyrrhotite and magnetite occur in association with gabbro dykes crossing Proterozoic formations of the Admiralty Inlet district on northern Baffin Island. Spectrographic analysis of a specimen from such an occurrence showed faint traces of nickel and cobalt. In the same district a replacement zone of pyrite has a maximum width of 500 feet and is exposed for at least 2 miles. The zone contains minor amounts of galena and sphalerite and spectrographic analysis of a specimen showed faint traces of silver and copper. Explorers have collected, in the district, specimens of pyrite containing platinum, and of calcite with breithauptite (nickel antimonide) and native silver. They also found native silver in float.

Gypsum. Some beds and lenses of gypsum occur in Silurian, Cambrian, and apparently Proterozoic strata in small amounts, and they appear to be somewhat more voluminous in Devonian strata. The mineral, more or less pure, occurs in layered sequences possibly as thick as 1,000 feet in Middle Ordovician formations ranging from northern Baffin Island to the mid-latitude of Ellesmere Island and from Cornwallis Island to the mid-longitude of Devon Island. It also occurs, possibly in sequence 600 feet thick or so, between northern Melville Island and northwestern Ellesmere Island, mainly in widespread diapir folds and piercement domes, where it is of Permo-Carboniferous age or older. A gypsum stratum 400 feet thick and exposed for some 1,000 feet occurs on the north coast of Ellesmere Island adjacent to pre-Pennsylvanian beds. No detailed mineralogical study has been made of these occurrences, but some thirty x-ray examinations of Ordovician and Permo-Carboniferous (?) gypsiferous sundry specimens showed these to be mainly gypsum (or selenite) with little or no anhydrite.

Graphite, Mica, and Miscellaneous Minerals. Industrial minerals occur in southern Baffin Island as products of metamorphism. Disseminated graphite is widespread in fine-grained gneisses and schists, in crystalline carbonate strata, and in some quartzite. It is occasionally concentrated in small pockets in these rocks and such occurrences have been mined intermittently near the Hudson Strait coast and in the region of Cumberland Sound. Shipments of dark mica, presumedly phlogopite, have been made from the same regions, where it occurs in pockets of concentrated coarse aggregates at the contact between crystalline limestone and

TABLE XXV

Synopsis of Coal Occurrences in the Arctic Archipelago

Age	Extent	Thickness	Rank (A.S.T.M.)	Distribution by Islands + Age known − Age uncertain		
Tertiary and Upper Cretaceous	Widespread and common	Up to 30 feet	Sub-bituminous C (1 analysis)	+ Axel Heiberg − Baffin − Banks	− Bathurst − Devon + Ellesmere	− Graham − Lougheed
Lower Cretaceous and/or Upper Jurassic	Widespread	Up to 5 feet	Lignite to sub-bituminous	+ Amund Ringnes + Axel Heiberg	+ Baffin − Bylot	+ Ellef Ringnes + Prince Patrick
Jurassic	Few known	Up to 3 feet	Sub-bituminous B (1 analysis)	− Cornwallis + Prince Patrick		
Upper Triassic and/or Lower Jurassic	Widespread	Apparently thin		+ Axel Heiberg − Cameron	+ Cornwallis + Ellesmere	
Pennsylvanian	12 occurrences	Up to 5 feet	Sub-bituminous C (1 analysis)	+ Cornwallis		
Permo-Carboniferous or earlier	1 occurrence			+ Axel Heiberg		
Upper Devonian	Widespread	Probably less than 3 feet	High volatile bituminous B (2 analyses)	− Banks + Bathurst − Byam Martin	+ Cameron + Devon + Ellesmere	+ Melville + Prince Patrick − Victoria

granitic rocks. Lenses of asbestos less than one inch wide occur in patches of serpentinite in a band of crystalline limestone on the east shore of Foxe Channel. Eskimos on southern Baffin Island make carvings from relatively soft and mainly dark green rocks commonly called 'soapstone'. Steatite occurs in small pockets as metamorphic products of impure carbonate rocks and as narrow contact bands between amphibolite and granitic rocks. Other occurrences of metamorphic minerals are garnet, sillimanite, cordierite, scapolite, spinel, diopside, and lapis lazuli and layers of colourful marbles.

Pegmatite Minerals. Pegmatite dykes of southern Baffin Island include apatite and the thorium mineral, allanite, but no economic concentrations are known. The pegmatite dykes of the Clyde district contain allanite, columbite, fluorite, and tourmaline.

Quartz Crystals. Crystals of quartz occur in quartzite on Foxe Peninsula and in the Clyde district, and in dolomite in the Admiralty Inlet district.

Sulphur. Native sulphur occurs in association with calcite in the gypsum of a diapir fold on western Axel Heiberg Island.

Coal. Coal is geographically widespread in the Arctic Islands and ranges over many geological periods (Table XXV). The thickest seams, up to 30 feet, are most common in Tertiary, or apparently Tertiary, formations of Ellesmere and Axel Heiberg Islands. A slacking, non-coking sub-bituminous coal which may date from Upper Jurassic to Tertiary, is mined near the settlement of Pond Inlet, on northern Baffin Island. Slightly more than 100 tons are produced annually, mainly for use of the local settlement. The few seams of the district range from a few inches to at least 5 feet in thickness.

Oil and Gas. There is neither exploration for nor production of, oil or gas in the Arctic Archipelago. The petroliferous nature of some formations, the varied lithologies and structures, and the wide distribution in time and space and the substantial volume of fossiliferous strata, are reasons for considering the Arctic Archipelago as a potential source of oil and gas.

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CHAPTER VIII

PLEISTOCENE GEOLOGY AND SURFICIAL DEPOSITS

(V. K. Prest)

Introduction

The bedrock surfaces throughout the greater part of Canada are for the most part mantled with unconsolidated deposits. These deposits vary from a few inches to over a thousand feet in thickness. They include both glacial and non-glacial deposits. The latter occur at the surface in a few widely scattered regions and are buried beneath other sediments in many places. By far the greater part of the surficial deposits, however, are the direct or indirect result of glaciation. Only in the western part of Yukon Territory and possibly in the westernmost Queen Elizabeth Islands are there sizable areas of unglaciated country. Local areas along the east side of the Mackenzie Mountains in the Northwest Territories, many mountain peaks in Yukon, a small area in southern Alberta on the International Boundary, the Cypress Hills on the Alberta-Saskatchewan boundary, and the Magdalen Islands in the Gulf of St. Lawrence, also appear to have escaped direct glaciation. The study of glacial events and of glacial and allied deposits in Canada is therefore well worthy of attention. The unconsolidated deposits, by their presence and nature or by their absence, have had a direct bearing on the development of the country, affecting inland transportation, agricultural development, and mineral exploration—vital parts of Canada's economy.

The following account deals with the unconsolidated deposits and with the events that took place during the last million years or somewhat more of the earth's history, which period may be considered as constituting Pleistocene time (Table XXVI). The Pleistocene epoch is set off from the Pliocene epoch of Cenozoic time by reason of major climatic changes which resulted in the build-up and movement of continental glaciers on four widely separated occasions referred to as glacial stages. It is generally believed that these were of roughly equal magnitude. The glaciers expanded and moved over mountain, plain, and lowland areas, scouring and overriding the bedrock and unconsolidated deposits in some areas while depositing great loads of debris in others. The four glacial stages were separated from one another by non-glacial intervals, of much longer duration, that are referred to as interglacial stages. These are believed to comprise about 60 or 65 per cent of Pleistocene time. During interglacial times, judging by records of flora and fauna and by soil development in the United States and Canada, the climates in areas of comparable latitude were similar to, or even milder than, those of the present.

TABLE XXVI

Chronology of the Pleistocene Epoch

Age (Stage) (Interglacial ages are underlined)	Possible duration in Years	Sub-age (Substage)	Probable age in Years
		Period of generally cool, wet climates, marked by glacial advances in some regions	
'Recent'	7,000	(Medithermal)	0– 4,500
		Interval of glacier retreat (Altithermal)	4,500– 7,000
		Cochrane	7,000– 8,000
		Interval of glacier retreat (Timiskaming)	8,000– 9,500
		Valders*	9,500– 11,000
		Interval of glacier retreat (Two Creeks)	11,000– 12,000
		Cary	12,000– 14,500
Wisconsin	100,000?	Interval of glacier retreat (Brady)	14,500– 17,000
		Tazewell	17,000– 18,000
		Interval of glacier retreat	18,000– 20,000
		Iowan	20,000– 21,000
		Interval of glacier retreat	21,000– 22,000
		Farmdale	22,000– 25,000
		Period of ice accumulation	25,000– 45,000?
		Probable non-glacial interval	45,000– 60,000?
		Period of ice accumulation	60,000–100,000?
Sangamon	125,000?		
Illinoian	100,000?		
Yarmouth	200,000?		
Kansan	100,000?		
Aftonian	300,000?		
Nebraskan	100,000?		

*Regarding the use of the term Valders instead of Mankato see article by Wright and Rubin in *Science*, vol. 124, pp. 625-626, Oct. 5, 1956.

About 20,000 years ago the last major glacier began to wane, but lengthy periods of recession of its margins were interrupted by significant advances of the ice-front in some regions. During the intervals of glacier retreat non-glacial conditions prevailed, as is recorded by the occurrence of fossiliferous deposits and poorly developed soil profiles indicating climatic conditions appreciably cooler than those of the present. These non-glacial breaks in the recession of the last major glacier are referred to as interstadial periods. They were formerly considered to have very wide application, but evidence is accumulating that, while non-glacial conditions prevailed in one region, a major ice-lobe advanced in another; hence the true significance of some of the interstadial periods is in doubt. One of these, however, known as the Two Creeks interval, appears to have very wide application. Also there may be a major non-glacial interval in mid-Wisconsin time.

The time interval since the last glaciers retreated from the southern parts of Canada is very short compared to the duration of the three interglacial ages. It is generally conceded that at these times the glaciers retreated from the northern parts of the continent to the same degree or greater than at present. This seems logical in view of the indicated warm climates in southern Canada and farther south, and the great lengths of time involved—roughly between 125,000 and 300,000 years. Thus only the future will reveal whether present conditions in southern Canada are truly post-glacial or just those of another interglacial stage of the Pleistocene epoch.

In many widely separated parts of Canada two or more tills (the direct deposits of glaciers) have been recognized, either by differences in lithology or by the occurrence of stratified deposits or buried soils lying between them. Though in many places it is not possible to ascertain whether such tills represent different glacial stages or merely substages or even lower rank ice-marginal fluctuations, sufficient data have been gathered to indicate that all the stages of the Pleistocene epoch as recognized in the upper Mississippi Valley are probably represented in Canada. Insufficient chronological work has been done, however, to permit a description of the glacial and interglacial stages in chronological order. Similarly, all too little is known of the substages of the last glacial stage in either Canada or the United States.

For the present, therefore, it is necessary to discuss the glacial and non-glacial deposits separately without regard to their chronological or stratigraphical order. One of the sections that follow therefore deals with the record of non-glacial conditions in Canada during the Pleistocene epoch, and where possible, gives some indication of the assumed age of these deposits and hence of the associated tills. Another section deals with the broad aspects of glaciation and with the record of deposits and ice-movements of the last glaciation which affected the greater part of Canada.

Many sources of information were used in preparing the following account of the Pleistocene geology and surficial deposits of Canada. Much information basic to this subject stems from the work of such well known geologists and geographers as Sir J. W. Dawson, J. B. Tyrrell, A. P. Coleman, F. B. Taylor, W. A. Johnston, J. W. Goldthwait, and E. Antevs, to mention but a few. Provincial governments, research centres, and universities are providing information on Canada's glacial deposits and some made important contributions in former years. Many valuable contributions to the Pleistocene geology of Canada are the result of the work of American geologists. The greater part of the information, however, is contained in reports of the Geological Survey of Canada. The writer received much new data from officers of the Survey who have a keen interest in various aspects of glacial geology, and especially from the Pleistocene section. Information on directions of ice-movements and on deposits from parts of the far northern mainland and adjoining islands was provided by the Geographical Branch of the Department of Mines and Technical Surveys. Information on the distribution of drumlins, drumlinoids, and related features and of eskers, in northern Quebec and the Northwest Territories, was the outcome of air photo studies for the Defence Research Board, Ottawa, carried out under the direction of Dr. J. T. Wilson, University of Toronto.

Record of Non-Glacial Intervals

In the main the non-glacial deposits are buried. They are overlain by till or other related materials and include both interglacial and interstadial deposits. Some of the non-glacial deposits mentioned below are not buried by glacial materials, as the later ice-advance did not reach the environs of the older deposit; also some deposits have been uncovered by erosion or are buried by younger alluvium. However, all these deposits can be related to either interglacial or interstadial times by means of their contained flora and fauna.

Maritime Region

The oldest record of a buried peat deposit in Nova Scotia is that of J. W. Dawson who in his "Acadian Geology" of 1868 states "the only evidence of organic life during the boulder period, or immediately before it, that I have noticed is a hardened peaty bed which appears under the boulder clay on the northwest arm of the River of Inhabitants in Cape Breton. It rests upon grey clay similar to that which underlies peat bogs, and is overlain by nearly twenty feet of boulder clay. . . . It contains many small roots and branches, apparently of coniferous trees allied to the spruces. . . ." This locality is west of the end of West Bay, Bras D'Or Lake. To the writer's knowledge no radiocarbon datings have been made on this material, but it appears likely that it is 'very old'. It is also interesting to note in passing that Dawson records the finding of bones and a tooth of mastadon (presumably *M. americanus*) from the surficial gravels of Cape Breton. These are presumably post-glacial in that area, but the precise age is unknown.

About 35 miles north of the above locality, near Hillsborough, marine clays and other stratified sediments, including peat with spruce logs, have been found between two tills. Pollen studies of the peaty materials have indicated an abundance of spruce and fir, with subordinate ferns, fungi, and mosses. A radiocarbon (C-14) dating of 38,000 years (W-157)* indicates that the deposit probably represents an interglacial stage.

In the village of Whycocomagh, about 20 miles east of Hillsborough, stratified sediments containing wood were recently exposed over a distance of about 150 feet in a roadside-cut for the Trans-Canada Highway. The sediments are overlain by 15 feet of till-like material composed of angular sandstone fragments in a clayey matrix. Yellow birch, larch, and beech wood have been identified. Pollen studies revealed the presence of the following trees, listed in their order of abundance: black spruce, white and red spruce, alder, jackpine, balsam, fir, paper birch, white pine, oak, and a trace of yellow birch. The tree assemblage is unlike that of the present.

*The letter and number here and on pages that follow refers to the laboratory where the age determination was made: W, Washington Geophysical Laboratory; Y, Yale University; L, Lamont Geological Observatory; C, University of Chicago.

Buried sediments containing wood and leaves have been observed on the north shore of East Bay, Bras D'Or Lake, near its head end. Here a low wave-cut cliff reveals a mantle of till-like materials overlying the stratified sediments. A few miles to the southwest, at Benacadie, a stream bed reveals similar sediments, with well-preserved wood and leaves, overlain by a few feet of alluvium. The character of the stream banks has not been recorded.

These localities of buried organic deposits seem to indicate that interglacial and possibly interstadial deposits occur over a wide area around Bras D'Or Lake. Near St. Lawrence at the north end of Cape Breton a 5-foot mantle of till-like material overlies 30 feet of sand and gravel with a one-foot layer of silt, peat and wood near the base, which is a marine-cut bench only 3 feet above high-tide level. Pollen studies reveal a plant assemblage that may represent an interglacial period.

An interesting occurrence of plant life was uncovered in 1954 near Milford, N.S., when some 40 feet of till was being stripped from an occurrence of gypsum. In the base of the till numerous stumps of trees and other pieces of wood were found which, from their shape and disposition, had obviously been transported but a short distance. Several stumps are reported to have been pointed as if cut by beaver. Bayberry, walnut and an unidentified nut are reported. Radiocarbon determinations on the wood by the solid carbon method indicate an age of at least 18,000 years (Dalhousie University, N.S.). The organic remains may indicate either an interstadial or an interglacial period.

No indisputably interglacial or interstadial deposits have been recorded from New Brunswick, Prince Edward Island, or Newfoundland. In the St. Georges Bay area in the southwestern part of Newfoundland, however, a local ice-advance deposited till and kame gravels over marine clays containing fossils which indicate water temperatures similar to those of the present. Possibly the general recession of the Newfoundland ice-cap just prior to the local readvance may correlate with a late Wisconsin interstadial period. Just west of Corner Brook on the west side of Newfoundland gravels containing marine shells were encountered between two tills during the sinking of a well. These gravels were at an altitude of 140 feet. They may therefore have been deposited during a Wisconsin substage. It is possible, however, that the upper till represents a slumped mass, as post-glacial marine terraces occur at an altitude of 160 feet at this location. The only report of a possible early Wisconsin or older drift is that of a much-weathered dark red drift near St. Lawrence on the south coast of Newfoundland, but nothing is known of the interval between these two glacial stages.

Near Saint John, N.B., marine shells were reported in a clay and a stony clay from between 'boulder clay' horizons at an elevation of 220 feet above the sea, but this occurrence needs confirmation in the light of present knowledge.

Quebec

In the St. Lawrence Lowlands inter-till sediments including peat have long been known, but because of insufficient work, interpretation has varied greatly. Detailed investigations of the surficial deposits in the Three Rivers area have revealed reddish pro-glacial varved clays and glacial till that were deposited, respectively, in front of and beneath southwestward moving ice. These deposits are overlain by stratified sediments, which include thick beds of peat, and these in turn are overlain by grey glacial lake deposits and sandy calcareous till. Extensive palæobotanical studies of the peat deposits and their contained wood indicate that the climate of the day was slightly cooler than the present climate of the region. A radiocarbon dating of the wood has indicated an age of more than 40,000 years (W-189); thus the organic materials are older than any proven Wisconsin interstadial. This non-glacial interval is known as the St. Pierre interval and may represent a significant retreat of the ice-front prior to the maximum advance of the Wisconsin ice-sheet in this area. A rather long non-glacial interval is indicated by the development, at this time, of a drainage system comparable to that of the present St. Lawrence system.

No records of organic horizons beneath till have been reported from northern Quebec.

Ontario

Toronto Interglacial Formation

By far the most famous of all interglacial deposits found in Canada, and indeed in North America, are those of the Toronto area. These are known as the Toronto Interglacial formation, composed of the Don beds overlain conformably by the Scarborough beds. The Don beds have a maximum thickness of about 35 feet and were deposited under climatic conditions somewhat warmer than the present; the Scarborough beds have a maximum thickness of about 155 feet and were deposited under climatic conditions slightly cooler than the present.

