CANADA
DEPARTMENT OF MINES AND RESOURCES

MINES AND GEOLOGY BRANCH
BUREAU OF GEOLOGY AND TOPOGRAPHY

GEOLOGICAL SURVEY

ECONOMIC GEOLOGY SERIES
No. 1

GEOLOGY AND ECONOMIC MINERALS OF CANADA

(THIRD EDITION)

BY

OFFICERS OF THE GEOLOGICAL SURVEY

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1947

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Mount Logan, elevation 19,850 feet, the highest mountain in Canada, situated in southwestern Yukon in the St. Elias Mountains, and named after Sir William E. Logan, founder and first director of the Geological Survey. View looking southeast from a distance of 15 miles and an elevation of 9,565 feet. Photo by T. C. Dennis. International Boundary Commission, Ottawa, July 1913.

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PREFACE

Two earlier editions of the Geology and Economic Minerals of Canada were published, in 1909 and 1926 respectively, under the authorship of G. A. Young, and are now out of print. Since the last appeared, the annual mineral production has risen from its 1926 value of $240,000,000 to nearly $567,000,000 in 1942, and several important events have changed the whole economic outlook. Oil has been found in the west in commercial quantities, and the search for more and larger fields is being vigorously prosecuted. The re-appraisal of the value of our currency in terms of gold, which took place in January 1934, made many low-grade gold deposits profitable to operate, so that the number of working gold mines increased from 38 in 1929 to 149 in 1940. The development of air transport has opened all of our previously inaccessible northland to the geologist, the topographer, the prospector, and the miner. Significant mineral discoveries, particularly of gold and iron, have already been made in parts of this area, but the flood of exploration and development is only beginning. The demands of war sharpened the search for ores of tungsten, molybdenum, beryllium, tantalum, uranium, and other strategic minerals, and brought to light many deposits that can be worked whenever it becomes necessary or profitable to do so.

The present report, which should be read in conjunction with the recently issued Geological Map of Canada (scale 1 inch to 60 miles), summarizes the geological investigations and mineral developments that have taken place during the century or more since the founding of the Geological Survey of Canada in 1842. The data given have been collected from the more detailed descriptions in the separate publications of the Geological Survey, from those of Provincial Government organizations, and from papers published by various learned societies. To them the reader who wishes for greater detail must be referred.

Production figures used throughout the report have been supplied through the courtesy of the Dominion Bureau of Statistics.

GEORGE HANSON,
Chief Geologist, Geological Survey

OTTAWA, November 29, 1946

Geology and Economic Minerals of Canada

CHAPTER I

INTRODUCTION

(George Hanson)

MAIN GEOLOGICAL DIVISIONS

Approximately half of Canada is a single, triangular-shaped area of Precambrian rocks known as the Canadian Shield (Figure 1). To the south this area of ancient rocks extends into the United States; to the northeast it occupies Labrador to the shores of the Atlantic Ocean; elsewhere in Canada it is overlapped by younger strata. This 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.

The Canadian Shield consists mainly of granite and granitoid gneiss, but includes also bodies 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. These ancient formations were folded in early Precambrian (Archæan) time by mountain building movements, and were intruded by granite. Later erosion has cut down to the roots of the old mountain systems. In the southeastern part of the Shield, in the area known as the Grenville sub-province, the complexes consist to a large extent of crystalline limestone, a rock of rare occurrence among the known Archæan formations. The granitic rocks of this sub-province are, however, not known to be different from those elsewhere in the Shield, and the sedimentary complexes, although possibly younger than those elsewhere in the Shield, are considered to be of Archæan age. Throughout the Shield the Archæan rocks are cut by large intrusions of anorthosite.

Unconformably overlying these ancient formations and much of the granite are extensive sheets of relatively undeformed volcanic and sedimentary rocks of late Precambrian (Proterozoic) age. No rocks of this type have been found in the Grenville sub-province. The Archæan and Proterozoic rocks are cut by late Proterozoic sills and dykes of diabase.

Except to the northeast where it meets the Atlantic Ocean, the Shield is overlapped on all sides by younger strata that were laid down mainly as sediment on its sloping sides. For some distance outward from the Shield boundary, as much as 500 miles through the southern part of the Prairie Provinces, the overlying rocks are essentially flat-lying, and have not been affected by mountain building movements. This region of horizontal strata forms a second geological unit called the Plains. In the Arctic it is bounded by the sea, and on the west and southeast it is interrupted by mountain systems.

Most of the rocks in the Plains region were laid down in the sea, in water of moderate to shallow depths. They range in age from early Palæozoic to Recent, and have not been intruded by igneous rocks. During some periods fresh- or brackish-water deposits accumulated in considerable volume.

Southeast of the Shield and the bordering strip of Plains is a broad belt of mountainous country known as the Appalachian region (*See* Figure 1). In it the rocks are severely folded and faulted, and in this respect are in sharp contrast with those of the adjacent Plains region. The Appalachian region occupies the Maritime Provinces, Gaspe, and part of the Eastern Townships of Quebec, and is the northeastern extension of a continuous geological structural unit stretching from northern Alabama in the United States. The folded rocks of this province range in age from Precambrian to late Palæozoic. Since late Palæozoic time the region has remained a land mass, and until late Pleistocene time no later formations of marine origin were deposited there. The formations of the region have been intruded by granitic and ultrabasic rocks of chiefly Palæozoic age.

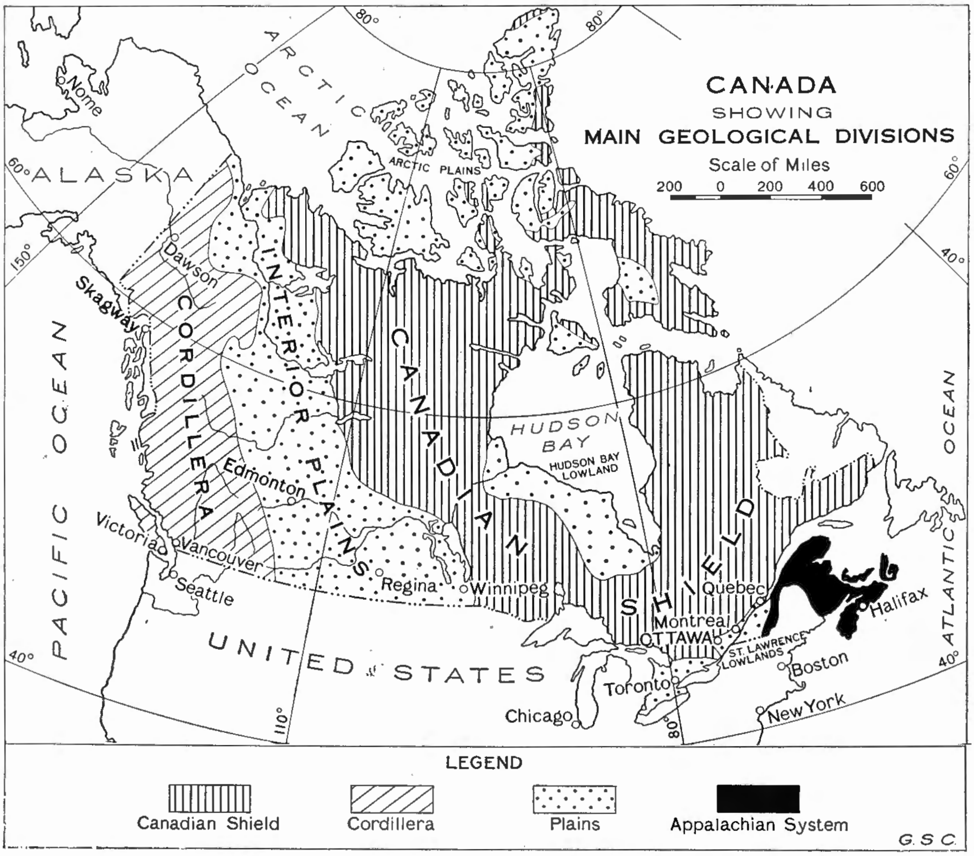


Figure 1. Canada, showing main geological divisions.

West of the Shield and the bordering Plains is another broad tract of mountainous country known as the Cordilleran region (*See* Figure 1). Geologically this region is also in sharp contrast with the adjacent Plains, and it differs from the Appalachian region in that it was elevated into mountains at a much later date. The Cordilleran region extends northwestward through Canada, embracing most of British Columbia, a small part of Alberta, nearly all of Yukon, and a small part of the Northwest Territories. It swings westward into Alaska and to the south occupies the western United States.

As in the Appalachian region, mountain building movements in the Cordillera deformed not only Cambrian and later formations but also affected rocks of Precambrian age. The latest major movements took place at about the close of the Mesozoic era, and since that time the region has remained above the sea. All except an eastern strip of the region is characterized by numerous bodies of intrusive rock ranging in composition from granite to peridotite, but composed dominantly of granodiorite and quartz diorite.

In summary, central Canada is occupied by the Canadian Shield, a large stable land mass that has not been folded since Precambrian time. Approximately horizontal strata lie on its sloping flanks on nearly all sides. Their horizontal attitude suggests that the underlying rocks of the Shield acted as an unyielding basement that prevented folding. Farther out, where the Shield surface was deeply buried and the basement thereby weakened, forces from the Atlantic folded and thrust the rocks in eastern Canada northwestward to form the Appalachian region, and later forces from the Pacific folded and thrust the rocks in western Canada northeastward to form the Cordilleran region.

GEOGRAPHIC SUMMARY

The Canadian Shield is in most places a region of low relief, in general less than 200 feet. Nearly all of the Shield is less than 2,000 feet above sea-level, but exceeds this altitude greatly in the east and northeast. Elevations in northeast Labrador exceed 5,000 feet, and on Baffin Island mountains rise to more than 8,000 feet above the sea. The northern part of the Shield is devoid of timber, and the ground is permanently frozen. Some of the Arctic Islands are capped by ice. The Shield contains many large lakes and a myriad of small ones knit together by an irregular drainage thoroughly charactertistic of the region.

The Plains region surrounding the Shield is level or rolling land less than 1,500 feet in elevation except in the west where the prairie level rises gradually to some 4,000 feet above the sea to merge with the foothills of the Rocky Mountains. Some of the Arctic islands of the Plains region are ice capped, and the northern plains are treeless and permanently frozen.

The mountains of the Appalachian region in Canada are low; only in Gaspe peninsula do they exceed 4,000 feet in elevation. The region is entirely south of latitude 50 degrees, and practically all the highest mountains are timbered.

In the Cordilleran region 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 nearby are only slightly lower. Much of Yukon is within the area of permanently frozen ground, and the northern part is treeless except in favoured valleys. Near the Pacific the precipitation is high, and large snowfields covering the high ground feed many alpine glaciers, some of which reach the sea.

MINERAL DEPOSITS

Each of the four geological regions of Canada is rich in mineral wealth, but each differs from the others in the variety and amount of its mineral resources. In 1939, the last normal year prior to World War II, mines in the Canadian Shield supplied 85 per cent of the gold, 38 per cent of the silver, 86 per cent of the copper, and all of the nickel, radium, platinum, and cobalt produced in Canada. On the other hand, the Shield contains no coal, oil, or gas. The Plains region produced 21 per cent of the coal, 61 per cent of the natural gas, and 88 per cent of the salt, but none of the metals. The Appalachian region produced 11 per cent of the salt, 94 per cent of the gypsum, 48 per cent of the coal, all the asbestos, and small quantities of various metals. The Cordilleran region produced 14 per cent of the gold, 61 per cent of the silver, 70 per cent of the zinc, 13 per cent of the copper, 99 per cent of the lead, 31 per cent of the coal, 96 per cent of the oil, all the bismuth and mercury, and nearly all the antimony and cadmium.

As was indicated earlier, erosion in the Archæan part of the Shield has cut down to the roots of early mountain systems, and, consequently, the type of mineral deposits are those normally formed at moderate to great depth. Such are most gold-quartz veins, large chalcopyrite deposits, and quartz veins containing tin or tungsten. Ores of gold and copper in Archæan rocks have been mined to a considerable extent, deposits of tin and tungsten are known to occur, but mercury or antimony ores and other deposits normally found at shallow depth are extremely scarce or lacking. Not only do the mines of the Archæan have ores of the moderate to deep seated type, but the mines themselves are very deep, and not only in Canada but throughout the world average much deeper than mines in younger rocks. No convincing explanation of this phenomenon of deeper mines has been given, but if the temperature changes above the source were gradual and long maintained, such conditions would permit of ore deposition throughout a considerable vertical range and might account, in some measure, for the great depth of mines in Archæan terrains.

Deposits associated with the basic Proterozoic intrusions are quite different from those in the Archæan rocks, probably not because they are younger but because they are associated with different sources. The great copper-nickel-platinum deposits at Sudbury are associated with a laccolith of norite, and the silver-cobalt ores at Cobalt with a diabase sill. The late Proterozoic diabase in various parts of Canada and the United States contains copper, suggesting that either the diabase or a related magma was the source.

The Grenville sub-province is not only different from the remainder of the Shield geologically, but also differs in its mineral assemblage. Mica, feldspar, and magnetite are characteristic of the Grenville, the first two associated with abundant pegmatites and the last with crystalline limestone. Recently, considerable quantities of brucite have been mined from Grenville limestones.

The bodies of anorthosite in the Shield also contain their own types of deposits. These are deposits of ilmenite and of titaniferous magnetite.

The rocks of the Canadian Shield are, as stated earlier, of Precambrian age. Plant life had not then begun, or at least has not left recognizable remains, and, as coal is formed from plants, no coal can exist in the rocks of the Shield. The earliest traces of animal life are recorded in rocks of late Precambrian (Proterozoic) age, and as it is believed that most of the earth's petroleum was derived from animals it is possible that Precambrian strata at one time contained petroleum. Heat and severe folding will, however, dissipate and permit the escape of petroleum and natural gas, so that the possibility of finding them in the rocks of the Shield are too remote to be considered seriously.

The rocks of the Plains region are not cut by intrusions of igneous rock. Conditions favouring metallic mineral deposition are, therefore, lacking, and mineral deposits of the types associated with igneous intrusions do not exist.

Although plant life had made a beginning on the earth in earlier time, it was prolific only in Carboniferous and later geological ages. Coal, therefore, does not occur in minable quantity in any rocks older than the Carboniferous. The rocks of late Palæozoic age in the Plains area were laid down in the sea, and do not, therefore, contain plant life, but extensive coal deposits do occur in Western Canada in Cretaceous and Tertiary rocks. Compaction and heat, which may result from folding of strata, drive out volatile constituents and raise the rank of coal, and as the Plains is an area of no folding the coal deposits there are of the lower ranks.

As animal life was plentiful in Palæozoic and later geological time, conditions in the Plains area are favourable for the formation of petroleum and natural gas. The strata there are at most only slightly warped, and for this reason are not conducive to the easiest migration of petroleum into pools or reservoirs. Even gentle dips, however, do permit migration, and the Plains may represent a considerable source of petroleum and natural gas.

Various periods in the geological past differed in climate from what might be considered normal. The great salt deposits of Ontario occur in the Plains region in rocks of Silurian age. The Silurian in North America was a period of drought, and rocks of this age in various places on the continent can be expected to contain common salt and other salts that result from evaporation.

In the Appalachian region the rocks range in age from Precambrian to Triassic. They have been folded and broken, and are intruded here and there by igneous rocks of mid-Palæozoic age and ranging in composition from granite to peridotite. Conditions are suitable for metalliferous deposits, and, in part, for the formation of coal, petroleum, and natural gas. The coal-bearing strata are of Carboniferous age, and have been sufficiently compressed to form a good grade of bituminous coal. Oil-shales are known, and if suitable conditions exist to prevent the escape of petroleum, reservoirs will probably be found. No reservoirs can be expected near younger igneous intrusions, however, as in such places any petroleum will have been driven off by heat. In the Maritime Provinces a dry period in Lower Carboniferous time resulted in the accumulation of extensive deposits of common salt and gypsum.

The metallic mineral deposits associated with the granitic intrusions of the Appalachian region contain the usual precious and base metals. Some of the ultrabasic rocks contain numerous deposits of chromite, and others are host rocks for large quantities of asbestos.

The eastern part of the Cordilleran region is folded and faulted, but is not cut by igneous intrusions. The western part is both folded and faulted and intruded by numerous igneous bodies of various types.

The rocks of the eastern Cordillera range in age from Proterozoic to Tertiary. Locally, in the eastern part of this sub-region, conditions favoured the accumulation of petroleum and natural gas in reservoirs, but farther west the petroliferous formations have been exposed by erosion, folding has been severe, and petroleum and natural gas have escaped. Possibly some areas in the western Cordillera that are free from igneous intrusions or that are underlain by formations younger than the igneous intrusions may contain petroleum and natural gas. The Carboniferous rocks of the Cordillera were laid down in the sea, and, consequently, do not contain the plant remains needed for the formation of coal. Some of the Cretaceous and later formations, however, are of continental type, and contain coal, and some of the Cretaceous formations have been folded sufficiently to raise the grade of coal to a high bituminous rank.

Practically all of the western Cordillera is favourable ground for metallic mineral deposits, and nearly all of the metals found elsewhere in Canada are represented there.

MINERAL PRODUCTION

As indicated by statistics and graphs (*See* Table I and Figure 2) the annual value of mineral production grew rapidly from $10,221,255 in 1886 to a maximum of $566,768,672 in 1942. The principal items produced are gold, silver, copper, lead, zinc, nickel, and asbestos. The following table lists these items and the production in the year of maximum output.

Gold	5,345,179	fine ounces	1941
Silver	32,869,264	" "	1910
Copper	655,593,411	pounds	1943
Lead	512,142,562	"	1942
Zinc	580,257,373	"	1942
Nickel	288,018,615	"	1943
Asbestos	467,196	tons	1943

Canada has been the world's second nation in gold production since 1941, being surpassed only by South Africa; in the production of silver, copper, lead, and zinc has stood among the top four nations for a number of years; and in nickel production has been first since the early 1900's and has produced 75 to 90 per cent of the world's total since 1910. She also produces 80 per cent of the world's asbestos. Since the early 1930's Canada and U.S.S.R. have been roughly equal as the main producers of the metals of the platinum group, and just prior to World War II Canada was producing 40 per cent of the world's radium.

Fluctuations in value of production prior to World War I resulted, in the main, from slight price changes, the abandonment or opening of mines, and from changes in mining and metallurgical practice. Decreased production of both metals and non-metals in 1914, the first year of World War I, presumably reflected uncertainty in industry and in the commencement of new enterprise. Rapid increase during the war years, essentially in base metals and coal, resulted from an increased demand and higher prices for base metals and an increase in the price of coal. The post-war years showed a rapid decrease in the value of metal production, resulting from falling prices for the base metals, copper, lead, and zinc, and a decreased demand for nickel. The total fluctuation was moderated to some extent, however, by a considerable jump in the production of structural materials and a further increase in the price and production of coal, both items indicating the beginning of new enterprise.

Though marked by considerable fluctuation, the total value of production increased following the war until 1929 when general world depression was beginning to be felt. From 1929 to 1932 the value of production dropped 38 per cent or $120,000,000. The prices of copper, lead, and zinc fell to a third of the 1929 price, and lack of demand curtailed production of nickel, coal, and structural materials. The great stabilizer in this period was gold, whose value of production rose more than $30,000,000.

Following the low of 1932 and 1933, a return to normal prices for the base metals, an upward revaluation of gold, and a return to stability in a growing industry had by 1939 more than doubled the value of production in 1933. Metallic mineral production accounted for 79 per cent, and gold alone 40 per cent, of the total increase.

From the beginning of World War II in 1939 to the end of the European phase in 1945 conditions were again abnormal. Requirements brought production of the metals, copper, lead, zinc, and nickel, to new highs. Shortage of labour and curtailment of industry not essential for war made itself felt in gold mining in 1941, and the forced closing of many gold mines drastically reduced production.

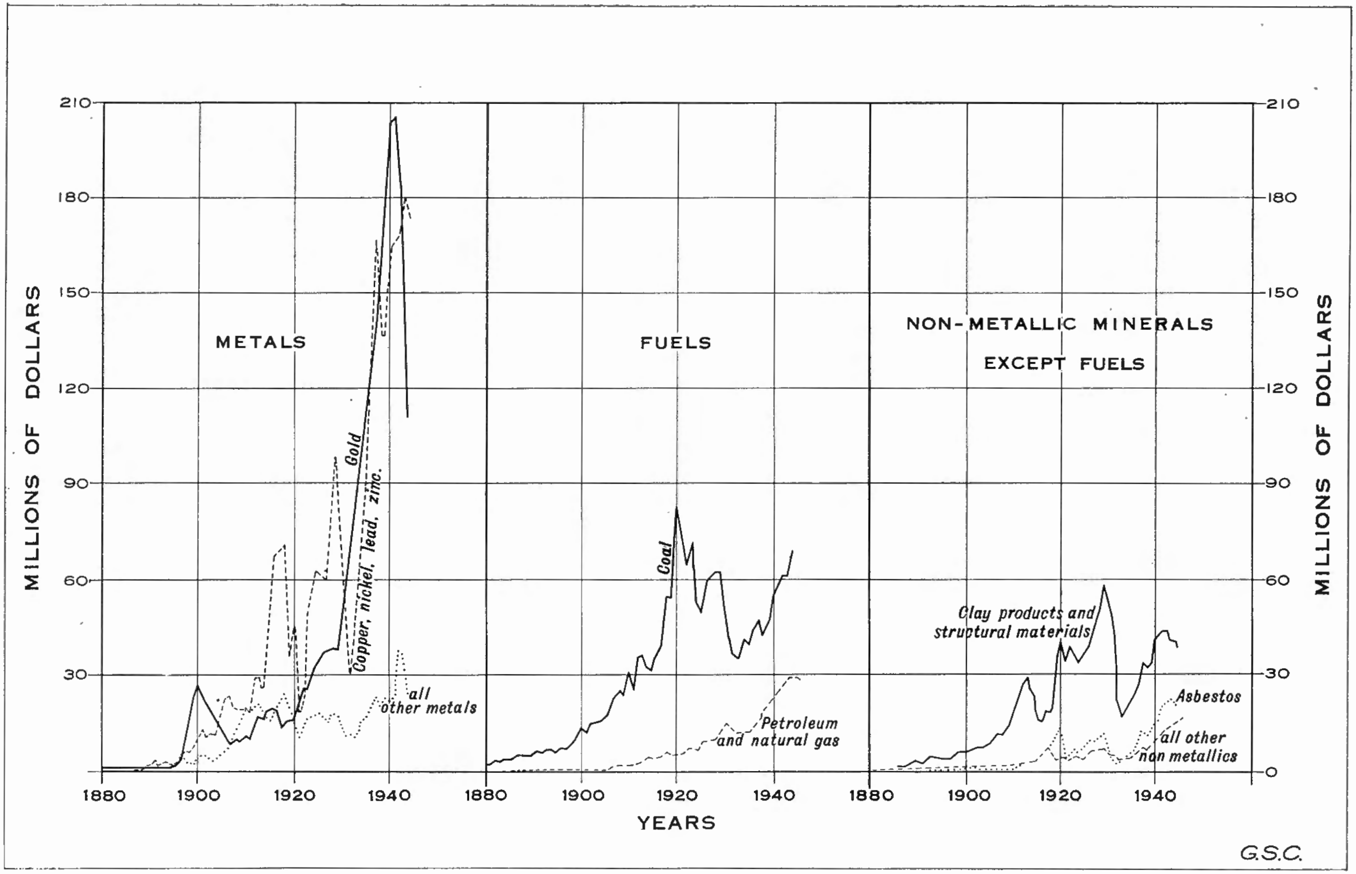


Figure 2. Graphs showing main items of mineral production in Canada, 1880-1944.

By examining the production statistics and seeking the causes of fluctuations, it becomes obvious that reduced production at any time was not the result of a lack of primary resources. An increase in demand and price has always brought production to new highs.

Structural materials and products such as coal, whose bulk or weight in comparison with value is high, cannot be shipped far, and production of such items is governed to a considerable extent by local population and industry. Their volume of production will, therefore, merely keep pace with growth of population and industry until such time as their value will permit transportation to distant markets. Very little detailed and authentic information is available on our actual resources of such materials, but our potential resources are believed to be very great and more than adequate for scores of years.

The situation in the metalliferous field is different in many respects, the chief of which is that metals can reach distant markets. In the ordinary course of events, therefore, the drain on metals will be world wide, and exhaustion of resources is certain if metals continue in use. Actual reserves in Canada are restricted to our presently known mines, and very little is known about our potential reserves. About 80 per cent of Canada is unmapped geologically, and much work must be done before any sound estimate can be made of our potential metal reserves. With so much ground yet untouched, however, it is expected that metal production will increase very materially before the peak is reached.