Although many aspects of the Pleistocene geology of the Toronto area had been recorded from about the middle of the last century, it was not until 1877 that the deposits received due attention. At this time G. J. Hinde described three sections along the Lake Ontario shore in the Toronto area, one of which was at Scarborough Bluffs. He realized that the 'Scarboro' clays and overlying fossiliferous sands, lying stratigraphically between two tills and carrying a cool-temperate climate fauna, represented the deposits of an interglacial lake. He also found that the upper of these two tills was overlain by lacustrine clay, which in turn was overlain by a third till. Though he found no fossils in these younger lacustrine clays, he postulated that they represented the deposits of another somewhat colder interglacial period.

The warmer climate Don beds were not known at that time though leaves, wood, and shells indicative of a warm climate had been found in various places both prior to and following Hinde's description of the Scarborough beds. In 1894 A. P. Coleman reported on the geological setting of the now famous Don Valley brickyards and accompanied his report with notes on the fossils identified by various authorities. Added prominence was given the Toronto interglacial beds in 1913 when Coleman prepared a paper for the International Geological Congress meeting in Toronto at that time. This paper was the first adequate description of the Pleistocene stratigraphy of the Toronto area, and the lists of fossils identified from the Don and Scarborough beds were most impressive. Coleman reported that the Don beds lay conformably below the Scarboro (Scarborough) beds, and termed the combined warm and cool climate deposits the Toronto Interglacial formation.

In 1932 Coleman issued a more detailed account on "The Pleistocene of the Toronto Region". He reported that the warm climate Don beds were laid down at the mouth of an ancient river in a lake (Lake Scarboro) that stood about 60 feet higher than Lake Ontario, and that the cool climate Scarborough beds were deposited in somewhat deeper waters when, at a much later date, the lake waters rose another 140 feet. He states that " . . . in spite of the apparent conformity of the two series very important events must have separated them." This has been confirmed by later work.

In his 1932 report Coleman referred the Toronto Interglacial formation to the Yarmouth stage, and the younger non-fossiliferous lacustrine clays to the Sangamon. In 1949 A. B. Gray gave a detailed account of the lithology of the Don beds with some notes on the Scarborough section, and followed Coleman's lead in assigning the Toronto formation to the Yarmouth but not in the simple two-fold division into warm and cool climate beds. The sequence of events appears to be quite complex. In 1954 A. K. Watt referred the Toronto Interglacial beds to the Sangamon, and the younger lacustrine clays and silts with local alternations of till to the Two Creeks interval of the Wisconsin.

Regardless of the exact position of the interglacial beds within the Pleistocene they are of great significance, lying as they do on an early till-sheet and being overlain by till and a complex of till and bedded deposits, with the whole overlain by Lake Iroquois deposits which formed following the last retreat of glacial ice from the Toronto region. The flora and fauna of the lower part of the Don beds indicate a warmer climate than at present, whereas the fossils of the Scarborough beds indicate one slightly cooler.

As Coleman records it, there have been thirty-eight species identified from the Don beds; of these thirty-two are deciduous types and seven do not occur naturally so far north today. Three were reported as extinct species but two of these were misidentified, and were already represented in the collections. Several smaller plants have also been identified, as have a few animal remains including groundhog, bear, deer, bison and beaver. Many species of freshwater clams and snails have been recorded and, again, some of these are no longer found in the area, but are present in the Mississippi drainage system. Nothing is known of the bird-life of the time, and partial remains of a large catfish record the only vertebrate life of the interglacial lake. Only two little shell fish out of the eighty fossils recorded from the Don beds survived to Scarborough time in the Toronto area.

A plentiful fossil record has also been obtained from the Scarborough beds. Thin peaty layers between clay laminæ in the lower beds have yielded both plant and beetle remains. The former include willow, alder, spruce, sedges, horsetails, cranberry, a cherry, and several weeds, indicative of a climate like the present or somewhat cooler; the beetles include some seventy-two species, only two of which have survived to the present. The Scarborough sands have also yielded tamarac and balsam and five species of clams and snails common in the present waters.

Study of the microfossils of the Toronto formation by Terasmae in 1955 has supported the evidence yielded by the megafossils as regards the climatic conditions at the time of the deposition of the Don and Scarborough beds, namely 4 to 5 degrees warmer, and somewhat cooler, respectively, than at present. Further, the microfossil assemblages of the Don and Scarborough beds are unlike, and indicate that deciduous trees much like those of the present prevailed in 'Don' time whereas coniferous trees were greatly preponderant in 'Scarborough' time.

This record of diverse organic life during Don and Scarborough times is usually regarded as induced by the climatic changes that brought the Wisconsin glacier over the Toronto region. It is possible, however, that two separate non-glacial intervals are represented by the Don and Scarborough beds.

Other Occurrences

Other deposits of inter-till peats containing wood are found about 500 miles north-northwest of Toronto. These are on the Missinaibi and Opazatika Rivers in northern Ontario just above their junction to form the Moose River which flows into James Bay. Palæobotanical studies of these organic deposits indicate a cool moist climate, cooler than that indicated by the buried peats near Three Rivers, Quebec, but commensurate with it considering the more northerly and inland location. The age of the deposits is greater than 38,000 years (W-242). Here again is evidence of either an interglacial deposit (probably Sangamon) or an as yet unproven early or mid-Wisconsin non-glacial interval. Recent studies at the Lamont Geological Observatory suggest a finite age close to 38,000 years and hence favour a Wisconsin interval.

Near Port Talbot on the north shore of Lake Erie fragments of wood (larch) were found in a till that overlies a few feet of lacustrine clay and this, in turn, rested on till. This wood has been dated at 27,500 ±1,200 years (W-177). South of Lake Erie, and southward to the glacial border in southern Ohio, wood has also been found in many places; radiocarbon dates on this wood become progressively younger going southward. It appears as if forest beds were overrun by glacial ice in southwestern Ontario some 27,500 years ago and that this glacier reached its southern terminus roughly 20,000 years ago. In Illinois, on the other hand, the Wisconsin ice reached its terminal position and began to retreat about 22,000 years ago. It would therefore appear that periods of movement and of retreat of major lobes of the Wisconsin ice-sheet took place at different times over a period of some thousands of years. In any case there were forests in southwestern Ontario immediately prior to 27,500 years ago, and these were destroyed by the advance of a major glacier. The precise relations of these forests with the close of the Sangamon or with early Wisconsin time are unknown at present.

Near Markham, Ontario, north of Toronto, a peat ball found in inter-till gravels was shown by radiocarbon dating to be more than 34,000 years old

(W-194). Pollen studies on this material indicated a cool moist climate that could indicate either an interstadial or the beginning or close of an interglacial period. The peat ball might therefore represent Scarborough time. In Toronto itself some organic material in stratified sediments lying between two tills, exposed in subway excavations, gave a date of more than 30,000 years (W-121). Pine, birch, spruce, and fir pollen were identified. These may also represent Scarborough time.

Manitoba

In Western Canada there are many records of interglacial deposits, but no detailed stratigraphic studies or regional correlations have been published to indicate their true significance. As long ago as 1890 J. B. Tyrrell reported interglacial sediments at the north end of Duck Mountain west of Lake Winnipegosis. These consist of fossiliferous sandy clay with some beds of clay, sand, and gravel, and have a thickness in places of about 75 feet. They are overlain by up to 22 feet of till and possibly by 10 feet of gravel which is probably a Lake Agassiz deposit. Tyrrell reports that these buried stratified deposits contain numerous freshwater shells with fragments of plants and fish remains essentially the same as those living in Lake Manitoba and the surrounding lake today. Five genera of diatoms, six genera of molluscs, and some plant remains including spruce cones have been identified. In the valley of Shell River, south of Duck Mountain, Tyrrell reports that a landslide revealed many mastadon bones (presumably *M. americanus*) but the stratigraphic position of the bone-bearing sediments was not determined. A well log from Turtle Mountain, straddling the Manitoba-United States boundary, also offers evidence of non-glacial periods prior to the present. Here spruce cones were obtained from beneath 100 feet of drift that is largely till. Old well records from other places also record sand and gravel, or brown till beneath a thick till covering; the brown till might represent a period of surface oxidation and hence a non-glacial interval prior to burial by the younger drift.

Saskatchewan

At Churchbridge, Sask., close to the Manitoba boundary and southwest of Duck Mountain, a log of a well with a diameter of 6 feet and a depth of 267 feet also provides evidence of a non-glacial interval. There, 8 feet of sandy loam is underlain by 24 feet of drift, which Tyrrell believed to be a till, and this overlies 1 foot of sand and 234 feet of soft blue clay with one-inch sand layers about every 2 feet. "At a depth of 200 feet a well preserved piece of wood six inches in length was found". This was described as a new species of larch *(Larix churchbridgensis)*. Other well records in the area also indicate a till, in places very thick, overlying stratified deposits.

Stratified deposits buried beneath about 200 feet of till and possibly other sediments occur in the Qu'Appelle Valley near Fort Qu'Appelle and LeBret. They contain bones and teeth of bison, mammoth, horse *(Equus niobrarensis)*, wolf, and bear. These fossils occur in a bed of gravel about 30 feet thick which is overlain by about 20 feet of sand containing a few snail and clam shells, and the whole is overlain by till. This deposit may well represent an interglacial stage but the

Pleistocene geology of the area has not been studied to provide a basis for correlation with other deposits on the prairies.

Near Saskatoon, approximately 150 miles farther northwest, similar horse teeth *(Equus niobrarensis),* occur in the basal part of a 10- to 12-foot gravel bed which forms small knolls on the prairie surface. Teeth of mammoth and bison, and a few bones, also occur in the base of the gravel. The gravel knolls are capped with a thin bouldery layer, considered to be a residuum of the erosion of similar gravels. The deposit is therefore considered to be post-glacial in this area but may represent a late Wisconsin interstadial. If the bouldery mantle on the gravel knolls should represent a residuum from erosion of a till, however, the deposits would be considerably older. Horse teeth have also been found in surface gravel deposits at Lancer, about 60 miles northwest of Saskatoon.

Inter-till sediments have been encountered in drilling operations in the Moose Jaw-Regina area. In a well drilled at McLean, 25 miles west of Regina, 495 feet of drift were penetrated without encountering bedrock. The well section indicated four layers of sand and gravel separated by clay; the latter is probably till. No fossils were found in these inter-till sediments.

At several places in southern Saskatchewan inter-till sediments and buried weathered surfaces have been observed within and near the northwest-trending Missouri Coteau which crosses the International Boundary at longitude 104 degrees and extends to the South Saskatchewan River. The Coteau is covered by an irregular morainal deposit which has a relief of 25 to 100 feet. At two localities near the International Boundary an upper till is underlain by about a foot of silt that grades down into 3 feet of sand. The silt contains freshwater shells, including several species of pelecypods, gastropods and ostracods, and some plant remains, including sporangia of *Chara.* The molluscs are types that live in cool-water ponds.

At Verwood, 75 miles to the northwest, where the upper till appears to be the same as that near the International Boundary, a non-glacial interval is represented by a zone of weathering below the till. This consists of a one-foot thick buff coloured zone containing plant roots. On the north side of Lake Johnstone, 50 miles north-northwest of Verwood, the upper till rests on a foot of sand and silt that locally shows the development of a buff or cream coloured soil believed to be the equivalent of a leached forest soil. Pieces of tree trunks up to 12 inches in diameter have been found in the till and in the disturbed zone beneath it. The underlying foot of sand contains a few gastropods and pelecypods and at least six species of ostracods. Impressions of a moss-like plant and numerous sporangia of *Chara* are also present. Up to 10 feet of sand and gravel without fossils lie unconformably below the fossiliferous layer. Inter-till sands containing some plant remains also occur at Lac Pelletier some 50 miles west of the Missouri Coteau moraine.

The character of the tills and the nature of the flora and fauna suggest that all the above-mentioned deposits represent the same non-glacial interval. It appears that a cool moist climate prevailed in the area, and that the fossiliferous materials and weathered zones represent an interstadial interval. The glacial drift of the Missouri Coteau is believed to be late Wisconsin in age, but sufficient work has not yet been done to indicate the precise interstadial interval represented by the sediments, fossils and weathered zones, and no radiocarbon datings have been made.

In the valley of Swift Current Creek near its junction with South Saskatchewan River, 80 miles west-northwest of Lake Johnstone, three tills are separated by deposits of two non-glacial intervals. The uppermost till, with a thickness of 20 to 70 feet, may be the same as the thin surface till farther southeast along the Coteau, and hence it is reasonable to assume that the immediately underlying non-glacial deposits represent the same Wisconsin interstadial interval in both areas. In Swift Current Valley this interval is represented by up to 35 feet of white sand and gravel with scant, poorly preserved plant material. These sediments rest on a dark grey till, 3 to 45 feet thick, which is underlain by stratified sand and gravel with some peat. The plant remains in these older non-glacial deposits are poorly preserved and little is therefore known of their character and hence of the climate of the non-glacial interval they represent. In one place these sediments are 225 feet thick and rest on bedrock. Elsewhere they are thinner and have been seen resting on a brown to yellowish till with a maximum observed thickness of 96 feet. In one place the upper 8 feet of this till displays a weathered zone containing plant materials, including roots, again too poorly preserved for identification. The great thickness of the older non-glacial deposits, with their contained plant materials, and the depth of weathering of the underlying till, indicate a long non-glacial interval, and probably a moist climate. This interval was probably an interglacial.

Peaty lignite, in places a foot thick, has been reported from the extreme southwest corner of Saskatchewan, south of the Cypress Hills. It occurs at the surface, except locally where it is overlain by a foot or two of till or possibly slide material. The peat rests on 30 feet or more of till. Although the relations of this peat to the Wisconsin are unknown, it was assuredly developed under climatic conditions unlike the present and may represent some Wisconsin interstadial period.

Alberta

In southern Alberta many non-glacial deposits have been reported but some of these require confirmation, and further regional study is needed in all cases to establish the stratigraphical and chronological relationships. The non-glacial sediments, and usually one or more tills, occur in buried pre-glacial valleys where they have been protected from later glacial erosion, but where subsequent river action has cut deep channels.

Such interglacial sediments are present along the Oldman River. At one site wood and cones of black spruce were found in the basal part of inter-till sand, silt, and gravel. A radiocarbon dating of more than 26,000 years (L-221C) was obtained on the wood. Judging by the different lithologies of the enclosing tills and by the character of the non-glacial sediments themselves, these sediments are present beneath the surface till in many places as far north as Edmonton. They are presumed to be of Sangamon age.

Two tills occur beneath the above-mentioned unit of stratified sediments at several places along the Oldman River and, in at least one locality, a weathered zone occurs at the top of the basal till. This weathering is believed to have taken place during one of the pre-Sangamon interglacial intervals. A similar zone of weathering has been noted at the top of the lower till at one locality on the Red Deer River. About 20 miles west of Leduc some 5 feet of sand occur between the lower and middle tills but no fossils have been reported. In the vicinity of Morinville, about 20 miles north of Edmonton, sediments carrying Pleistocene spores and pollen occur between two tills which lithologically resemble the lower and middle tills elsewhere in southern Alberta. There is thus some scattered evidence of an interglacial stage older than that presumed to be Sangamon. The precise dating of these interglacial deposits cannot of course be ascertained at present.

Bones of bison, *Simobison antiquus,* and of a small horse were found in gravels where the Edmonton-Grande Prairie highway crosses the Smoky River Valley, 25 miles east of Grande Prairie. Their state of preservation suggests burial for a long period, and of course, the record of the extinct bison and of what is probably a native American horse further suggests some antiquity. It is believed that the gravels are part of a terrace that is assigned to the late-Wisconsin and may be Valders in age.

Near Smoky Lake, about 60 miles northeast of Edmonton, a log of spruce was found in till at a depth of 24 feet. This location is west of the limit of the Valders ice. The wood has been dated at 21,600 ±900 years (University of Manitoba), but may well be older. The occurrence confirms the presence of forests in this northerly area, however, in a former non-glacial interval.

British Columbia

Inter-till non-glacial sediments have not been reported widely in British Columbia. They have been reported from the lower Fraser Valley, the coastal lowlands of Vancouver Island, and small islands in the Strait of Georgia.

In the lower Fraser Valley non-glacial sediments are overlain by a widespread till and are separated from it by an erosional interval of considerable magnitude. These sediments, known as the Quadra, contain peat beds that are believed to have been deposited under climatic conditions slightly cooler than the present. In Lynn Canyon the hard-packed peat has a thickness of 3 feet and its upper and lower parts contain spores and pollen that indicate a cooler climate than do the spores and pollen from the central part. The peat bed is believed to represent a long period of non-glacial conditions. Plants identified from a study of the microfossils in the peat include pine, mountain and western hemlock, spruce, fir, birch, alders and scant Douglas fir. Sedges and other small plants were also abundant. The deposits are considered to be either Sangamon or mid-Wisconsin in age.

Fossils of a different type and much younger also occur in the Fraser Lowland. These are mainly marine organisms that are found in a till-like mixture (stony clay) that was presumably deposited in the sea from the base of a floating glacier. The marine organisms represented by the fossils inhabit more northerly waters today. Though correlation with standard Pleistocene sections east of the mountains may not yet be tenable, it would appear that the stony clays with their related glacial and glacio-fluvial deposits, represent a large part of the Wisconsin glacial stage, and hence include one or more non-glacial substages. A younger ice-advance, largely confined to valleys, extended down the Fraser Lowland to within 25 miles of Vancouver. As the lower part of the Fraser Lowland was submerged at that time, many miles of the ice-advance was into the sea, partly as floating ice. This glacier overrode forests growing on the mountain slopes so that pieces of wood were incorporated in the stony clay and in the till it laid down. A radiocarbon dating on this wood gave its age as 11,300 ±300 years (L-221E′). The non-glacial stage represented by the wood may therefore correspond to the Two Creeks interval and the advance of the valley ice, to the Valders glacial substage.

On Vancouver Island deposits related to the last regional glaciation also include a stony clay that contains marine organisms. Again there is evidence of a period of erosion separating these glacial deposits from older non-glacial sediments that contain peat with wood and leafy layers. Both the peat and the wood were radiocarbon dated at greater than 26,000 years (L-221). Spore and pollen grains are poorly preserved in the peat but are readily identifiable in silt horizons in the peaty sequence. The overall assemblage indicates a climate slightly cooler than the present. The non-glacial sediments are assuredly the same as those in the Fraser Lowland. Locally they are some 250 feet thick. The non-glacial sediments on the island are underlain by another glacial complex including stony shell-bearing marine clays similar to those in the deposits of the last regional glacial stage.