TABLE I

Annual Value, Mineral Production of Canada since 1886

Year	Metallics	Non-metallics: Fuels and other non-metallics	Non-metallics: Clay products and structural materials	Total	Value per capita
	$	$	$	$	$
1886	2,118,608	5,627,271	2,225,376	10,221,255	2.23
1887	2,073,746	6,290,006	2,707,579	10,321,331	2.23
1888	2,628,292	6,842,601	2,798,001	12,518,894	2.67
1889	3,251,299	7,264,940	3,247,674	14,013,113	2.96
1890	3,614,488	9,137,594	3,761,271	16,763,353	3.50
1891	5,421,659	10,230,423	3,074,534	18,976,616	3.92
1892	3,698,697	9,076,265	3,603,455	16,623,415	3.39
1893	4,630,495	10,020,641	5,133,946	20,035,082	4.04
1894	4,685,852	9,990,898	5,004,408	19,931,158	3.98
1895	6,087,114	9,585,482	4,726,368	20,505,917	4.05
1896	8,030,633	9,976,338	4,327,542	22,474,256	4.38
1897	13,780,314	10,242,566	4,338,550	28,485,023	5.49
1898	21,741,865	11,385,010	5,273,146	38,412,431	7.32
1899	29,282,823	13,832,921	6,168,283	49,234,005	9.27
1900	40,408,676	17,423,560	6,355,801	64,420,877	12.04
1901	41,939,500	17,295,822	6,803,836	65,797,911	12.16
1902	35,792,325	19,876,636	7,896,836	63,231,836	11.36
1903	33,210,147	19,786,619	8,443,747	61,740,513	10.83
1904	30,924,897	20,666,897	8,182,103	60,082,771	10.27
1905	37,400,204	22,216,699	9,608,267	69,078,999	11.49
1906	42,376,927	25,132,466	11,779,304	79,286,697	12.81
1907	42,426,607	31,275,546	12,863,049	86,865,202	13.75
1908	41,774,362	32,142,784	11,339,955	85,557,101	13.16
1909	44,156,841	31,141,251	16,533,349	91,831,441	13.70
1910	49,438,873	37,757,158	19,627,592	106,823,623	14.93
1911	46,105,423	34,405,960	22,709,611	103,270,994	14.32
1912	61,172,753	45,080,674	28,794,869	135,048,296	18.33
1913	66,361,351	48,463,709	30,809,752	145,634,812	19.35
1914	59,386,619	43,467,729	26,009,227	128,863,075	16.75
1915	75,814,841	43,373,571	17,920,759	137,109,171	17.44
1916	106,319,365	53,414,983	17,467,186	177,201,534	22.05
1917	106,455,147	63,354,363	19,837,311	189,646,821	23.18
1918	114,549,152	77,621,946	19,130,799	211,301,897	25.37
1919	73,262,793	76,002,087	27,421,510	176,686,390	20.84
1920	77,939,630	108,027,947	41,892,088	227,859,665	26.40
1921	49,343,232	87,842,682	34,737,428	171,923,342	19.56
1922	61,785,707	82,976,744	39,534,741	184,297,242	20.55
1923	84,391,218	91,936,732	37,751,381	214,079,331	23·41
1924	102,406,578	71,796,009	35,380,869	209,583,406	22.71
1925	117,082,298	71,851,801	37,649,230	226,583,333	24.19
1926	115,737,581	85,240,144	39,959,398	240,437,123	25.61
1927	113,561,030	88,986,246	44,809,419	247,356,695	25·67
1928	132,012,454	93,239,852	49,737,181	274,989,487	27.96
1929	154,454,056	97,861,356	58,534,834	310,850,246	31.00
1930	142,743,764	83,402,349	53,727,465	279,873,578	27.42
1931	120,930,147	65,346,284	44,158,295	230,434,726	22.21
1932	112,041,763	56,788,179	22,398,283	191,228,225	18.20
1933	149,015,593	57,782,973	16,696,687	221,495,253	20.74
1934	194,110,968	64,763,861	19,286,761	278,161,590	25.67
1935	221,800,849	67,328,208	23,215,400	312,344,457	28.56
1936	259,425,194	76,723,437	25,770,741	361,919,372	32.82
1937	334,165,243	88,324,150	34,869,699	457,359,092	41.13
1938	323,075,154	84,869,417	33,878,666	441,823,237	39.42
1939	343,506,123	95,733,177	35,362,759	474,602,059	41.94
1940	382,503,012	104,849,372	42,472,651	529,825,035	46.39
1941	395,346,581	119,521,437	45,373,272	560,241,290	49.06
1942	392,192,452	128,846,413	45,729,807	566,768,672	48.63
1943	356,812,760	131,230,952	42,010,254	530,053,966	44.87
1944	307,572,217	137,004,020	41,347,711	485,923,948	40.58

Table II

GEOLOGICAL TIME SCALE

Era	Period	Characteristic life	Total estimated time in years
Cenozoic	Recent Pleistocene	Man	1,000,000
	Pliocene Miocene Oligocene Eocene Paleocene	Mammals and modern plants	60,000,000
Mesozoic	Cretaceous Jurassic Triassic	Reptiles and cycad-like gymnosperms	200,000,000
Palæozoic	Permian Carboniferous	Amphibians and lycopods (giant club-mosses)	
	Devonian Silurian	Fishes	
	Ordovician Cambrian	Higher invertebrates	500,000,000
Precambrian: Proterozoic	Keweenawan Huronian	Primitive invertebrates and algæ	
Precambrian: Archæan	Timiskaming Keewatin	Nil	2,000,000,000

CHAPTER II

THE CANADIAN SHIELD

(H. C. Cooke)

The Canadian Shield is the great region of Precambrian rocks that constitutes the central backbone of Canada. It is a crudely shield-shaped area with its base on the Arctic Ocean and narrowing to a point in the United States south of Lake Superior. Its position and boundaries are indicated on Figure 1, and its area is approximately 1,800,000 square miles, or about half of all Canada.

PHYSICAL FEATURES

The Canadian Shield is a peneplain[1], which was uplifted to approximately its present position, it is estimated, in middle or late Pliocene time. During this uplift it was warped and faulted in places so that parts of it now stand much higher than others. Since its uplift the Shield has been somewhat dissected by stream action, particularly in the more elevated parts; and the topography has been further modified by the ice of the glacial period. This scoured away much of the soil and weathered rock of the pre-glacial surface, smoothed off the hills, filled the valleys with debris, and thus completely disorganized the pre-glacial drainage.

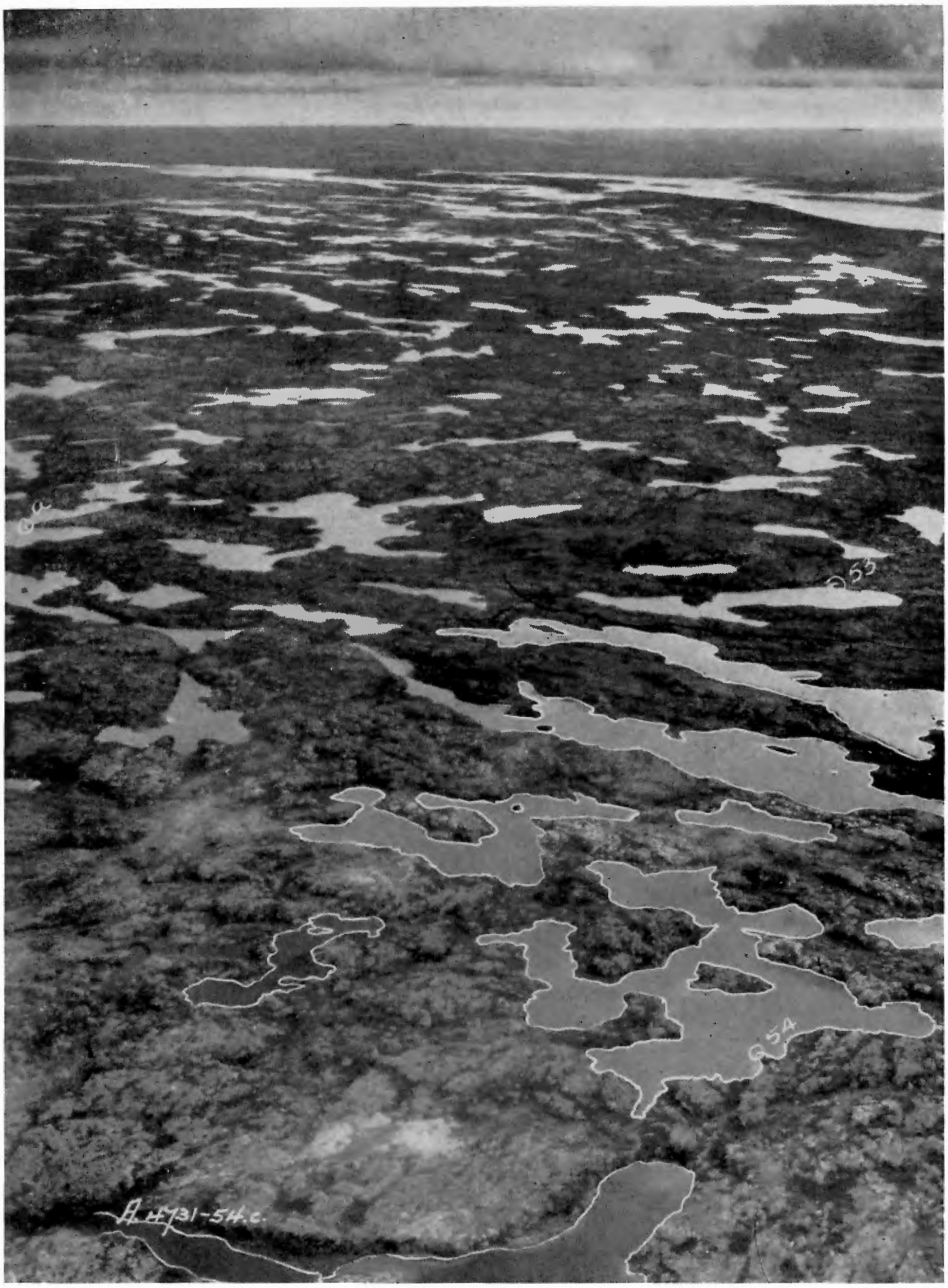
The combined result of these processes is the characteristic topography of the Canadian Shield (Plate II). From almost any elevation the skyline appears monotonously level, regardless of the differing hardnesses of the underlying rocks. Only at long intervals does a low hill break this even line, some remnant that escaped the prevailing peneplanation. Viewed more closely, however, the surface is rough, with low hills and ridges rising a few hundred feet above the valley levels. This dissection, in part at least, undoubtedly took place after the peneplain was uplifted, and streams could once more commence vigorous erosion.

Warping during uplift gave the Shield a saucer-like shape, with high edges sloping in general toward the central depression of Hudson Bay. The rim of the saucer is broken in places by depressions, such as the low valley of Ungava Bay, and the relatively depressed area south of James Bay through Lake Timiskaming. The remaining higher parts of the rim may be briefly described. At Cape Wolstenholme, at the southwest entrance to Hudson Strait, the plateau fronts on the strait in cliffs about 1,500 feet high, and slopes southward. Across Ungava Bay it attains its greatest elevation, between 5,000 and 6,000 feet. The dissected edges of this plateau, facing the Atlantic, are known as the Torngat Mountains (Plate III). Southward along the Labrador coast the elevations decrease, but still are greater than 2,000 feet between Hamilton Inlet and the Strait of Belle Isle.

Turning west along the north shore of the Gulf and River St. Lawrence, the edge of the plateau maintains its height nearly to Quebec, north of which it

[1]A peneplain, or almost-plain, is a part of the earth's surface subjected to erosion until reduced to a plain-like surface, regardless of the varying hardnesses of the underlying rocks. As erosion must continue until the surface is reduced nearly to sea-level, it follows that a true peneplain must have lain, when completed, close to that level. As most of the Shield area now lies as much as 1,500 feet or more above sea-level, uplift of the peneplain can be inferred.

PLATE II



Illustrating peneplaned surface of the Canadian Shield, and the numerous lakes of Northwest Territories. Photo by permission Royal Canadian Air Force. (A.4731-54.C.)

is still 1,800 feet above sea-level. Farther west its elevation falls off gradually to about 800 feet, some distance west of Ottawa. From there to Lake Huron the Shield ceases to rise as an abrupt wall above the surrounding plains, but passes without perceptible change of gradient beneath the horizontal Palæozoic beds that underlie these plains. Still farther west, north of Lakes Huron and Superior, the surface of the plateau rises again to above 1,500 feet; and similar or higher elevations are maintained to the northwest as far as the Arctic Ocean.

PLATE III

Torngat Mountains, near the northern Labrador-Ungava boundary, illustrating a particularly rugged area of the Canadian Shield. Photo by A. P. Coleman, Geological Survey (95915).

During and after the uplift streams cut and deepened their valleys, not only in the plateau surface, but in the upraised, rim-like edges. Later, when the ice came, these stream channels formed convenient conduits through which it could flow to the Atlantic and to the south. The powerful erosive action of the moving ice and its load of boulders widened and deepened the valleys to produce the magnificent fiords of the Labrador coast (Plate IV), the famous valley of the Saguenay, and many other features of the topography. The Great Lakes, as well as the large lakes of the Northwest Territories, originated in large part through glacial action.

Throughout the interior of the Shield the effect of glaciation was profound. The ice planed off the deep soil formed by centuries of weathering, and thereby destroyed its possibilities for agricultural development. It removed all weathered rock beneath the soil, and with it all the placer deposits that undoubtedly existed in gold-bearing areas, and all the secondarily enriched zones above ore deposits of all kinds. In partial recompense, it left the rock surfaces polished and clean, and exposed to a degree far greater than before, so that they can be readily studied and easily prospected for mineral deposits.

The debris of this great erosion was in part carried completely off the Shield, and in part scattered over its surface, choking old stream valleys and in some cases forming great ridges that extend for miles. As a result, the original well established drainage pattern is completely disorganized, so that only a few of the larger pre-glacial valleys can now be recognized. The effect has been to create a multitude of lakes, which spill at random across the lowest points in their rims. Many have more than one outlet, and where such lakes lie on a divide, they may drain to two entirely different river systems. In some parts of the northwest the number of lakes is so great that they constitute 25 to 35 per cent of the total area. The accidental irregularities of the ground determine the courses of the streams draining these lakes, with the result that they are a succession of quiet, lake-like stretches connected by rapids or falls.

PLATE IV

Fiord, Labrador coast, within the area of the Canadian Shield. Photo by Forbes Expedition, Boston, 1931 (95916).

A consequence of this unusual situation was the development by the aboriginal inhabitants of the birch-bark canoe, a light craft that could navigate the stiller waters and be easily carried past the more difficult obstructions. By it all parts of the Shield were penetrated and explored. The white man on entering the country adopted this craft, and later designed similar ones of tougher materials, with which all exploration of the country, up to recent years, was carried on. Since the development of the airplane, the lakes have been utilized as ready-made landing fields, and enable exploration to be carried forward at a steadily increasing rate.

Lakes were both more numerous and larger than at present toward the end of the glacial period, when the melting ice supplied great volumes of water, and at the same time the unmelted ice blocked the normal drainage toward Hudson Bay. Some very large lakes formed at that time around the edges of the receding ice, and persisted for hundreds of years. The silts and clays deposited in the lake beds constitute practically the only good agricultural land now found on the Shield. Examples are the so-called 'clay belt' of northern Ontario and Quebec, and the rich soils north and south of Winnipeg.

The southern part of the Shield is a forested region whose timber and pulpwood are of great value. Northward the forests are thinner and the growth less vigorous, until they merge into the open barrens of Ungava Peninsula and the Northwest Territories.

The uplift of the Shield, and the subsequent disorganization of the drainage by glaciation, have combined to give rise to immense waterpowers. A few of the more accessible have already been harnessed to supply eastern Canada with some of the cheapest power in the world and to run great manufacturing industries. There can be little doubt that these waterpowers will be increasingly utilized in the future as the other great source of power, coal, becomes more expensive with the gradual exhaustion of the deposits. The Canadian Shield may yet become the great storehouse of power for North America.

Other resources of the Shield, outside of its mineral deposits, are its fur-bearing animals and its tourist possibilities. Its fine furs were the principal cause of its early exploration and settlement; they have ever since furnished a considerable part of the world supply, and undoubtedly will continue to do so. As the country is opened up, the numerous lakes and streams will increasingly attract fishermen and those who like a wilderness holiday, even though the mosquitoes, black flies, and other stinging pests may repel all but the hardier souls. Big game offers attractions to the few interested in hunting; and, in the winters, the more accessible parts invite thousands annually for winter sports.

EXPLORATION

The exploration of the Canadian Shield may be said to have begun when Jacques Cartier sailed up the St. Lawrence in 1534 and began the settlement of what was later New France. At that time, as later transpired, the entire area of the Shield was inhabited by nomad tribes of Indians and Eskimos; but these, of course, have left no records of what they knew. The French established the fur trade with the natives, and it is likely that some of the bolder spirits took to the woods with the Indians; at least by 1656 the possibility of reaching Hudson Bay by an overland route from the St. Lawrence seems to have been generally accepted. The French regulation of the fur trade was rigorous; any one proposing to go inland after fur had to secure a licence, and anyone who omitted this formality was fined so heavily as to lose the greater part of his gains. Dissatisfaction with this state of things caused Radisson, a man from Three Rivers, to appeal to the British Government and urge on them the advisability of entering the fur trade via Hudson Bay. Hudson Bay was already well known from the explorations of Henry Hudson, Sir Thomas Button, Jens Munck, Luke Foxe, and Thomas James. Most of these navigators were searching for a northwest passage to the Orient, but the net result of their labours was a fairly good map of Hudson Bay. Charles II, urged by Radisson, sent out a vessel in 1668 that wintered in the bay and traded with the Indians. The results of the voyage were so gratifying that in 1670 the King signed the charter of The Governor and Company of Gentlemen Adventurers of England Trading into Hudson's Bay, or, as it is more commonly called, the Hudson's Bay Company. The Company survived its long struggle with the French that ended only with the English conquest of New France in 1763; and also that with its great rival, the North-West Company; and during its chequered career established trade routes along the principal streams of Ungava and the Northwest.

After the conquest of New France was completed, systematic efforts to explore the far northwest were undertaken, some by the fur companies, some by the British Government. The better known of these were the explorations of Hearne, Mackenzie, Franklin, and Back. Samuel Hearne, a clerk in the employ of the Hudson's Bay Company at Fort Churchill, was commissioned to investigate the Indian reports of native copper deposits somewhere to the northwest. He undertook to go out with the Indians in their migrations, sharing their movements and privations. In 1770 these movements took him northwest around what is now Dubawnt Lake and nearly to the head of Chesterfield Inlet. A second trip (1771-2) carried him to the mouth of Coppermine River on the Arctic, and back to Fort Churchill via Great Slave Lake. Alexander Mackenzie of the North-West Company (1789) explored the river that bears his name, from Great Slave Lake to its mouth. Sir John Franklin, on behalf of the British Admiralty, spent several years in the country (1819-22, 1825-7), and, along with Richardson, his second in command, explored and mapped routes from Port Nelson to Lake Winnipeg, from Lake Winnipeg to the Mackenzie, the Mackenzie itself, and two routes from Great Slave Lake to Coronation Gulf, one down Coppermine River. Back, who accompanied Franklin, later (1834) made an independent survey of Great Fish River, now known as Back River.

Geological exploration of the Shield did not begin until after the organization of the Geological Survey of Canada in 1842. Confined in the first few decades to studies of the more accessible parts, such as the Grenville area of eastern Ontario and the north shores of Lakes Huron and Superior, it went forward rapidly after the completion of the Canadian Pacific Railway in 1885 put thousands of starting points within easy reach of Ottawa. These early workers, who include such well-known geologists as William McInnes, A. P. Low, Robert Bell, and J. B. Tyrrell, surveyed the major watercourses and studied the rocks they traversed. Beginning about 1910 much of the actual surveying was taken over by the newly formed Topographical Branch of the Geological Survey, and the geologist was able to give more attention to the study of the rocks; as a result, he was able to undertake the complete examination of areas, instead of confining his work to the shores of streams. The development of the airplane has made it possible to map large areas rapidly by photography, requiring only a minimum of ground surveys for control purposes; to some extent also the major features of the geology can be determined from the photographs, enabling the geologist to concentrate his efforts on critical areas, so that exploration can now go on at a rate undreamed of by earlier workers.

GEOLOGY

Anyone attempting to describe the geology of the Canadian Shield is confronted at the outset by two grave difficulties. The first is that not more than about 20 per cent of it has been explored in any degree of detail, and the only information we have on the remainder is that furnished by rather widely spaced explorations. Thus little can be said either of the areal distribution of the various rocks, or of their correlation. The second difficulty is the absence of fossils in the Precambrian rocks, so that, lacking this reliable means of correlation, the geologist is reduced to less satisfactory methods, such as petrographic resemblances, structural similarities, and so forth. As a result, Precambrian literature is flooded with papers of correlation, each emphasizing some factor of importance, and each urging a different arrangement of the formations in the geologic column. Some of the hypotheses advanced have later been discarded, following more extended areal examinations or more intensive field studies, and doubtless others will be similarly discarded in the future; but many questions are likely to remain unanswered forever, or for a very long time. The following description, therefore, can do no more than reflect the trends of present opinion in matters of correlation, coloured no doubt to some extent by the writer's personal views. Ten or 20 years hence quite different conclusions may have been reached on some of the problems.

The Precambrian rocks of the Shield, according to present views, are considered to fall into two main groups, separated by a great interval of folding, mountain building, and long-continued erosion. The older group, known as the Archæan, is again subdivided into an older and a younger sub-group. The names Keewatin and Timiskaming are applied to the rocks of the older and younger sub-groups in some parts of the Shield; but as Archæan time was extremely long, perhaps one-half, roughly, of all recorded geologic time, and as there is as yet no means of knowing whether the scattered remnants of rocks of these group-types are really of the same age or not, local names have commonly been applied in the scattered areas where they are found. About all that can be said, definitely, is that in no area yet explored has there been found more than two sub-groups of Archæan rocks separated by an unconformity.

The second great group, that of the Proterozoic rocks, has been subdivided in turn into four sub-groups, namely those of Lower Huronian, Middle Huronian, Upper Huronian or Animikie, and Keweenawan ages. The classification has been established after intensive study of the rocks south of Lake Superior. Proterozoic rocks are much less widely distributed over the Shield than those of Archæan age; also, no single area includes formations of all the above sub-groups. Hence, in assigning the known rocks to one or another of these age groups one must depend on such features as stratigraphic succession and petrographic resemblances. It is perhaps needless to add that any classification based on such uncertain factors unavoidably contains large possibilities of error.

In addition to the above-mentioned strata, which are all rocks of sedimentary or volcanic origin, there are enormous volumes of intrusive igneous rocks. The great bulk of these are granites of various types; in fact, it has been estimated that 80 per cent or more of the Shield consists of granite. There are also relatively small but still important amounts of various basic intrusive rocks, such as gabbros, norites, and peridotites.

ARCHÆAN ERA

Keewatin Time

The term "Keewatin" was first applied as a formational name by Lawson about 1885 to certain lavas in the Lake of the Woods and Rainy Lake districts of Ontario. For some reason the term won immediate popularity, so that within a few years similar lavas throughout northern Ontario and Quebec were also called "Keewatin," though actually nothing was known as to any correspondence in age with the original Keewatin. Fortunately, however, subsequent geological work has proved that at least a rough similarity in age and geological relationships does exist.

Work done since 1920 has shown also that on both the eastern and western sides of the Shield the lavas are interbedded conformably with large volumes of sedimentary rocks. Some of these appear to be volcanic ashes deposited in bodies of water, but others are more normal sedimentary types. It, therefore, becomes necessary either to enlarge the term Keewatin to include these sedimentary rocks, or to invent a new term that will include both. The writer prefers the former procedure, using the term Keewatin as the name of a period during which there was great volcanic activity and a yet unknown amount of sedimentation. This usage is not, however, as yet generally adopted.

The supposedly Keewatin rocks of the central part of the Shield are dominantly volcanic types, mainly basalts and andesites, but locally, as near Noranda, trachytes and rhyolites may occur in considerable volume. These rocks are for the most part very thoroughly altered to aggregates of chlorite, epidote, and secondary feldspar. Rather singularly, the alteration has not destroyed the original structure such as pillows (Plates V and VI), flow lines, amygdules, or grain, so that these features can still be used to distinguish the tops and bottoms of the flows, and thereby to determine the strike and dip, the positions of fold axes, and other large structures.

PLATE V

Pillow structures in lavas of the Yellowknife group, southeast of Gordon Lake, Northwest Territories. Shape indicates that top of flow faces towards upper left-hand corner. Photo by J. F. Henderson, Geological Survey (84169).

Here and there relatively small bodies of sedimentary rocks are interbedded between flows. Many of these are ash rocks, ranging from fine tuffs to coarse boulder agglomerates, and they are commonly though not invariably bedded, indicating that they were deposited in bodies of water. Traced along the strike such bodies rarely extend more than a few miles. suggesting that they were deposited in ponds or lakes.

Another type of sediment interbedded with the lavas consists of bedded chert or cherty quartz. Such bands are rarely more than a few inches or a foot thick, and are mainly useful in delineating flow boundaries. In a number of places, however, they attain thicknesses of hundreds of feet and are associated with iron minerals, and are then known as iron formations. In some of these layers of chert-like quartz alternate with layers of magnetite, hematite, or both. In other districts the banded strata consist of finely granular quartz, iron carbonate, and pyrite in varying proportions. The iron content of these rocks is usually low, less than 38 per cent iron, so that they are valueless at present, though they constitute a great reserve that will doubtless be utilized when the present high grade deposits are exhausted.

The part of the Shield in which the oldest rocks are chiefly lavas is indicated roughly in Figure 3. The absence of large bodies of ordinary sediments within this area suggests that it was probably a land area, undergoing erosion in Keewatin time. In support of this conclusion are the facts that the sedimentary bodies that do occur are small, indicating deposition in ponds or lakes; and that the cherts and iron formations must similarly have been deposited in land-locked bodies of water. Had the iron- and silica-bearing solutions been poured out into a sea, one would expect that dilution and dissipation by waves and currents would have prevented deposition. The Keewatin surface, indeed, may be imagined as a maze of lakes, for the great outpourings of lava must have choked watercourses in all directions, affecting the drainage much as glaciation has done.

Plate VI

Variolitic structure in andesitic pillow lavas, southern Rouyn township, Quebec. Photo by M. E. Wilson, Geological Survey (3-44).

On the west side of the Shield, and roughly at the boundary indicated in Figure 3, sedimentary rocks in large quantity begin to appear in the group of oldest rocks. Much of the sedimentary material is undoubtedly volcanic ash, but other parts are quartzites, slates, and other normal types. Very commonly the sediments have been sheared, recrystallized, and converted into sedimentary gneisses. In Rainy Lake district the Couchiching, a thick series of sediments, seems to underlie the Keewatin lavas. On the east side of Lake Winnipeg the oldest rocks have been termed the Rice Lake series, and consist of a central band of lavas both overlain and underlain conformably by thick bands of sediments. Around McVeigh Lake in northern Manitoba J. D. Bateman describes the oldest rocks, which he terms the Wasekwan series, as consisting of some 18,000 feet of interbedded lavas and sediments, with the lavas considerably in excess.

Between Athabaska and Great Bear Lakes the oldest rocks, variously termed the Tazin, Yellowknife, and Point Lake-Wilson Island groups, are mainly altered sediments with minor amounts of lavas. In the vicinity of Rankin Inlet, on the northwest shore of Hudson Bay, L. J. Weeks reports the presence of bands of pure white quartzite some thousands of feet thick interbanded with the upper horizons of the lava series.

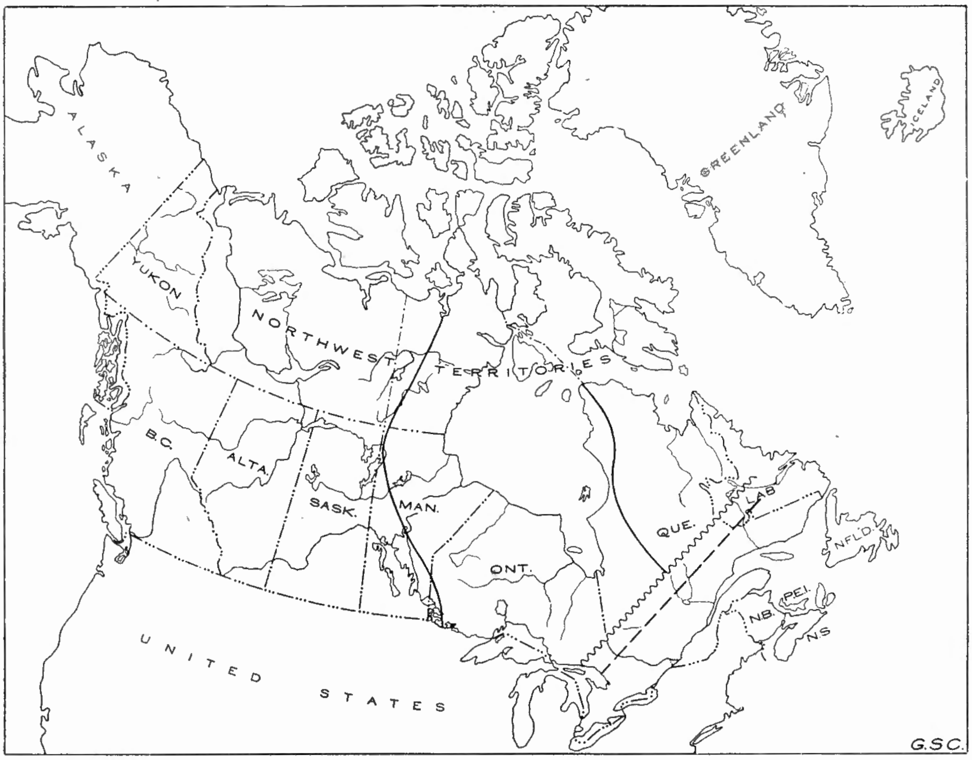


Figure 3. Keewatin Period. The area within the solid line has little sedimentary material associated with the lavas, and is, therefore, considered to have been mainly land during Keewatin time. Outside this line there is much sedimentary material, so that it was probably shallow epicontinental sea.

The wavy line indicates the known and possible fault(s) separating the Keewatin area from the Grenville-Hastings area. The broken line is the approximate northern boundary of occurrences of crystalline limestone.

These relationships suggest that the area west of the solid line in Figure 3 was covered by the sea, in which were deposited the materials eroded from the land area to the east.

The eastern side of the Shield is as yet very imperfectly known. Prior to the development of the airplane the interior of Ungava was difficult of access, and knowledge of it limited mainly to that obtained from a few widely spaced traverses along the principal streams. The descriptions seem to indicate that the oldest rocks are mainly sedimentary gneisses with minor quantities of lavas. For the most part these gneisses have not been separated in mapping from the igneous gneisses and granites that invade them. It would seem, however, that the situation in Ungava is not very different from that prevailing on the west side of the Shield.

In eastern Ontario and the adjacent parts of Quebec the oldest rocks are sedimentary gneisses associated with great thicknesses of crystalline limestone and a little lava. These rocks have been termed the Grenville series. The relations of the Grenville series to the oldest rocks elsewhere are as yet entirely unknown. T. T. Quirke, who worked for years in the district north of Lake Huron and northeast of Georgian Bay, believed that he had found in the latter district Huronian rocks highly metamorphosed by intrusion of the Late Precambrian Killarney granite, and on this evidence advanced the hypothesis that the Grenville may be the metamorphosed equivalent of the Huronian. Since his work was done, however, it has been discovered that a great fault, upthrust on the south side, cuts off the Huronian from the rocks to the southeast, so that the accuracy of his conclusions are rendered doubtful. Again, in a single locality about 80 miles south-southwest of Lake Mistassini, the writer in 1916 found sedimentary gneisses overlying the lavas and apparently in conformity with them; and traced the formation, by very numerous inclusions, across the barely unroofed crest of a granite batholith into the Grenville series north of Ottawa. In 1938, however, G. W. H. Norman found that a strong fault zone, upthrust on the southeast, runs northeast along the southeast side of Lake Mistassini and cuts off the rocks to the northwest from the Grenville type of sediments to the southeast. The accuracy of the writer's conclusions are, therefore, also rendered doubtful.

The two great faults mentioned above are closely on strike with each other, and some 350 miles to the east-northeast, according to information received from geologists studying the iron deposits of central Labrador; the Late Precambrian sediments of that district end on the south against a strong upthrust fault. A line connecting these localities is practically straight (*See* Figure 3), and may mark the approximate position of a zone of late Precambrian faulting, which separates strata of Grenville from Keewatin types. The problem of this supposed fault zone, and whether it will forever obscure the relations between the Keewatin and the Grenville, still remains to be investigated.

Within the Grenville sub-province, which lies southeast of the supposed fault line above mentioned, the oldest rocks are the Grenville series. They appear to have been originally shales, sandstones, limestones, and some lavas; but owing to the intense metamorphism to which they have been subjected, the shales have been recrystallized to biotite schists and sillimanite-garnet gneisses, the sandstones to vitreous quartzite, and the limestones to crystalline limestone. Lavas, mostly of basic types, appear to be interbedded with these sediments and to occupy various horizons; it should be added, however, that in these much deformed and metamorphosed rocks structure is commonly difficult to determine.

In southern Ontario, particularly in Hastings county, a second series makes its appearance. This, known as the Hastings series, overlies the Grenville with erosional unconformity, but, apparently, 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 a group of gabbros, anorthosites, pyroxene diorites, and pyroxene syenites, 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.

The economic products found in the Grenville and Hastings rocks are chiefly those occurring in pegmatite veins, such as quartz, feldspar, and mica, and those produced by contact metamorphic action, such as graphite, talc, actinolite, pyrite, and some iron ores. Gold-bearing veins are found, but have mostly proved too lean to be worked profitably; a few, however, have been valuable for their arsenic content. Veins of galena, fluorite, and barite are known in these rocks near their boundary with overlying Palæozoic formations, but similar deposits also occur in the Palæozoic rocks, and they are probably all of Palæozoic or later age.

Timiskaming Time

Timiskaming is here defined as the later part of Archæan or Early Precambrian time. In a number of places in the southern part of the Shield a group of sedimentary rocks, interbedded in places with small amounts of lava, has been found overlying the Keewatin rocks with known or inferred unconformity. At Porcupine, northwest of Porcupine Lake, Timiskaming sediments overlie the older rocks with a discordance of 40 to 45 degrees. Elsewhere discordances are much smaller, generally not more than 5 or 10 degrees, and even these may be disputed, as the actual contact of the two series is rarely observable. Commonly the basal conglomerate of the rocks classed as Timiskaming carries boulders of iron formation, and, as this was laid down as a sediment, the presence of such boulders implies erosion of the underlying rocks, perhaps accompanied by uplift or folding, before the conglomerate could be laid down.

It is not known whether the separate bodies classed as Timiskaming are all of the same age or not. They are merely classed together because, at the present stage of knowledge, they appear to have similar relations toward the older Keewatin rocks. The development within the last 25 years of methods of determining structures in lavas has made it possible to decide questions of structural unconformity with much more certainty than before, with the somewhat unexpected result that several sedimentary groups petrographically resembling the Timiskaming have been found to overlie or underlie the Keewatin-type lavas with apparent conformity. In such cases the sediments are classed with the Keewatin group.

The largest known single area of Timiskaming strata stretches from a point somewhat west of Swastika, Ontario, eastward across the interprovincial boundary into Quebec, a distance of some 60 miles. Small areas of similar rocks—the Cadillac group—are found for many miles farther east. Near Cobalt, Matachewan, Timmins, and Opeepeesway Lake, in Ontario, there are bodies of these rocks. The Dore series of Michipicoten, and the Windigokan series east of Lake Nipigon are considered to belong to this group; and west of that lake many bodies of similar rocks have been described, among which might be mentioned the sediments of Lake Savant and the Seine series of Rainy Lake and Steeprock Lake areas.

Sediments of somewhat similar appearance have been observed on Broadback and Eastmain Rivers of northern Quebec, but recent work has failed to demonstrate unconformity between them and the underlying volcanic rocks, so that it seems safest at present to regard them as Keewatin.

Northwest of Lake Winnipeg strongly folded and gneissic sediments have been described under various local names, such as the Missi series, Sickle series, San Antonio formation, and Kisseynew gneiss. A sharp difference of opinion in regard to the classification of these rocks has arisen between different workers in the area. Some geologists, looking at the rather intense metamorphism of these rocks, have been inclined to class them with the Timiskaming group. Others point out that the structural discordance between them and the older rocks is far larger than between the type Timiskaming and Keewatin, as it approaches a right angle in many places. For this reason they would classify these rocks with the Proterozoic, and ascribe their greater metamorphism to the intrusion of the Late Precambrian granites of the northwest. At present there is no means of resolving these differences.

In the area between Athabaska and Great Bear Lakes are the ancient sediments of the Yellowknife, Tazin, and Point Lake-Wilson Island groups, but it has not yet been established whether some or all of these belong to the oldest known Archæan, or fall into a later Archæan group. In one or two places there does seem to be unconformity between an older, mainly lava, series, and a younger and mainly sedimentary group, but the relationships are still imperfectly known.

Post-Archæan Interval

The sedimentation of late Archæan time was brought to a close by an intense diastrophism, by which the lava flows and sedimentary beds were thrown into near-vertical positions and in places overturned. At the same time, approximately, immense bodies of granite were injected, and stoped away or otherwise destroyed great parts of the older surficial rocks. As folding and granitic intrusion in later times are concomitants of mountain building, it is generally considered that the Shield must have been a region of lofty mountains during this interval.

The post-Archæan interval, or as it is sometimes termed the Eparchean interval, was very long. Mountain building is a slow and gradual process; and the next rocks that appear are deposited on peneplaned surfaces, so that at least small parts of the mountainous area must have been eroded down to near sea-level before the interval closed. The interval must, therefore, have endured for some millions of years, and may be considered, tentatively, equivalent to a geologic period at least.

Throughout most of the Shield the general strike of the ancient rocks varies between east-northeast and east-southeast. In the Northwest Territories, however, the general strike is northerly. Thus the present continental structure appears to have been initiated in the first great folding of which we have well-preserved records.

PROTEROZOIC ERA

The Proterozoic era, or era of first life, has been so called because during it life on the earth is supposed to have begun and developed. When fossil records in general begin to appear, in succeeding Cambrian time, evolution of life forms was already far advanced. From the primitive one-celled scraps of protoplasm, which are supposed to have been the natal manifestations of life, had developed multicellular forms with highly specialized structures such as shells, muscles, nerves, and organs of sight, feeling, and locomotion. 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. There is, of course, no evidence that this period of evolution was confined to the Proterozoic. Many writers have supposed that it must extend back into the Archæan era, which they would term the Archæozoic, or time of ancient life.

Many years ago, accordingly, it was inferred that Proterozoic time must have been exceedingly long; but only in recent years has it been possible to estimate even roughly how long. Research on the radioactive elements has shown that they break down, through a succession of changes, into two ultimate products, helium and lead; and that this change occurs at a uniform rate, the speed of which has been measured. If, therefore, the relative proportions of the radioactive elements and the lead or helium produced by their decomposition can be accurately determined, the length of time needed for that amount of decomposition can be calculated. Unfortunately, radioactive substances in quantities large enough for analysis are rare; and the analysis, which requires a high degree of accuracy, is beset by a number of difficulties that cannot be dwelt on; so that reliable age determinations are as yet all too few. Those that have been obtained indicate the conclusion that the Proterozoic era lasted some 500 or 600 millions of years; as long or somewhat longer than all time from the beginning of the Cambrian to the present.

This vast interval not only would seem to afford opportunity for the evolution of life above described; but it also throws a different light on the subdivision of the Proterozoic. It has been customary, on the Shield, to subdivide the era into four "periods", the Lower Huronian, Middle Huronian, Animikie or Upper Huronian, and Keweenawan; and it is probable that most geologists instinctively think of these "periods" as roughly equivalent to the Cambrian or the Cretaceous. Now it would seem that if these "periods" have any meaning at all; if the remnants of the Proterozoic rocks possess any more significance than isolated straws floating down this vast river of time; then these so-called "periods" take on the aspect of eras. Give them lengths of 100 million years or more apiece, and they each become roughly equivalent to the whole Mesozoic; and correlations, so-called, lose their import. Instead of fixing closely the ages of formations, they merely group them loosely within time limits that range over millions of years.

Lower Huronian Time

Lower Huronian rocks of the Canadian Shield, termed in Canada the Bruce series, are confined to a narrow belt along the north shore of Lake Huron, and extending about 23 miles east of Sudbury. They appear to have been laid down in a rather narrow trough that extended westward along the south side of what is now Lake Superior through Michigan and Wisconsin.

The oldest Huronian rocks are found only near Sudbury, but the actual base is not exposed, as a profound fault forms the contact between them and the older, presumably Keewatin, rocks. The oldest existing formation is a thick succession of rhyolite flows termed the Copper Cliff rhyolite. These are overlain conformably by the McKim formation, a succession of thick beds of impure quartzite and thinner, varve-like beds of greywacke. The McKim appears to have a thickness of some 7,000 feet, although faulting and brecciation render the estimate very doubtful; and it passes by conformable interbedding into the next overlying formation, the Ramsay Lake conglomerate, which lies at the base of the Mississagi quartzite. The McKim and Copper Cliff are formations of local extent, and the former extends only from a few miles east of Sudbury to a point about 75 miles west of it. West of that point the Mississagi quartzite either rests directly on Archæan rocks or is faulted against them.

The remaining formations of the Bruce series are the Ramsay Lake conglomerate and Mississagi quartzite, the Bruce conglomerate, the Bruce limestone, the Espanola formation, and the Serpent quartzite. North of Georgian Bay these formations attain a total thickness of nearly 15,000 feet, but they thin rather rapidly westward to about 3,000 feet. All the rocks of the series display crossbedding, ripple-marking, and other evidences of shoal-water deposition. The basin in which they were deposited must, therefore, have been in a very delicate state of isostatic adjustment, as such great thicknesses of sediments were deposited in it under shoal-water conditions throughout.

Middle Huronian Time

Lower Huronian time closed in Lake Huron district with an uplift that brought the newly deposited sediments under erosion, and thicknesses up to 1,700 feet were removed before the next overlying series, the Cobalt, was laid down. The movement does not appear to have been accompanied by folding, however, as there is little or no structural discordance between the two.

The Cobalt series overlaps the Bruce, and extends about 100 miles north of it. Like the Bruce, it lies on a surface of low relief bevelling the Archæan formations and the granite that intrudes them. Peneplanation of the Shield area had, therefore, advanced considerably by the time Cobalt deposition began.

The Cobalt series consists of the Gowganda formation at the base, overlain by the Lorrain formation. The Gowanda 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 that can only have been dropped 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 in thickness, 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 more than 99 per cent silica. Cross-bedding and ripple-marks are common throughout, indicating shoal-water conditions of deposition. Thin streaks and disseminated particles of specularite occur here and there, and in one place a lean iron ore forms a bed 75 feet or more in thickness. Banded cherty quartzite 200 to 700 feet thick, and a second white quartzite formation some 2,000 feet thick, overlie the Lorrain proper.

Lavas have not been found in the Cobalt series, except in Leonard township, Ontario, where a rhyolite is described as part of the Gowganda formation.

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

Much more doubtful is the stratigraphic position of a body of sediments in Richmond Gulf, on the east shore of Hudson Bay, which C. K. Leith has termed the Richmond series. It consists of coarse arkoses grading upwards into sandstones and argillites and interbanded with some basic lavas. Leith describes the group as composed of coarse and ill-assorted sediments deposited in low, tide-swept fans, and exhibiting the wide variety of ripple- and current-marks duplicated in the tide flats of today. The whole assemblage dips seaward at angles of 5 to 45 degrees, and lies with small unconformity beneath the Nastapoka series, which bears so strong a petrographic resemblance to the Animikie of Lake Superior district that the two are generally correlated. The Richmond group may, therefore, be considered Middle Huronian, but Leith himself suggests that the unconformity may not represent any great time interval, in which case it would be necessary to class the Richmond group with the Nastapoka series in the Upper Huronian.

Middle Huronian time was brought to a close, in Lake Huron district, by a mountain-building movement that folded the Bruce and Cobalt series rather closely along east-west axes. Farther north the Cobalt strata were only gently flexed, and lie in broad open folds with dips rarely exceeding 20 degrees. The folding movements were preceded or accompanied by the intrusion of the great sills and dykes of gabbro commonly termed the Nipissing diabase, with which the important silver deposits of Cobalt and Gowganda were associated. Some bodies of granite in Sudbury district may also have been injected about this time.

Upper Huronian Time

In Sudbury area, Upper Huronian time was one of long continued erosion, during which the mountain chain raised at the end of the last period was gradually reduced to an area of low relief. Elsewhere on the Shield the Archæan mountains appear to have been pretty well reduced to base level, with the result that small downwarpings of the surface caused rather widespread inroads of the sea, establishing basins in which sedimentary rocks could be laid down. It is freely admitted that these conclusions depend for their accuracy on the correctness of the correlations between the different areas; and that the correlations attempted are based wholly on the unsatisfactory grounds of petrographic resemblance; but until some better means shall be found it is difficult to see what else can be done. The reader should keep in mind, however, that the correlations are merely tentative, and that new discoveries at any time may change the picture.

The rocks here assumed to be of Upper Huronian, or as it is frequently called, Animikie, age include the Animikie of the northwest shore of Lake Superior; the Nastapoka series of Belcher Islands and Richmond Gulf; the similar rocks of Sutton Lake area, in Patricia district, northern Ontario; the Mistassini series; and the Late Precambrian rocks of central Ungava.

West of Hudson Bay there are several groups of rocks whose inclusion in the Upper Huronian is doubtful. These are the Great Slave group of Great Slave Lake, the Nonacho series southeast of the lake, the Beaverlodge group on the north side of Lake Athabaska, the Snare group south of Great Bear Lake, the Echo Bay and possibly Cameron Bay groups of Great Bear Lake, and the Epworth dolomite and possibly Goulburn quartzite of the Arctic coast.

The name Animikie was first applied by Sterry Hunt in 1873 to a group of rocks near Port Arthur. They extend southwesterly from a point about 25 miles northeast of that city to cross the International Boundary some 65 miles west-southwest of it. The rocks consist at the base of a basal conglomerate 4 feet or less in thickness, followed by cherty iron formation up to 500 feet thick. It 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, some beds containing angular and rounded fragments of lava, and some shaly members. The iron formation is characterized by many peculiar structures like inverted bowls or thimbles, which have concentric shells of silica and iron minerals. These, commonly termed "algal structures", have been considered by some writers to be of organic origin, but the consensus of opinion at present is that they have been formed by inorganic means. The iron formation ranges in its iron content from 5 to 40 per cent, and may average about 25 per cent.

Overlying the iron formation is a formation of slate and greywacke 1,300 feet or more in thickness. Part of it may represent volcanic ash or dust. A few thin beds of limestone are locally present.

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 lavas; sandstones, shales, and slates; 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 high dips are found. Granite intrudes the rocks of the Richmond group on the shores of Richmond Gulf.

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

A long band of Late Precambrian sediments extends north-northwest through the Ungava district of northern Quebec, from the western side of Ungava Bay to Lakes Petitsikapau and Michikamau. In the Koksoak River basin Low estimated their thickness to be more than 2,500 feet. At the base is more than 600 feet of coarse red and grey sandstone, overlain successively by about 200 feet of calcareous chert, 230 feet of shales and cherty dolomites, 850 feet of ferruginous chert interbedded with jasper and magnetite, and 600 feet of shale. In a number of places Low records the presence of ripple-marks. The western edges of this band are comparatively undisturbed, with low dips at 5 or 10 degrees, but the eastern side displays dips of 45 to 90 degrees. Whether this is due to faulting, as at Lake Mistassini, or to folding, is not yet known. It is known, however, that faults are numerous, and also that in places the shales and limestones are metamorphosed to schists and crystalline limestones. Granites are said to intrude the sediments in places.

In the explored part of the Northwest Territories several groups of rocks have been found whose inclusion with the Animikie is as yet unproved. They are generally conceded to be Proterozoic, and they lie unconformably beneath strata that have commonly been correlated with the Keweenawan. Only the two Proterozoic groups have been found as yet, as no strata resembling the Bruce or Cobalt series are known there. Consequently, on the recently issued geological map of Canada (Map 820A) it was thought best to term these groups merely "Early" and "Late" Proterozoic.

Nevertheless, the best developed of the groups mapped as Early Proterozoic, the Great Slave group, has certain characteristics found in the Animikie farther south, and not in the Bruce or Cobalt series; partly for this reason, and partly because these groups directly underlie the Keweenawan, they are described here. The true age relations are, however, as yet too doubtful for any more definite correlation to be attempted.

On the north side of Athabaska Lake the Beaverlodge group forms a number of remnants scattered throughout an area 20 miles long and 12 miles wide around the town of Goldfields. The group comprises a basal conglomerate 40 feet or less in thickness, and the remainder is white and reddish quartzite. Associated with the quartzites in one locality are red and bluish beds containing so much hematite that the rock may be termed an iron formation. In the main the beds lie in broad open folds very like the Cobalt series in Cobalt district, but in places dips up to vertical have been reported. The strata are intruded by the Late Precambrian granite. The granite and older sediments are overlain unconformably by the Athabaska sandstones, and are closely similar to the lower beds of the Great Slave group, hence are correlated with them.

On Great Slave Lake, the Great Slave group, in its lower part at least, shows some resemblance to the Animikie of other districts. At the base of the series there is perhaps 3,000 feet of sandstone and quartzite, much of it red. The rocks are well bedded, and in places crossbedded and ripple-marked. Above them lie about 1,000 feet of red argillites, which pass at the top into iron formation and laminated limestone. The iron formation consists of oolites of hematite in a siliceous and calcareous matrix, and is associated with volcanic material. Above these beds, in turn, is about 1,500 feet of limestone and dolomite, and much of the limestone displays excellent 'algal structures.' This succession is called by Stockwell the lower part of the Great Slave group.

The upper part comprises about 1,000 feet of dolomites and limestones, with some shale, overlain by a thick assemblage of sandy shale and sandstone. In most places these rocks lie with apparent conformity on the upper limestone of the lower part of the group, but in one locality they are found close to the underlying argillites. Stockwell was unable to determine whether the relations were due to erosion or to faulting. All the rocks of the upper part of the Great Slave group display characters that evidence shoal-water or subaerial conditions. The sandy shales interbedded with the limestones are red and ripple-marked. The limestones have 'algal structures.' The sandy shales and sandstones overlying the limestones are red and chocolate coloured; they display ripple-marks, crossbedding, and mud-cracks; and some have cubical cavities that may have been filled with salt crystals.

Between Athabaska and Great Slave Lakes, around Thekulthili and Nonacho Lakes, sediments termed the Nonacho series have been found. In the former locality they consist only of coarse conglomerates and light purple, green, grey, and buff arkoses. In the latter place they are somewhat more extensively developed. A coarse conglomerate at the base is several hundred feet thick, locally as much as 2,000 feet. This is overlain by slates and greywackes, 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 steeper in places. The formation is intruded by Late Precambrian granite and locally metamorphosed.

Between Great Slave and Great Bear Lakes rocks of the Snare group are rather extensively developed. These rocks strongly resemble the lowest beds of the Great Slave group. The basal strata are coarse arkoses and quartzites, ripple-marked and crossbedded, with some lenses of conglomerate. Locally thin flows of andesite or dacite are near the base. A rather thick succession of argillites and greywacke follows, some of the greywackes being crossbedded. This is overlain in turn by some limestone and dolomite, characterized by some 'algal structures', and more or less interbedded with greywacke and quartzite. The rocks strike north-northwest in open folds, with dips commonly less than 45 degrees. They are locally invaded by Late Precambrian granites and metamorphosed. These strata have been traced as far as the headwaters of Coppermine River, east of Great Bear Lake.

On Great Bear Lake itself rocks are known (Echo Bay and Cameron Bay groups) with many resemblances to the Snare group. They are, however, so greatly broken by faults that the relations and succession are far from certain. Investigations of this area are still in progress.

On Bathurst Inlet, Tree River, the upper part of Coppermine River, and to the west of Darnley Bay, J. J. O'Neill has mapped areas of a series that he termed the Epworth dolomites. The rocks consist wholly of dolomites and limestones, except for a thin basal band of conglomerate and arkose, and are comparatively flat-lying. These beds have thicknesses up to 1,800 feet, and the limestones are characterized by the same cup and ball 'algal structures' found in the Great Slave group and the Nastapoka group of Richmond Gulf.

In Bathurst Inlet O'Neill found two other formations, which cannot be correlated as yet with any others. The Kanuyak formation appears in remnants less than 100 feet thick, comprising buff-coloured conglomerates and ash rocks now largely altered to carbonate. The Epworth dolomite seems to have been flexed gently and deeply eroded before the Kanuyak formation was laid down on it. The Goulburn quartzite, a formation reported as more than 4,000 feet thick, and including thick beds of conglomerate, was not seen in contact with the earlier formations, but was inferred to be younger because the conglomerates carry pebbles apparently of the Epworth dolomite and Kanuyak formation. If the determinations are correct, these formations must have been subject to erosion before the Goulburn was laid down. The Kanuyak and the Goulburn are referred, doubtfully, to the pre-Keweenawan because O'Neill reports that bodies of Late Precambrian granite and pegmatite appear to cut the Goulburn.

End of Upper Huronian (Animikie) Time. Assuming that the correlations of the preceding pages are in the main correct, it would seem that by the beginning of Animikie time the Shield was fairly thoroughly peneplaned and reduced nearly to sea-level by erosive processes. Local downwarpings then carried parts of the surface below sea-level, forming shallow gulfs or bays in each of which thousands of feet of sediments were laid down, along with volcanic materials. In each trough the sediments, throughout their entire thickness, are characterized by the marks of shoal-water or subaerial deposits; hence it must be concluded that subsidence of the troughs kept pace with deposition, forming geosynclines of deposition. The presence of iron formation in places, as indicated on page 19, suggests the existence of some closed basins.

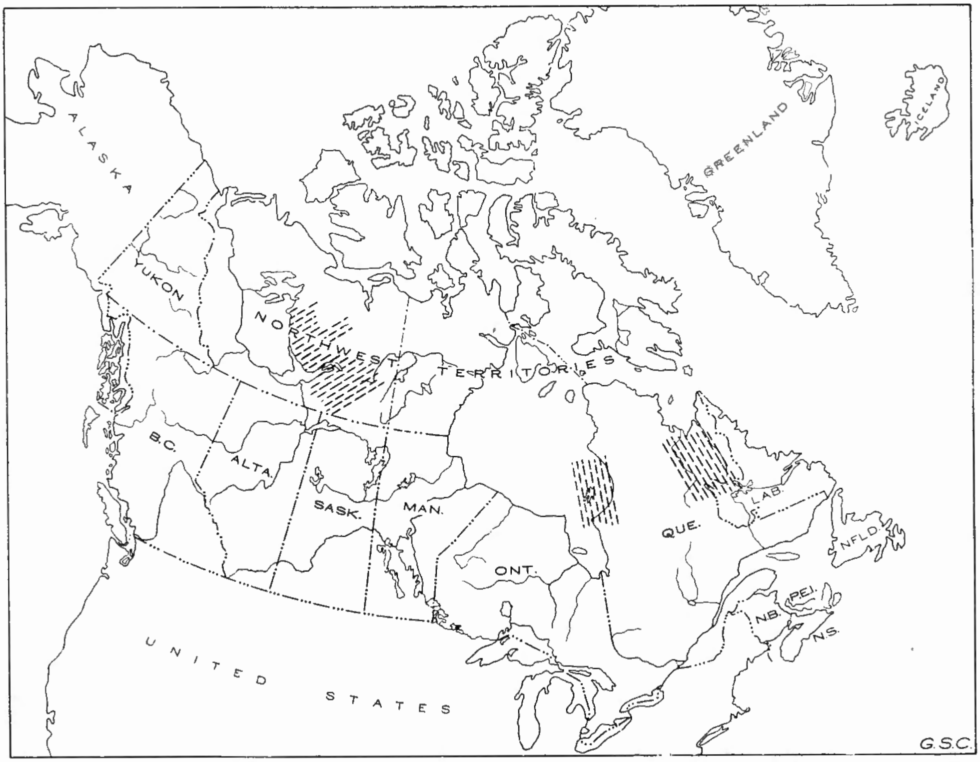


Figure 4. Mountain ranges after the close of Animikie time.

It is now well recognized that when such accumulations of sediments become sufficiently great, subsidence ceases and is followed by uplift generally accompanied by folding, faulting, and injection of igneous masses. This was no exception. In the three troughs where deposition was greatest the period ended with moderate folding, much faulting, and intrusion of granites. These three were the Richmond Gulf and Belcher Islands area, the Central Ungava area, and possibly the region between Lake Athabaska and Great Bear Lakes. In each it seems likely that a range of hills or low mountains was formed, striking north, north-northwest, and north-northeast, respectively (Figure 4). Granite intrusion seems to have been particularly great and widespread in the Northwest Territories, but its limits have not yet been defined. Throughout the remainder of the Shield uplift seems to have accompanied crustal disturbances elsewhere, possibly accompanied by some faulting.

The economic importance of the Animikie formations to Canada in the future will be very great. The iron formations of the Ungava band have been proved recently to contain large bodies of merchantable ore; and the leaner ores of the Belcher Islands and the district west of Port Arthur remain as a vast reserve when the richer ores now mined shall have been exhausted. In the Northwest Territories discoveries of pitchblende and silver ores of excellent grade have been found in the rocks tentatively grouped here, and important gold deposits appear to have originated from the granites intrusive into these rocks.