In central and northern British Columbia interglacial sediments including organic materials have been reported but the significance of some of these is doubtful. Non-glacial intervals are indicated in some places by the presence of deep river channels cut into older tills or bedrock, and by the occurrence of placer deposits, both buried by later glacial deposits. Lignite (peat?) has been reported from gravels lying beneath till along the Stikine and Tuya River but no studies have been made of their true nature. It is believed that the uppermost till is Wisconsin, but the age of the interval represented by the valley erosion and buried gravels is unknown.

Yukon Territory

Evidence of non-glacial intervals in the glaciated part of Yukon is sparse. No buried peat has been found—but at an archæological site on the Firth River, R. S. MacNeish found a buried humus horizon at a depth of 4 feet. The site is at an elevation of 315 feet above sea-level, 16 miles inland from Mackenzie Bay. The humus is associated with artifacts and bones and is established on beach sand and gravel overlying blue marine clay. The humus horizon is overlain in turn by a layer of windblown sand, followed by grey marine clay, more windblown sand, humic sand, and finally the modern humus. The nature of the buried humus indicates a sparse cover of lichens, mosses and shrubs, and pieces of bark along with the pollen spectrum indicate local forest coverage; the climate of that period must therefore have been more favourable than that of the present. Bones in the buried humus include those of deer, caribou, and giant bison.

The giant bison have also been found in the windblown sand overlying the grey clay, but in the humic sands above this only the modern wapiti (elk), modern bison, caribou, and muskox have been recorded. Several periods of human occupation have been indicated, the oldest dating from the period represented by the buried humus. The age of this nonmarine and non-glacial interval is unknown. The sea that deposited the grey clay has left strand lines on hills to the southeast up to at least 500 feet, and the depression of the land is believed to have been caused by the last ice-advance in this region. The micro-fauna assemblage in the blue clay below the buried humus indicates water depths of at least 70 feet and hence very significant changes of sea-level have taken place. Three miles east of the site a short esker post-dates the grey clay and marks the most westerly advance of the Laurentide ice in that region. The archæological site and buried humus must therefore be of considerable age but a radiocarbon dating is required to establish the chronology.

The only other evidence of non-glacial conditions, in the glaciated part of Yukon, is the presence of Pleistocene gravels and weathered horizons beneath till that was presumably deposited by a widespread early Wisconsin glacier.

Northwest Territories

Mainland

Near Reindeer Depot on the east branch of the Mackenzie River, interbedded peat and silt up to about 10 feet thick are buried beneath more than 200 feet of drift and may represent an interglacial age, possibly the Sangamon. Studies of pollen from the buried peat revealed abundant birch and alder, important amounts of white and black spruce, jackpine, tamarack and willow, along with Ericaceous shrubs, small herbaceous plants, grasses, sedges, and ferns. The pollen and vegetal remains indicate an assemblage similar to that now growing in an area some 50 to 75 miles south of Reindeer Depot.

The thickness of some surface peat deposits in the Mackenzie delta area, and the occurrence of a 20-foot thick peat deposit on a boulder island in Great Slave Lake, seem to indicate accumulation over a long period that may date well back into the Wisconsin and include interstadial periods. Plant and animal remains are found in the surficial deposits of the Mackenzie delta that are unlike those living there today.

Two buried peat deposits that mark very short non-glacial intervals late in the Wisconsin period are known in the District of Keewatin. One of these occurrences is on the north side of Rankin Inlet where a trench, in the lee of a rock knob, revealed a 6-inch band of peat resting on decomposed bedrock and overlain by 4 feet of till and thin patches of sand. A radiocarbon dating of 5,220 ±340 years (Y-231) indicates that the peat developed during the Altithermal interval. The till must have been the result of an ice-advance from the Keewatin divide. The other occurrence represents an even more recent period of vegetal growth during the waning stages of the Keewatin ice. This consists of a thin peat horizon lying between pro-glacial lake clays. The site is near the big bend in the Back River at a point due north of the extreme west end of Baker Lake. The peat was dated at 4,140 ±150 years (Y-261). A very late advance of the Keewatin ice did not quite reach this locality but did block the drainage and bury the peat under a mantle of lake clays.

Arctic Islands

Near Cape Kellett at the southwestern end of Banks Island, and presumably beyond the limit of Laurentide glaciation, a 100-foot cliff reveals an upper 10 to 15 feet of gravel resting on silty sediment containing organic material. Plentiful pieces of wood, with diameters up to about 10 inches, are scattered through much of the silt, and lenses of peaty material occur in a zone between 20 and 30 feet above sea-level. The silty sediments with many pieces of wood occur along most of the west coast but the peat is seldom seen because of slumping and solifluction. The peaty silts contain an abundance of spores and pollen. The abundance of pollen of spruce, pine, birch, and alder indicates that the wood was native to the region rather than transported from far south on the mainland as earlier believed. Scattered pollen grains of trees characteristic of a warm, temperate climate were also identified. (Erosion of the organic-bearing silts along the coast has released much wood which has been redeposited on raised strand lines and modern beaches; some modern wood that has been transported northward from the mainland occurs along with the older wood on some of the modern or near sea-level beaches.) The assemblage of spores and pollen indicates a much milder climate than that of the present, which supports only an Arctic type tundra and bog. The latter is comprised of undecomposed peat up to at least 4 feet and probably as much as 8 feet in thickness. Dwarfed willows are the largest plants on the tundra. The buried organic materials are believed to represent an interglacial deposit, probably Aftonian or Yarmouth.

On the Queen Elizabeth Islands two occurrences of buried organic deposits again indicate a mild climate early in the Pleistocene epoch. Buried peat has been observed in a cut-bank of the Slidre River near Eureka, Ellesmere Island. There, 3 feet of thinly bedded sand rests on 3 to 10 feet of boulder gravel, which contains a layer of peat and which, in turn, rests on 30 feet of thick-bedded sand. The peat varies from a feather-edge to 8 inches in thickness and is for the most part at the bottom of the boulder gravel. The organic layer contains well-preserved mosses, grasses, and twigs. Its character and position clearly indicate a former climate more moderate than that of the present, but whether the deposit is interstadial or interglacial is unknown.

On the south side of the broad stream-cut valley of the Stuart River, in the northeastern part of Bathurst Island, buried organic deposits have been found about 100 feet above the river and nearly 300 feet above the sea. A terrace, which is mantled with marine deposits, occurs at the top of the sections and extends inland to the base of a bedrock cliff at an elevation of 335 feet. Beneath the marine sediments, and forming the uppermost part of the modern valley wall, are 2 to 5 feet of river-deposited silts with a basal gravel layer. The gravel rests on the organic deposits which consist of three layers of peat separated by thin beds of silt resting on clayey layers, the whole about 4 feet thick. The clayey layers are underlain by 20 feet of river gravels which rest on a base of at least 40 feet of possible Tertiary sediments. The three peat layers are 15, 6, and 9 inches thick, and thin, leached zones are present beneath the upper and lower layers. Pollen studies of the peat reveal that the vegetation was largely composed of grasses, sedges, mosses, small herbaceous plants, and some alder. Scant pollen of spruce, birch, and willow may have been blown in from other areas. The period of marine overlap, represented by the fossiliferous sediments on the terrace above the peaty beds, is believed to be the same as that which post-dates the retreat of the ice-sheet from the eastern part of the Queen Elizabeth Islands. The peat deposits therefore may represent an interglacial period, probably the Sangamon stage.

On Prince Patrick Island logs of driftwood, with diameters up to about 14 inches, occur in the Beaufort formation which overlies Tertiary sediments and outcrops on the 800-foot high southern part of Prince Patrick Island. It is believed to underlie most of the low western side of the island and parts of adjacent islands to the northeast. It was, however, deeply eroded prior to the development of the ice-cap which formerly mantled the higher part of the island. As the ice-cap probably existed at the time of the maximum development of the Queen Elizabeth ice-sheet, the Beaufort formation is clearly pre-Wisconsin. The Beaufort formation consists of sand with thin gravel layers and a capping of coarse gravel. This capping contains boulders, up to 2 or 3 feet in diameter, probably derived from Melville and Victoria Islands. It is conceivable that this material has a glacial origin. The underlying sands and the wood may represent an early Pleistocene interglacial period. A radiocarbon dating indicated an age of greater than 31,840 years (Y-284).

Sticks and logs of wood have also been noted in the frost-disturbed clayey soils of other low western islands such as Borden, Ellef Ringnes, and parts of Melville. Though the nature of these occurrences has not been determined, and the wood has generally been regarded as post-glacial driftwood, their wide distribution coupled with the occurrences of wood in silt and sand from Banks and Prince Patrick Islands, makes an *in situ* origin very probable. It may well be that trees covered this far northern region in either the Aftonian or Yarmouth interglacial ages.

Record of Glacial Periods

The problems of the development of continental glaciers on four occasions during the Pleistocene epoch have been well analysed by Flint. He concluded that the cause of glaciation is essentially two-fold "(1) fluctuation of solar radiation as the cause of world-wide temperature changes, and (2) the presence of highlands as the prime factor determining the accumulation of snow and the distribution of glaciers."

By far the greater part of Canada has been glaciated. The four glaciations as recognized most clearly south of the Great Lakes are believed to have occupied roughly equal periods of time, but one or more of the earlier glacial stages was of greater extent than the last, or Wisconsin, glaciation. This is indicated by the occurrence of remnants of older drift beyond the limits of the Wisconsin drift south of the Great Lakes and in Yukon, and at higher elevations on mountains in many parts of the Cordillera. The record of glaciation most apparent in Canada is of course that of the Wisconsin glacial stage; the following section, therefore, deals mainly with the glacial events and deposits of that period. When the Wisconsin ice-sheet was at its maximum it covered about 27 per cent of the land surface of the earth as compared to only 10 per cent covered by ice at present, and the greater part of this difference was due to the glacier that covered most of Canada.

The Wisconsin continental ice-sheet is discussed in three parts according to main physiographic regions upon which major ice-sheets developed, namely the Cordillera, the interior and eastern region, and the Queen Elizabeth Islands.

Cordilleran Glacial Complex

Early in Wisconsin time large glaciers must have developed along the Coast Mountains as moisture carried by winds from the Pacific was chilled upon moving inland and precipitated as snow on the mountains. As the glaciers expanded the ice would flow westward into the sea and eastward onto the interior plateaux. The latter ice together with that moving off other mountainous areas east of the Coast Mountains would build up in the interior. This movement of glacier ice from the higher gathering areas into the interior lowlands continued until a vast ice-sheet occupied most of the Cordillera (Figure 81). It extended from the Pacific Ocean eastward to the Foothills of the Rocky Mountains. Its southern margin, though somewhat indented, lay roughly 100 miles south of the International Boundary in most places; its northern margin was more irregular; the ice extended along the Coast Mountains but did not occupy the lower-lying Yukon Plateau or many mountain areas in northern Yukon and the adjoining part of District of Mackenzie. This great body of ice is commonly referred to as the Cordilleran ice-sheet or the Cordilleran glacial complex, but has been more fully described by Johnston as the "Cordilleran system of intermontane, piedmont and valley glaciers".

Topography played a dominant role in the movement of glaciers in the Cordilleran system. Initially, valley glaciers flowed off the mountains onto the lowlands and, as these became filled with ice, other valleys must have served as escape routes to lower ground away from the centres of accumulation. On the filling of the lowlands, however, topographic influence was apparently less important and regional movements were perhaps dominant for a while at the time of maximum glaciation. In any case, striæ and other indications of the direction of ice-movement reveal similar directions of glacier flow on the higher part of mountains, and on high plateaux, over broad areas.

In south-central British Columbia glacier movements were generally southward; the high Selkirk, Purcell, and Monashee Mountains evidently served as important centres of snow and ice accumulation, and the resulting glaciers, being hemmed in by the Cascade and Rocky Mountains, moved southward to the lower ground of the Columbia Plateau across the International Boundary. In the Nelson area of the Selkirk Mountains the upper limit of the ice-sheet was at 7,300 feet. To the west, in the Okanagan Range of the Cascade Mountains, there is evidence that the ice at one time overrode mountains up to 8,500 feet, but did not reach over 7,500 in Wisconsin time. In the Skagit Range west of the Okanagan Mountains, the Wisconsin ice-sheet does not appear to have reached above 6,500 feet.

In central British Columbia glaciers formed in the Coast Mountains and moved eastward, down the valleys, into the central (Nechako) plateau and plain which occupy an area of several thousand square miles. As the glacial maximum was reached the ice occupied the lowland and moved eastward to the Rocky Mountain Trench. This ice deposited till up to 6,000 feet, and left glacial erratics on the Omineca Mountains as high as 7,600 feet. The surface of the ice-sheet may therefore have attained an altitude of around 8,000 feet and hence been some 6,000 feet thick over the Nechako Plain. On reaching the Rocky Mountain Trench the eastward ice-flow was deflected northward along the trench and final release was attained to the east through the Peace River Valley.

In far northern British Columbia the interior Cassiar Mountains served as a glacier gathering-ground and strong movements took place to the south and southwest into the interior. The surface of the ice appears to have reached an altitude of about 7,000 feet. Some of the interior ice escaped to the Pacific Ocean through the valleys of the Stikine and Taku Rivers in the Coast Mountains. Some eastward movement no doubt took place off the Cassiar Mountains into the northward extension of the Rocky Mountain Trench and thence eastward through the Liard River Valley.

In Yukon Territory the picture of glacial events is complex and little understood. Many mountain peaks and even mountainous areas in the interior projected above the surface of the ice-sheet. In the Pelly Mountains the main ice-surface stood at an altitude of 6,200 feet and perhaps higher in some places. The surface was lower in those valleys where the ice could escape northward or northwestward. Many of the mountains projected above the main surface as nunataks. On the western flank of the central part of the Selwyn Mountains erratics left by the Pleistocene glaciers have been found up to an elevation of 5,600 feet, and farther north in the Selwyn Mountains, up to 5,400 feet. Eastward moving ice carried granitic erratics into the Mackenzie Mountains. Westward the ice-sheet sloped off onto the Yukon Plateau with its upper limit at an elevation of 4,500 feet near Mayo Lake. In many places over this plateau there is evidence of an earlier glaciation when the ice-sheet was at least 500 feet thicker. At the northwest end of the Selwyn Mountains the ice-surface lowered rapidly, and where the ice left the mountains in the Wind River Pass leading towards the Peel River and the unglaciated area it was at 3,500 feet. The Ogilvie Mountains protruded into the unglaciated part of Yukon and supported only local Pleistocene ice-fields which did not extend beyond the enclosing mountains. Here also there is evidence of an older and more extensive glaciation.

The St. Elias Mountains are the highest in Canada with numerous peaks rising to elevations of over 15,000 feet. They form a very effective barrier to moisture-laden winds moving inland from the Pacific Ocean and now harbour immense ice-fields. The fields were no doubt much more extensive during the glacial stages of the Pleistocene epoch but nothing is known of the upper limit of any continuous ice-field. On the northeastern flanks of the mountains the glaciers moved into the Shakwak Valley and thence northwestward along the valley. On at least one occasion the ice succeeded in crossing the valley and pushing through the Ruby Range. As the main glacier moved northwest along the Shakwak Valley its upper limit lowered from just over 6,000 feet at the south end of the valley to 5,000 feet at Kluane Lake, to 4,500 feet at the Donjek River, and to 3,500 feet at the Yukon-Alaska Boundary. In this end of the valley the glacier found relief northwards along the Kluane, Donjek, and White Rivers. The northernmost limit of the ice in the White River Valley was at the junction of the Donjek River at an elevation of 2,500 feet.

Erratics along the southwest side of the Shakwak Valley, near Kluane Lake, at elevations around 7,000 feet and in one case at 7,600 feet, are believed to record an earlier, more extensive glaciation.

Very little is known about the Pleistocene stratigraphy and history of the Cordillera. This is in part due to the effects of valley glaciation which, in some regions at least, followed the ice-sheet stage and destroyed or mantled its deposits. Drift deposits are very thick in many valleys. In some places in the Columbia River Valley overburden is at least 200 to 300 feet thick, and in the Arrow Lakes basin, near the International Boundary, the drift is 600 feet thick.

In the vicinity of the Rocky Mountain Trench, east of the Nechako Plateau, a lower till containing materials derived solely from the Rocky Mountains has been noted beneath the surface till. The lower till appears to represent an earlier advance of ice from the Rockies prior to the near-maximum advance of ice from the Coast Mountains. Elsewhere the Rocky Mountain glaciers did not contribute to the ice-sheet occupying the interior areas west of the Trench. In places on the Nechako Plain, rivers have exposed till as much as 400 feet thick.

The best record of the glacial history in the Cordillera comes from the lower Fraser Valley and from the east coast of Vancouver Island. In the Fraser Lowland three glaciations are currently recognized, known from the top down as the Vashon, Semiamu, and Seymour. The upper and lower of these were of ice-sheet proportions, probably 7,500 feet thick over the lowland, and the ice moved in a southerly direction off the Coast Mountains. Direct evidence of the Semiamu glaciation is poorly preserved as a result of a subsequent long erosion interval but it is believed to have been a major glaciation. Drill-hole data give some indication of a pre-Seymour glaciation. On Vancouver Island the Semiamu stage has not been recognized. In both areas a glacial stage of the Pleistocene, known as the Quadra, is separated from the overlying Vashon till by a major erosional interval. This erosion interval was largely responsible for the present topography; the Vashon till merely mantles the hills and conforms to their slopes.

During each major glaciation the land was depressed relative to the sea, possibly as much as a thousand feet. At each maximum the ice was on the sea floor, scouring the fiords, but later it thinned and floated. While it floated, debris was dropped from the base of the glaciers and gave rise to till-like mixtures containing marine fossils. These are very characteristic deposits of the coastal areas and in places reach thicknesses of several hundred feet. They are known in connection with the Seymour and Vashon glaciations and with the post-Vashon valley ice which reached the sea, then about 25 miles inland from the present shore.