Keweenawan Time

Surficial rocks supposedly of Keweenawan age are found on the Canadian part of the Shield in only three places, namely, the north shore of Lake Superior and Sudbury, in the Northwest Territories, and along the Arctic coast.

East of Port Arthur what T. L. Tanton has called the Sibley series is found overlying the Animikie sediments with some unconformity. It also overlaps the Animikie to lie directly on the Archæan basement for about 100 miles north of Lake Superior, extending north somewhat west of Lake Nipigon almost as far as the north end of that lake. The rocks are mainly mudstones, with some sandstone and a little chert and limestone. In places the mudstones and sandstones have a calcareous cement. Many of them are red or purple, and many are ripple-marked or exhibit textures indicating mud flowage. West of Lake Nipigon, some beds of reddish dolomite are considered to belong to the Sibley series. The Sibley series has been considered, somewhat doubtfully, as equivalent to the Lower Keweenawan of the south shore of Lake Superior.

What Tanton has termed the Osler series directly overlies the Sibley series 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.

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 are a very thick succession of volcanic breccias and tuffs, with some lava. These tuffs exhibit little bedding, so that they may have been deposited on land. At the top they grow finer in grain, and bedding appears; they thus pass gradationally into the Onwatin black slate, a formation estimated as about 3,700 feet thick. It is very thinly and perfectly laminated, and altogether lacks ripple-marks, crossbedding, or other evidences of deltaic deposition or wave or current action. At the top, the Onwatin slate begins to include sandy material, and passes into the Chelmsford sandstone, or quartzite, several hundred feet thick. This formation exhibits crossbedding and other features that suggest deposition on tidal flats.

Associated with all these Keweenawan surficial formations are immense volumes of basic intrusive rocks. In the main these appear as great sheets, such as the Logan sills of Thunder Bay district and the norite mass of Sudbury district, but dykes are also numerous, particularly in Thunder Bay district.

Along the Arctic coast, at or soon after the beginning of Keweenawan time, a downwarping appears to have begun creating a new element of major structure, a synclinal basin of deposition that may be termed the Victoria Island trough. The basin is described by O'Neill as oval in shape, extending from Cape Lyon eastwards to Boothia Peninsula, a distance of about 600 miles, and having a width of about 300 miles. In this trough the Coppermine River series was deposited, together with Palæozoic rocks at least as late as Silurian.

The Coppermine River series occupies large areas along the Arctic coast, and dips northward at angles of 8 to 12 degrees. According to O'Neill's descriptions, the lower 14,000 feet consists predominantly of basaltic flows with thin interbeds of conglomerate. These are succeeded by dark red to brown, sandy shales, and these in turn by fine- to medium-grained, red to brown, arkosic sandstones, interbanded with a few flows and intruded by sills of diabase. This upper, sedimentary part of the series, if the beds are not repeated by faulting, is of enormous thickness; O'Neill calculates at least 34,000 feet. The whole succession resembles so strongly that on the south shore of Lake Superior, termed by Leith the Middle and Upper Keweenawan, that the two have always been correlated.

The Athabaska series underlies two large areas in the northwest, one south of Lake Athabaska, the other occupying much of a large area of Proterozoic rocks that extends from Dubawnt Lake almost to the head of Chesterfield Inlet. A wide branch of the same body extends up Thelon River, and may continue north from this stream to the Arctic Ocean. The rocks are described as rather coarse, reddish sandstones with conglomeratic phases in many places. Throughout most of this region they lie almost flat and thus afford little information as to their thickness and succession. On the north side of Lake Athabaska, however, the rocks are folded into a syncline trending northeast, in which the dips on the limbs average 35 degrees, and may attain 65 degrees locally. The section thus obtainable indicates that the beds there have an aggregate thickness of about 8,000 feet. They are made up of reddish sandstones and conglomerates, the latter in greatest abundance toward the base of the series. The boulders of the conglomerate are of all the underlying sedimentary and igneous rocks, are well rounded, and up to 3 feet in diameter. The series shows a great deal of cross-bedding, and ripple-marks, sun-cracks, and rain-prints are common. It overlies Beaverlodge sediments with a structural unconformity of 50 degrees, and also overlies the Late Precambrian granite that cuts the Beaverlodge. Interbedded with the sandstones and conglomerates are five flows of dense amygdaloidal basalt. The series is cut in places by dykes of diabase.

The lithological and structural features of the Athabaska series indicate that it was a subaerial deposit, probably laid down in broad basins between mountains of considerable relief. These were, as we have seen, the conditions prevailing in this region after the close of the Animikie period. The petrographic make-up of the series and its relations to older and younger formations seem to demand its correlation with the Keweenawan.

Outliers, probably, of the Athabaska series, have been found on the south shore of Great Slave Lake and the northeast shore of Great Bear Lake. They have been termed the Et-Then and Hornby Bay groups, respectively.

The Et-Then group consists of conglomerate at the base, succeeded by coarse sandstones and quartzites with a few pebbles. The conglomerate is made up of well-rounded boulders mostly 6 inches to 2 feet in diameter, and ranges from 400 feet to several thousand feet in thickness. The sandstones and quartzites are red, white, or greenish, exhibit excellent crossbedding, and are ripple-marked. The group lies on an erosion surface that bevels the Great Slave group, various diorites, granite, and all sediments older than the granite. Commonly dips vary from 5 to 20 degrees, though they may be higher near faults. The group seems to contain a few flows of amygdaloidal lava, and is cut by sills and dykes of diabase.

The Hornby Bay group likewise consists of conglomerate at the base, overlain by sandstones and quartzites, some of them pebbly. The conglomerate is made up of well-rounded boulders up to 10 inches in diameter, and is more than 100 feet thick. The sandstones and quartzites are buff, pink, mauve, white, and dove-grey; they are interbedded with conglomerates. The total thickness of the group is reported as about 500 feet.

End of Keweenawan Time. Keweenawan deposition appears to have ended with an uplift that must have been followed by long-continued erosion, for later rocks are not found over most of the Shield, and those that do appear are mostly of much later age. On the Arctic coast, Great Slave and Great Bear Lakes, and Hudson Bay the next rocks to appear are Ordovician. Along the southern edge of the Shield they are very late Cambrian and early Ordovician.

The uplift in a few places was accompanied by small folding movements, such as those that formed the syncline in the Athabaska sandstones just north of Lake Athabaska, the low dips in the Et-Then series, and the subsidence of the Victoria Island trough that produced the low dips of the Coppermine River series.

An important movement, which, however, began long before the end of the period, was the development of the Lake Superior syncline. The downwarp began in Middle Keweenawan time and continued throughout the remainder of the period. This is indicated by the fact that the lakeward dips of the lower beds of the series are greater than those of the higher beds. Downwarp was practically complete by the end of the period.

There was some igneous activity during the later part of Keweenawan time. At Sudbury big dykes of olivine diabase cut both the Whitewater series and the norite irruptive. The Murray and Creighton granites, which are probably correlative with the Killarney, also cut the norite. The Killarney granite itself is a great mass extending from near Sudbury southeast for an unknown distance into eastern Ontario. Along the Arctic coast basic dykes and sills cut the Coppermine River and Athabaska series.

Keweenawan strata have carried important deposits of native copper on the south side of Lake Superior, but on the north shore only commercially unimportant occurrences have been found. On the Arctic coast the Coppermine River series has long been known to contain native copper, from which Indians and Eskimos for generations have made tools and weapons. O'Neill's explorations indicated the likelihood of finding valuable deposits there, but although some search has since been made no important orebody has been discovered. At Sudbury, the great deposits of copper-nickel ores appear to have been formed in late Keweenawan time.

PALÆOZOIC AND LATER HISTORY

Following the close of Keweenawan volcanism and sedimentation a very long period ensued, lasting until late Cambrian or early Ordovician time, of which there is no record. During this interval winds, rains, and streams gnawed at the surfaces of the Shield, rotted the exposed rocks, and carried the debris to the sea. At the end of that time the Shield appears to have been a flat plain, featureless except for a few scattered hills and some low broken ridges representing the roots of the Proterozoic mountain ranges. The plain lay close to sea-level, and stretched from the waters of the Atlantic westward across what are now the Great Plains to a long, narrow embayment of the sea occupying the present site of the Rocky Mountains. The west side of this embayment appears to have been a hilly area on the site of the present Purcell and Selkirk ranges.

The subsequent history of this great plain illustrates excellently the real instability of the apparently solid crust of the earth. It is easy to see that a comparatively slight downward movement of such a low, flat surface would result in the flooding of wide areas by the sea, and that an equally slight upward movement would cause correspondingly widespread withdrawals. The Palæozoic history, as registered in the rocks, is a succession of such advances and retreats of the sea.

Space does not permit here of more than a thumb-nail sketch of these movements, which are treated in detail elsewhere in this volume and in other published accounts[1]. It will be sufficient to say that in early Ordovician time the Canadian Shield was an island, bounded on the north and east as at present by the Arctic and Atlantic Oceans; on the south by a shallow epicontinental sea, the shore of which was approximately St. Lawrence and Ottawa Rivers and the north shore of Lake Huron, and passed westward somewhat south of the Manitoba boundary; and on the west by the Cordilleran trough, which occupied the present site of the Rocky Mountains and may have extended east past the mouth of Mackenzie River.

In mid-Ordovician (Trenton) time a small downwarping of the surface permitted the sea to enter the basin of Lake St. John, Quebec, where limestones and other sediments were laid down, of which remnants still remain.

Toward the end of Upper Ordovician (Richmond) time a large downwarping of the western part of the Shield took place. The Cordilleran trough was widened until its waters extended across the Prairie Provinces into Manitoba. A great depression formed in the middle of the Shield, allowing waters from the Arctic to flood in and form the earliest ancestor of the present Hudson Bay. The east shore of this great bay appears to have lain farther west than at present, and may have been formed by the hilly remnants of the older Belcher Range. A long, narrow extension to the south reached to the present basin of Lake Timiskaming; but a barrier, perhaps the remnants of the old mountain range along the north shore of Lake Huron, separated this extension from the seas occupying the Lake Huron basin. On the west, at the time of greatest submergence, the waters of this bay extended across northern Manitoba to unite with those of the Cordilleran trough. These conclusions are indicated by comparison of the fossil faunas of the rocks in the areas mentioned.

The Ordovician period closed with a widespread uplift of the land and a consequent withdrawal of the sea. However, in early Silurian time a second downward movement of the land surface brought the seas back to approximately the same positions they had previously occupied in Richmond time. This submergence was ended by a second widespread emergence that lasted throughout early Middle Silurian time, when a third submergence again drowned the Hudson Bay and Lake Timiskaming regions, but did not enter Manitoba. At this time the barrier between the Lake Timiskaming and Lake Huron areas was finally broken down, so that the faunas mingled. Towards the close of the Middle Silurian another general uplift drained the Hudson Bay trough.

The Shield continued to be a land area during Upper Silurian and the first half, roughly, of Lower Devonian time. Deposits of Middle and Upper Devonian

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[1]Cooke, H. C.: Trans. Roy. Soc., Canada, 3d ser., vol. 25, sec. IV, pp. 127-80 (1931).

age are found in the regions of James Bay and southwestern Ontario, and the similarity of faunas indicates that an open seaway between the two areas existed.

The Cordilleran trough was also greatly widened during Middle Devonian time, so that rocks of this age are found as far east as Manitoba. There is little similarity, however, between the faunas of these rocks and those of James Bay, so that probably submergence did not extend across the gap between them, except possibly for a short interval during latest Middle Devonian time.

The close of the Devonian period was marked by a strong upward movement that drained the seas completely from the Hudson Bay trough and the southern Ontario areas, and greatly constricted the Cordilleran trough. This movement seems to have coincided roughly with the intense folding and mountain building of the later Devonian, which took place in Gaspe and the Eastern Townships of Quebec.

During the remainder of Palæozoic time, so far as the records indicate, no sediments were deposited on the Shield, so that it probably remained a land area. In late Pennsylvanian time there were strong orogenic movements in the east, when the Appalachian ranges were built. Events in the west are more obscure. Uplift may have occurred at intervals in late Palæozoic and early Mesozoic times, but at least some Permian and considerable Triassic marine sediments were laid down in the Cordilleran trough and in more western parts of the Cordilleran region.

It is not to be supposed, however, that the sum of these uplifts, known and possible, was very great, in the western part of the Shield at least. The total thickness of Palæozoic strata, both in the Manitoba and Hudson Bay areas, was only about 1,000 feet; and these strata were mainly soft limestones and dolomites, with minor amounts of shale and sandstone. Yet in spite of the fact that these easily eroded strata lay above sea-level from the end of the Devonian to Jurassic or early Cretaceous time, they have been completely removed only across a gap 200 miles wide. It may, therefore, be inferred that the region lay close to sea-level, so that erosion proceeded very slowly.

It has been rather commonly considered that this long erosion period must have resulted in very perfect peneplanation of the Shield, and formed the so-called "Cretaceous peneplain"; but however great may be the inherent probability of this assumption, direct evidence of its truth is as yet very scanty, and more observations are urgently required before it can be considered proved.

Much of Canada, including all of the central and eastern parts, remained above sea-level during early Mesozoic time. Marine Triassic and Jurassic sediments, however, are found in parts of the Cordilleran trough. Knowledge of the diastrophic history of British Columbia in Mesozoic time is incomplete, but in late Jurassic time a long, narrow area, west of the Rocky Mountain Trench and including Selkirk Mountains, was elevated into high mountains. At about the same time the country to the east, the site of the present Rocky Mountains and Great Plains, was depressed. As a result, the Cretaceous period was marked by a great transgression of the sea over the western interior of the continent. Cretaceous deposits extend from the Rocky Mountains almost to Lake Winnipeg, and once probably extended farther to the east over the western side of the present Shield.

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, as 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. They did not, however, extend as far east as the south end of James Bay, for late Jurassic or early Upper Cretaceous strata fou... Mattagami River are definitely non-marine deposits, with abundant ... remains.

The Cretaceous period ended with a gentle uplift that caused the s... retire from the Great Plains. The land remained low throughout mo... Paleocene time, until the great thrust from the west that formed the R... Mountains. With the uplift of the Rockies, the western plains appear a... have been raised, and it may be presumed that the western edge of the S... was raised with them.

Another long period of erosion lasted from late Eocene to Pliocene t..., again resulting in a fairly perfect peneplanation of the Shield. The remain... this peneplain are to be seen today in the even skylines of the Shield.

At some time in the Pliocene, probably after the middle of the epoch, ... Shield was uplifted, warped, and faulted. After the uplift, according to the data at hand, the land surface stood between 300 and 700 feet higher than today, and the present Hudson Bay depression was not so pronounced, so that the land surface sloped more to the north than it does now. With this exception, the contour of the surface appears to have been much the same as at present, with high lands on the Atlantic and St. Lawrence sides. Some streams, specifically Hamilton, Moisie, Saguenay, and Stillwater Rivers, appear to have maintained their courses throughout the period of uplift. The faulting that accompanied the uplift was no doubt widespread, but only a few faults can now be recognized as probably developed at that time. The Lake Melville-Double Mer basin, at the mouth of Hamilton River, is a downfaulted block of about this time; the Lake St. John basin is a second, and the Lake Timiskaming basin a third. The steep south-facing scarp of the Shield has been proved a fault scarp in several places, and though these faults may not have originated during the uplift of the Shield, movement on them was almost certainly renewed at that time.

The Pliocene uplift of the Shield was followed by renewed erosion, during which the larger streams cut moderately wide valleys with fairly well graded bottoms. Exceptions are the valleys of those streams that cut through the uplifted edges of the plateau; these have narrower, canyon-like valleys. Outside of the main valleys, the general surface was dissected to about the extent it is today, and acquired a relief of 75 to 150 feet.

The next episode was glaciation. The whole Shield was covered by vast sheets of ice, probably a mile or more in thickness. As the effects of glaciation are considered in another chapter, discussion will here be confined to pointing out that the weight of these ice-sheets depressed the land surface of the Shield, on the average, a distance of 1,000 to 1,200 feet. The central, Hudson Bay region was depressed somewhat more than the rest, so that ice flowed into it from the east and west to escape through Hudson Strait. This movement gave Hudson Strait, which prior to that time was probably merely a river valley or estuary, its present great width and depth; it probably also scooped out to some extent the present Hudson Bay depression.

When the ice disappeared, a certain amount of elastic rebound took place, and the land surface rose again. It did not, however, recover its former height. The Atlantic coast rose only some 250 to 350 feet, the north shore of the St. Lawrence 400 to 600 feet, and the east side of Hudson Bay apparently 600 feet or more. It is obvious, therefore, that the recovery was accompanied by some warping of the surface, but the rise was not sufficient to bring the Hudson Bay area above sea-level, so that it has remained an inland sea.

ECONOMIC GEOLOGY

The mineral resources of the Canadian Shield are numerous and varied. Gold is the substance of greatest dollar value produced, but nickel, copper, and iron are also mined in quantity. The Cobalt camp has been one of the great silver producers of the world; and silver can still be mined at various places on the Shield. Pyrite has been utilized for its sulphur content, in considerable quantity, and great deposits of it still remain. Ores of lead, zinc, cobalt, and radium, and deposits of corundum, apatite, graphite, feldspar, fluorspar, mica, and a variety of other substances are known and have been mined to a greater or less extent. Conspicuously lacking are deposits of coal and oil. Such deposits were the products of animal and vegetable life; and if life existed at all in Precambrian time, it had not progressed to the stage where it could leave recognizable remains.

The geological map of the Shield shows it made up of islands of volcanic or sedimentary rocks, surrounded by a great sea of granitic rocks. Except for the minerals found associated with pegmatite veins, such as feldspar, cassiterite, molybdenite, beryl, spodumene, and tantalite, and those genetically related to bodies of basic intrusive rocks, all the ore deposits of the Shield are associated with the non-granitic "islands" though in a few instances ore is found to extend outward for short distances into the granite itself. The "islands", particularly if large, may include more than one mining camp, each with its own peculiar geological or structural characteristics.

GOLD

Gold has been found in many places throughout the Canadian Shield from Great Bear Lake southeastward through northern Saskatchewan and eastern Manitoba into western and northern Ontario and western Quebec. In addition to deposits valued solely or chiefly for their gold content, other ores hold the precious metal, such as the nickel-copper ores of Sudbury, the copper ores of Noranda, and the Flin Flon sulphide body in Manitoba. Discoveries have been made in areas of varying size, which may be separated from one another by very broad areas where no deposits have yet been found. Most of the discoveries have been made in the more readily accessible areas, but, so far as known, the general geological conditions are much the same in the rest of the Shield.

In 1942 there were one hundred and six gold mines in operation on the Shield, twenty-seven in western Quebec, sixty-five in Ontario, five in Manitoba, one in Saskatchewan, and eight in the Northwest Territories. Many, due mainly to war conditions, have since been forced to cease operations. Of the mines, eighteen may be classed as large, as they treat 1,000 tons a day or more. The largest is the Hollinger, which in 1942 treated 5,700 tons a day. Of the others, seventeen milled between 500 and 1,000 tons a day, the remainder smaller amounts.

All the orebodies are of the vein or lode type; placers are entirely lacking on the Shield. In many, belts of sheared rock carry stringers and veins of quartz between layers of schist, and the schist may be more or less silicified or mineralized. In others, brittle rocks adjacent to faults or lying between closely spaced faults may have been shattered so as to allow ingress to the mineralizing solutions, and wide belts of mineralized and silicified material may constitute the ore.

In most of the types, depth alone appears to have little effect on the size or the grade of the orebodies. Mining has been carried in many of the larger mines to depths of about a mile without appreciable change in the character of the ores. Difficulties, however, such as rock bursts, do appear in mines carried to such depths, and these will, presumably, limit eventually the depths to which mining can be carried.

All the veins are of the deep zone type. None of them exhibits the crustified structure found in many veins in later rocks, which is due to the gradual filling of open fissures. All appear to have been formed by solutions forced [illegible] closed fissures under pressures sufficient to push the enclosing walls apart. The vein-forming solutions appear also to have had high temperatures, for many of the veins now carry minerals such as tourmaline, specularite, and a [illegible] feldspar, which so far as known are formed only under such conditions.

It may be inferred from these facts that the veins were formed at profound depths and at temperatures that changed very little throughout a great vertical range, so that in the relatively shallow depths penetrated by mining operations little change in the character of the ores may be expected.

The most productive part of the Shield, as yet, is the Porcupine-Kirkland Lake-western Quebec section, roughly 200 miles long and perhaps 5,000 square miles in areal extent. This district, in which are the important gold mines of Porcupine and Kirkland Lake, in 1940 produced 3,512,875 fine ounces of gold, or more than 66 per cent of the total Canadian production for that year.

The first discovery on the Shield was made in southeastern Ontario in 1866, and further prospecting continued to reveal veins throughout Peterborough, Hastings, Addington, and Frontenac counties, a distance of 70 miles. The rocks are ancient crystalline limestones and sedimentary gneisses of the Grenville and Hastings series, together with granite, diorite, and other intrusive rocks. Some ancient lavas also occur. The veins are found in any of these rocks but seem more common near the contacts of granite or diorite, though later than both. They consist of quartz, accompanied in places by carbonates, and mineralized most commonly by visible gold and arsenopyrite, though in some deposits pyrite occurs instead. The Deloro deposit in Hastings county contained so much mispickel that it was mined for arsenic as well as gold.

Most of these deposits were of rather small size and of low to medium grade. From the information available, they also appear to have become rapidly leaner with depth. A considerable amount of gold was taken from them, chiefly during the nineties and the first 3 or 4 years of the present century, when costs of extraction were perhaps $2 a ton lower than at present. Attempts were made to operate several of them again in the 1935-40 period, but with indifferent success.

The next discoveries in the Canadian Shield followed closely the completion of the Canadian Pacific Railway in 1886. These deposits were found throughout western Ontario between Port Arthur and the Manitoba boundary, but were most numerous near Lake of the Woods. Intense excitement prevailed, and development was carried rapidly forward, although much of it, as in all such cases, was unjustified. The field produced, however, more than $2,000,000 in gold, mainly between 1897 and 1903, although several of the properties have been operated intermittently since that time. None of the mines was carried below a depth of 600 feet.

The veins for the most part occur in altered Keewatin lavas in the neighbourhood of granite contacts. Some of them run into the granite or lie wholly in granite. The more productive veins have been as a rule rather narrow, not more than 5 feet in width. Larger veins are apt to be of the lode type, composed of a multitude of quartz stringers separated by bands of country rock. The veins vary greatly in width, a 5-foot vein narrowing in places to 1 foot or 2 feet, and swelling in others to 7 or 8 feet.

The gangue mineral is chiefly quartz, accompanied as a rule by some calcite, ankerite, or other carbonate. Tourmaline is present in many veins. The principal constituent of value is native gold. Much of the gold was coarse, so that individual specimens and short sections of veins were extraordinarily rich and spectacular. This condition rendered the mines unusually liable to theft, and large quantities of gold are known to have been lost in this way. Tellurides of gold were found in some of the more important mines; pyrite is the principal sulphide; arsenopyrite, bismuthinite, chalcopyrite, and molybdenite also occur. The most important mines in the district were the Mikado, Regina, and Sultana. The first two produced about $500,000 each, the last about $1,000,000. Spasmodic attempts have been made to re-open these and other properties from time to time, but they have remained open for short periods only.

The failure of the Lake of the Woods area to fulfil the bright promise of its early days discouraged gold seeking in the Precambrian for many years. Fortunately, however, the great silver discoveries at Cobalt in 1903-4 caused an influx of thousands of prospectors into northern Ontario; and as the Cobalt field was taken up, these men spread far and wide over the surrounding country in the search for new deposits. The result was the discovery in 1909 of the great Porcupine gold field, and, in 1911-12, of the Kirkland Lake field. The yield from these fields made Ontario the premier province of the Dominion as regards gold production, and eventually brought Canada into second place as a world producer.

For some 20 years the four great mines of Porcupine district—Hollinger, McIntyre, Dome, and Vipond—together with those of Kirkland Lake district, Teck-Hughes, Kirkland Lake, Lake Shore, Wright-Hargreaves, Tough Oakes, and, in the later part of the period, the Sylvanite, remained almost the only gold producers of the Shield. Some gold was obtained from the Croesus property in Munro township, the Barry-Hollinger mine at Boston Creek, the Argonaut mine in Gauthier township, the St. Anthony mine on Sturgeon Lake, and the Central Manitoba mine in the southeastern part of that province. Minor amounts were also won from a number of properties that were worked for short periods or at intervals, but presumably at a loss.

In 1929, however, at the end of a long period of boom expansion and inflated stock market values, foresighted persons began quietly to turn their paper profits into gold. Results were twofold; the boom collapsed, to be succeeded by a great depression in which prices of commodities dropped; and governments, unable to withstand the drain on their gold resources one after another "went off the gold standard", that is, they refused to exchange their paper currencies for gold. In consequence, the value of the currencies depreciated in terms of gold, or, as it is commonly put, the "price" of gold, expressed in currency, rose. Wages and other costs being still payable in currency, however, underwent no change or even fell. The gold mines thus benefited doubly; their costs fell, and the "price" of their product was increased. The process culminated in January 1934 when the price of gold in currency was officially set by the United States at $35 an ounce. Disturbances of trade later caused Canadian currencies to depreciate still further, so that the United States price of $35 became equivalent to $38.50 in Canadian currency.

These changes stimulated Canadian gold mining enormously. Ores that previously would barely have paid the costs of extraction became highly valuable; and ores much lower in grade, if present in large volume, became minable at a profit. Existing mines had large volumes of low-grade ore added to their reserves, and their lives were extended accordingly. New mines sprang up on the Shield like mushrooms; and where before there had been only some fifteen or sixteen gold mines in profitable operation, the number rose rapidly to one hundred and six in 1942. All the mines of western Quebec, some twenty-six in number, were developed during this period, together with all the mines of Thunder Bay district (nine) and of Patricia district (twelve), and about twenty-five properties in the old established Porcupine-Kirkland Lake area and the adjacent country. A few of these properties, it proved, could have operated profitably at the old price of gold, but the remainder could not.

During the closing years of the last war prospecting has been vigorous, and coupled with intensive diamond drilling has brought to light many new orebodies, particularly in western Quebec and the Northwest Territories. Now that mining machinery is once more available, steps are being taken to bring them into production, and some will undoubtedly have reached that stage by the time this report appears in print. Obviously, no description of these is here included.

In the following pages the principal features of the more important gold camps of the Shield today are briefly outlined. The descriptions begin with the easternmost field, that of western Quebec, and continue with those lying successively farther west. Lack of space precludes extensive description of individual properties, and confines the accounts, in the main, to the major features common to groups of mines, or camps.

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 the Keewatin lavas. Seven mines, the Siscoe, Sullivan Consolidated, Lamaque, Sigma, Cournor, Perron, and Payore Holdings, 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 tension cracks associated with them; and in places the walls are replaced by mixtures of albite, ankerite, and quartz, with more or less pyrite and tourmaline.

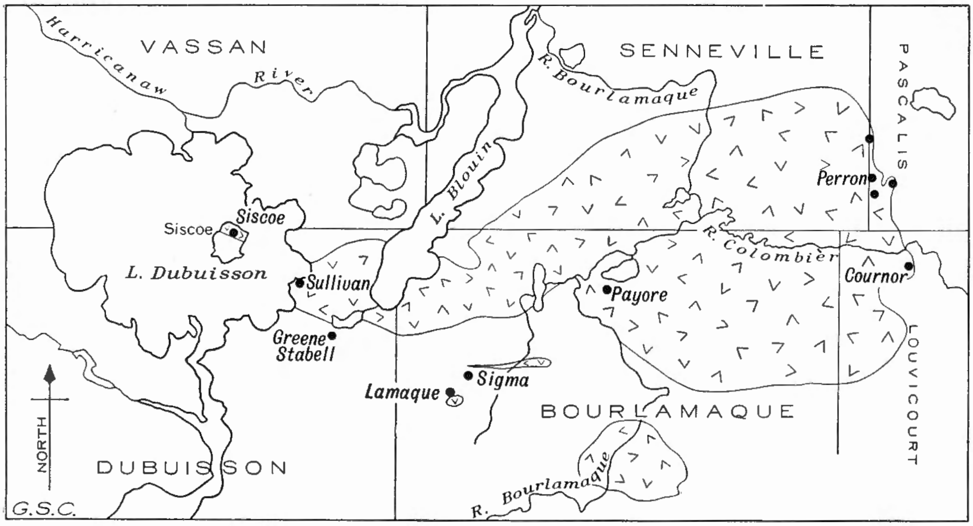


Figure 5. The Bourlamaque granodiorite (V-pattern) and gold deposits in its vicinity.

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). At the east end of this break, Canadian Malartic, Sladen Malartic, East Malartic, and Malartic Goldfields are grouped together because they display certain similarities. Unlike the mines of the western end of the break, their ores contain no arsenopyrite or 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 mines are silicified and mineralized greywacke; those of the East Malartic and Malartic Goldfields properties are 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.

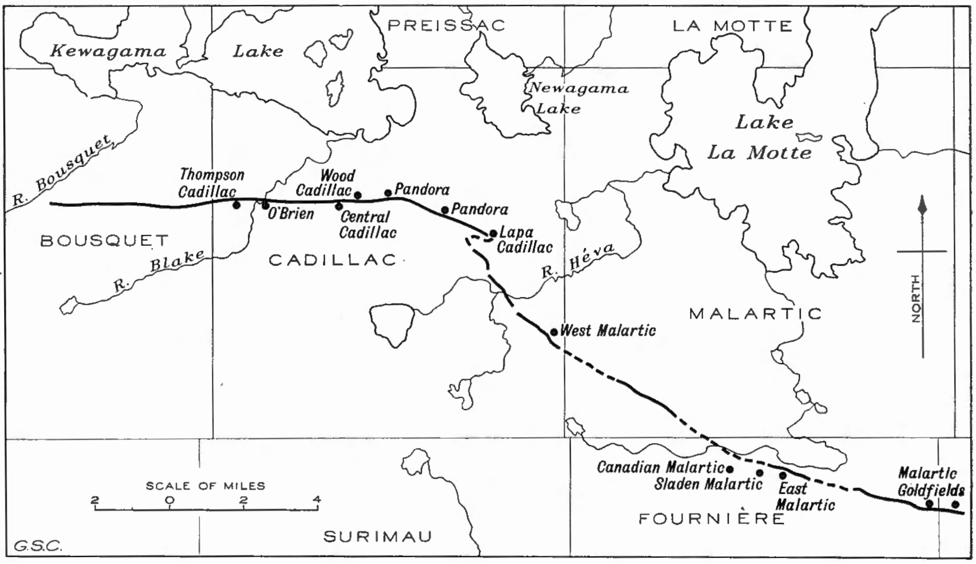


Figure 6. The Cadillac "break" (heavy line) and the mines related to it.

The second group of mines associated with the Cadillac break lies a few miles to the west in Cadillac township (*See* Figure 6). The O'Brien mine has been the principal producer; others are 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 to 10 feet wide; these carry gold values and materially increase the minable 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, a wide band of contorted mica-chlorite schist, but in subsidiary fractures, usually south of the break, where hard or brittle rocks that fracture rather than shear happen to occur.

Space does not permit the description of several other, more isolated gold mines in western Quebec, the Belleterre Quebec, Beattie, Arntfield, Francoeur, McWatters, and Granada.

The chief gold producer of western Quebec, however, is Noranda Mines, at Noranda, of which the principal product is copper, and the gold merely a valuable by-product. At this property, acid lavas and tuffs of the Keewatin type have been bent and shattered by intense drag-folding, and then replaced by pyrite, pyrrhotite, and chalcopyrite. The copper ores thus formed carry gold values, 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 values up to 0·25 ounce a ton. More than 4,000,000 ounces of gold were produced from this mine between 1927, when smelting began, and the end of 1944.

Ontario

Larder Lake. At Larder Lake the country rocks are altered along wide shear zones to masses of ferruginous carbonate shot through with small quartz veins, and in places coloured green by small flakes of mariposite, a green mica. These carbonate bodies contain scattered flakes of native gold, and parts of them are rich in the precious metal. For many years exploratory operations on these bodies were carried on without success; after 1934, however, it became possible to mine some of the higher grade lenses. The Kerr Addison, milling 2,000 tons a day, has been able to mine profitably ore carrying only a little more than one-fifth ounce a ton; the Chesterville, an adjoining property, is operating on ore of even lower grade.

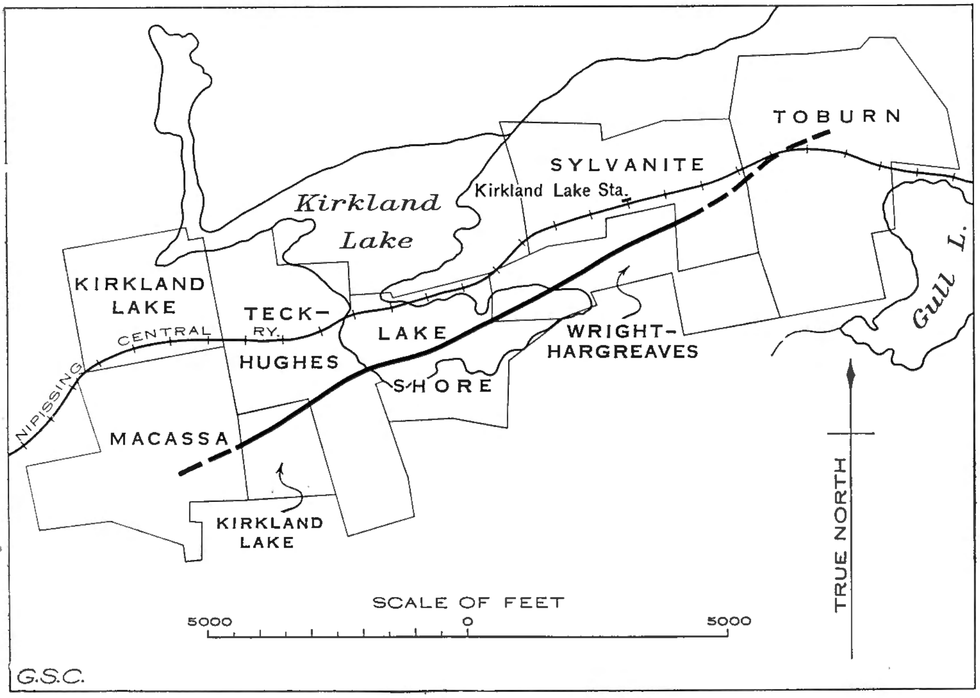


Figure 7. Position of principal gold mines, Kirkland Lake district, Ontario. Mineralized fault shown by heavy black line.

Kirkland Lake. Kirkland Lake area comprises a group of seven large mines, Macassa, Kirkland Lake, Teck-Hughes, Lake Shore, Wright-Hargreaves, Sylvanite, and Toburn (formerly Tough Oakes) (Figure 7). All are in Teck township. The Lake Shore, Teck-Hughes, and Wright-Hargreaves have been the largest producers.

These properties are situated in the midst of a synclinal mass of Timiskaming sediments, closely folded and dipping at high angles. The sediments are mainly conglomerates and greywackes, with some slate. Where the orebodies occur, the sediments are intruded by two igneous rocks, the older a diorite, the younger a reddish syenite porphyry. The syenite porphyry forms a large mass on Wright-Hargreaves property that extends almost to the Lake Shore boundary and throws off long fingers or dykes into the Lake Shore and Teck-Hughes properties to the west.

A large, pre-mineral fault cuts all the rocks with a strike of north 62 degrees east and a dip of 85 degrees south (*See* Figure 7). It is a reversed fault, and the south side has been thrust upward about 2,000 feet. On the Kirkland Lake, Teck-Hughes, and western half of the Lake Shore properties the greater part of the fault movement has been concentrated along one plane. To the east the fault is split, appearing as two faults 300 to 600 feet apart on the eastern part of the Lake Shore and the Wright-Hargreaves properties. Still farther east, on the Toburn, the fault splits into several branches.

The ore has been formed in the crushed and shattered zones of the fault. The width of these zones varies greatly. In places the walls of the fault are close together and the orebody is lean and narrow, as the clayey gouge was not readily replaced. For the most part the brecciated zones are 5 to 10 feet wide, and yield good-grade ore. In a number of places the fault splits into two branches that come together again, leaving a horse of country rock between; such a horse, in many instances, was sufficiently brecciated to permit the entry of ore-bearing solutions, with consequent formation of great widths of ore. Rich bodies up to 50 feet in width or even more have thus been formed.

The nature of the country rock influenced ore formation profoundly. The syenite porphyry, a hard brittle rock, shattered readily in faulting but did not form schist, and, consequently, the veins in porphyry are of good width and grade. The complex of porphyry dykes and diorite on the Teck-Hughes and western part of the Lake Shore properties shattered even more readily and widely, and, consequently, in this section the veins are widest and richest. Where the fault passes into other rock types, such as diorite or sediments, shearing rather than shattering occurs. Such schistose fault gouge does not appear to have been favourable for passage of solutions or for replacement, because though scattered nests of ore occur in it, these are not numerous nor large enough to be mined profitably.

The ore consists mainly of mineralized porphyry with more or less quartz. In places quartz occurs in large masses nearly the full width of the vein, but more often it is found intersecting the porphyry in numerous thin stringers and ribbons. Some calcite is present. The wall-rock is commonly altered to a mass of sericite and carbonate. Gold and gold tellurides are the principal constituents of value, and the tellurides are present in considerable variety and amount. Altaite (PbTe) is the most abundant, but calaverite ($AuTe_2$), petzite ($AgAu_2Te$), hessite (Ag_2Te), coloradoite (HgTe), tetradymite ($Bi_2(TeS)_3$), and melonite ($NiTe_3$) are present in lesser quantity.

These mines have produced, up to the end of 1943, approximately 15.000,000 fine ounces of gold.

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. Various other properties were worked for longer or shorter periods; the largest was the Vipond mine, which operated from 1911 to 1918, and again from 1923 to 1936. After the currency change of 1934 made it profitable to mine lower grade ores, however, a dozen new mines were opened and have produced important amounts of gold. These mines are the Aunor, Broulan

Porcupine, Buffalo Ankerite, Coniaurum, Delnite, De Santis, Faymar, Hallnor, Moneta, Naybob, Pamour, Paymaster Consolidated, and Preston East Dome (Figure 8).

The rocks of Porcupine district include basic altered lavas and some slaty sediments, all of Keewatin age, which are unconformably overlain by conglomerates, greywackes, and slates of the Timiskaming series. These are folded into steeply inclined attitudes and the lavas are intruded by bodies of a grey quartz-feldspar porphyry, and cut by numerous faults (Figure 9).

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 rocks are the Keewatin lavas. The sheared zone 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 south, but a few, toward the northern side of the sheared zone, 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 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* (Figure 10).

A number of 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, with its west end on Hollinger property about 1,400 feet from the McIntyre boundary. The outcrop is canoe-shaped, and underground work has shown that the western "prow" of the canoe dips or rakes eastward at about 40 to 45 degrees along a line striking north 85 degrees east (Figure 11). In depth, therefore, the porphyry is found to lie progressively farther and farther south of the vein zone, which strikes about north 50 degrees east. The recognition of this structure has been of the highest importance in directing the development of the McIntyre mine.

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 values drop off rapidly and become non-commercial (Figure 12), though there have been recent reports that this condition is undergoing some change at depth.

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 recession with depth, other members of the Hollinger vein system appear at depth on McIntyre ground *beneath* the porphyry mass (Figure 13). 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.

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 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.

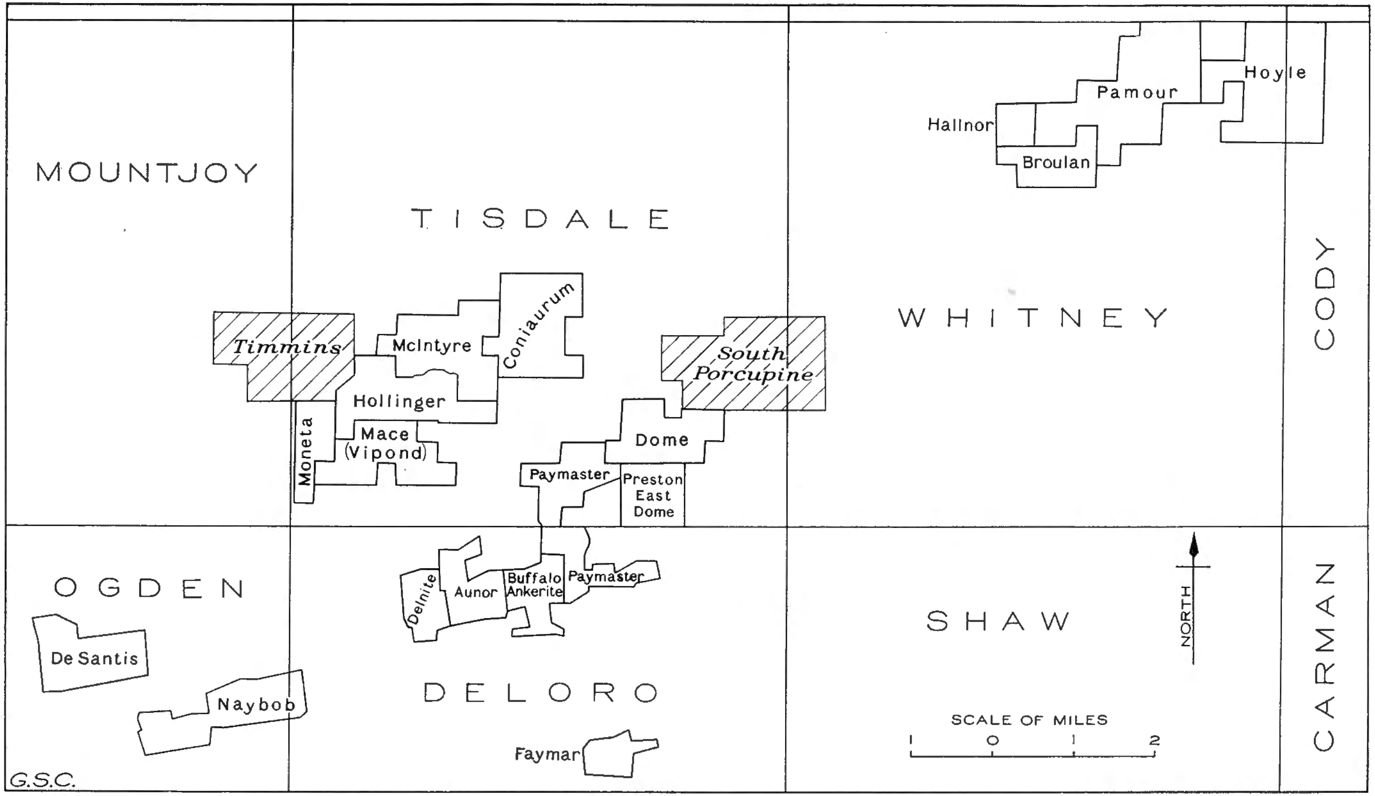


Figure 8. Position of principal mines, Porcupine district, Ontario.

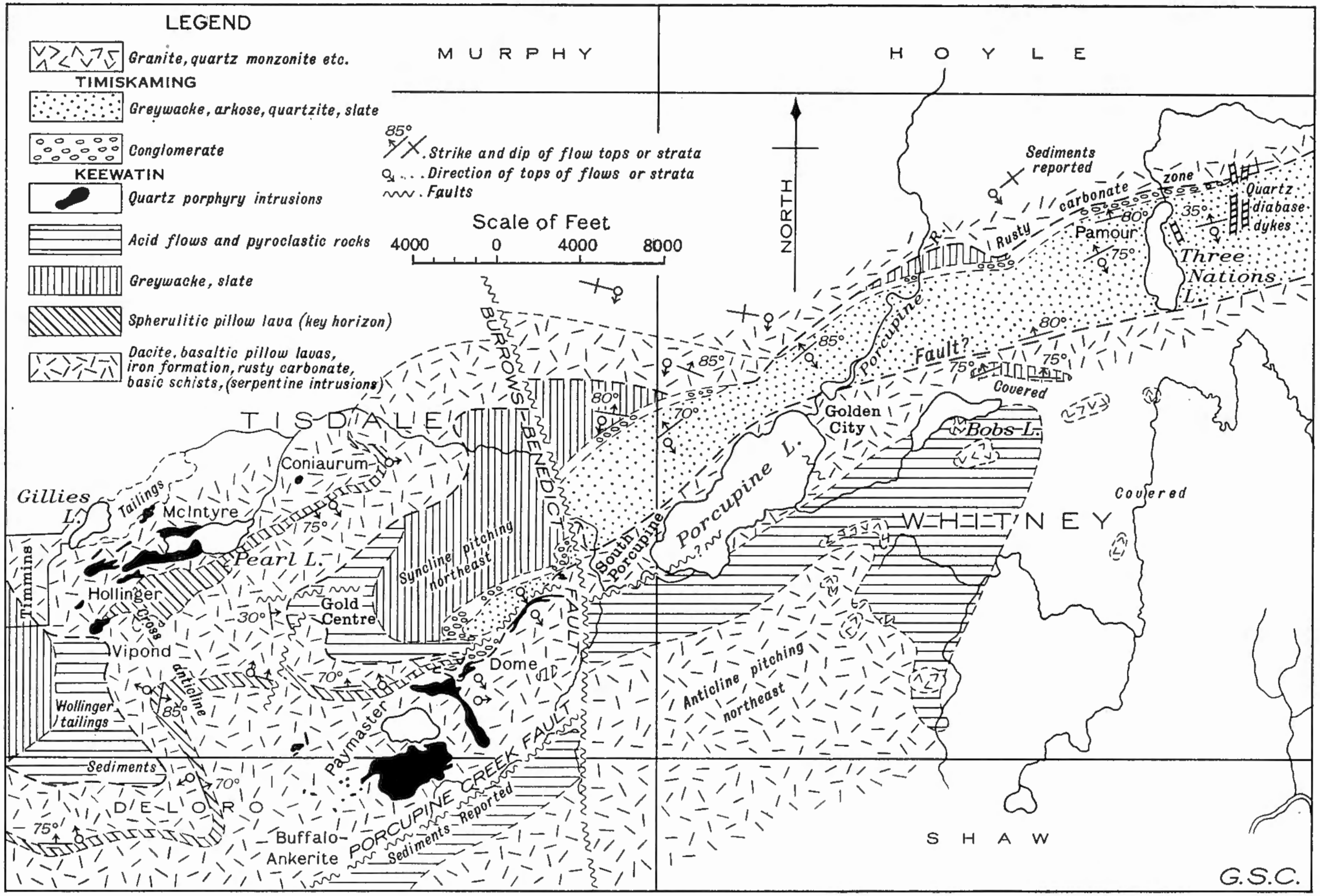


Figure 9. Generalized geological map of the central part of the Porcupine district. (After M. E. Hurst.)

The Dome mine was so called because the original stakings were on large dome-shaped outcrops of quartz. The mine, in the southeast quarter of Tisdale township, lies near the extreme south edge of the basin of Timiskaming sediments, which has a general synclinal structure, plunging northeast. At the south edge of the main syncline a deep, narrow, synclinal trough of the sediments 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. Much of the ore was simply a dark grey schist spotted with auriferous pyrite, and cut by vague veinlets of quartz. This syncline carried the sediments to depths of about 2,500 feet.

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 syncline. 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 14). 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. The dacite fractures more readily than the andesite, so that some important orebodies are found in it alone.

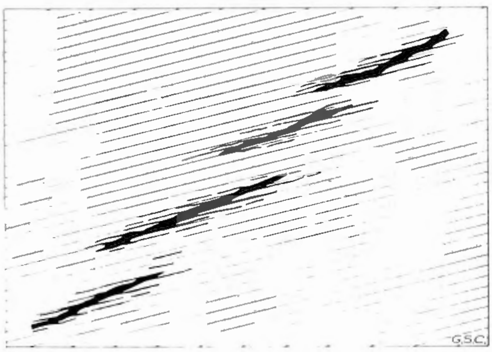


Figure 10. Offsetting of ore lenses in Hollinger mine. Schistosity indicated by fine parallel lines; veins in solid black.

The fracture zones are a complex of quartz veins, which in general strike northeast and dip 35 to 45 degrees northwest, thus crossing both the strike and the dip of the zones. Individual veins may attain widths of 2 feet. Small quartz veins also fill fractures running in various directions, yielding irregular and interlocking masses. Altogether about 30 per cent of the volume of the fracture zones is quartz.

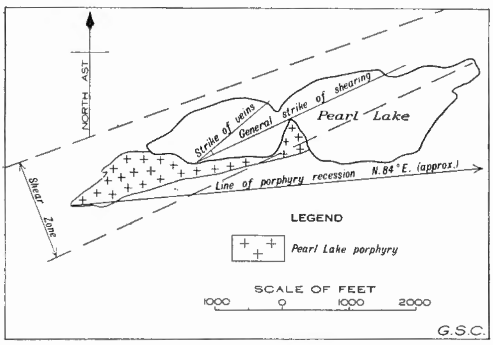


Figure 11. Sketch showing the structural factors of McIntyre geology. (After H. V. Skavlem.)

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 older 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

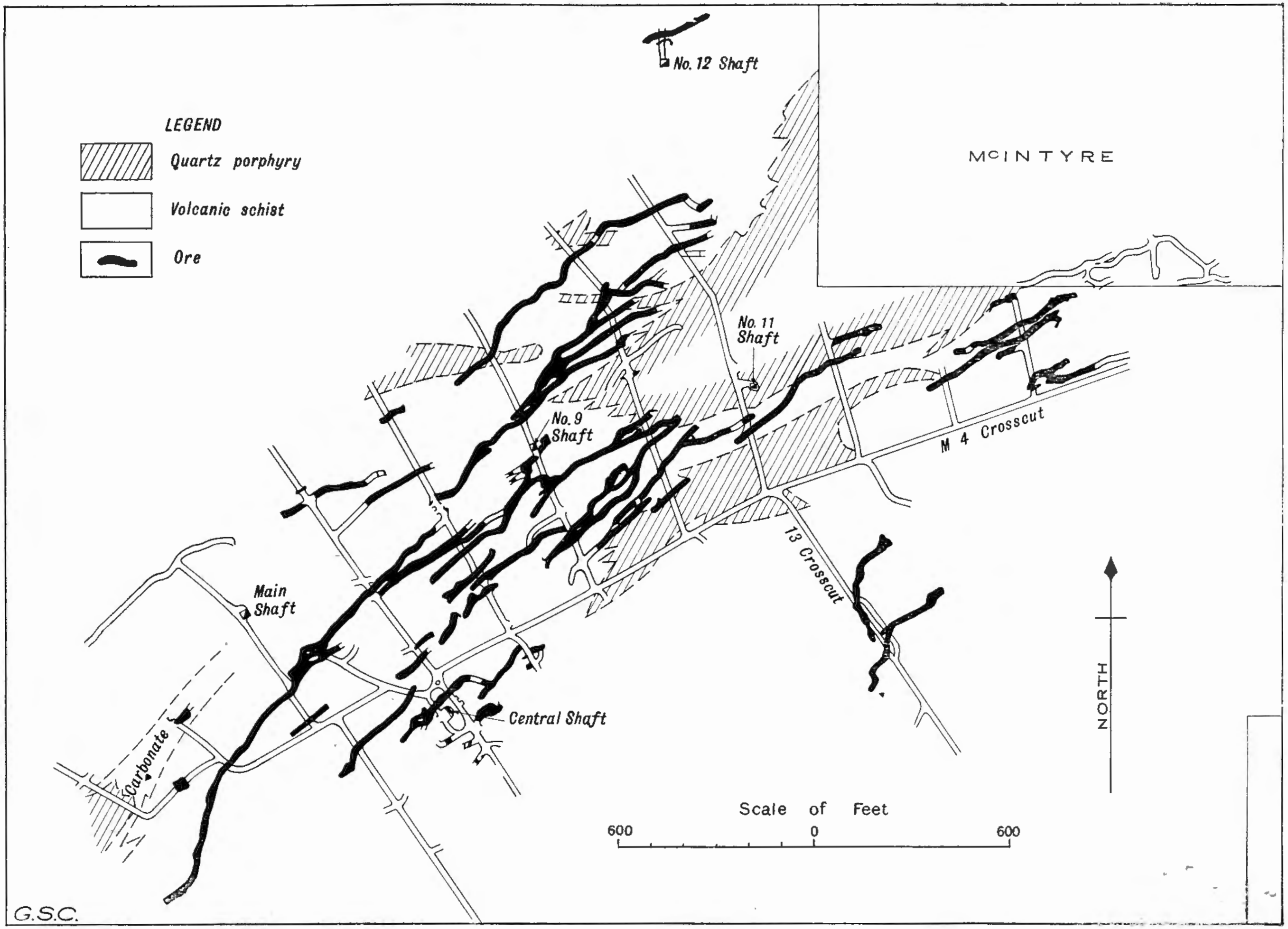


Figure 12. Plan of 550-foot level, Hollinger mine, May 1924, showing how vein zone splits at nose of Pearl Lake porphyry. (After A. G. Burrows.)