As the Wisconsin ice began to wane in mountainous areas and the upper limit of the ice-sheet dropped to lower levels, topography again played a dominant role in the movement of the ice. Widely variant directions of ice-movement, and even complete reversals, are therefore to be found in nearby locations. The pattern of ice-flow features left by the last active ice in any region is, therefore, complicated by the record of earlier movements. Nevertheless, the pattern is sufficiently well-developed to indicate that the glaciers did not always retreat along their original paths of advance, but rather that they retreated towards the areas from which the ice flowed at the glacial maximum (Figure 81). Thus the pattern of ice-flow features in south-central British Columbia indicates a general northwestward retreat towards a recessional ice-divide extending from the mountains east of Quesnel Lake, southwest to a point near Taseko Lake. From this point the ice-divide trends northwestward along the eastern side of the present area of Coast Mountains glaciers, cuts inland around the drainage basin of the Skeena River where it flows southwest, and then trends north-northwest through north-central British Columbia and northward into Yukon Territory. The retreat of the ice in central British Columbia was therefore northward to the Quesnel-Taseko Lakes part of the divide, westward to the eastern side of the Coast Mountains and northwestward up the valleys of Stuart, Takla, and Babine Lakes systems to the ice-divide along the east side of Skeena River. In northern British Columbia and in Yukon the recession of the ice-sheet is more complicated by mountain ranges and is less understood.

Glacial lakes formed at many stages during the retreat of the valley glaciers, as meltwater was dammed behind ice-barriers or end moraines. The largest lakes were in the Okanagan Valley of southern British Columbia and in the Prince George area of the central part of the province. In coastal areas marine overlap has modified the glacial record (Figure 82). Uplift in the Port Alberni area of Vancouver Island is around 300 feet, near Nanaimo it is 450 feet, and in the Fraser Lowland is about 750 feet and perhaps as much as 1,000 feet. Despite this uplift the fiords of the British Columbia coast originally scoured by the glaciers, are known to have an average water depth of 1,000 feet and to be flooded with a thick deposit of glacial silt, which in turn may rest on older glacial sediments. One fiord has a water depth of 2,400 feet.

Interior and Eastern Regions

The origin and development of a great inland ice-sheet is not as easy to visualize as in the case of a mountainous region. Ice-caps of appreciable size, however, occur on Baffin Island (Figure 81) and very small remnant glaciers are known in the Torngat Mountains of northern Labrador. These regions, and the highlands of central Quebec-Labrador, which are in part over 3,000 feet above sea-level, have a significant rain and snowfall and a very short cool summer. It is, therefore, quite conceivable that a slight drop in the mean annual temperatures of these regions would soon result in the expansion of the present-day glaciers and ice-caps and in the development of new ones. Continued outward migration from the many centres of accumulation would lead to coalescence of these ice-caps into a single elongate ice-sheet along the northeastern side of the mainland. It is postulated that events such as these took place in very early Wisconsin time. Local ice-caps would also form in the highland areas of Newfoundland, Cape Breton, Gaspé, and New Brunswick and these, in turn, at a later period, would become confluent with the major ice-sheet of Quebec-Labrador.

Moisture-laden winds from the west, southwest, and south probably dropped their load as snow along the southwestern side of the elongate northwest-trending ice-sheet. The ice-sheet was therefore thicker near its marginal position than towards its centre and, being unrestricted by major topographic features, the ice moved and expanded in a general southwesterly direction. Nourishment of the northern part of the ice-sheet, as it expanded westward across the northwestern part of the mainland and adjoining Arctic Islands, required some moisture-laden winds moving southeasterly from the Arctic Ocean. Ultimately a single vast ice-sheet occupied Canada east of the Rockies, spread far southward through the Great Lakes basins into the United States, and northward onto some of the Arctic Islands.

The inland ice-sheet of the Wisconsin glacial stage is known as the Laurentide ice-sheet. Though some of the outermost glaciated areas may not have been affected by the Wisconsin ice it was presumably of comparable size to those of the earlier glacial stages. It had an areal extent of over four million square miles. It has been estimated that at its maximum the Laurentide ice-sheet attained a thickness of about 10,000 feet. Such a thickness may have existed over a broad marginal zone extending from the St. Lawrence Lowlands westward through the upper Great Lakes and thence northwestward in an arc around, but far west of, Hudson Bay. Such a thickness appears necessary to account for the movement of glaciers far to the south of the Great Lakes basins, and westward to the Foothills of the Rocky Mountains where Canadian Shield erratics are found at altitudes of over 5,000 feet. Such a thickness is also necessary to account for the amount of depression of the land in glacial times as is now recorded by raised and warped strand lines. The Great Lakes basins, for instance, were in places depressed several hundred feet, and parts of the St. Lawrence Lowlands and the coasts of Hudson Bay, in the neighbourhood of 500 to 800 feet. This adjustment of the land masses to the weight of the ice, and later upon the removal of this load, is a slow elastic or isostatic response. There is evidence that parts of the Canadian coasts and of the Great Lakes Basins are still slowly rising. A thickness in the order of 10,000 feet of ice is also in keeping with the thickness of ice recently determined by seismic means in the present Greenland ice-sheet.

The directions of the flow of the early Wisconsin Laurentide ice are practically unknown. The great majority of all ice-flow features, that remain today as a record of the trend of the ice movements, were formed by active ice in the marginal portions of the glaciers and ice-sheets. As the glaciers receded, the active or forward moving ice of their marginal zones left a record of ice-movements impressed on bedrock and drift in many areas. As the influence of topography was not as great as in mountainous regions, the pattern of ice-flow features is usually more apparent. It is, however, complicated to some extent by major and minor lobations of the ice, and these were commonly controlled by topography. In general, the trend of eskers also indicates the direction of glacier flow, as this flow had an influence on the development of meltwater channels; moraines indicate marginal positions of the ice-front during halts or advances during the period of general recession. Only in the fringe areas of glaciation are there apt to be features related to earlier glaciations.

The pattern of ice-flow features, eskers, and moraines in the interior parts of Canada, indicates that there was a general recession to two areas on either side of Hudson Bay (Figure 81). These have been widely known as the 'Keewatin' and 'Labrador' Ice Centres. As a result of the study of air photos of the regions and of intensive ground investigation, it is now known that the Laurentide glacier receded to two elongate areas rather than to 'centres'. The last remnants of inland ice must have lain along these indicated recessional divides, probably as a row of small ice-fields.

The Labrador ice-divide forms a large asymmetrical 'U' far inland from, but roughly parallel to, the shores of Ungava Bay. The Keewatin ice-divide forms a gentle arc roughly paralleling the shore of the northwest side of Hudson Bay but some 200 miles inland. It extends from the vicinity of Wager Bay southwestward to within 80 miles of the Manitoba boundary east of Ennadai Lake where it appears to die as a single unit. It may extend farther southeast, however, as an intermittent divide, there being evidence of ice-movements into the bay as far south as Churchill, Manitoba.

The locations of the Keewatin and Labrador ice-divides are not related to topographic features, but rather they extend across areas whose elevations vary from near sea-level to about 3,000 feet. Even in Labrador the position of the ice-divide does not conform to the trend of adjacent more rugged ground, though in north-central Quebec it does coincide with a belt of high gneissic hills along the southwestern side of the Labrador Trough. The position of the ice-divides appears to be the result of a general overall shrinking of the Laurentide ice-sheet, modified by the maritime influence of marine waters encroaching on the depressed coasts of the Arctic, Atlantic, and Hudson Bay regions.

More detailed information on Wisconsin glacial events and deposits in various parts of Canada affected by the Laurentide ice is given below.

Maritime Region

The Island of Newfoundland. Knowledge of Pleistocene deposits and events in Newfoundland is largely the result of studies by Coleman, MacClintock, Twenhofel, and Flint. The island was completely covered with glacier ice in Wisconsin time. Labrador-derived ice probably invaded the western parts at the maximum of Wisconsin glaciation, but as the glaciers waned, Newfoundland developed its own independent ice-cap and the glaciers moved outward in all directions, cutting deep fiords. The ice probably did not spread very far beyond the present island shores. With continued waning of the Wisconsin glaciers it appears, as might well be expected, that a separate ice-cap developed on the Avalon Peninsula so that glaciers also moved off this landmass to produce its outward-trending striæ. As the ice retreated from Newfoundland, the sea invaded the coastal areas; terraces or benches were cut and deltaic deposits bearing marine shells were laid down in many places. These are today elevated above the sea; along the west coast their height increases progressively northward from less than 50 feet in Port au Port Bay to over 250 feet as they approach the Strait of Belle Isle and the isobases apparently trend east-northeast. A few poorly developed benches in the southern and eastern coastal areas afford some evidence of uplift that appears to represent an earlier land adjustment to the removal of ice from the more easterly parts of the island. The shells contained in the marine deposits of the coastal areas indicate water temperature similar to, or only slightly cooler than, that of the present water.

Till and kame gravels overlying marine beds in the St. Georges Bay area on the west coast, and a marked attendant moraine, denote a late Wisconsin readvance, possibly a late Wisconsin substage. Till overlying gravels west of Corner Brook may be further evidence of such a substage.

Cape Breton Island. Cape Breton must have had its own ice-cap during the greater part of Wisconsin time. It is not known if this ice was ever confluent with Labrador-Newfoundland ice, but there is no evidence that such northern ice overrode any part of Cape Breton Island. Striæ on Cape Breton indicate two major movements, one off the highlands in all directions and the other to the southeast in the southern parts of the island with a swing to the northeast through the Bras D'Or Lakes. A piling up of Cape Breton-derived ice in Northumberland Strait and George Bay on the west side of the island might well have been sufficient to produce the southeasterly movements through the Strait of Canso and bordering areas, but these movements probably also received considerable impetus from ice from New Brunswick moving eastward along Northumberland Strait. The outflow of ice from Cape Breton was of considerable magnitude. It appears to have moved northwestward in the Gulf of St. Lawrence to the vicinity of the Magdalen Islands, and westward to cover the eastern end of Prince Edward Island, and probably also over the northern side of Nova Scotia.

Nova Scotia Mainland. The Wisconsin glaciers moved southeastward and southward over the mainland of Nova Scotia as indicated by glacial striæ, drumlins, crag and tail features, and the distribution of certain erratics. The ice apparently moved in a general southeasterly direction from the highlands of New Brunswick, crossed the Bay of Fundy at right angles and continued southeastward across the greater part of Nova Scotia. As might well be expected, ice-movements were more southerly towards the mouth of the Bay of Fundy so that striæ trend south along the southwest end of this province. Southward trending striæ also occur across the north-central part of Nova Scotia. These apparently are due to glacial ice from New Brunswick that, on moving eastward along the Northumberland Straits, encountered ice from the Cape Breton region moving westward along the straits and was thereby deflected southward over northern Nova Scotia.

Prince Edward Island. As may already have been inferred from the foregoing, Prince Edward Island, which forms the northern coast of Northumberland Strait, was scoured by both eastward and westward moving glaciers. The broad eastern end of the island, rising to a maximum of 425 feet, was overridden, at least in large part, by ice moving almost directly westward and no doubt derived from Cape Breton. Foreign stones are common in the red till of the eastern end of the island but they become progressively less numerous towards the central part. Locally some of the foreign pebbles and small cobbles have been derived from a conglomeratic horizon, exposed at one locality along the eastern shore, but most of them have been brought to the island from beyond its shores. Cape Breton ice may have extended along the northern shore area as far west as New London Bay. In the interior it may have advanced a short distance west of Charlottetown and then been deflected by the high, central part of the island where elevations reach about 460 feet. Glacial striæ along the south coast west of Hillsborough Bay indicate that the early glaciers moved into Northumberland Strait at almost right angles to the shore. It appears that movement westward along the strait was impeded by eastward moving ice from New Brunswick.

The glacier advance from New Brunswick gradually dominated the Cape Breton ice and moved eastward along Nothumberland Strait, into Hillsborough Bay and inland for some miles. Here melting was great and glacio-fluvial materials and possibly ablation till, were spread over the east-central part of the island, earlier occupied by Cape Breton ice. The western end of Prince Edward Island was overridden by the same eastward moving glacier, and it deposited a mantle of till that, in the western part of the province, is loaded with foreign stones derived from the bedrocks of New Brunswick. The New Brunswick glacier, moving over the western part of Prince Edward Island and along Northumberland Strait, was soon overloaded with the soft red rocks of the region so that igneous or foreign stones rapidly decrease eastward. They are a rarity in the Summerside-Charlottetown section of the island, and are uncommon even as far as Malpeque Bay. The south shore of this bay was strongly scoured by eastward moving ice. In the waning stages of the New Brunswick glaciers, this ice was deflected northward in the bay, and glacier ice moved northeastward into the Gulf of St. Lawrence. A sporadic, thin mantle of till on the high central part of the island seemingly devoid of foreign stones is of uncertain derivation. Foreign stones do occur in the till in the lower areas on the north side of this highland; their source is unknown.

No raised beaches or marine-cut terraces have been recognized except in the western part of the island. The maximum uplift is along the west coast where evidence of the former presence of the sea may be found up to 75 or 80 feet. In the northwestern corner of Malpeque Bay, uplift is between 25 and 30 feet. The hinge line is presumably a short distance east of Malpeque Bay, and probably trends northeast. Considerable submergence of the island has taken place in the last few thousand years and is still in progress. Deposits of peat and stumps of trees occur on tidal flats and even below the water at low tide, and many parts of the coast are being actively eroded.

Magdalen Islands. Lying well out in the Gulf of St. Lawrence are the Magdalen Islands, whose glacial history has long been a subject of controversy. From 1880 until 1915 it was generally accepted that these islands had not been glaciated and from that date on, with the discovery of till on the southernmost island (Amherst), that they had been glaciated. Later reports of till, and of a morainal ridge on Coffin Island, at the northern end of the island group, seemed to confirm the glaciation of the Magdalens. The rolling, hummocky, boulder-strewn ridge on Coffin Island, however, is not an end moraine but rather a thick deposit of ice-contact stratified drift, largely silt and sand, overlain by a mantle of ice-rafted boulders deposited during a later marine stage. Some thin till-like layers, commonly associated with gravels and in places showing a small amount of water-sorting, may rest on weathered bedrock or occur bedded with the sand and silt and comprise an integral part of the ice-contact stratified drift. Where the till-like drift or sandy till rests on bedrock, usually a soft red sandstone, there is no evidence of glacial scour, but rather this debris appears to have been sloughed from nearby ice during the cycle of ice-contact sedimentation. Glacial ice therefore, probably at the Wisconsin maximum, appears to have just reached the northeastern end of the Magdalen Islands and to have deposited ice-contact stratified drift in this vicinity. These deposits with their bouldery mantle may be found up to an elevation of about 120 feet. The drift on Coffin Island may be termed a kame moraine and it appears to be related to the farthest advance of Cape Breton ice, though a Labrador or Newfoundland source cannot be ruled out. No evidence of ice-contact stratified drift or of till was observed on East Island or Grosse Isle, lying to the north of Coffin Island, and high bedrock hills on these islands were certainly not overridden by glaciers.

The more southerly Magdalens, except for an occasional occurrence of till on the east and south sides of Alright Island and on the south side of Amherst Island, show no evidence of glaciation. This till is considered to be a glacio-marine deposit, gently laid down on a very uneven and commonly soft, weathered surface with no evidence of ice-scour. The till was observed only at altitudes below about 30 or 35 feet but it may have been removed by erosion from somewhat higher places. There is no other evidence of glaciation of the Magdalens and the writer believes they were not overridden by Laurentide or other glaciers. 'Glacial' erratics on the western side of Grindstone Island at elevations of 90 to 120 feet are assuredly ice-rafted boulders; marine gravels, almost devoid of foreign stones, are evident up to elevations of 90 or 95 feet. Only on a west-facing slope of the eastern side of Alright Island is there an erratic above the observed marine limit of about 120 feet. There a large quartzite boulder occurs in the pastureland 'soil' at an elevation of about 170 feet and it appears to be in an undisturbed position. Possibly it is an expression of an earlier period of marine overlap, or a very early and otherwise obliterated glaciation. The great sand bars and spits that unite the Magdalen Islands into a unit are the result of marine erosion on ice-contact stratified drift deposits, directly related to those on Coffin Island and which no doubt were formerly more extensive.

New Brunswick. In all probability Laurentide ice covered the whole of New Brunswick at the Wisconsin maximum, moving in a southerly to southeasterly direction. Very strong ice-movements took place down the Madawaska-Saint John River Valley, and spread across the southwestern part of the province. In north-central New Brunswick the record of glacial events and movements is little known, the area being heavily forested and rather difficult of access. This is a highland area, roughly 1,000 to 2,000 feet above sea-level and with a high point of 2,690 feet. The highland appears to have deflected the Laurentide ice, at least in the later stages, so that on its southeastern side there is evidence of eastward and northeastward ice-movements. In the latter part of the Wisconsin an ice-cap is believed to have formed on the highland area. Radial flow from this ice-cap probably accounts for the northeast-trending striæ on the south side of the Bay of Chaleur, and for some other striæ, at variance with the regional trend, elsewhere in the province. Over most of the province, it is at present impossible to separate the results of the Laurentide ice-lobe from those of the local ice-cap and it is therefore perhaps best to refer to the resultant effect of Wisconsin ice on the region as that of the New Brunswick ice.

As the New Brunswick ice waned the glacier in the Saint John Valley retreated northward with some halts and readvances and left a succession of overlapping valley train gravels, in places separated by glacial lake deposits. One of these lakes, Lake Madawaska, was dammed behind the Grand Falls moraine. Wood contained in an organic layer at the top of the Madawaska clay beds has been radiocarbon dated at 8,200 $\pm$300 years (L-190B). The Grand Falls moraine, pre-dating both this organic layer and the clay beds, would therefore appear to mark a major advance of the ice in late Wisconsin time. Palynological studies of peat bogs south of Grand Falls indicate that a tundra climate followed the retreat of the glaciers and was in turn followed by a warmer period, possibly the Two Creeks interval. The pine maximum of post-Valders time appears to have taken place about 6,000 years ago.

Gaspé Peninsula. Laurentide ice probably invaded all parts of the Gaspé Peninsula. This is indicated by the distribution of erratics of anorthosite, granite gneisses, and a few other rock types characteristic of the region north of the St. Lawrence River. Evidence of glaciation of the summit of Mount Albert (3,775 feet) at the east end of the Shickshock Mountains by southward moving ice, and the occurrence of granite gneiss erratics at lower levels nearby, and to the south of the whole length of the Shickshocks, is assuredly indicative of Laurentide glaciation. On Mount Jacques Cartier (4,160 feet) the highest point on the peninsula, located in the Tabletops east of the Shickshock Mountains, cirques and striæ have been found up to 3,500 feet and erratics of local granites, up to 3,700 feet. It therefore seems logical to assume that the entire peninsula was covered by Laurentide ice presumably in Wisconsin time. In general the movement appears to have been southeastward and it was strongest and no doubt continued longer down the Matapedia Valley at the west end of the peninsula.