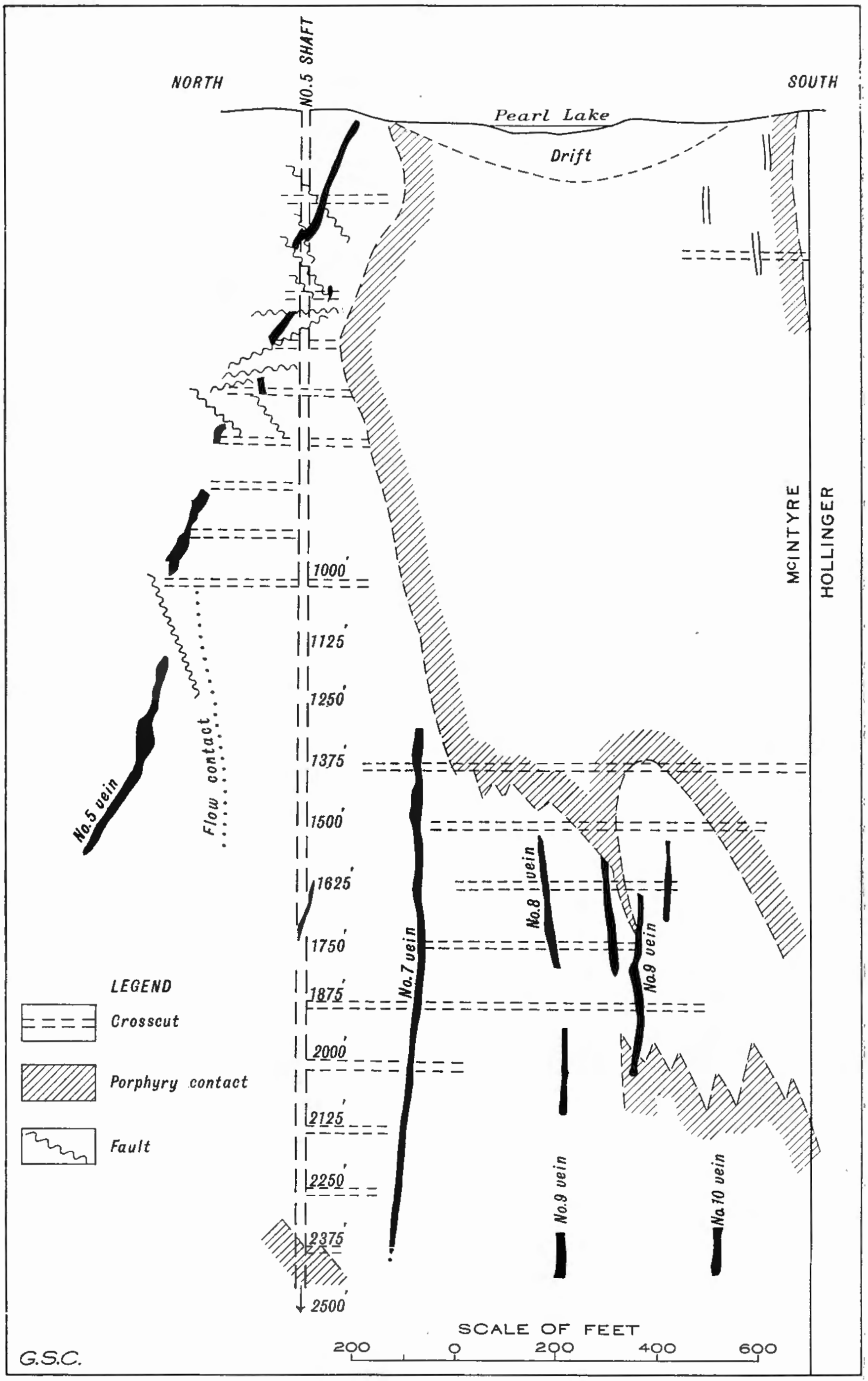


Figure 13. Composite section of McIntyre mine, June 1924, showing development of veins beneath the Pearl Lake porphyry. (After A. G. Burrows.)

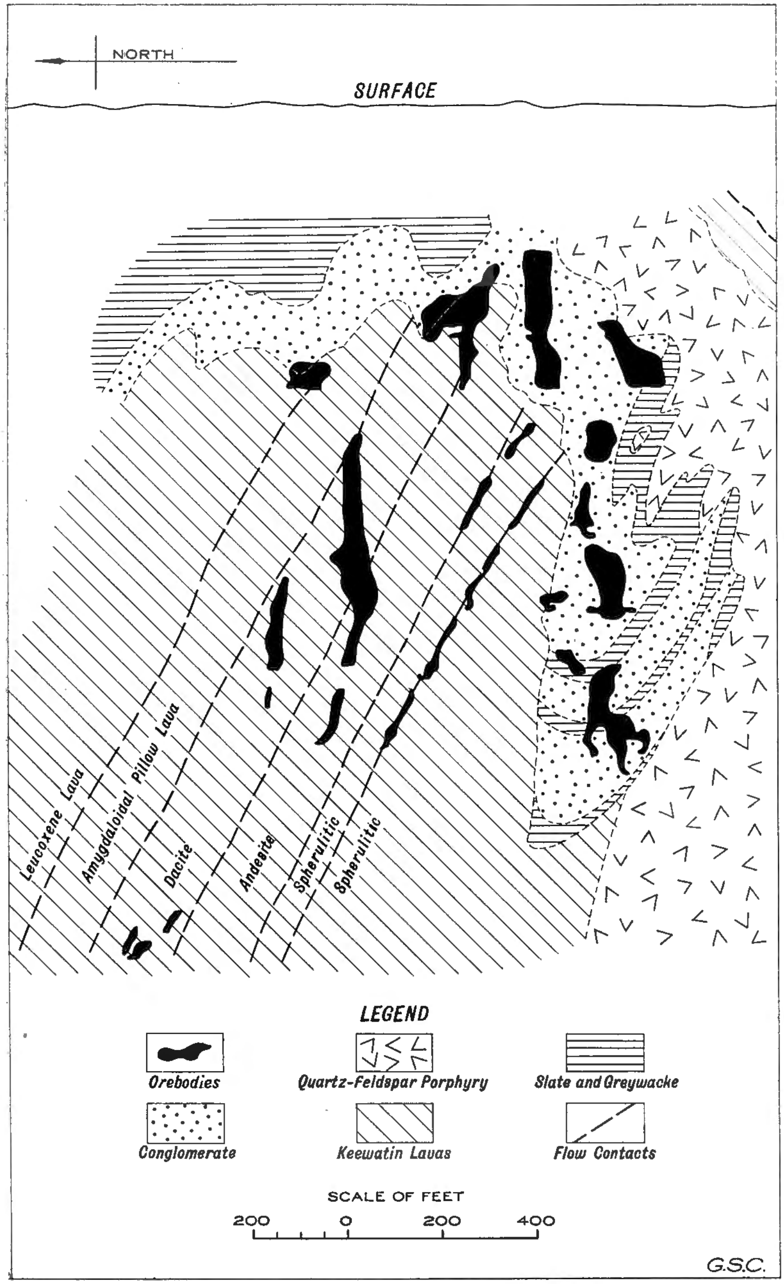


Figure 14. Cross-section of Dome mine, showing orebodies formerly found in syncline of Timiskaming rocks and now exhausted (right), and (left) orebodies now being worked in vertical fracture zones in lavas and in tuff beds between flows. (Courtesy of Dome Mines.)

a little pyrite and pyrrhotite. This quartz forms a series of veinlets crossing the older vein material in a ladder structure. Bodies thus formed range from a few inches to 14 feet in width, and some of them have been proved to have vertical and horizontal dimensions of more than 1,000 feet.

In the northeast part of Whitney township a group of four mines—Hallnor, Broulan, Pamour, and Hoyle—was brought into production in the 1936-41 period. They all lie on or close to the north contact of the Timiskaming syncline with the underlying volcanic rocks. Differential movements between strata of different competency have 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 may, however, be mentioned as the only mine in which important orebodies have been found in porphyry, if very recent reported discoveries in the McIntyre mine are excepted. A large body of porphyry has been much broken by fault movements, and ore-bearing solutions entering these fissures have altered and mineralized the porphyry to form large bodies of replacement ore. Small, high-grade veins serve as "sweeteners," and have supplied perhaps one-quarter of the total gold production.

Michipicoten-Goudreau District. Gold was discovered in 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. Most of them are now closed. The principal mine, Cline Lake, in Goudreau district, operated on a fairly wide silicified and mineralized shear zone carrying gold values. The grade of the ore was about one-sixth ounce a ton.

Thunder Bay District. Within a belt of lavas and sediments extending from Lake Nipigon eastward 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 15). The Jellico, Northern Empire, Sand River, and Tombill 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, and other minerals are scanty in amount.

On the Little Long Lac property, the largest gold producer of the group, arkose beds 1,500 to 2,000 feet thick are folded into an anticline, along the crest of which there are a number of shear zones striking 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.

The Hard Rock and MacLeod-Cockshutt mines are adjoining properties 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 sediments and, to a lesser 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 one-fourth ounce a ton.

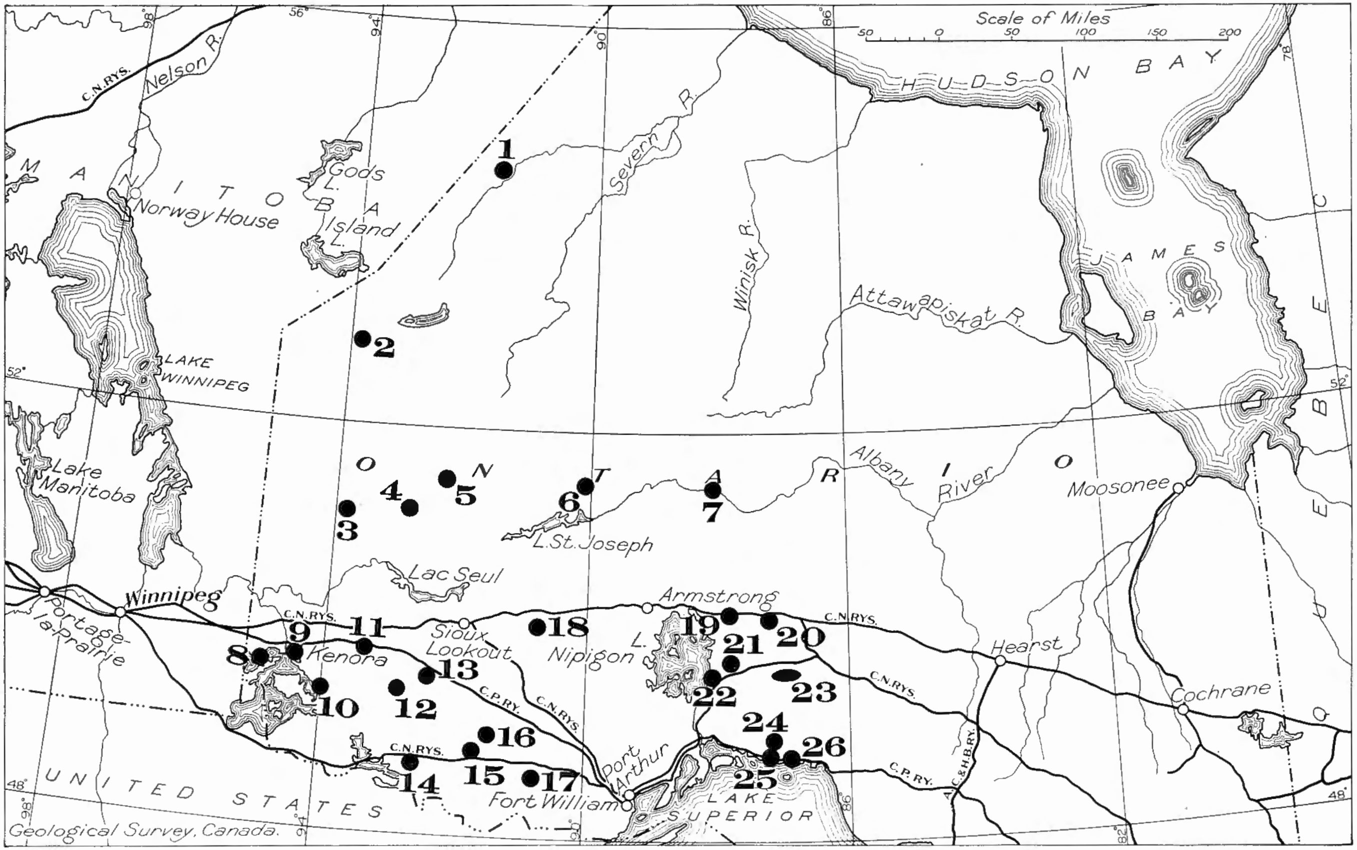


Figure 15. Index map of Lake of the Woods, Patricia, and Thunder Bay districts, Western Ontario, showing principal known occurrences of gold. 1, Sachigo; 2, Favourable Lake; 3, Red Lake (Gold Eagle, Hasaga, Howey, Madsen Red Lake, McKenzie Red Lake, Red Lake Gold Shore); 4, Woman Lake (Hudson Patricia, 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.

On the Bankfield and Tombill properties dykes of feldspar porphyry 10 to 60 feet wide have been sheared and fractured, and the fractures filled with tiny veins of quartz. Pyrite, arsenopyrite, and native gold are found in the veins and disseminated through the sheared wall-rock, giving rise to westward-raking ore shoots.

Patricia District. In Patricia district sixteen 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 change in the price of gold, but the growth of air transportation. Only ten of them are still operating (Figure 15).

As in so many places elsewhere on 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 two or three of the principal mines will illustrate this.

At the Howey mine, Red Lake, the orebody was a dyke of quartz porphyry ranging from 30 to 100 feet in width. A brittle rock, this porphyry was fractured readily, and so severely that large parts of the dyke were converted into ore when invaded by gold-bearing solutions. Fracturing took place in two stages. During the first, lenticular veins of high-temperature quartz, rarely more than a foot wide, were formed and carried some pyrite. In the second, a fracturing of the earlier quartz was followed by deposition in the fractures of native gold with small quantities of galena, sphalerite, and gold telluride. Although the grade of the orebody on the whole was less than one-tenth ounce a ton, its size permitted large-scale operations (1,250 tons a day) so that it could produce at a profit. Milling, which began in 1930, ended in the autumn of 1941; during this time 421,322 ounces of gold were won.

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, is a brittle rock that fractures easily. It has been folded into an overturned syncline that pitches northeast. On Central Patricia, drag during the folding movements has shattered the iron formation in places, and ore-bearing solutions entering the shattered zones formed pipes of ore raking northeast. The quartz of the ore is heavily mineralized with auriferous pyrrhotite and arsenopyrite, and smaller amounts of pyrite and chalcopyrite. The carbonate and chlorite of the adjacent iron formation is replaced to a considerable extent by auriferous pyrrhotite. 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 minerals of the vein are the same as at Central Patricia, with the addition of native gold. 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.

Manitoba and Saskatchewan

Although prospecting began in Manitoba about 1910, results have been somewhat disappointing. Only ten properties showed sufficient promise to justify the erection of a mill, and on most of these the orebodies proved to be either small or too low grade for profitable operation. Only three, Gods Lake, Gunnar, and San Antonio, are still working. On one, Central Manitoba, due to peculiarities of structure, the ore bottomed at shallow depths so that mining ceased in 1937 (Figure 16).

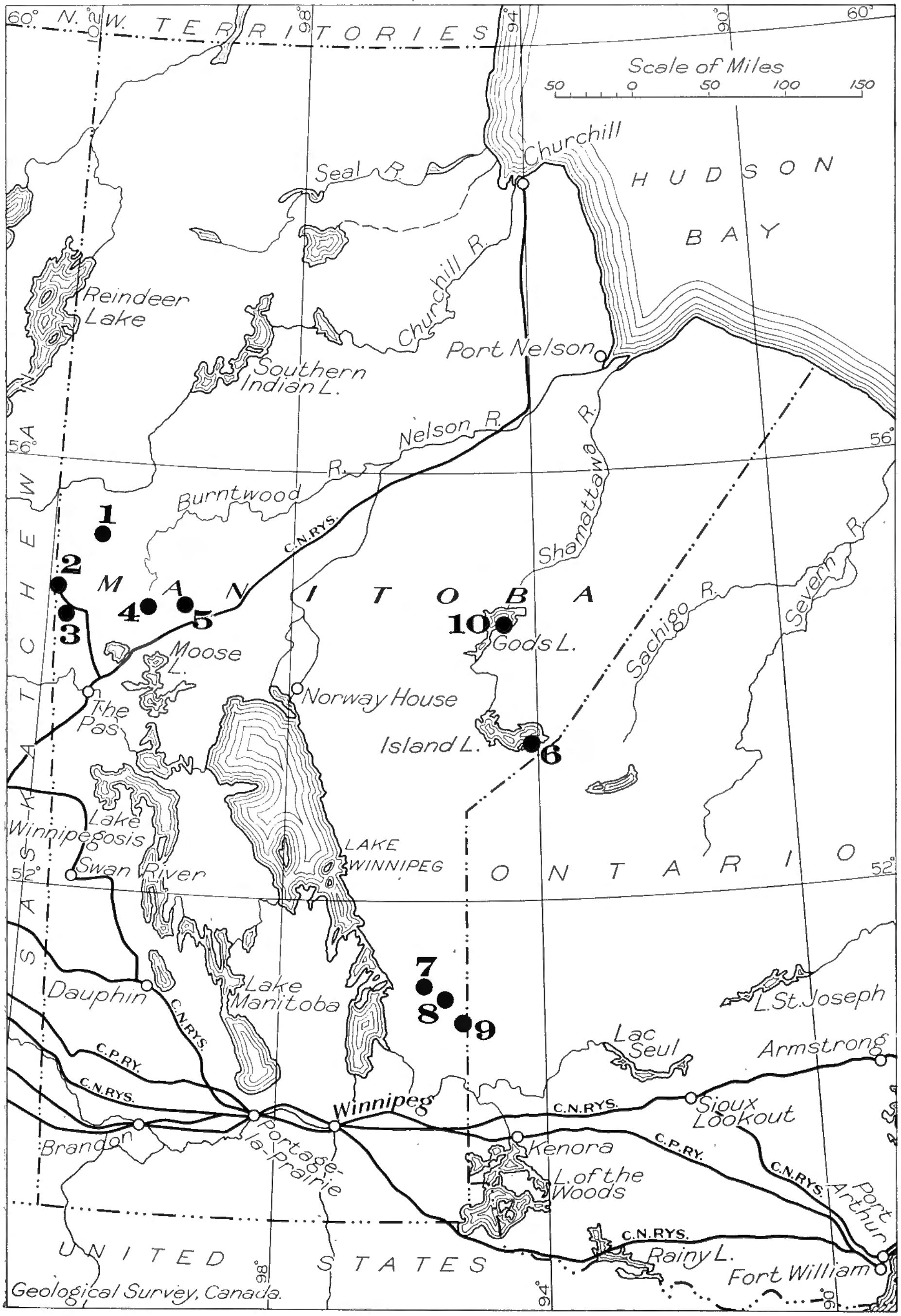


Figure 16. Index map of Manitoba, showing principal known occurrences of gold. 1, Sherritt Gordon (copper-zinc-gold); 2, Mandy, Flin Flon (copper-gold); 3, Gurney; 4, Reed Lake; 5, Laguna; 6, Island Lake; 7, San Antonio, Forty-four; 8, Central Manitoba; 9, Diana, Gunnar, Beresford Lake; 10, Gods Lake.

Conditions at Gods Lake are somewhat unusual. A sill of augite diorite with a known length of 10 miles and an average width of 300 feet seems to have been injected along the contact of a bed of basic tuff. Thicknesses of tuff ranging from 1 foot to 18 feet have been found along its north side throughout an explored length of 5 miles. Where the thicker parts occur, the tuff is fractured and the fractures cemented by dark bluish or grey quartz mineralized with sulphides and native gold. Fragments and bands of the tuff also carry disseminated sulphides. The predominant sulphide is pyrrhotite, but there is also considerable pyrite and a little chalcopyrite and sphalerite. The ore has an average tenor of 0·25 to 0·3 ounce a ton.

The San Antonio mine, on the north shore of Rice Lake, is on a diabase sill 200 to 700 feet in width, which strikes southeast and dips about 45 degrees northeast. Two complementary sets of fissures dip vertically and cut the edges of the dyke at about 45 degrees. They narrow and die out as the edges of the diabase body are approached; only in rare instances 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 ores of the Gunnar mine are very similar to those of Lake of the Woods district. Shear zones in massive basalts and andesites contain lenses and veins of quartz that in places pass into stockworks of ramifying veinlets. The quartz is mineralized rather plentifully with pyrite, galena, chalcopyrite, sphalerite, pyrrhotite, and native gold. Orebodies are for the most part rather narrow, but of high grade. The wall-rock is but little altered, and never constitutes ore. Rich orebodies have been found in several places where shear zones are constricted in passing through dykes of porphyry or lamprophyre.

Most of the gold of Manitoba and the adjacent part of Saskatchewan comes, however, not from the gold mines proper but from copper ores of the Mandy, Flin Flon, and Sherritt Gordon mines (Figure 16.) Since these mines began their smelting operations, in 1931, they have recovered more than 1,550,000 ounces of gold up to the end of 1942—more than double that obtained from the gold mines.

No gold mines are at present operating in Saskatchewan. At Goldfields, on the north shore of Lake Athabaska, 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 17), the Consolidated Mining and Smelting Company 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.

Northwest Territories

Most of the deposits of Northwest Territories are in Yellowknife district, northeast of the north arm of Great Slave Lake. The rocks are lavas and tuffs ranging in composition from basaltic to rhyolitic, overlain and in part interbedded with sediments of all types from conglomerate to slate, but mainly impure quartzites. The rocks, the Yellowknife group, are intruded by great bodies of granite, and are more or less metamorphosed near the contacts to knotty schists and hornfels. They 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 both in the lavas and the sediments. Those in the sediments are mainly bedded veins, saddle reefs, and veins introduced along the fractured axes of the folds. They appear near the outer edge of the aureole of metamorphosed sediments surrounding certain granite bodies and run outward into less metamorphosed sediments. Nearest the granite they consist of glassy, bluish quartz carrying crystals of feldspar and needle-like tourmaline; with increasing distance the tourmaline disappears, then the feldspar, and finally the quartz becomes white or milky and carries much rusty weathering carbonate. Two small mines, the Ptarmigan and Thompson-Lundmark, commenced milling in the latter half of 1941, but wartime conditions compelled both to close, in 1942 and 1943 respectively (Figure 17).

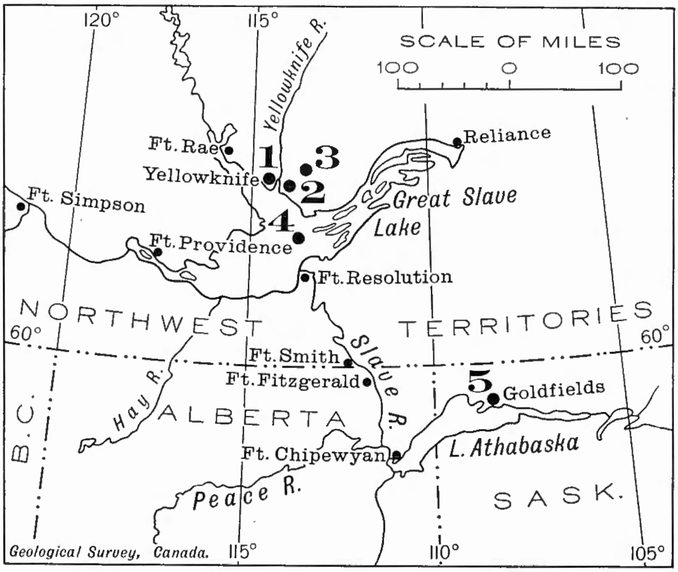


Figure 17. Index map of part of Northwest Territories and Saskatchewan, showing principal known occurrences of gold. 1, Giant Yellowknife, Con-Rycon, and Negus; 2, Ptarmigan; 3, Thompson-Lundmark; 4, Outpost Islands; 5, Box.

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 filled with a great variety of minerals, not only the commoner sulphides such as chalcopyrite, sphalerite, galena, and arsenopyrite, but a great variety of 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. Owing to war conditions these properties closed in September 1943 and October 1944 respectively.

The latest discoveries such as Giant Yellowknife are of a somewhat different type. They are rather wide shear zones that trend north-northeast.

These shear zones have widths up to 150 feet—possibly more in places. The typical ore in them consists of grey sericite schist with 30 to 75 per cent of quartz as stringers or lenses; it generally has a banded or ribboned appearance. Auriferous arsenopyrite and pyrite are abundant in the schist and to a lesser extent in the quartz; native gold is rarely seen. In places considerable carbonate is present, and gold values are usually lower. An ore shoot may comprise up to 90 per cent of the width of the shear zone. On both sides the ore grades into chlorite or chlorite-sericite schist, which rarely carries values of importance; and this in turn passes into massive greenstone. Rather numerous post-ore faults cut and displace the ore shoots.

An occurrence on Outpost Islands, opposite the mouth of the north arm of Great Slave Lake, has attracted a good deal of attention. The rocks are sediments of the Wilson Island group, an early Precambrian series; they strike east-northeast and dip steeply south. Certain beds of impure quartzite have suffered brecciation across widths of 4 or 5 feet, in some places as much as 8 feet. The brecciation extends along the strike for 300 or 400 feet and then seems to die out or possibly to be transferred to a different bed. It dips vertically, so as to cross the bedding at a small angle. The fracture zones have been healed by the deposition of chalcopyrite and pyrite, together with a great variety of other minerals such as ferberite (tungstate of iron), magnetite, hematite, marcasite, bornite, and chalcocite. Quartz is present only in minute stringers. Coarse native gold occurs in fractures both in the sulphides and the quartzite, but though values are locally high they are extremely erratic and the tenor of the whole mass is too low to mine profitably. Of late years attempts have been made to operate the property as a tungsten mine, with the gold merely a valuable by-product. The average tungsten content is said to be about 1 per cent.

SILVER

In 1942 deposits within the Canadian Shield produced 9,616,316 ounces of silver. Of this total, 8,056,507 ounces were derived from copper, lead, and zinc ores; 722,194 ounces formed part of the bullion from the gold mines of the Shield; and only 837,615 ounces came from ores mined mainly for their silver. In other words, 90 per cent or more of the silver now being produced from the Shield is merely a by-product from the mining of other metals. It seems likely that this condition will continue to prevail in the future, unless a pronounced rise in the price of silver stimulates mining it for its own sake. The condition is the exact reverse of that which prevailed some years ago. In 1924, for example, 10,699,684 ounces of silver were mined from the Shield area, and of this all but 763,782 ounces were produced from ores worked mainly for their silver. At that time, of course, silver prices were much higher than at present, and the great Cobalt silver camp was not quite worked out.

Besides the Cobalt camp and its subsidiary districts, which taken together stretch 75 miles westerly from Lake Timiskaming, a second district around Port Arthur has produced some silver; and of recent years silver ores have been found at Great Bear Lake.

Ontario

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, as the silver veins are nearly worked out.

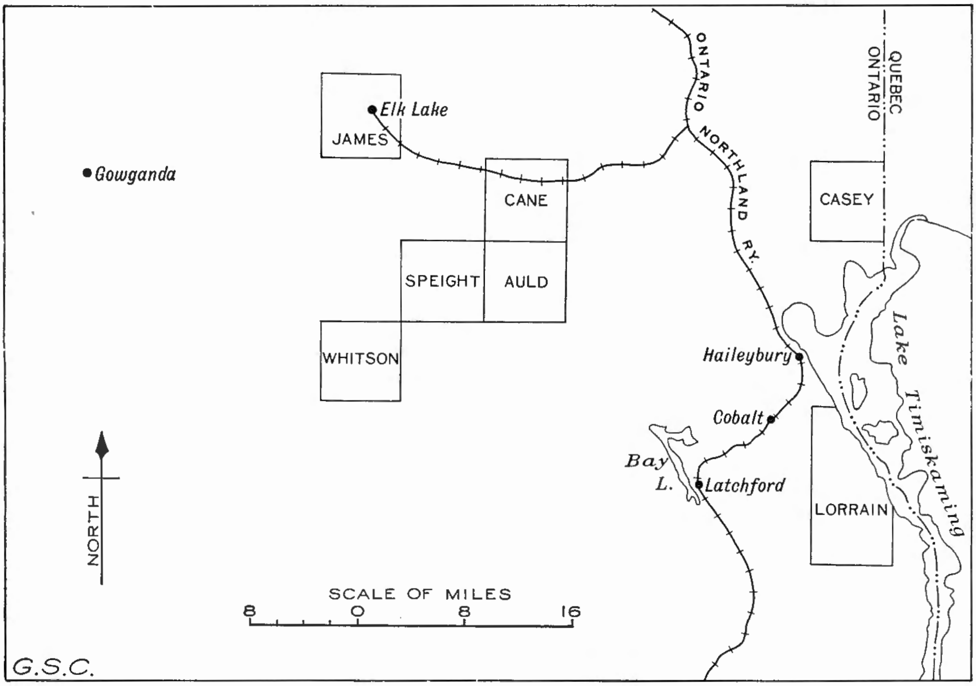


Figure 18. Index map showing positions of chief silver-bearing areas in the Cobalt region, Ontario.