As the Laurentide glaciers waned, retreat took place northward up the Matapedia Valley and great quantities of outwash sand and gravel were deposited as valley train, but the sequence of events has not been established to date. On the retreat of the Laurentide ice from the highlands of Cape Breton, two important ice-caps developed, one centred on the Tabletops and the other on the Béland-Upper York Highland farther east. Radial outflow took place from these highland areas and distributed erratics of the local rock over adjacent areas of other rock types. Tabletops granite erratics are to be found as much as 15 miles outward in all directions except westward where Mount Albert restricted the radial flow and appears to have been only partly covered by the Tabletops ice. There is some evidence that as the Tabletops and Béland-Upper York ice-caps waned, minor independent ice-caps developed on Mount Albert and on the eastern part of the Shickshock Mountains.

Northern Quebec and Labrador

Retreat of the Labrador glacier from the St. Lawrence River northward to the area of large lakes immediately south of Knob Lake, at the head of the Quebec North Shore and Labrador Railway, took place in late Wisconsin time. This lake area is part of a low plateau within the major Labrador plateau, and is bounded on the north and west by highlands with altitudes up to 3,000 feet, about 1,500 feet higher than the lake area. While this northward retreat was taking place, the glacier was also shrinking from the eastern, northern, and western coasts of the Labrador Peninsula (northern Quebec and Labrador), with the result that in the closing stages of deglaciation, small residual ice-caps formed along a belt already referred to as the Labrador recessional ice-divide.

The glaciers later expanded from several of these focal points, moved in nearly opposite directions in areas only a few miles apart, and engraved sets of faint striæ with directions that contrast markedly with the older, well-developed regional sets. Probably the last glacier remnant along the ice-divide was situated in the Knob Lake region. Eskers are absent, or very poorly developed, in this final position and elsewhere along the ice-divide, over a band about 100 miles wide. This appears to be related to the scarcity of englacial debris; meltwaters eroded numerous channels through the thin drift mantle but deposited little gravel. Clayey to silty till occurs in the Knob Lake part of the Labrador Trough and appears to be about 10 feet thick on the average. Outside of the trough in this area gravelly drift, which includes till, glacio-fluvial, and glacio-lacustrine deposits, prevails and is usually very thin; this drift thickens to the south.

St. Lawrence Lowlands

In the non-glacial (St. Pierre) interval that preceded the maximum advance of the Wisconsin ice-sheet, a drainage system comparable to that of the present

St. Lawrence River system was developed. Valleys carved during this interval were filled with grey varved sediments of pro-glacial lakes as the Wisconsin glaciers advanced from the north. As the glaciers expanded they overrode the grey varved sediments and older deposits and laid down a mantle of grey sandy till. The St. Lawrence Lowlands are believed to have been ice-bound during the greater part of Wisconsin time. The great ice-sheet from northern Quebec moved south into the northeast-trending Lowlands, was deflected southwestward by relatively high ground to the south, and moved up the St. Lawrence Valley. At one stage the ice succeeded in pushing laterally over the confining high ground on the south and, becoming confluent with probable Appalachian glaciers, moved southeastward to the Atlantic Ocean. A lobe of the ice-sheet south of Montreal moved down the Lake Champlain-Hudson River Valley system. But at the same time, and even later when Appalachian glaciers fed ice northward into the Lowlands, the main direction of movement was southwestward up the St. Lawrence Valley. With ice being constantly fed into the Lowlands from all along the north side of the valley the glacier continued on into the basins of Lake Ontario and Lake Erie.

On retreat of the Valders ice a glacial lake known as Lake Frontenac occupied the Lake Ontario basin and the western end of the St. Lawrence Lowlands. In the latter area its northern, ice-confined shore extended from a point south of Hawkesbury east-southeastward to a point a few miles south of Montreal. A long narrow arm of this lake probably extended down the Lowlands between the ice on the north and the higher ground on the south, possibly to the vicinity of Drummondville.

As the ice withdrew from the vicinity of Quebec City, marine waters flooded the lowlands but not to elevations as high as the Lake Frontenac levels. This marine stage is known as the Champlain Sea. It flooded the lowlands as far west as Brockville, Ontario, occupied the Lake Champlain basin, and extended up the Ottawa Valley as far as Petawawa (Figure 82). The water was rather brackish due to the great additions of meltwater directly from the retreating ice along the northern shores and from drainage of the Great Lakes basins. A readvance of the ice in the area northeast of Three Rivers resulted in the super-position of till over marine deposits and in the establishment of a prominent moraine, known as the St. Narcisse moraine. No wood has been found in the marine deposits or in the St. Narcisse till to provide a date on these events.

Readjustment of the land on release of the ice-load caused a relatively rapid and more or less continuous retreat of the Champlain Sea. Marine beaches north of Ottawa may be found at elevations up to about 700 feet and at Montreal up to 564 feet. As the sea withdrew, fluvial drainage of the present St. Lawrence system was established.

Great Lakes Basin

General. As the Wisconsin glaciers retreated from the southwestern part of the Erie basin—probably in early Cary time—and shortly afterwards from the most southerly part of Canada, meltwaters were ponded at the front of the waning glaciers. These were the first of the glacial Great Lakes, whose complex and fascinating history was long ago indicated by the work of Leverett and Taylor, Gilbert and Spencer, and later by Stanley, Putnam and Chapman, and Hough. Continual changes in the ice-marginal northern shores of the glacial lakes, coupled with readjustments of the land surface consequent upon the retreat of the glaciers, and the down-cutting and shifting of outlet channels, resulted in a very complex system of glacial lakes throughout the remainder of Wisconsin time. Changes in the lakes were most marked in late Cary to early Valders time. The last change, largely due to erosion of outlet channels, resulted in the Great Lakes as we know them today. High level strand lines, in places considerably warped due to differential uplift, abandoned river valleys, and lake deposits of various kinds remain as indicators of these former lake positions. The shore features and their manner of disappearance when traced northward indicate that the majority of the lakes were confined by ice on their northern or northeastern sides.

Southwestern Ontario was the first part of the Canadian side of the Great Lakes basin to be uncovered by the ice, and this took place during the retreat of the Cary glaciers. The low westerly part of this area was immediately flooded by glacial meltwater which was ponded between moraines on the south and the ice on the north. High ground to the northeast between the Lake Ontario and Lake Huron basins, however, remained as an 'island' surrounded by the active glaciers of the Huron, Ontario, and Erie basins. This 'island' has been given the name, "Ontario Island". Meltwaters were channelled around it and escaped southward into the glacial lake occupying the lower ground. Fluctuations in the various ice-lobes resulted in marked changes in the shape of the 'island' throughout the remainder of Cary time, and again during a large part of the Valders substage. Great moraines were built around its margins as one ice-lobe or another made sporadic advances, or long halts, during the deglacial process. Ontario Island thus forms a marked physiographic feature on the landscape of southwestern Ontario.

Cary Substage. Meltwaters from the waning Cary glaciers accumulated in the western end of the Erie basin to form the first of the glacial Great Lakes, known as Lake Maumee. Its outline, like that of most of its successors, varied greatly due to fluctuations of the ice-fronts that formed its northern shores and to consequent changes in its water level and outlets. The lake at first drained southwestward via the Wabash and Ohio Rivers into the Mississippi River. As the Huron ice-lobe waned an ice-marginal channel was opened and led northwestward to connect with the Grand River of central Michigan; thence the waters drained into glacial Lake Chicago in the Michigan basin and south through the Chicago outlet into the Mississippi system (Figure 83A). The lake that existed at this time is known as Lowest Lake Maumee. Still later, both the Wabash and Grand River outlet systems were in use together. At a later stage, resulting from a readvance of the ice, Middle Lake Maumee was formed. It drained via the Imlay-Grand River outlet (Figure 83B).

With continued retreat of the Cary ice the greater part of the Erie basin and the southern end of the Huron basin were flooded to form glacial Lake Arkona. This lake drained directly westward through the Grand River into the Michigan

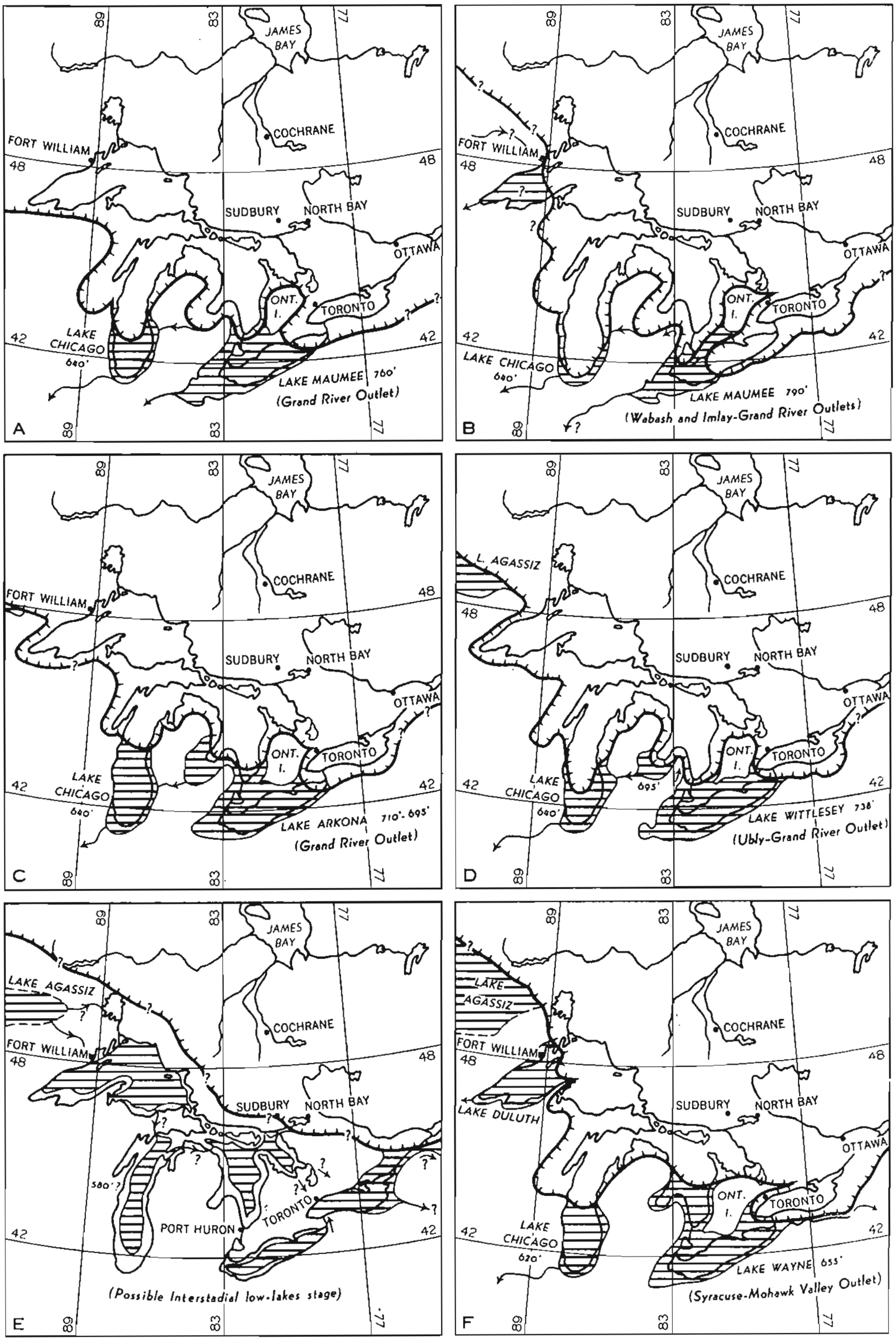
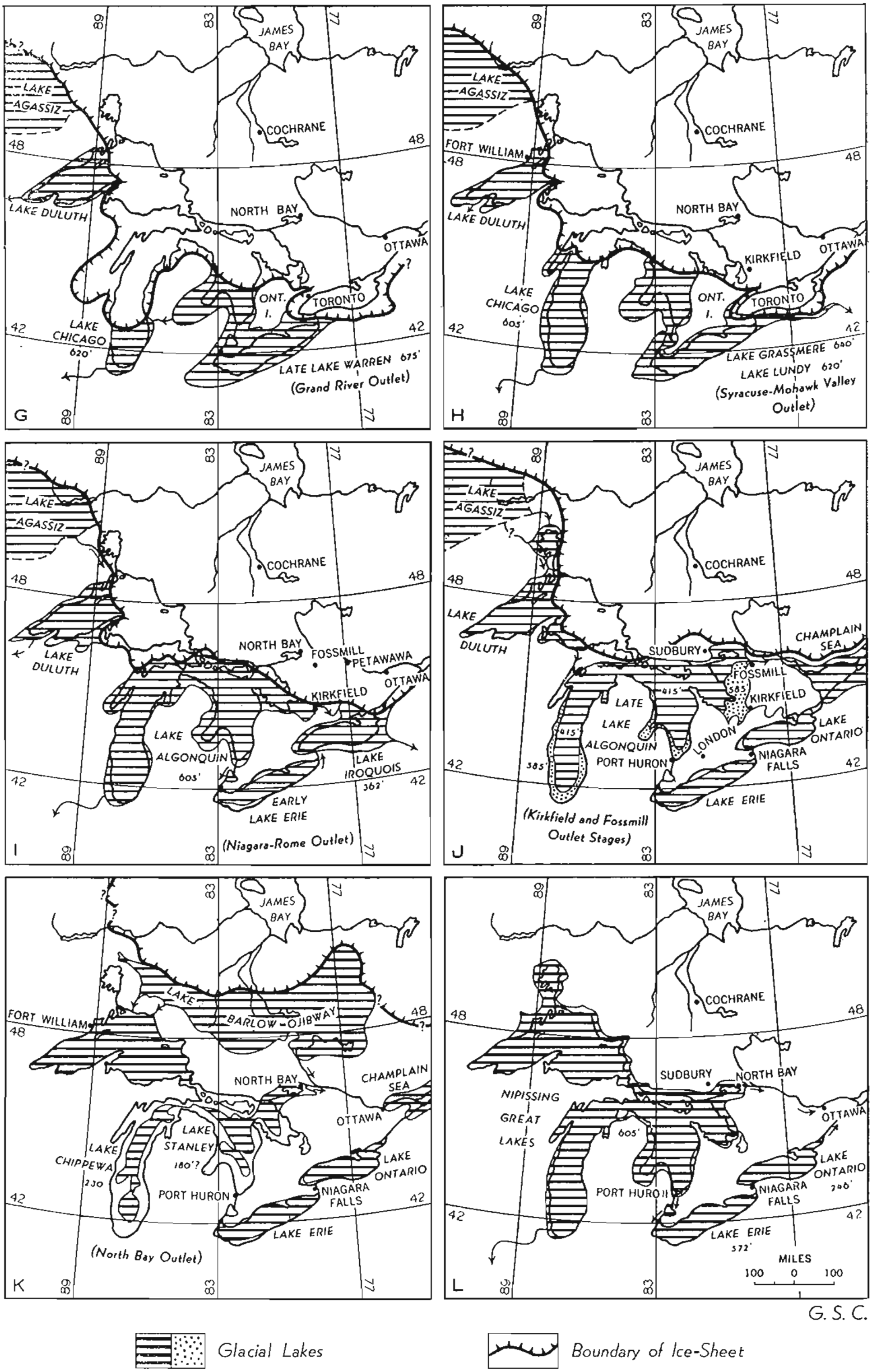


FIGURE 83. The glacial Great Lakes. (Modified after J. L. Hough and others.)



G
LAKE AGASSIZ
LAKE DULUTH
LAKE CHICAGO 620'
JAMES BAY
COCHRANE
NORTH BAY
OTTAWA
ONT. I.
TORONTO
LATE LAKE WARREN 675'
(Grand River Outlet)
H
LAKE AGASSIZ
FORT WILLIAM
LAKE DULUTH
LAKE CHICAGO 605'
KIRKFIELD
LAKE GRASSMERE 640'
LAKE LUNDY 620'
(Syracuse-Mohawk Valley Outlet)
I
LAKE DULUTH
FOSSMILL
PETAWAWA
LAKE ALGONQUIN 605'
LAKE IROQUOIS 362'
EARLY LAKE ERIE
(Niagara-Rome Outlet)
J
CHAMPLAIN SEA
SUDBURY
LATE LAKE ALGONQUIN
LONDON
PORT HURON
LAKE ONTARIO
NIAGARA FALLS
LAKE ERIE
(Kirkfield and Fossmill Outlet Stages)
K
LAKE BARLOW-OJIBWAY
LAKE CHIPPEWA 230
LAKE STANLEY 180'?
(North Bay Outlet)
L
NIPISSING GREAT LAKES
605'
LAKE ONTARIO 246'
LAKE ERIE 572'
MILES
100 0 100
G. S. C.
Glacial Lakes
Boundary of Ice-Sheet

basin and thence into the Mississippi system (Figure 83C). An important glacial advance then took place and the Ontario, Huron, and Michigan lobes built a well-marked moraine. This extends from Long Point Bay on the north shore of Lake Erie northward around Ontario Island and thence southward around the Lake Huron basin some miles inland from the present lake shores. This morainic system was formerly believed to mark the Mankato (now the Valders) maximum but is currently considered to be late Cary in age. The differences of opinion regarding the time of this advance necessarily bring about a great variation in the interpretation of the lake history. Following the current trend, the new higher level lake in the Erie Basin is known as Lake Whittlesey. This lake was at its maximum 12,800 years ago according to a radiocarbon dating (Y-240), and drained northwestward through an ice-marginal channel into a glacial lake in the Saginaw Bay area and thence into the Grand River (Figure 83D). Minor glacial retreat and resulting expansion of the lake gave direct access to the Grand River with a resulting drop in lake level to form Early Lake Warren.

Two Creeks Interval. It is believed that an important 'warming-up' period then took place with a resulting major retreat of the Wisconsin glaciers. This corresponds to the Two Creeks interstadial or non-glacial interval. The amount of retreat in the Great Lakes region is not accurately known but it is believed that the ice-front lay well to the north (Figure 83E). There is evidence of low-water stage lakes in the Erie and Upper Lake basins and these demand very low-level outlets eastward to the Atlantic. The escape route is not known but it may have been by some now buried route between Georgian Bay and Lake Ontario or via an Lake Nipissing-Ottawa Valley route. The lower part of the St. Lawrence Lowlands was blocked by ice so that the water probably escaped to the sea by way of the Hudson Valley system.

Valders Substage. Major advances in the Valders substage brought the ice once again into the Great Lakes basin. Numerous radiocarbon datings on wood from the till indicate that the Valders maximum occurred about 11,400 years ago. In Canada this front is believed to correspond with a chain of moraines extending from Niagara westward around the end of the Ontario basin and forming a large easterly pointing re-entrant north of Toronto, corresponding with the Oak Ridges moraine (which had probably formed in part in Cary time and even earlier), and thence westward around the north side of Ontario Island and across the central part of Lake Huron. The glaciers re-occupied the Lake Ontario basin, the northern parts of the Michigan and Huron basins, and at least the eastern part of the Superior basin. These glaciers more or less destroyed all evidence of older lakes in these areas.

Prior to the Valders maximum the advance of the ice into the Lake Ontario and Lake Huron basins once again resulted in a ponding of confluent waters in the Lake Erie and southern part of the Lake Huron basin. The glacial Lake Wayne beaches that show some modification by later lake action have therefore been recently assigned to this stage. The escape route was probably eastward along the south side of the ice-lobe in the Ontario basin and thence through the Finger Lakes into the Mohawk Valley, the Hudson River, and the sea (Figure 83F). At the Valders maximum this route was cut off by the ice so that the lake deepened until a route westward via the old Grand River channel, leading to the Mississippi system, once again became operative (Figure 83G). The resulting lake in the Erie-Huron basin is therefore known as Late Lake Warren. Retreat of the Valders ice soon re-opened the escape route along the south side of the Ontario basin and two long stands of the water are marked by prominent beaches referable to Lakes Grassmere and Lundy. These two lake levels are probably relatable to changes in the drainage route through the Finger Lakes and Syracuse outlet into the Mohawk Valley (Figure 83H). During the drop from the Grassmere level at 640 feet (Atlantic tide) to the Lundy level of 620 feet the waters of the Huron and Erie basins were early separated, but down-cutting of the broad, shallow channel of the St. Clair River system again brought the lakes in these basins to the same levels, hence glacial Lake Lundy towards its close also occupied part of the Huron basin.

Meanwhile, persistence of the ice-lobe in the Ontario basin while the northern ice was retreating resulted in an expansion of the re-entrant between these two glaciers. Glacial debris was washed into this re-entrant over a long period of time and was there hastily deposited as the meltwater escaped westward to the flanks of Ontario Island and south into the glacial lakes which occupied the Erie basin over the same period of time. The great load of ice-contact stratified drift left in the re-entrant, along with that similarly deposited in Cary or earlier times, remains today as a broad, high, east-trending ridge of hills, some 30 miles north of Toronto, known as the Oak Ridges interlobate moraine. The crest of this moraine is the highest physiographic feature along the Toronto-Peterborough highway. This ridge now stands hundreds of feet above the level of Lake Ontario yet at the time of its formation it formed the bottom of a cleft between the glacier in the lake basin and that on the north. The drift in this moraine is several hundreds of feet thick in many places.

The retreat of the Valders glaciers was not a continuous process. Following a considerable retreat of both the northern ice-lobe and that in the Ontario basin, the northern lobe readvanced and overrode the Oak Ridges moraine, leaving a thin till capping in many places along the crest, and a markedly drumlinized terrain on either side. The southern terminus of this advance is not known; possibly the two glacier lobes became confluent once again. Retreat began within a short time so that no new interlobate moraine was formed. The Oak Ridges moraine must soon have protruded through the decaying ice; some till would be removed by erosion and some additions of sand and gravel added to the moraine at this stage. At the eastern end of the Oak Ridges, north of Trenton, a long esker cross-cuts the drumlin field and is believed to mark the position of this late stage split between the two glaciers. Meltwater from the stagnating northern lobe was ponded between the ice and the Oak Ridges as a series of disconnected ponds and lakes. These are known as the Schomberg Ponds.

Meanwhile, the Ontario ice-lobe, in withdrawing from the Ontario basin, shortly uncovered a much lower channel into the Mohawk Valley via Rome, New

York (Figure 831). This brought about the separation of the Erie and Ontario basin waters with the Niagara River serving as the connecting link. The Ontario lobe withdrew to the eastern end of the basin before halting for a considerable period. The lake existing in the Ontario basin over this period is known as Lake Iroquois. Well developed beaches in the Hamilton area, where unaffected by differential uplift, indicate that the lake stood at 362 (A.T.) feet or 116 feet above the present level of Lake Ontario. The Iroquois beaches are today strongly warped along an axis trending north 20 degrees east and may be found at elevations up to a maximum of 730 feet north of Belleville. The differential uplift amounts to 2.85 feet per mile. Precise levelling and water gauge records indicate that crustal uplift is still going on in the Ontario basin along an axis trending north 40 degrees east and at a rate of 0.53 foot per hundred miles per century.

The establishment of Lake Iroquois, and the opening of Niagara Falls and the Niagara River, brought about a lowering of the lake occupying the Erie and southern part of the Huron basin. This shortly resulted in a separation of the waters in the two basins. That in the Erie basin, no longer in contact with the ice, may be referred to as Early Lake Erie. Its level was no doubt much lower than that of the present lake, the Niagara outlet having since been raised by differential uplift. (Lake Erie has a present elevation of 572 feet.) The lake in the southern part of the Huron basin at that time was the first of several stages of glacial Lake Algonquin. It drained southward into Lake Erie via the Port Huron outlet and the St. Clair River system. The sill at Port Huron was at an elevation of 605 feet.

The Port Huron outlet has long been regarded as having functioned over an extended period, on occasions along with the Chicago outlet and the Kirkfield outlet, while lakes of greatly variable size and shape existed in the Huron and Michigan basins and while differential uplift of the northern part of the basin was in progress. All these lake stages were therefore referred to Lake Algonquin. The main and highest beach, known as the Algonquin beach, formed prior to the start of differential uplift, and other important beaches below the Algonquin beach were formed during halts in the uplift. For this reason the terms Early Algonquin and Late Algonquin were employed for the high level and lower level stages, respectively. There is evidence in Canada that Early Algonquin time also included several important events. It is, furthermore, currently recognized that at least some of the 'upper' Late Algonquin beaches converge southward on the main Algonquin beach whereas the 'lower' Late Algonquin beaches are parallel to it and hence resulted from the opening of new outlets rather than from differential uplift. The term Late Algonquin, therefore, may not be strictly applicable to these low-level stages, but until the sequence of events is better understood it seems advisable to refer to these stages as Late "Algonquin". The following sequence of events during Algonquin and Late "Algonquin" time is considered to be best in accord with the geological data as applied to Canada.

As the Lake Huron ice-lobe retreated northward, Lake Algonquin may have obtained entry into Georgian Bay and the Lake Simcoe area, and there found a new, low-level outlet to the east via Kirkfield, Fenlon Falls, and the Trent Valley system. The lake level is believed to have been lowered as much as 50 to 100 feet. (This lowering would account for the occurrence, at several places in the Lake Simcoe area, of shallow-water, non-fossiliferous, lacustrine sands that lie buried by fossiliferous sands of the main, high level stage of Lake Algonquin. The fossiliferous sands lie disconformably on the lower sands, and in one place the base of these was not exposed at 90 feet below the main Algonquin water-plane.) Advance of the Lake Simcoe ice-lobe closed the Kirkfield outlet causing the lake level to rise until the water could spill-over again at Port Huron.

Further retreat of the Lake Huron lobe, along a northwest-trending front, allowed the separate lakes in the Huron and Michigan basins to merge, fortuitously with little change of level. The enlarged Lake Algonquin then drained for a time via the Chicago outlet to the Mississippi River, and the Port Huron outlet to the Erie-Niagara-Iroquois-Hudson system; the Port Huron outlet soon handled most, if not all, of the drainage. Though the lake expanded, its level was maintained by the Port Huron outlet at an elevation of 605 feet. The main Algonquin shoreline was formed at this stage. Whether or not the Kirkfield-Fenlon Falls outlet, at this time plugged with debris from the Simcoe lobe, was also in operation is dependent upon the presence or absence of the main Algonquin shoreline to the north of Kirkfield; this is a controversial matter, identification of the beaches being difficult in this part of the Canadian Shield due to the complications resulting from some differential uplift, in a direction north 22 degrees east, at about this time. The strength of the Algonquin shoreline indicates a long stand of the lake and this might well have been realized by the operation of the Kirkfield outlet, for some time at least, along with the Port Huron outlet. Considerable northward expansion of the lake in the Georgian Bay area may have taken place at this time.

There are seven well-marked strand lines below the main Algonquin beach, in the Lake Simcoe region, that may be considered as representing Algonquin and late "Algonquin" time. The first three of these, the Ardtrea and Upper and Lower Orillia beaches, are believed to have formed during halts in the period of differential uplift, and are referred to as the 'higher' Algonquin beaches. It is believed that the Kirkfield-Fenlon Falls outlet was raised above the lake-level before the third of these was formed and Lake Algonquin once again drained via the Port Huron outlet. Its northern, ice-confined shore probably coincided with the present shoreline north of Manitoulin Island, thence continued eastward for about 25 miles to where it abutted against the Precambrian highland and swung southward towards Lake Simcoe. (When Manitoulin Island emerged above the lake water, vegetal materials began to accumulate in swamps and bogs. A sample of peat from the basal 1 inch of a 4-foot section, whose surface elevation is 720 feet (68 feet above the Lake Nipissing beach), has recently been radiocarbon dated. This peat, which rests on a thin layer of lake clays was dated at 9,130 ±250 years (W-345); this is about 1,000 years older than would have been surmised from the radiocarbon dates, by the solid carbon method, of some earlier lake stages farther south. The age of the Valders stage lakes must therefore be considered doubtful pending more radiocarbon datings and further field studies.) The remaining four well-defined beaches, formerly termed 'lower' Algonquin beaches, are here called Late "Algonquin". These beaches and their elevations are as follows: Wyebridge 515 feet, Penatang 475 feet, Cedar Point 455 feet, and Payette 415 feet. They have been shown to be essentially parallel to the main Algonquin beach in the Lake Simcoe area. This indicates that there was a halt in the uplift in this region and the lowered water levels must therefore have resulted from the opening of new outlets. The only known outlet, and seemingly the only possible outlet, is that at Fossmill leading eastward through the Petawawa River Valley to the Ottawa Valley and the head of the Champlain Sea (Figure 83J). The opening of this channel may have lowered the lake level about 150 feet. The four lower beaches may therefore be related to periods of down-cutting, possibly when this channel was first functioning in an ice-marginal position. A subsidiary channel, a few miles north of Fossmill, would permit a further lowering of about 60 feet. (Chapman, however, believed that the Fossmill and subsidiary channel did not come into operation until after the lowest of the four beaches was formed and that differential uplift of 150 feet took place prior to that event.) The elevation of the sill at Fossmill is now at 1,130 feet and that of the subsidiary channel at 1,090 feet.

The level of the lake that formed the lowest beach, known as the Payette beach, was at 415 feet according to Hough. This is 190 feet lower than the sill at Port Huron and hence the southern shore of this lake must have been some 25 or 30 miles north of Port Huron, but its northern shore overlapped on the depressed land in the Georgian Bay area and probably extended eastward into the Lake Nipissing basin, where terraces occur at the level of the Fossmill outlet. Drainage eastward through North Bay into the Mattawa River Valley was apparently prohibited for some time by an active glacier but finally this escape route opened and allowed the lake to discharge into the Ottawa Valley and the head of the Champlain Sea (Figure 83K). Exceptionally low lake levels were established in the Michigan and Huron basins. The lake in the Michigan basin has been named Lake Chippewa and that in the Huron-Nipissing basin, Lake Stanley. The former lake was established at 250 feet and discharged through a deep channel, known as Mackinac River, into Lake Stanley whose surface was at least as low as 180 feet. By this time the glacier had withdrawn from the eastern end of the Lake Superior basin and the resulting lake also drained into Lake Stanley.

According to Hough, the main period of crustal uplift, formerly considered to be an Algonquin event, then took place. All the strand lines were elevated by at least 420 feet. (The amount of uplift between the time of formation of the main Algonquin strand line and the first of the lower "Algonquin" beaches is difficult to assess but may well have amounted to another 200 to 300 feet in the North Bay area.) As the North Bay outlet was elevated, discharge was reduced and the lake-level began to rise. When the North Bay outlet, and hence the lake-level, reached an elevation of 605 feet discharge was again possible through Port Huron and Chicago. The rise in lake-level also drowned the outlet channel at the east end of the Superior basin and raised that lake to the 605-foot level, and part of this water escaped westward via Duluth. Continued uplift did not change the lake-level but merely closed the northern outlets, sending all the drainage southward. This great body of water is known as the Nipissing Great Lakes (Figure 83L). Its raised shoreline may be seen today in many places as an exceptionally well-developed beach or a terrace and scarp. Radiocarbon datings on wood from Nipissing Great Lakes beaches indicate an age of about 3,500 years.

Meanwhile, in the Ontario basin, Lake Iroquois had been succeeded by Lake Frontenac, which drained via the Lake Champlain and Hudson River Valleys, and this lake in turn was succeeded by Lake Ontario: discharge was eastward to the Champlain Sea, which occupied the St. Lawrence Lowlands as far as Brockville and the Ottawa Valley as far as Petawawa. This sea was forced to withdraw by the same period of uplift that brought about the establishment of the Nipissing Great Lakes.

In the Superior basin glacier retreat was more or less from west to east and meltwater was therefore ponded in the western end of the basin to form Lake Duluth. The history of the lakes in the Superior basin has not yet been adequately established. The lake may have come into existence at the time that Lakes Grassmere and Lundy existed in the Erie-Huron basin. Lake Duluth first drained westward to the Mississippi River; later, as it expanded eastward it found a lower outlet to the south into the Lake Michigan basin where it joined Late Lake "Algonquin". Upon the complete removal of the glacier from the lake basin, Early Lake Superior came into being and discharged past Sault Ste. Marie into Lake Stanley. At the Nipissing Great Lakes stage some of the drainage was diverted once again through the Duluth outlet to the Mississippi River.

Though the continued uplift of the northern part of the upper Great Lakes basins and at the North Bay outlet above the 605-foot elevation could not bring about a further rise in lake-level it did divert all the drainage to the southern outlets. The increased discharge through these outlets contributed to a relatively rapid down-cutting of the channels and a consequent drop in lake-level. The Huron and Michigan basins were lowered to the 596-foot level at which point a halt in the lowering levels resulted in a well-marked strand line. The lake is known as the Algoma stage of the Nipissing Great Lakes. During the drop to the 596-foot level the lake in the Superior basin was separated from that downstream to be left as Lake Superior with a present elevation of 602 feet. A sample of charcoal from an archæological site on the southeast shore of Lake Huron at the Algoma level, has been radiocarbon dated at 2,619 $\pm$220 years (C-608) and may well represent the Algoma stage. Drainage of the lakes was through the Port Huron and the Chicago outlets with the former carrying the bulk of the waters. A recent lateral shift in the river channel south of the Port Huron outlet brought about down-cutting and consequent lowering of the lake-level. This drop appears to have been rather rapid, with only very minor pauses, and culminated in the present level of 581 feet for both Lake Huron and Lake Michigan.

Summary. The Wisconsin glacial history of the Great Lakes system began in Cary time when the waning glaciers first exposed the southeastern end of the Erie basin and probably 'Ontario Island'. The lakes expanded through a complex sequence of events until, during the Two Creeks Interval, the whole region was probably free of ice. A major glacial advance of Valders ice re-occupied the greater part of the lake basins. This glacier reached its southern limit, immediately south of Lake Ontario and extending around the north side of Ontario Island and across Lake Huron, roughly 11,400 years ago. As the Valders glaciers waned another complex series of lakes occupied the lake basins. Their size, shape, and distribution varied greatly with fluctuations in the ice-front, upon uncovering of new, low-level outlets and as a result of differential uplift of the northern parts of the lake basins. The whole of the Lake Huron basin may have been uncovered by ice over 9,000 years ago and human occupation of the area apparently followed closely on this event. The low-level Great Lakes stages and their transitional periods occupied several thousand years. Differential uplift finally brought about the Nipissing Great Lakes stand approximately 3,500 years ago. A drop in lake-level brought about the Algoma stage some 2,600 years ago, and finally in the not too distant past the Huron level dropped to that of the present lake, and the modern Great Lakes were thereby established.

Northern Ontario and Western Quebec

As the Valders glaciers waned and the ice-margin reached a point beyond the height of land, north of the upper Great Lakes, the meltwater was ponded between the high ground and the ice-front. This gave rise to glacial Lake Ojibway, with its western end at a point just north of Lake Nipigon. Meltwater was also ponded in the Lake Timiskaming basin, presumably as a result of blockage of the outlet to the Ottawa River by glacial ice and debris, and gave rise to glacial Lake Barlow. With continued retreat of the glaciers to the north and northeast the waters of the two lakes merged to form glacial Lake Barlow-Ojibway (Figure 83K). This lake attained a maximum width of 150 miles and a length of about 600 miles. Many excellent raised beaches mark its former positions (Plate XLIII). It had at least two outlets into Lake Superior but its main escape route appears to have been via the Ottawa River. Later, the lake appears to have had lower, ice-confined channels northward into James Bay.

Plate XLIII

Raised boulder beach, third highest beach of Lake Barlow-Ojibway, on west side of Plamondin Hill, Quebec.

Plate XLIV | Morainic topography, 35 miles north of Drumheller, Alberta.

Glacial Lake Barlow-Ojibway probably did not drain completely prior to a readvance of the ice-margin from a point at least 35 miles north of Cochrane to a point 35 miles south of that town. This is known as the Cochrane advance and is considered to have substage rank. This advance left a mantle of till on the varved clays of the northern part of Lake Barlow-Ojibway. The till is commonly about 15 feet thick and is locally more than 30 feet thick. A lake was no doubt ponded south of the ice-margin and hence varved sediments would be deposited in some parts of the lake basin during the Cochrane glacial stage and in the following post-Cochrane lakes stage, but differentiation of the varves of these lake stages has not yet been possible. Varved sediments that occur in many places on top of the Cochrane till were apparently deposited in several small lakes. These varved deposits are usually only 3 to 5 feet thick but some are up to 15 feet.