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 lavas, tuffs, and iron formation. A sill of the 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 lay 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 apparently emanated from the diabase sill. No ores have been found where the diabase sill is absent, and all the ores were found within a few hundred feet of the diabase 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 was absent. Nevertheless, veins did not commonly extend into the Keewatin much below the base of the Cobalt series; and when they did the silver values 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. In a few instances veins were found near

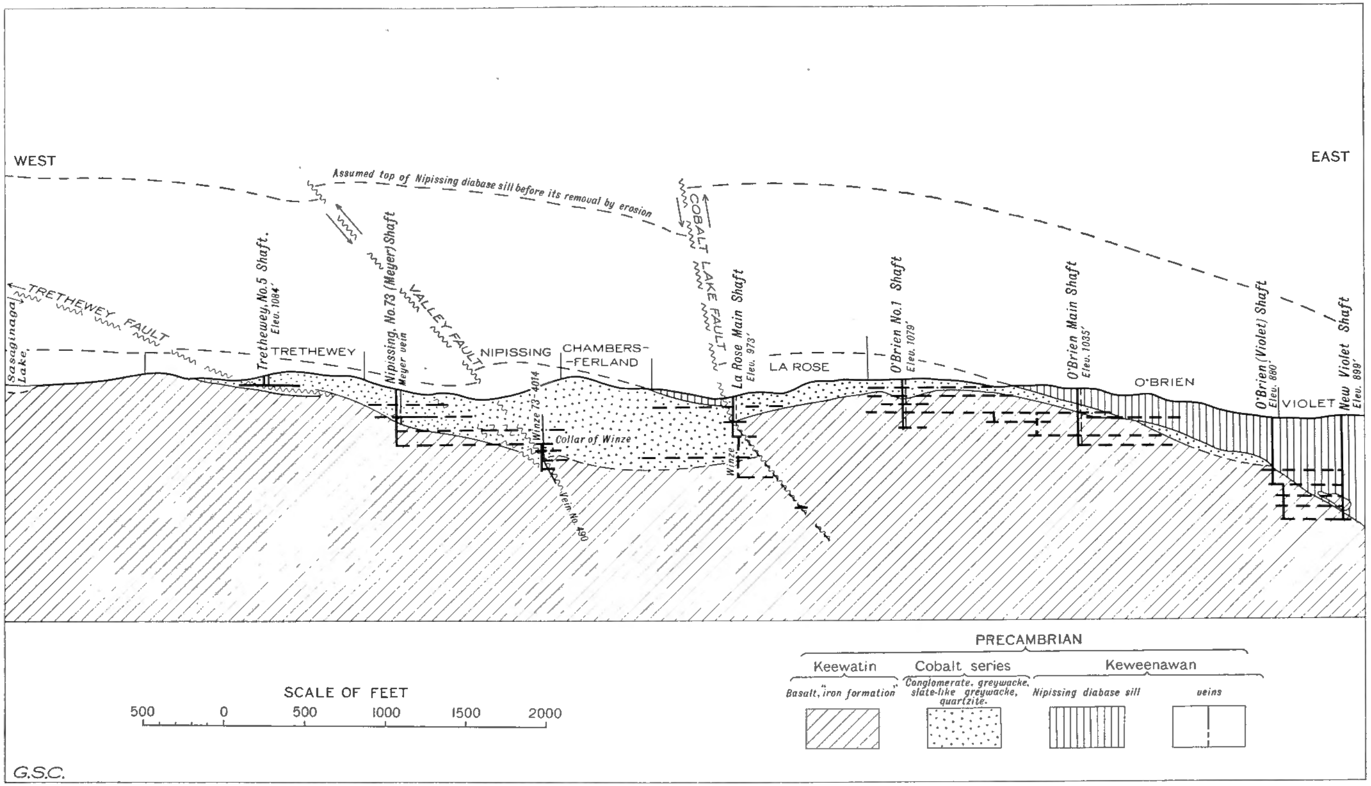
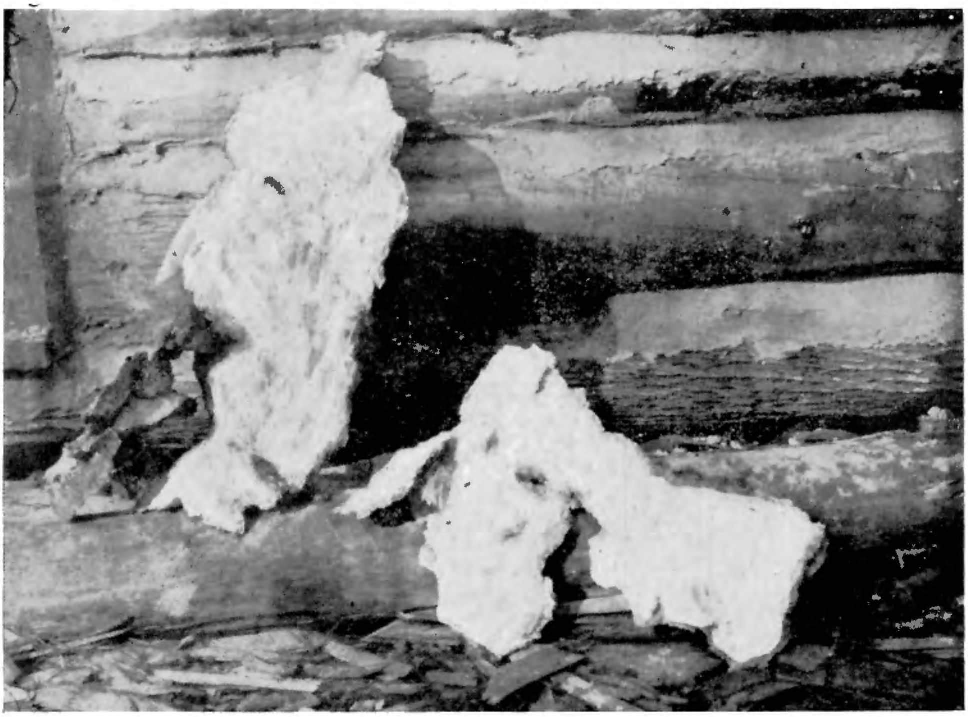


Figure 19. Vertical section through north part of Cobalt, Timiskaming district, Ontario. (After C. W. Knight.)

the middle of the sill, but such veins were rare. 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.

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 (Plate VII), in places the wall rocks were broken by innumerable tiny cracks into which the vein-forming solutions penetrated and deposited silver (Plate VIII). Considerable widths of rock were thereby converted into a low-grade ore, locally termed mill-rock.

PLATE VII

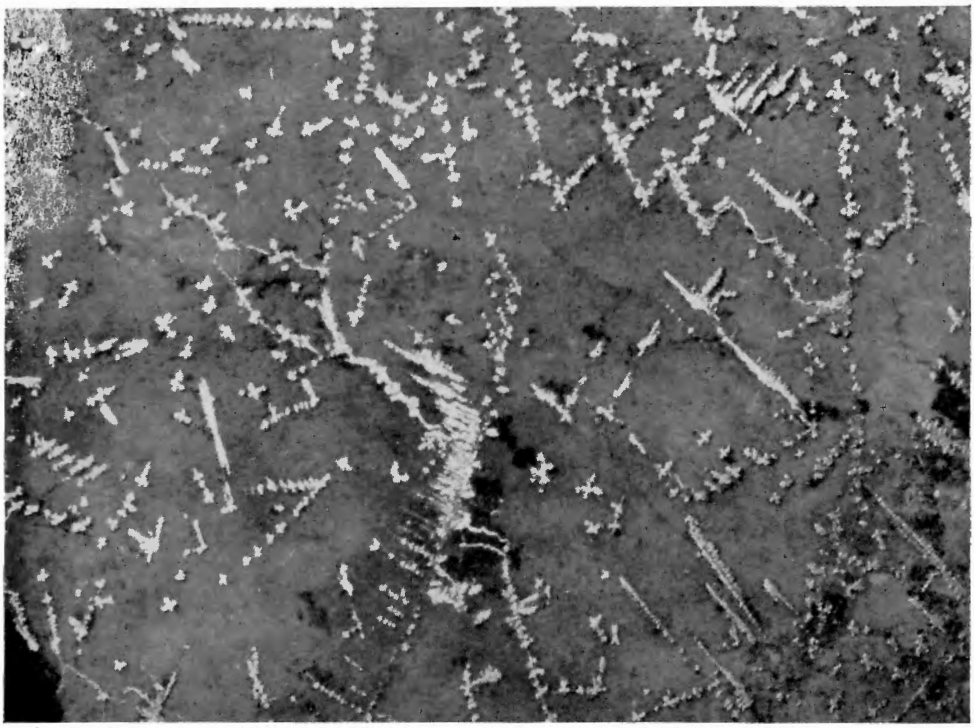


Slabs of native silver from the Trethewey mine, Cobalt, Ontario. The upright slab weighs 79 pounds. After Willet G. Miller, Ontario Bureau of Mines Report, 1913 (95918).

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 limited 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. The less fractured parts are less deeply altered. The alteration converted the country rock, first, into a soft, greenish, highly decomposed clay, and still further oxidation transformed this into a reddish or ochre-yellow clay, by conversion of its iron from ferrous to ferric oxides. In the upper or ferric parts of the vein almost all of the original vein material has been dissolved and carried away, apparently to be re-deposited where the down-moving solutions came into contact with the greenish, ferrous clay. The result was the formation of immensely rich bonanza masses of native silver, argentite, and ruby silver. Below the altered zones the usual Cobalt-like vein minerals are found.

PLATE VIII



Native silver (white) in calcite, Temiskaming mine. Cobalt, Ontario. scale, about natural size. After Willet G. Miller, Ontario Bureau of Mines Report, 1913 (95917).

In 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, unlike Cobalt, there is evidence that directly relates the silver veins to the diabase. The diabase displays a consistent series of differentiation products that progress through a rather acid aplite to an aplite carrying little feldspar but much calcite and some chalcopyrite. It would seem, therefore, that the veins must have formed by the gradual accumulation, through continuing crystallization of the siliceous constituents, of calcite material in the vein-forming solutions. According to Burrows, some aplite veins carry irregularly distributed masses of calcite accompanied by native silver, smaltite, and niccolite.

Considerable silver was obtained from Casey township, 15 miles northeast of Cobalt. The usual calcite veins occurred in Cobalt sediments, 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 (*See* Figure 18); and south of Larder Lake. The total production, however, has not been large.

In Port Arthur district Archæan rocks are overlain by gently dipping Animikie sediments, 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 almost flat-lying Animikie shales, 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 has been 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 located. However, continued exploration did not substantiate the earlier expectations, and now it does not appear likely that the possible production will be great. Total production to the end of 1940 was less than 2,000,000 ounces; there was no production in 1941-2.

Both the composition of the ores and their history of deposition are complex so that the interested reader must be referred to the more detailed descriptions of them. All that can here be said is that a complex of Proterozoic rocks, both igneous and sedimentary, has been cut by faults along which repeated movements have taken 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

Sudbury Ores

Nickel occurs in several places on 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.

At present these mines furnish approximately 90 per cent of the total world production of the metal. From the initiation of production in 1889 up to the end of 1945 they have supplied 2,213,094 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. Roughly two-thirds of the above amount of nickel has been produced since 1928, following an intensive program of research by the International Nickel Company that vastly increased the peace-time uses of the metal.

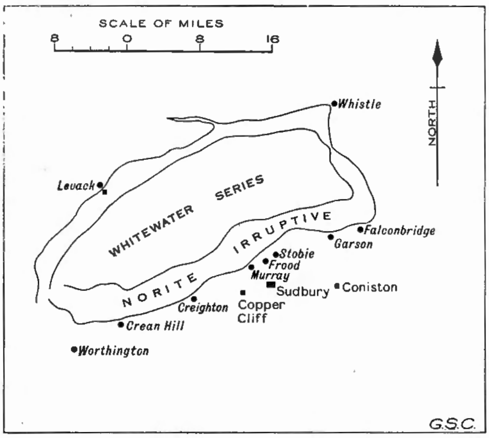


Figure 20. The Sudbury copper-nickel deposits, showing their grouping around the edge of the norite irruptive.

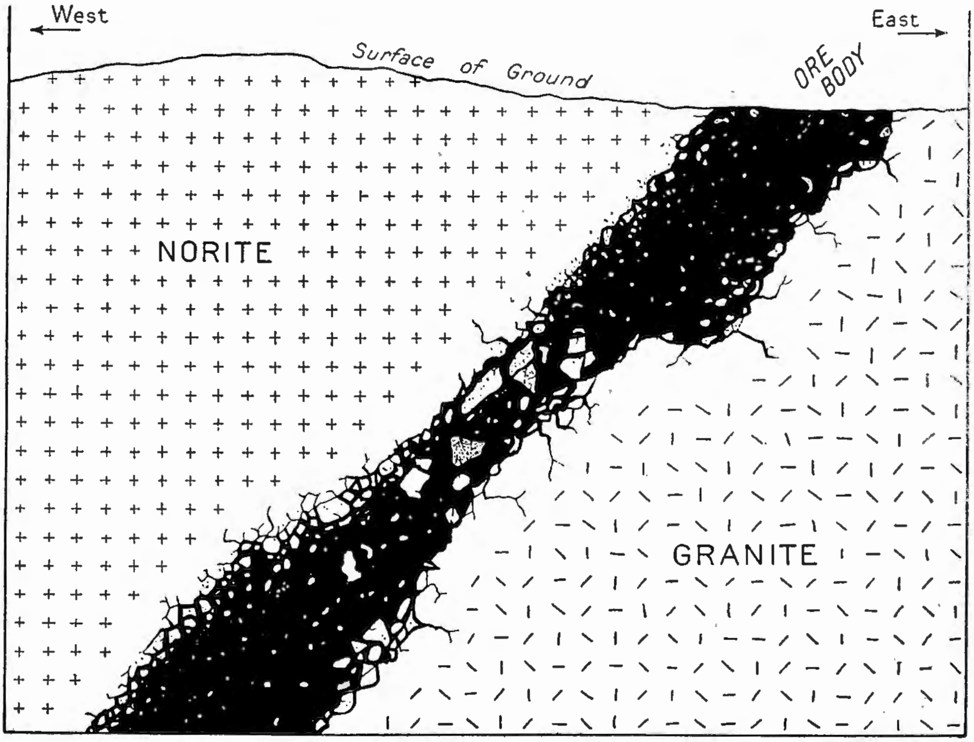
The Sudbury ore deposits (Figure 20) are closely associated with a body of norite and micropegmatite that outcrops as an oval ring 37 by 17 miles in diameter, and 1 to 3·6 miles broad. The outer part of the ring is norite, and the inner, micropegmatite, with a fairly rapid gradational change from one to the other. Inside the oval ring of norite-micropegmatite, the Whitewater series of volcanic agglomerates, tuffs, and sedimentary rocks is disposed in a broad syncline or compound syncline. Wide dykes of olivine diabase cut indiscriminately through norite, Whitewater series, and older rocks; and small bodies of Proterozoic granite invade the norite in places.

The 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 combine to suggest that the igneous mass is a thick sheet intruded along the contact of the Whitewater series with the older rocks. Consonant with this conclusion, mining operations have shown that in many places the lower contact of the norite dips inward at 35 degrees or thereabouts. In other places, on the other hand, the contact is nearly vertical or dips outward at high angles. There is reason to believe, however, that such relations are due to faulting.

The orebodies lie either along or close to the outer margin of the norite—the so-called "marginal deposits"—or they form dyke-like or irregular bodies in the older rocks—"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 orebodies consist of rock fragments cemented by the sulphides and partly replaced by them. The rock 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 great sheet-like mass of norite-micropegmatite. Investigations since 1930 by the geological staff of the International Nickel Company seem to prove, however, that the ore is almost everywhere closely associated with a quartz diorite that forms thin, dyke-like masses against the south contact of the norite, and dykes in the older rocks. Where this rock is cut by faults, or is

PLATE IX



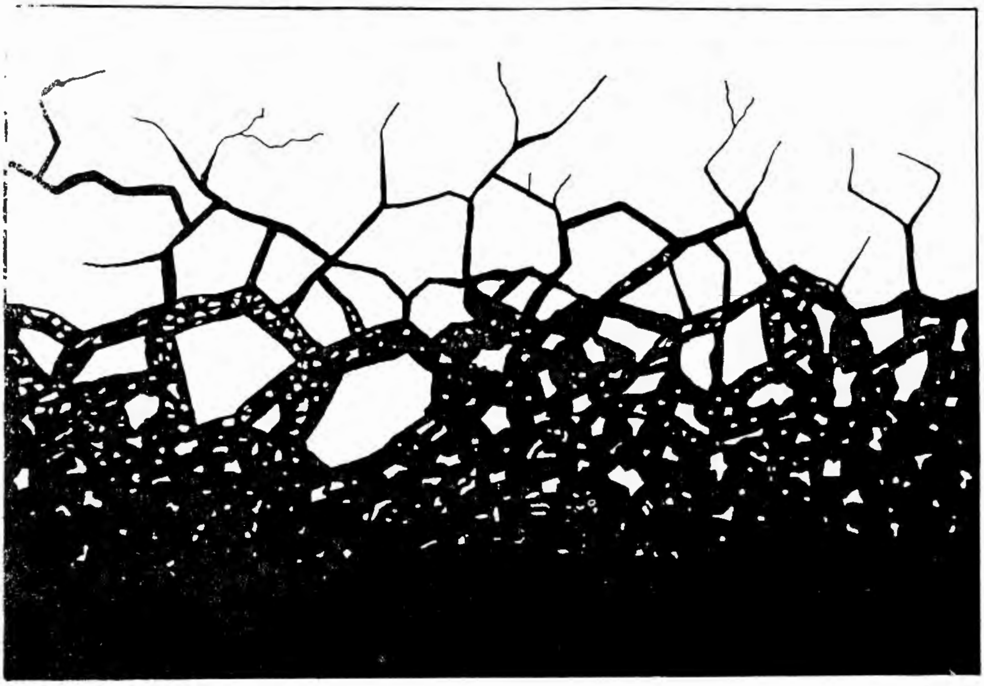
Ideal cross-section through Creighton mine orebody, from surface to 18th level. Black represents ore. After C. W. Knight, from Report of the Ontario Nickel Commission, 1917 (95917).

brecciated in one of the unusual breccia zones found at Sudbury, ore commonly occurs. The quartz diorite was considered by earlier observers to be a phase of the norite, but the later investigations have proved it to be much younger. The Creighton mine is an example of an orebody formed by intense faulting and subsequent mineralization (Plates IX and X); the great Frood orebody is localized along an intensely brecciated dyke 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 a dyke of the quartz diorite. The relatively

The age of some of the ores is indicated by a recent discovery at the Garson mine, where a body of ore some 40 feet in width cuts directly across a dyke of olivine diabase, the youngest Precambrian rock of the region.

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 1942 the average tenor was about $1\frac{1}{4}$ per cent copper and slightly less than that amount of nickel. This is due to the inclusion with the higher grade ores of large amounts of low-grade material, particularly from the open pit at the Frood mine.

PLATE X



Sketch illustrating contact between massive sulphides (black) and norite (white), Creighton mine, Surbury, Ontario. The face represented has a length of 20 feet. After C. W. Knight, from Report of the Ontario Nickel Commission, 1917 (95920).

Some nickel has been produced from the Alexo mine, on the boundary between Clergue and Dundonald townships, northwest of Timmins. There Keewatin lavas are intruded by bodies of peridotite now altered to serpentine. The nickel ore occurs at the edge of a body of serpentine and was proved to be some 700 feet long at the surface. The contact, and the orebody, had a dip of 65 to 80 degrees, and was followed downward for several hundred feet. The ore varied in width from a few feet to 40 feet, and consisted of a core of massive sulphides bordered on the foot-wall side by sulphides disseminated in peridotite. Veinlets of solid sulphides extended outward from both sides of the massive core. The ore was chiefly pyrrhotite, carrying small amounts of pentlandite, chalcopyrite, and pyrite. The massive ore varied in width from a few inches to 20 feet; the 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, but if it be assumed that the average grade of ore shipped was 4 per cent, about 2,000 tons of nickel must have been obtained. Late in 1942 Harlin Nickel Mines was organized to take over the property and shipment of ore was recommenced in 1943.

Other Nickeliferous Deposits

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 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, and values up to 7 per cent in nickel are reported.

At Dinty Lake, about 24 miles northeast of Goldfields, Saskatchewan, 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.

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. Drill samples indicate an average for the massive ore of about 9 per cent nickel, and for the disseminated ore about 3 per cent.

Quite a number of other occurrences of nickeliferous ore in Ontario and Manitoba are known. Most are either too small or too low in grade to be commercial, though a recent discovery by Sherritt Gordon at Lynn Lake in northern Manitoba holds considerable promise. Nickel was found in the silver ores of Cobalt district, in the minerals niccolite and smaltite-chloanthite, and 6,230 tons of the metal have been recovered from these ores.

COPPER

Up to 1927 almost the only copper producers on the Canadian Shield were the nickel-copper mines of Sudbury district, which have already been described[1]. In 1927, however, copper began to be turned out by Noranda Mines, Quebec, and other mines in its vicinity have since added to the production of that district. In 1930, mining began at the Flin Flon mine in Manitoba; in 1931 the Sherritt Gordon mine, Manitoba, began shipping concentrates to the Flin Flon smelter. Both the Quebec and Manitoba districts have continued to yield large amounts of the metal up to the present time.

Ontario

In 1942 the copper production of Sudbury district was 154,141 tons. The total production of Ontario from 1886, when Sudbury came into production, until the end of 1945 was 2,412,334 tons. The only other copper producers in Ontario in that period were Bruce Mines 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 2,000,000 tons.

At Bruce Mines, on the north shore of Lake Huron, copper mining began as early as 1846 and continued, with interruptions, until 1921. Veins that traverse diabase sills in Huronian sediments consist of quartz and chalcopyrite with minor amounts of calcite and barite. They vary from mere stringers to

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[1] During the years 1917-20 the Mandy Mine, Manitoba, shipped 25,000 tons of copper ore averaging nearly 20 per cent copper and 0·25 ounce of gold. This ore was teamed some 50 miles to Sturgeon Landing, taken by barge a farther distance of 120 miles to The Pas, then sent by freight 1,200 miles to the Trail smelter, B.C. This achievement was made possible by the wartime price of copper, 26 cents a pound.

veins 50 feet wide. The 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 1908-9, it lay idle until purchased by the Mond Nickel Company, which shipped the ore to Coniston as a flux. Mining was carried on by them 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 all have proved too small or low grade for operation at prevailing prices.

Quebec

Noranda Mines, situated in Rouyn township, Quebec, blew in its smelter in 1927, and has been operating continuously since. In addition to Noranda, other properties, Waite-Amulet, Aldermac, and Normetal, have produced considerable amounts of copper (Figure 21). The total production of this group of mines to the end of 1945 was 815,372 tons of copper, together with important amounts of gold, silver, and zinc.

All these ores are of the same general type. They are massive sulphides, mixtures of pyrite, pyrrhotite, and chalcopyrite in varying proportions; in the Waite, Amulet, and Normetal ores there are also important amounts of the zinc sulphide, sphalerite. The ores have formed by replacement, usually of rhyolitic agglomerates and tuffs, or of rhyolite lavas 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 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 22). 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.

Manitoba

In northern Manitoba, close to the Saskatchewan boundary, three mines, Mandy, Flin Flon, and Sherritt Gordon, have produced considerable amounts of copper. Of these the Flin Flon is the largest and most important; it overlies the boundary between the two provinces, and part of its production is credited to Saskatchewan in the statistical returns. The principal production from the Mandy was during the first great war, though some low-grade ore was salvaged from it in 1943-44. The remaining production has been from the Flin Flon and Sherritt Gordon mines. The Flin Flon smelter was blown in in 1930, and from that year to the end of 1945 these two mines have yielded 581,150 tons of copper, together with important amounts of zinc, gold, silver, and cadmium.

The Flin Flon deposit lies in a strong drag-fold that strikes north 30 degrees west and pitches to the southeast. The orebodies follow a contact between

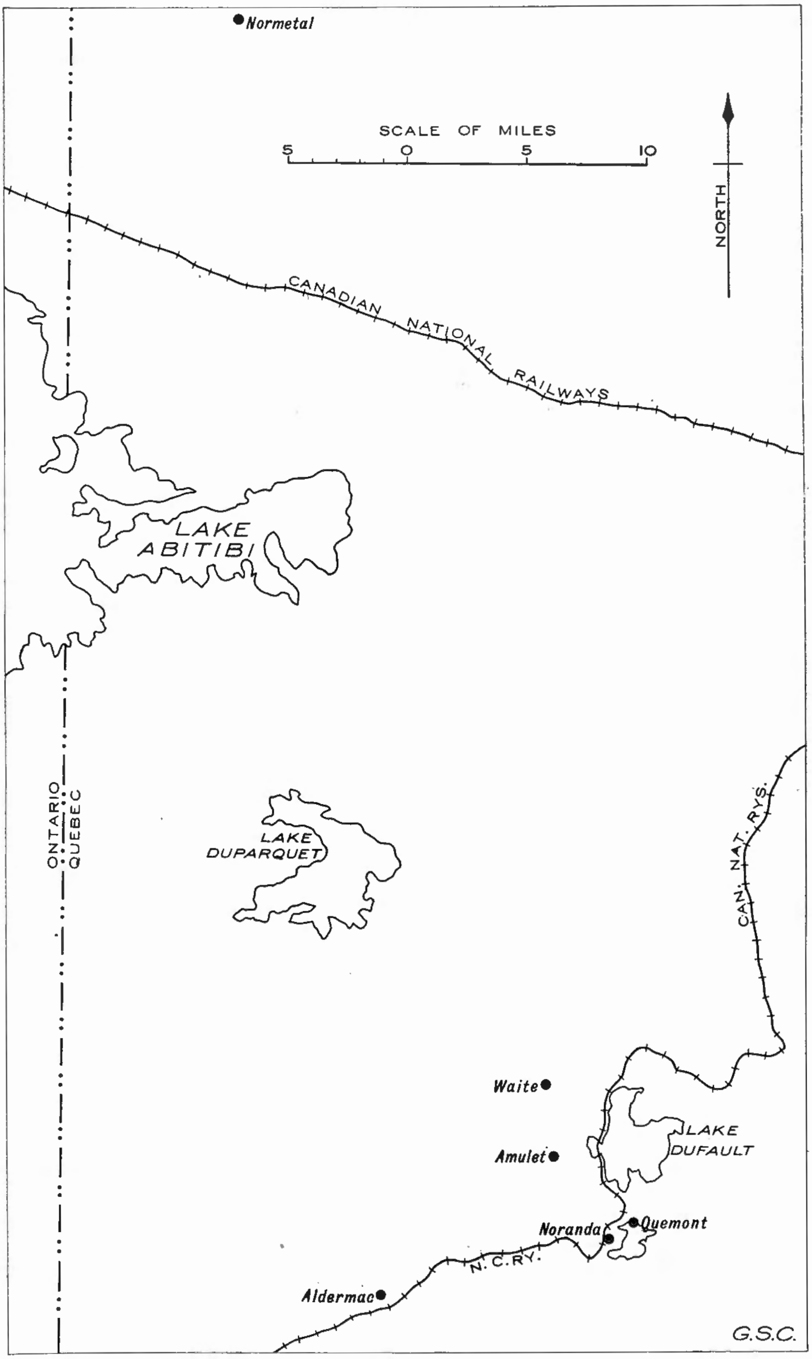


Figure 21. Index map showing position of main copper mines of western Quebec.