A short distance west of Cochrane a sample of wood from near the base of a 4-foot section of peat was radiocarbon dated at 6,380 ±350 years. This peat rests on varved silts of a post-Cochrane lake stage. The Cochrane ice-advance into the Barlow-Ojibway lake basin must, therefore, have occurred some 7,000 years ago, at about the time of the Late "Algonquin" stages in the Great Lakes basin, and long prior to the Nipissing Great Lakes, but several check dates are required to establish adequately the age of the Cochrane events.

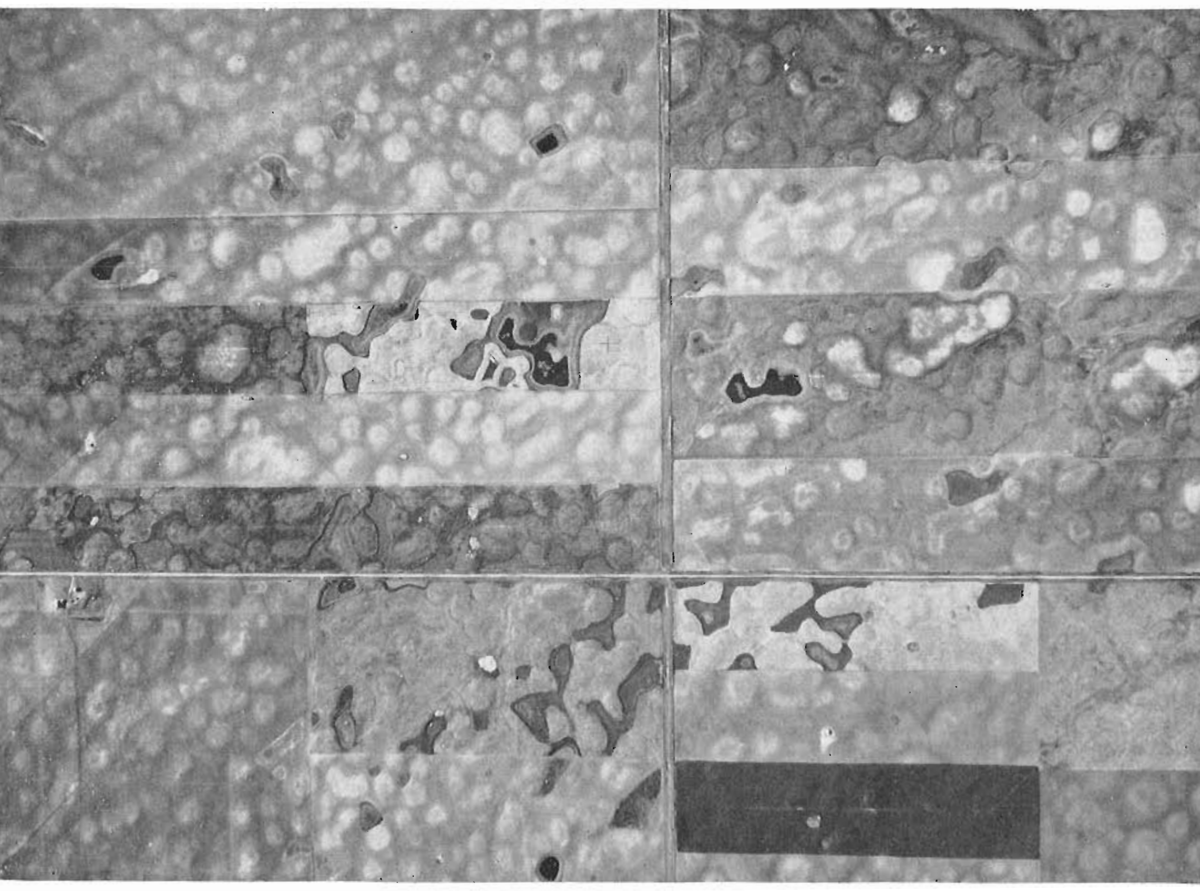
The post-Cochrane lakes were all drained to the north when the glacier receded into James Bay. The area surrounding James Bay and Hudson Bay, being greatly depressed by the former weight of the ice, was inundated by the sea. A broad area in northern Ontario varying from 50 to 175 miles in width was flooded to an elevation of almost 500 feet (Figure 82).

Interior Plains

The bedrocks of the Interior Plains are soft, easily eroded sedimentary rocks. These are almost everywhere mantled with glacial drift. Moraines are common (Plate XLIV) and, unlike Eastern Canada, eskers, kames, and outwash are rare. Windblown deposits are more prevalent than in the east, and longitudinal dunes are noteworthy in parts of central and northern Alberta. In southern Alberta, areas of till mounds formed under a periglacial environment are well developed and in some places are associated with glacial fluting (Plate XLV). Till-sheets of more than one glacial stage are known in several places, but stratigraphic studies of the unconsolidated deposits are as yet insufficient to outline the sequence of glacial events.

It is clear that glaciers of Wisconsin time moved over the Shield area of the Prairie Provinces in a general southwestward direction. Formerly they were thought to have continued in this direction across the Plains. Well defined to poorly defined southeast trending drift ridges on the Plains were regarded as end moraines of these glaciers but are now thought to be lateral and interlobate moraines. These vary from ½ mile to about 50 miles wide and have lengths measurable in hundreds of miles. Geological studies in recent years, however, have indicated the validity of J. B. Tyrrell's deductions made late in the 19th century, namely, that the last glaciers moved southeast across the southern part of the Prairies. The reason for this marked southeast movement in southern Saskatchewan and part of southwestern Manitoba is not yet fully understood. It may be that the glaciers on coming southwestward off the Canadian Shield were deflected to the southeast on encountering the generally southeast striking Palæozoic and Mesozoic formations, which

Plate XLV | *Periglacial till mounds and subdued glacial fluting, southern Alberta; scale about 1 inch to 3/8 mile.*



rise to the west as reflected in the three Prairie Steppes. However, in an occasional valley along the northeastern edge of the Plains there is evidence of the glaciers having continued southwestward for some distance beyond the Shield; also, in the vicinity of topographic knobs, ice-flow features indicate southwest movements, but these may be due to deflections of the ice or to lobate movements at the margin. In southern Alberta, movements were in general more southward than farther east on the Plains, and irregular directions due to lobations of the ice-front are evident. The ice also moved southward in the Red River Valley in Manitoba.

The southern borders of the Wisconsin drift are believed to lie south of the International Boundary. Wisconsin glaciers appear to have been slightly less extensive than the earlier glaciers in the western Prairie regions. In the southwest corner of Alberta erratics from the Canadian Shield have been found at elevations up to 5,500 feet but these are believed to have been left by pre-Wisconsin glaciers. Erratics left by Wisconsin ice have been found at altitudes up to 4,500 feet in the Foothills. The thickness of the drift varies considerably on the Prairies; bedrock escarpments in some places have negligible drift along their crests, whereas elsewhere pre-Wisconsin valleys, cut into bedrock, lie deeply buried. Several hundred feet of drift are known in some of these valleys and in some morainal deposits. The drift mantle in most places is composed of till. This is often associated with ice-contact stratified drift but not to the same extent as in Eastern Canada. The till may be overlain by sediments deposited in glacial lakes or in spillway channels, or by windblown silt and sand. In some places the Wisconsin drift rests on older drift.

A boulder train of blocks of quartzite and pebbly quartzite, generally only a few miles wide, has been traced for several hundred miles along the Foothills of southwestern Alberta. It consists of several thousand blocks of the quartzite ranging in size from small cobbles up to an estimated 18,000 tons. They occur at elevations between 3,300 and 4,100 feet. The boulder train is of Wisconsin age and it is believed to lie near the southwestern limit of the Wisconsin Laurentide glacier. It is thought that the blocks were carried down from the Rocky Mountains on the surface of valley glaciers, and were distributed along the Foothills when this ice merged with the Laurentide glacier.

A remarkable boulder pavement may be seen at many places in southwestern Manitoba at the contact between a lower clayey, sandy till and an overlying sandy till. The stones of the pavement vary from small cobbles to boulders 4 to 5 feet or more in diameter. Their upper surfaces are planed off locally to a remarkably constant level and they are strongly striated (Plate XLVI). The striæ indicate that the last ice in this area moved to the southeast. The shapes of some of the hard, granitic and gneissic boulders indicate that several inches to about a foot has been planed off.

As in the Great Lakes basin, glacier retreat in south-central Canada resulted in the ponding of meltwaters in front of the ice. Except for glacial Lake Agassiz, these lakes were relatively small. They moved northward as the ice-margins retreated and successively lower lake-levels were established. As a result of the gradual lowering of levels, strand lines were not well developed. The positions of

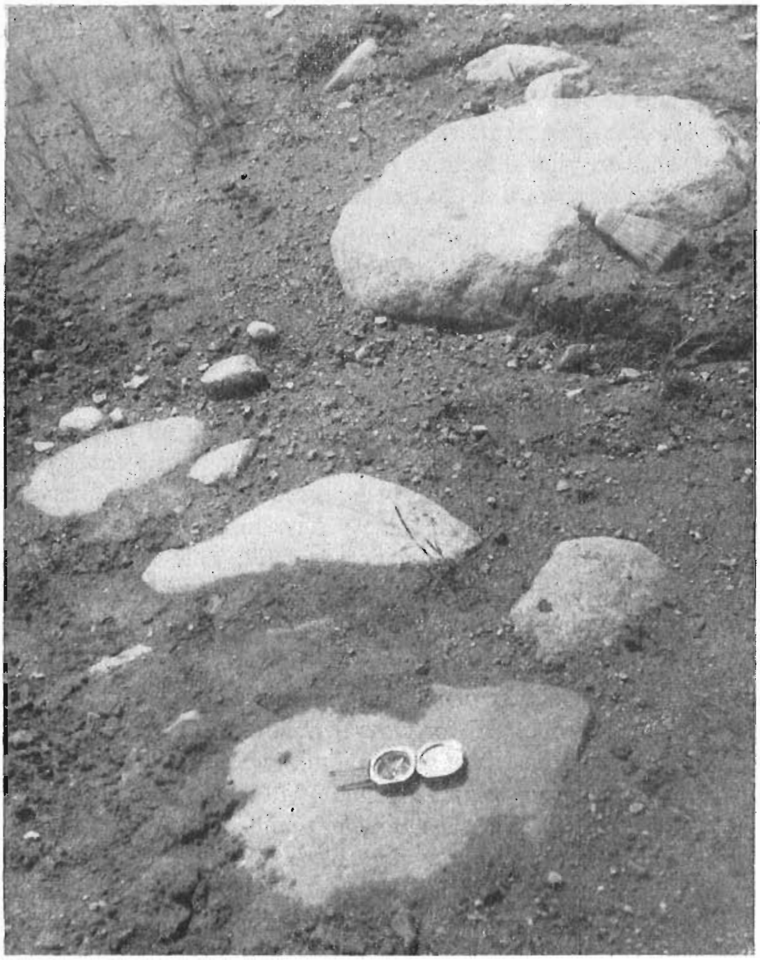


Plate XLVI | *Boulder pavement at contact between two sheets of till, 6 miles south of Killarney, Manitoba.*

the lakes have therefore been determined largely from the occurrence of deltaic and bottom deposits and from spillway deposits or channels. The glaciers retreated from southern Manitoba in three directions, to the northwest, the north, and the northeast. The general recession of the glaciers was marked by halts and by minor readvances of lobes of the various glaciers affecting the region. Because the readvances and the rates of retreat of the separate ice-lobes were seldom synchronous, an intricate arrangement of morainal deposits was left and a complex system of glacial lakes and spillways was developed.

Glacial Lake Agassiz, the one exception to the generally small size of glacial lakes, occupied, over a period of thousands of years, much of central and southern Manitoba and overlapped into Ontario and the United States. This gigantic lake may have been, at its maximum, the biggest of all our glacial lakes. It began to form in the upper part of the Red River Valley, far south of the International Boundary, and followed the retreating ice-front northward into Manitoba, and northeastward into Ontario. It discharged southward into the Mississippi River. Meanwhile another lake had begun to form south of the border, farther west, in the Souris River Valley and likewise expanded northward into the southwest corner of Manitoba. This lake, known as glacial Lake Souris, discharged southward into the Missouri River.

The first glacial lake to form entirely within Manitoba was a small one in the Whitewater Lake basin, on the north side of Turtle Mountain. It first discharged eastward into the Pembina River and later westward into glacial Lake Souris, as an ice-lobe in the Souris valley retreated northward.

Farther north a second lake, recently referred to as the Carroll glacial lake, formed in a re-entrant in the ice-margin and discharged southeastward through the Souris-Pembina Valley into the Lake Agassiz basin near Walhalla, North Dakota. As the northwestern ice-lobe retreated, the opening of a spillway into the Carroll lake, caused Lake Souris to abandon its southern outlet. Subsequent retreat of the ice caused Lake Souris and the Carroll lake to merge. The resulting lake expanded northward as the ice withdrew but its area steadily diminished as a result of down-cutting of the outlet. Ultimately the lake was drained through the Souris-Pembina Valley.

Meanwhile, well to the northeast of Turtle Mountain small glacial lakes formed on the north side of the Tiger Hills along the edge of the ice-lobe in the Lake Winnipeg basin; this lobe was beginning to recede from the Manitoba escarpment. These lakes soon coalesced to form the Brandon glacial lake which at first discharged southward through Pembina River and later, through a channel west of Treherne, directly into the Lake Agassiz basin. An ice-barrier separated the lake basins during the existence of the Brandon glacial lake, the level of which was lowered 140 feet, to an altitude of about 1,260 feet.

The highest level of Lake Agassiz in southwestern Manitoba remains at a present altitude of about 1,250 feet, and this stand is believed to have existed when the northern ice-margin of the lake lay at a latitude of 50 degrees.

The margin of the glacier in southeastern Saskatchewan meanwhile had retreated north of the Qu'Appelle Valley and all the meltwater and much of the drainage from the plains west of the Manitoba escarpment discharged eastward through the Qu'Appelle-Assiniboine Valley into Lake Agassiz. This valley had originally been carved over a period of millions of years in pre-Pleistocene time but had been filled by drift and recarved on at least one occasion in Pleistocene time prior to the last ice-advance. The last glacier that covered the valley left a thick mantle of drift but did not fill it completely; hence, on the retreat of the glacier, meltwater followed the resulting shallow depression eastward, eroded through the drift and some of the underlying deposits and formed the present deep valley. The sediment carried by the Qu'Appelle-Assiniboine system was deposited as a large delta in Lake Agassiz, partly filling the large pre-Pleistocene glacial valley where it crossed the escarpment west of Brandon. This deposition took place before the lake-level had fallen more than 50 feet from its highest level. By the time the ice-front had receded to a latitude of about 51 degrees, the lake-level had fallen about 100 feet. The glacial meltwater from the western plains at this time entered Lake Agassiz west of Dauphin, and still later near Swan River, Manitoba, but most non-glacial run-off continued to flow through the Qu'Appelle-Assiniboine system. The ice-margin retreated farther northward in the Lake Winnipeg basin while the lake-level dropped another 100 feet. A long stand of the lake then followed, during which down-cutting of the southern outlet into the Minnesota and Mississippi Rivers was retarded by a bedrock ledge. This stand is marked by a well developed scarp and beach that is traceable for hundreds of miles around the Lake Agassiz basin and is known as the Campbell strand line.

While Lake Agassiz was expanding northward, following the retreating ice-margin, it was also expanding eastward into Ontario. An eastern outlet or outlets lower than the southern, Lake Traverse, spillway was exposed leading into Lake Superior, and Lake Agassiz was largely drained. Deep gulleys and valleys were eroded in the Manitoba escarpment and in the Assiniboine delta.

The advance of Valders ice west of Lake Nipigon and Lake Superior 11,000 years ago, as previously referred to under the Glacial Great Lakes, closed the eastern outlet and brought about a reflooding of the Agassiz basin. The lake deepened until the Campbell strand line was reached and once again discharged through the southern outlet to the Mississippi River. The valleys along the Manitoba escarpment were drowned and lake sediments were deposited in them. Human occupation of the area dates from about the time of this second Campbell phase. Later retreat of the glacier from the Lake Nipigon area reopened low outlets so that the level of Lake Agassiz fell leaving a record of strand lines. Finally a northern outlet to Hudson Bay was opened and new low levels were no doubt established prior to the draining of the lake. This event is believed to have occurred about 5,000 years ago. The northern part of the Agassiz basin has risen at least 400 feet relative to the southern part and the present drainage system reflects the operation of the northern outlet in balance with the amount of uplift.

The various phases of glacial Lake Agassiz therefore appear to have lasted from Cary to early 'Recent' time. Its many beaches provide excellent sources of gravel and sand in areas where there is otherwise a very short supply. In the central part of the basin the lake clays, mostly varved, are locally more than 130 feet thick.

At various times during the existence of the Manitoba glacial lakes, waters were being ponded and later released in both Saskatchewan and Alberta. A fairly large but shallow glacial lake that existed in south-central Saskatchewan is known as Lake Regina. This lake formed as the ice retreated northwestward and it discharged to the southeast through the Souris Valley. When the glacier retreated to expose the Qu'Appelle Valley, Lake Regina was drained. A succession of glacial lakes existed in the valleys of the South and North Saskatchewan Rivers during glacier retreat from this region. The total area covered by this succession of lakes is large but very little is known about their individual size or escape routes, except that discharge eventually entered the Lake Agassiz basin. Small glacial lakes also existed in the valleys of the Oldman and Red Deer Rivers in southern Alberta, and even shorter-lived lakes existed in front of ice-margins along the Foothills.

Glacial retreat from the Interior Plains onto the Shield area left several end and marginal moraines, some of which have been traced intermittently over great distances but only tentative correlations with their counterparts in Eastern Canada and in the United States have as yet been worked out.

When the retreating ice first exposed the basins of major lakes such as Athabasca, Cree, Wollaston, and Reindeer, these basins were occupied by larger bodies of water than at present. The glaciers retreated from this part of the Shield towards the Keewatin ice-divide just west of Hudson Bay in the Northwest Territories.

Northwest Territories

Mainland. At some glacial maximum the Keewatin part of the Laurentide ice-sheet reached the mountains west of the Mackenzie River but in this region, as on more southerly parts of the Interior Plains, glacial trends appear somewhat incongruous, being distinctly northwestward along the Mackenzie Valley. This ice probably advanced to the vicinity of Herschel Island and formed a large lobe in Mackenzie Bay. The Mackenzie delta appears to be a compound body of which the present delta is only a small part. The major unit is believed to contain some morainal deposits.

Between the Mackenzie delta and Great Bear Lake the ice moved in various directions and more than one period of movement is probably represented. Air photos show complex morainal systems and intricate spillway channels.

From the Great Bear-Great Slave Lakes area eastward to the Keewatin divide, and on the flanks of this tract, the terrain is remarkably scoured by ice. Both the bedrock and the unconsolidated deposits show a parallelism of ice-flow features, and some glacial flutings are measurable in tens of miles. Eskers are also remarkably well developed and conform to the glacial trend. One great esker chain may

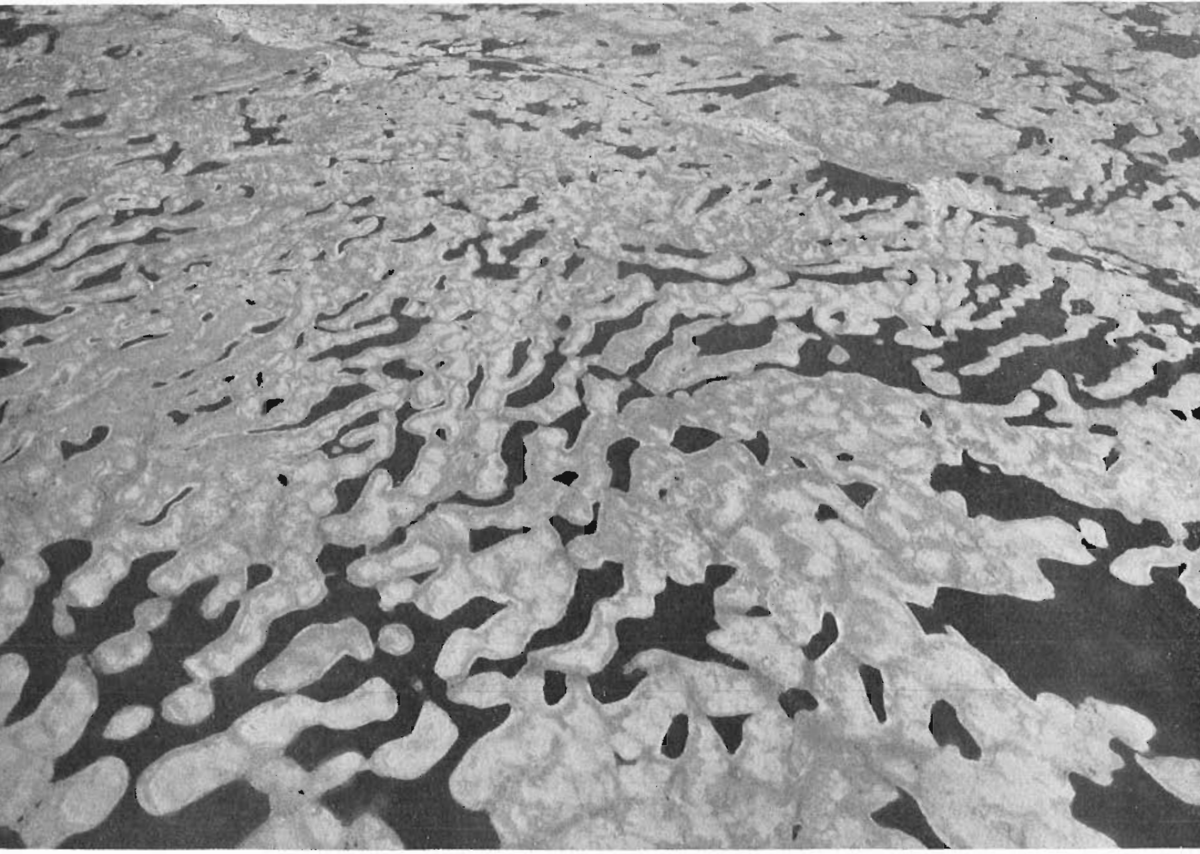


Plate XLVII

Morainal ridges viewed towards the west, 40 miles east of Kasba Lake, N.W.T.; depth of photo about 10 miles.

have a length of over 350 miles. Lobate ice-movements during the glacial retreat are indicated in this region and ice-marginal lakes existed in connection with many of them. Many of the present lake basins were the sites of appreciably larger glacial lakes. At some time during the retreat of the glaciers from the Mackenzie region towards the Keewatin divide, the ice also retreated inland from Hudson Bay. The latter event probably occurred when the retreat of the Labrador and Baffin ice-sheets opened Hudson Straits, allowing marine water to enter the bay and produce a maritime climate.

As the active glaciers retreated towards the Keewatin ice-divide they left a trail of morainal ridges (Plate XLVII), eskers, and ice-flow features such as striæ, grooves, glacial flutings (Plate XLVIII), and drumlinoid ridges (Plate XLIX). The ice-flow features lead back to the ice-divide (Figure 81) and indicate that the ice moved westward towards the Mackenzie River drainage system, eastward towards Hudson Bay, southward towards Manitoba, and northward towards the Arctic Coast. The linear features west of the divide also indicate a broad fanning or lobation during the retreat. This lobation brought about a marked break in the general westward and northwestward trends extending from Dubawnt Lake northwest to the Coppermine River between Great Bear Lake and Coronation Gulf.

This break is not to be confused with an ice-divide. As previously mentioned, active ice existed along the Keewatin ice-divide as recently as 4,000 years ago.

Retreat of the Keewatin ice allowed the sea to transgress the land to a present altitude of about 560 feet at a point 120 miles south of the west end of Baker Lake, and to about 580 feet on Southampton Island. The sea extended up the Thelon River basin to longitude 101 degrees (Figure 82). Strand lines west of this point appear to be due to ponded meltwaters prior to the marine invasion. Farther to the northwest, in the vicinity of Victoria Island, the marine limit may be at an altitude of more than 675 feet.

Arctic Islands. The eastern side of Banks Island shows many features believed to be due to glaciation but these have not been seen on the west side, which may not have been glaciated. Victoria Island, Prince of Wales Island, and Boothia Peninsula show unmistakable evidence of Laurentide glaciation and Victoria Island may also have supported its own ice-cap at a late stage of deglaciation. Somerset Island does not show the marked flutings and other glacial features of Boothia Peninsula but was nevertheless overridden by glacial ice, as indicated by the presence of foreign stones believed to have been derived from the Proterozoic rocks of the eastern side of Boothia Peninsula. Baffin Island had its own ice-cap

Plate XLVIII

Glacial flutings, 55 miles north-northwest of Dubawnt Lake, N.W.T.; distance from lower left corner to river (the Thelon) about 10 miles; ice moved towards observer.

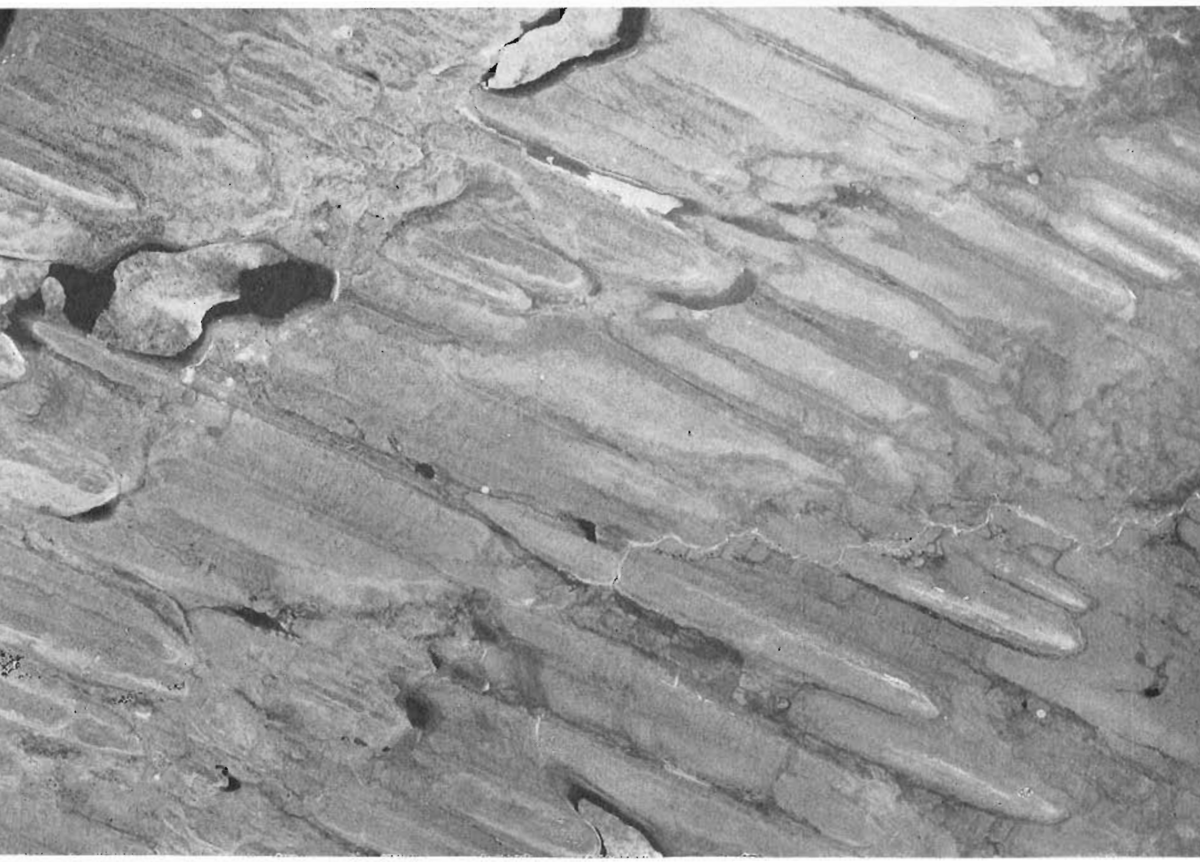


Plate XLIX

Drumlinoid ridges, average length about a mile, height 30 feet; ice moved from right to left. At bend in Thelon River 75 miles west of Aberdeen Lake, N.W.T.

and this must have been confluent with the mainland ice during the Wisconsin maximum. Remnants of the Baffin ice-sheet remain today along the eastern side of this rugged land and some of the glaciers have advanced in relatively recent time (Plate XXXVII). At the Wisconsin maximum, Baffin ice and Labrador ice no doubt merged in Hudson Strait. Movements of Labrador ice northward out of Ungava Bay appear to have been strong enough at one stage to cross the straits and scour the southeastern tip of Baffin Island.

The Queen Elizabeth Islands

Development of an ice-sheet to cover the eastern part of the Queen Elizabeth Islands is readily visualized by a glance at the map showing the present-day distribution of glaciers (Figure 81). These cover highland areas with elevations of up to 9,500 feet and in places extend down to sea-level. Though the present mean annual precipitation is very low, from less than 2 inches at Eureka to about 9 inches at Dundas Harbour, the summer melting season is very short, roughly 4 to 8 weeks. A slight annual increase in precipitation or a decrease in the amount of melting would result in the expansion of these glaciers. If glacier expansion continued over a long period of time the many glaciers and ice-caps might well coalesce to form an ice-sheet.

There is good evidence that the whole of Ellesmere, Axel Heiberg, Devon, and Cornwallis Islands, and at least part of Bathurst Island have been glaciated, presumably in Wisconsin time. A small ice-cap is present on Meighen Island. Several small fields of snow and ice occur on the western part of Melville Island, and the drainage pattern suggests that these have been more extensive in the past. Glacial striæ have been reported, furthermore, from Melville and Prince Patrick Islands, but there is no conclusive evidence of any overall glaciation of these and the other western islands. Boulders and cobbles of quartzite, granite, and gneiss have been observed on most of the western islands but their mode of emplacement is unknown. They may represent a pre-Wisconsin glaciation. The Beaufort formation, which contains stones foreign to the host islands, is another possible source of such boulders, and the floating ice-islands of the Arctic Ocean, or icebergs, might also deposit foreign stones on any area below the level of maximum marine overlap. This level is not known in most places, however, as the character of the surficial materials and extreme frost action have together resulted in intense solifluction which has largely destroyed shoreline phenomena. In the light of present evidence it appears that the eastern part of the group was mantled by a continuous ice-sheet in Wisconsin time, and that extensive fields of snow and ice existed on Melville and Prince Patrick Islands.

At its greatest development the Queen Elizabeth Islands ice-sheet was probably confluent with that of Greenland on the east and with Baffin ice on the south. There is, however, no reliable evidence of this northern ice having pushed southward across Lancaster Sound and Barrow Strait, nor that Baffin ice pushed northward across these same waters. It seems logical to assume that the maximum glacier coverage of the Queen Elizabeth Islands was attained at about the same time as the glacier maxima on the mainland to the south, and that both bodies supplied ice to Lancaster Sound. Within the Queen Elizabeth Islands group, ice-movements appear in general to have remained individual to each island. Studies of glaciers and related phenomena on Ellesmere and Axel Heiberg Islands have revealed that the glaciers are advancing in many places (Plate XXXVIII). This advance post-dates the period of marine overlap, raised marine deposits having been ploughed-up by glaciers in many places. It is probable that the advance of remnant glaciers on these islands took place in late Altithermal or more recent time and may well coincide with the formation of shelf ice which has since been largely broken up to give rise to the ice-islands of the Arctic waters.

Raised beaches are prevalent in some parts of Ellesmere, Axel Heiberg, Devon, Cornwallis, Bathurst, and Melville Islands but in general they are uncommon and, on Prince Patrick, Borden, Ellef Ringnes, and Amund Ringnes Islands they are rare. In general, beaches are best developed at near sea-level relative to the postulated maximum limit of marine overlap. This is due to the destruction of the higher, and older, beaches by solifluction. On Prince Patrick, Borden, and the Ringnes Islands the clayey character of the surficial materials has facilitated solifluction processes and may well account for the rarety of beaches. Though on some islands shells or beaches have not been found above elevations of 60 to 100 feet, shell occurrences on nearby islands at elevations of 250 to 425 feet appear to indicate rather widespread submergence to these greater depths. There is as yet, however, no direct evidence of the submergence of Prince Patrick, Borden, and the Ringnes Islands to more than 60 to 100 feet.

At Dobbin Bay on the east coast of Ellesmere Island shell-bearing beaches are present up to an altitude of 100 feet; glaciers probably occupied the land above this level during the higher stages of marine overlap. At the northeastern end of the island a wave-cut bench occurs at an altitude of 250 feet. Along the north shore, shells have been found up to 230 feet and the tops of delta-like deposits have been recorded between 200 and 300 feet and at 500 feet. Along the south coast of Greely fiord shells have been found up to an altitude of 250 feet.

Well developed marine beaches occur along the southern and western shores of Devon Island. At Dundas Harbour the highest beach is at an elevation of 85 feet and, again, it appears that glaciers prevented the formation of beaches above this level.

Excellent emerged strand lines are present around Cornwallis Island at elevations up to 275 feet and marine shells have been found up to 425 feet. There is also some evidence of a wave-cut bench at this elevation. It is possible that two periods of marine overlap are represented; this is in accord with observations on other islands.

Economic Geology

Much of the development of Canada as related to agriculture, mining, transportation, and water supply has been affected by glaciation. The deposits themselves are used extensively in the construction industry.

The deposits laid down in glacial lakes form some of the best soils in Canada. For example, the former sites of Lake Agassiz and Lake Regina now provide some of the richest grain growing areas in the southern Interior Plains. The clay belt of northern Ontario and Quebec, once covered by Lake Barlow-Ojibway, forms agricultural land in an otherwise rocky region. In British Columbia the silt and clay deposits of glacial lakes confined to valleys provide good agricultural land. The deposits of the Champlain Sea comprise much of the fertile farm land of the St. Lawrence Lowlands. Locally, deposits of loess and alluvium provide fine agricultural land. Knowledge of Pleistocene Geology is fundamental to a better understanding of the character of soils. Many of the more bouldery, gravelly, and sandy types of glacial deposits are not suitable for agricultural purposes and are better left as forest or grassland. Areas of ice-contact stratified drift provide the locale for great stands of forests, especially pine.

The effect of glaciation on mineral development varies in different districts. In areas where soil and weathered rock have been removed prospecting has been facilitated though the result is perhaps not an unmixed blessing as, doubtless, quantities of valuable mineral have been eroded in the process. Thus, much of the upper parts of sulphide deposits that were secondarily enriched during pre-glacial weathering have been removed, and many placer deposits, which no doubt existed in the Shield and in glaciated parts of the Cordillera and elsewhere, have been dispersed. In most areas potential mineral deposits are covered with glacial drift, and in the search for such deposits it is important to know the mode of origin of the local glacial deposits and the direction of ice-movement. Where fragments of ore are found in the drift, careful studies have resulted in tracing the material back to the source, as has been demonstrated, for example, in the case of the iron ore deposits of Steep Rock Lake.

The occurrence of beach and terrace deposits and eskers has determined the location of roads and railways in some areas. The numerous lakes that occupy depressions gouged by glacial ice, or that were formed as a result of disorganization of the drainage by glacial drift have proved to be very important in meeting transportation problems within the vast area of the Canadian Shield. These lakes form innumerable canoe routes and serve as landing places for aircraft in summer and winter.

A knowledge of glacial deposits is important in the search for underground water supplies. Porous sand and gravel in the drift form reservoirs for the storage of subsurface water, used for private and industrial purposes.

Increasing attention is being given to a study of glacial deposits in connection with engineering problems such as are encountered in the building of foundations and dams.

Marine and freshwater clays have supplied much of the raw material used in the brick and tile industry but are gradually being superseded by the use of shales. The clay is especially useful where it occurs near urban centres, such as do those of the Champlain Sea and those on the Pacific coast, but in remote areas, as at Hudson Bay, they have, as yet, no economic significance. Sand and gravel derived from eskers, kames, spillways, beaches, deltas, and marine deposits are used for road metal, fill, and for concrete aggregate and other constructional materials. The many beaches of glacial Lake Agassiz provide excellent sources of sand and gravel in areas where there is otherwise a very short supply. Readily available shoreline deposits formerly supplied sand and gravel requirements of growing urban areas such as Montreal and Toronto, but these deposits have long-since been worked out or overrun by the cities' growth.

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