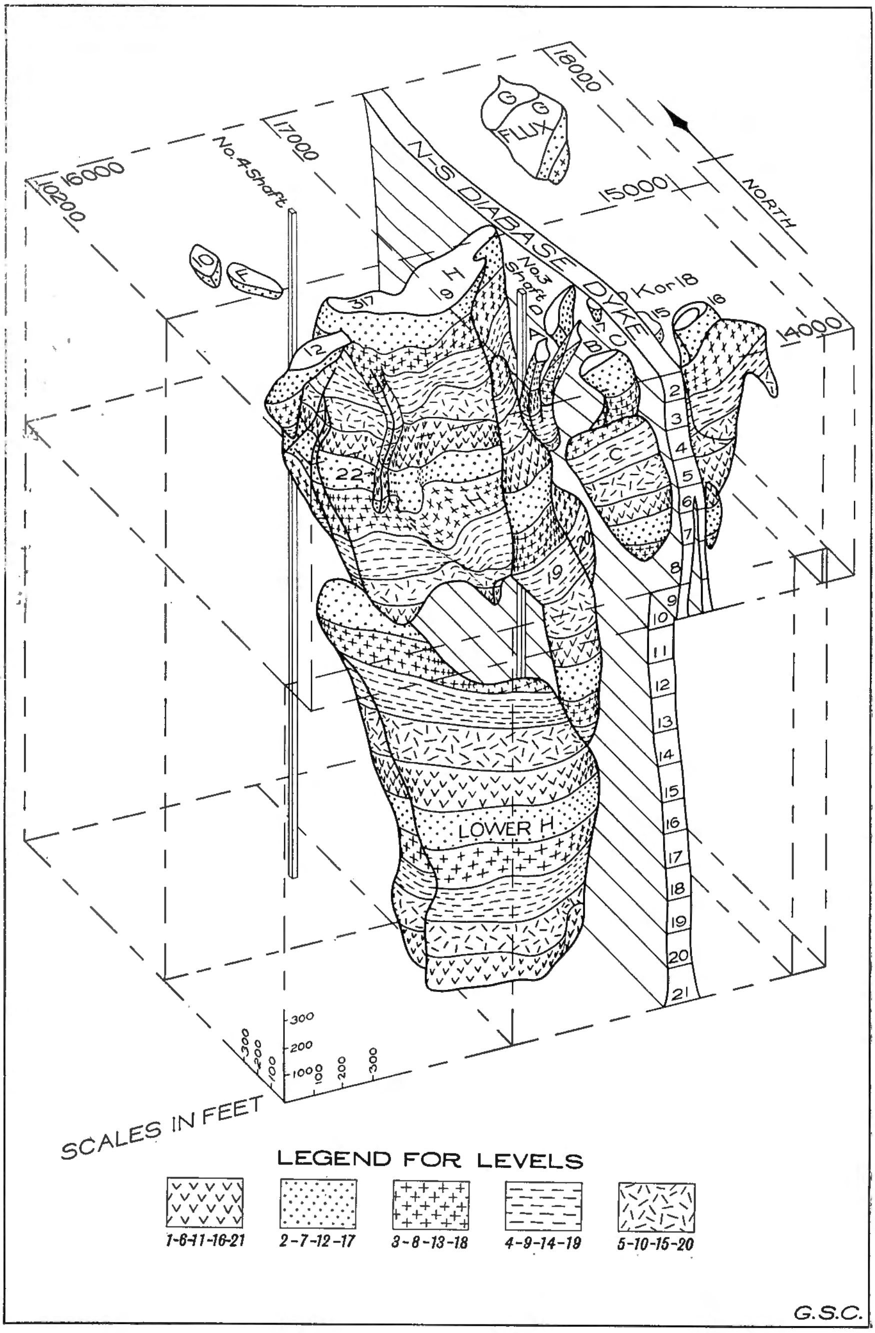


Figure 22. Isometric projection of orebodies at Noranda Mines. (After Peter Price.)

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. 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, other parts converted into chlorite and talc. The latter in places is 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. The grade of the ore is said to be remarkably constant; for the year 1934 it averaged 1·71 per cent copper, 4·4 per cent zinc, 0·095 ounce gold, and 1·45 ounces silver a ton. Beginning in 1936, cadmium, selenium, and tellurium have also been recovered from the ores. Reserves at the close of 1945 were estimated at 26,000,000 tons, averaging 2·99 per cent copper, 1·24 per cent zinc, 0·089 ounce gold, and 1·25 ounces silver a ton.

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.

The Sherritt Gordon mine is 40 miles northeast of Flin Flon. Production commenced in 1931, but the mine was inactive from 1932-7. During the recent war years the mine yielded nearly 15,000 tons of copper annually; in 1943 more than 28,000 tons of zinc concentrate were also produced. The average grade of the ore is about 2·5 per cent copper and 2 per cent zinc, but there are rather wide variations in grade from place to place.

The orebody, unlike all others, lies in Kisseynew gneiss, a complex of ancient, much recrystallized and granitized sedimentary rocks. The ore is mainly pyrrhotite, locally enriched by chalcopyrite and sphalerite. It has been formed along the contact of a brittle bed, the Sherridon quartzite, with a thick and strong bed of gneiss. Fracturing of this quartzite during folding movements is supposed to have permitted entry of the ore-bearing solutions. The ore now forms two long, shallow lenses with a gap between them 3,600 feet in length (Figure 23). As this gap is localized on a cross-anticline, it is supposed that the two lenses were originally one body, but that erosion has removed the ore from the central anticlinal gap. 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.

Northwest Territories

Statistics of copper production show a few tons of copper from this district. These have been derived from the complex ores of Outpost Islands, Great Slave Lake, which have already been described under "Gold".

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

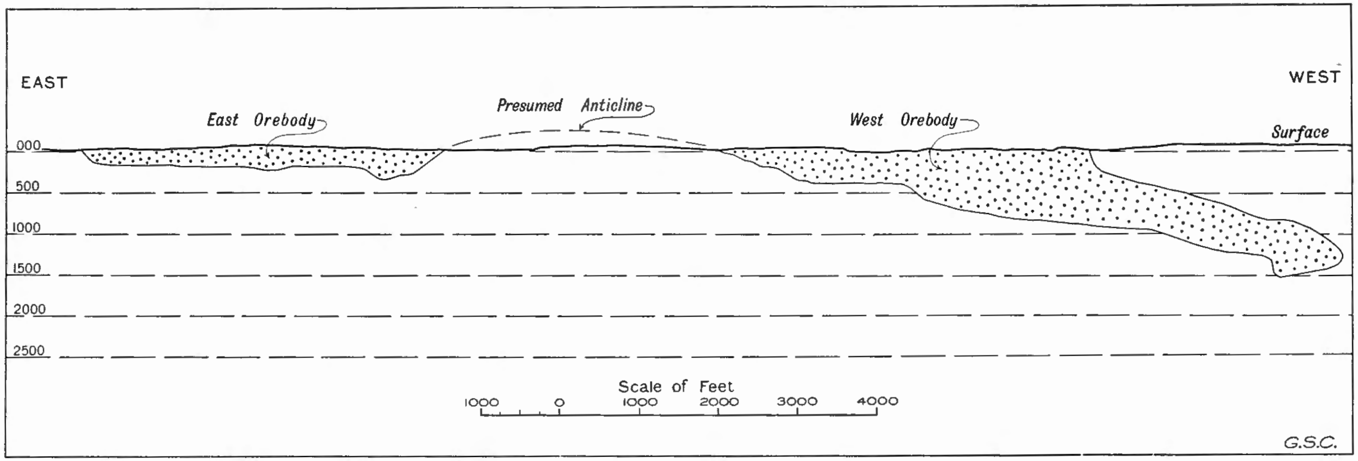


Figure 23. Longitudinal section, Sherritt Gordon mine, showing east and west orebodies and presumed anticline between.

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 closed permanently.

Continued exploration has shown that iron orebodies on the Shield are both numerous and large, but, on the Canadian side of the border, are mostly so low grade that to be successfully smelted they require "beneficiation", that is, the grade must be raised by roasting or magnetic concentration. The only deposits where this has been unnecessary are those of the old Helen mine, the newly developed ores at Steeprock Lake, and certain bodies now under development in the interior of Ungava.

The ores are of three main types, namely, those of the Keewatin iron formations, those of the Animikie iron formations, and ores formed by differentiation from bodies of gabbro or anorthosite. Besides these main types, some small bodies seem to be of contact metamorphic origin.

Keewatin Iron Formations

The Keewatin iron formations run easterly through northern Ontario into Quebec, and northwest into northern Manitoba. Up to the present, little or none has been recognized in the Northwest Territories. The iron formation forms bands ranging in width from a foot or two to perhaps 100 feet, and in length from a few hundred feet to several miles. In some areas it occurs in two or more roughly parallel zones, which may belong to different horizons or may be the same horizon repeated by folding or faulting. The iron formation is generally interbanded with Keewatin lavas, without evidence of any stratigraphic break either at the top or bottom.

In most districts the iron formation consists of thin alternating layers of cherty quartz, or jasper, and magnetite or hematite. Some of the iron oxides may be mixed with the quartz, and some quartz in the layers of iron oxide. In places, iron carbonate accompanies the cherty quartz, or may form thin or thick zones of nearly pure carbonate.

Magnetite-rich ores of this type were mined at Moose Mountain, near Sellwood, 35 miles north of Sudbury, during the years 1907-20. The ore, certain bodies of which were especially rich in magnetite, was concentrated magnetically and the concentrates shipped. The product was of excellent quality, very low both in sulphur and phosphorus, but the briquetted product offered some difficulties in smelting.

In Michipicoten district the Keewatin iron formation differs considerably from that found elsewhere. Its stratigraphy is summed up by W. H. Collins as follows: (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; (3) in sharp, partly alternating contact below the banded silica is a pyrite member that grades downward into a carbonate member (4), 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 24).

All these members are not invariably present. Thus, at the Magpie mine the formation lacks the banded silica member and the pyrite member is rudimentary. The Dreany Range has only a rudimentary pyrite member and apparently no carbonate member. Many small iron formations consist only of banded silica. Most of the larger ranges, however, have all members arranged as indicated.

The carbonate member is either directly, or by conversion into secondary ores, the source of all the iron ore deposits of Michipicoten district. It attains a maximum thickness of 240 feet at the Helen mine, and in other places ranges

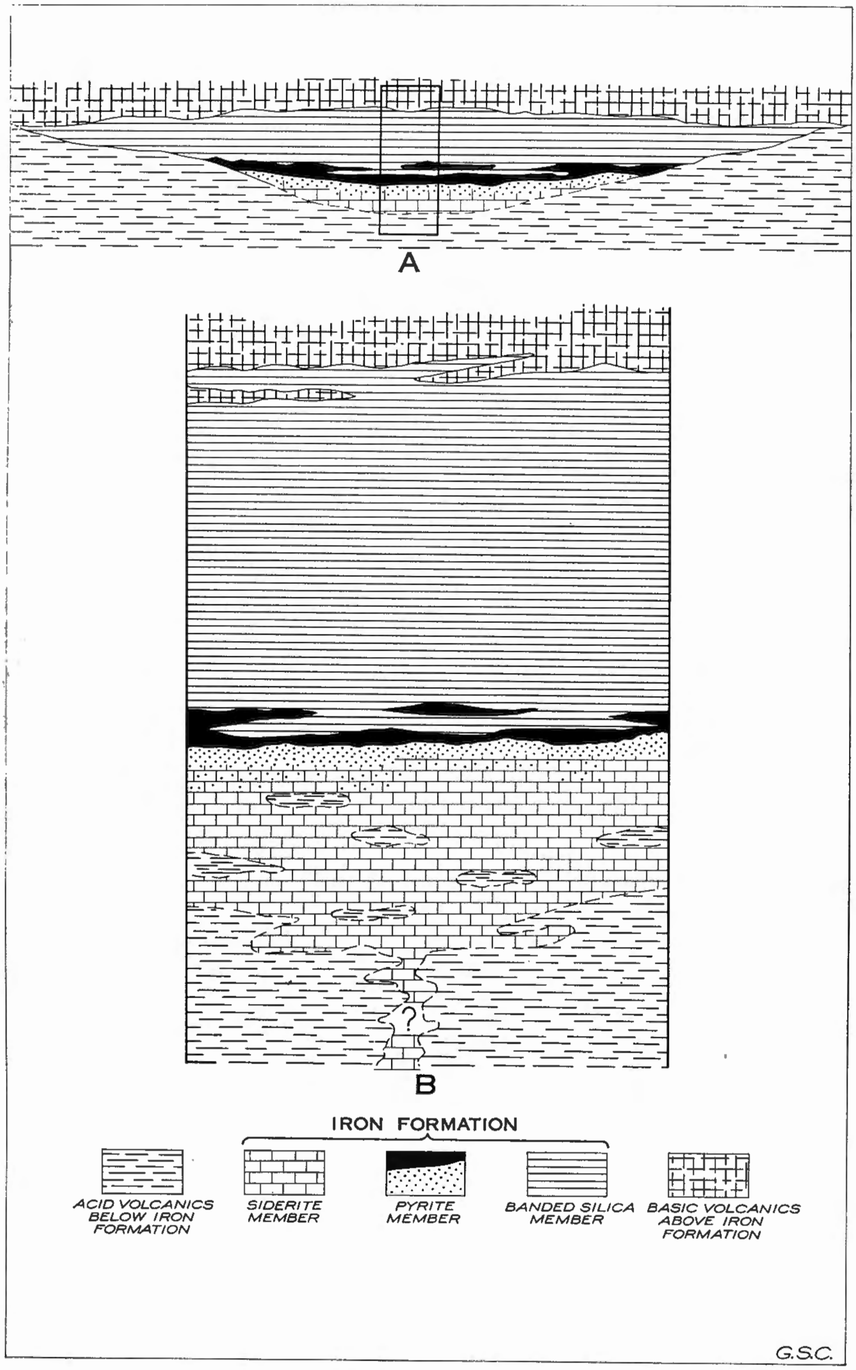


Figure 24. Diagrammatic vertical cross-sections of a typical unfolded iron formation to show stratigraphic arrangements and relationship to adjacent volcanic formations. A—entire cross-section, with thickness exaggerated about ten times. B—enlarged and more detailed representation of part of A indicated by the small rectangle. (After W. H. Collins.)

in thickness down to nothing. Even in the same iron range there are wide variations in thickness within short distances. Abundant evidence has been gathered to indicate that this carbonate member has been formed by replacement of the underlying acid lavas.

At the Helen mine, Figure 25, the carbonate member extends from the west end of Boyer Lake eastward 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 by 200 feet and 651 feet deep. This constituted the old Helen mine, which was worked from 1900 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 shipped.

The Magpie mine, about 13 miles due north of the Helen, was developed on a similar carbonate band about 1,400 feet long and 45 feet thick. The ore, which contained much pyrite, was roasted. The product carried more than 2 per cent manganese, and enough lime and magnesia to make it almost self-fluxing. Mining was done from 1910 to 1921, with occasional interruptions, in which time about 1,500,000 tons of siderite were mined, yielding 1,193,480 tons of the roasted concentrates.

According to Collins' hypothesis, deposits like those at the Helen and Magpie mines 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. This hypothesis, though possibly correct, has been somewhat shaken by recent developments at the Steep Rock and Josephine mines.

The Steep Rock orebody underlies the bed of Steeprock Lake, and its development, requiring the draining of the lake and the diversion of Seine River, which flowed through the lake, has been one of the outstanding achievements of recent years. This work, started in 1943, was completed and mining begun late in 1944 (Figure 26).

Three ore zones have been established by exploratory drilling (Figure 27). The "A" zone is 3,600 feet long and ranges in width from 150 to 300 feet. The "B" zone has a known length of nearly 3,000 feet with a probable length of 5,000 feet, and widths ranging from 100 to 225 feet. The "C" zone is as yet incompletely explored, but a length of about 1,000 feet seems to have been indicated, and a width of about 200 feet. These bodies strike northwest in a general way and dip steeply southwest. The foot-wall or north side is the Steeprock "limestone", formerly considered a sedimentary rock, but now known to have been formed by replacement, like the carbonate member of the iron formation at Michipicoten. Above it lie the ore zones, overlain in turn by greenstones and "ash rocks." The ore, which consists of massive goethite brecciated and recemented by botryoidal and vuggy hematite, is clearly formed by replacement of the siliceous carbonate rocks and, to a lesser extent, of the greenstones. Solid lenses of ore have also been found in the greenstones, well away from the main body. The iron-bearing zones contain ore of extremely high grade, averaging 60 per cent iron or better, and very low in silica, sulphur, and phosphorous. Above the level reached by the drills about 31,000,000 tons of proved and probable ore have been indicated in the "A" and "B" bodies alone.

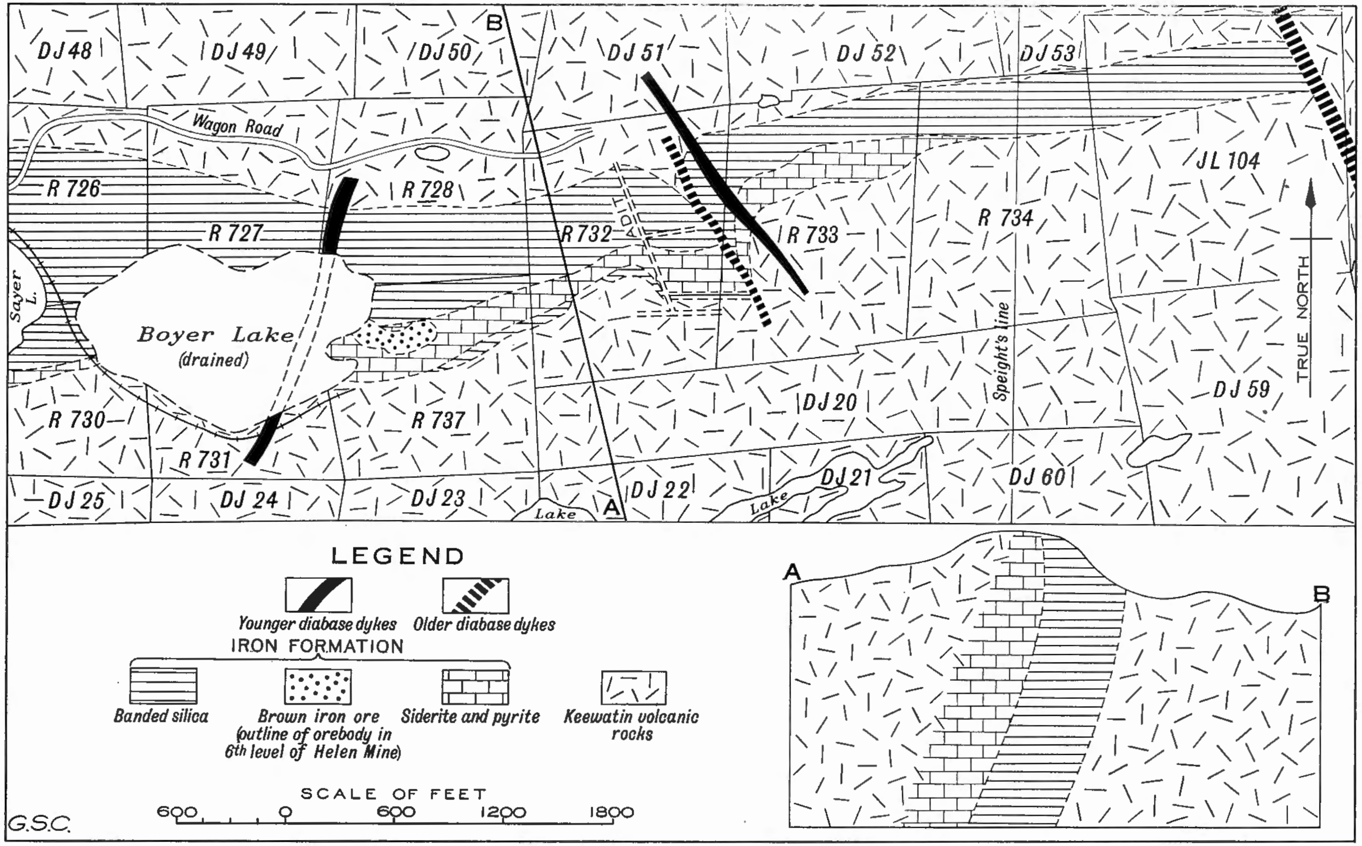


Figure 25. Plan and vertical cross-section of main part of Helen iron range. (After W. H. Collins.)

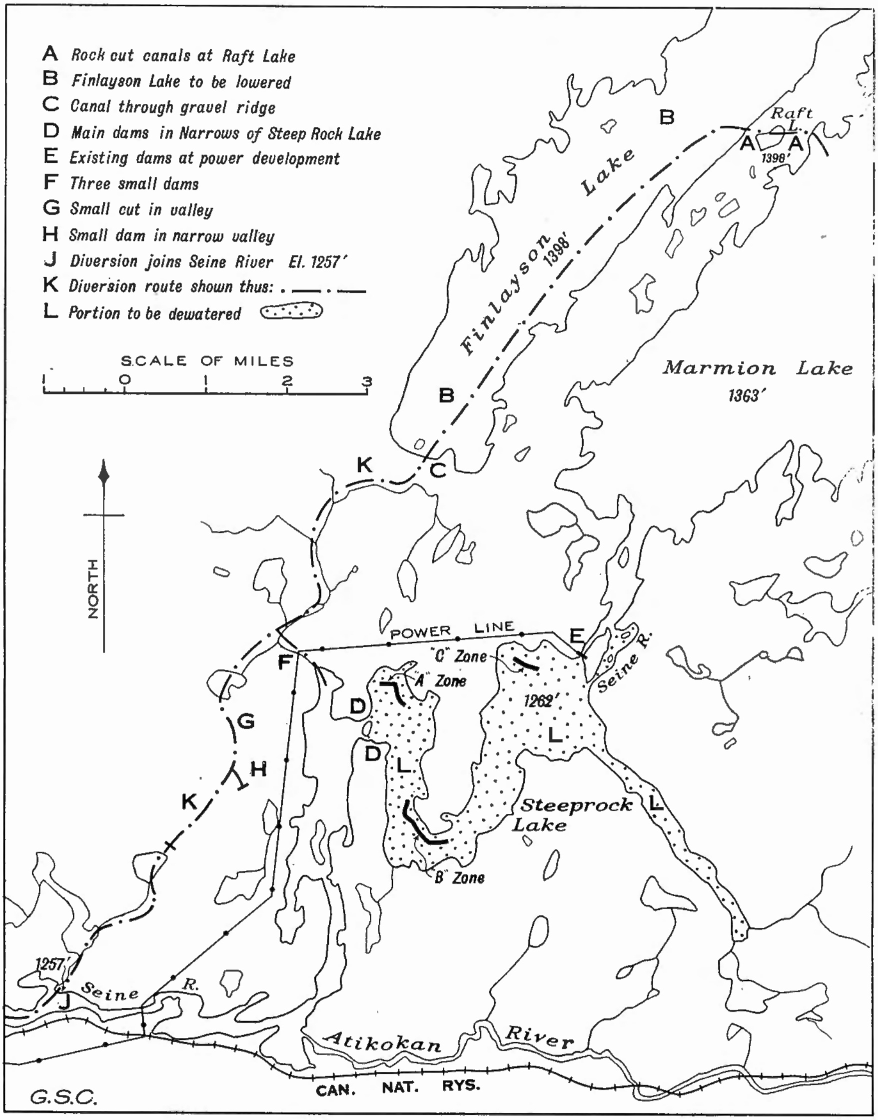


Figure 26. Plan of Steeprock Lake area, showing water-diversion scheme. (After Roberts and Bartley.)

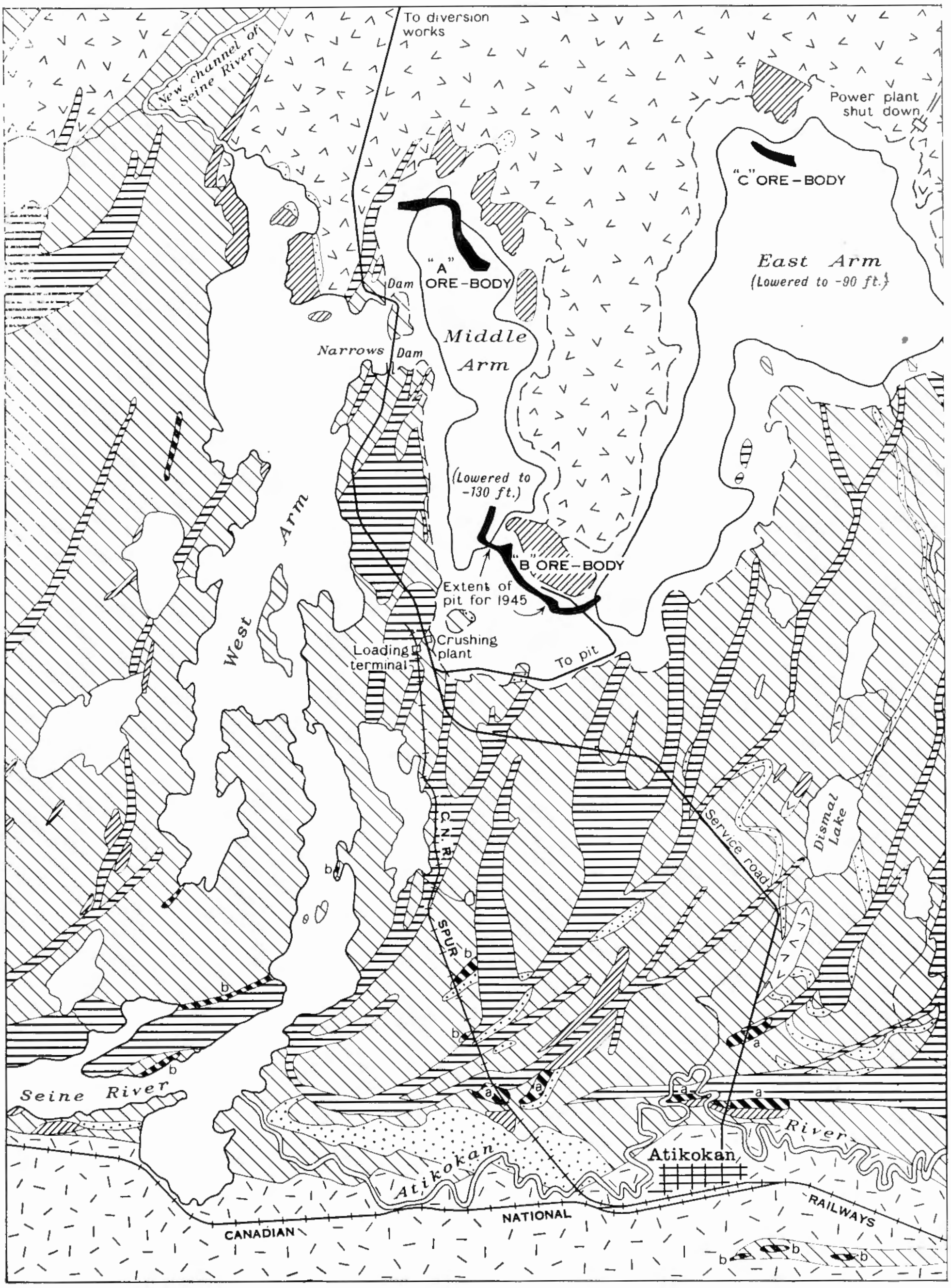
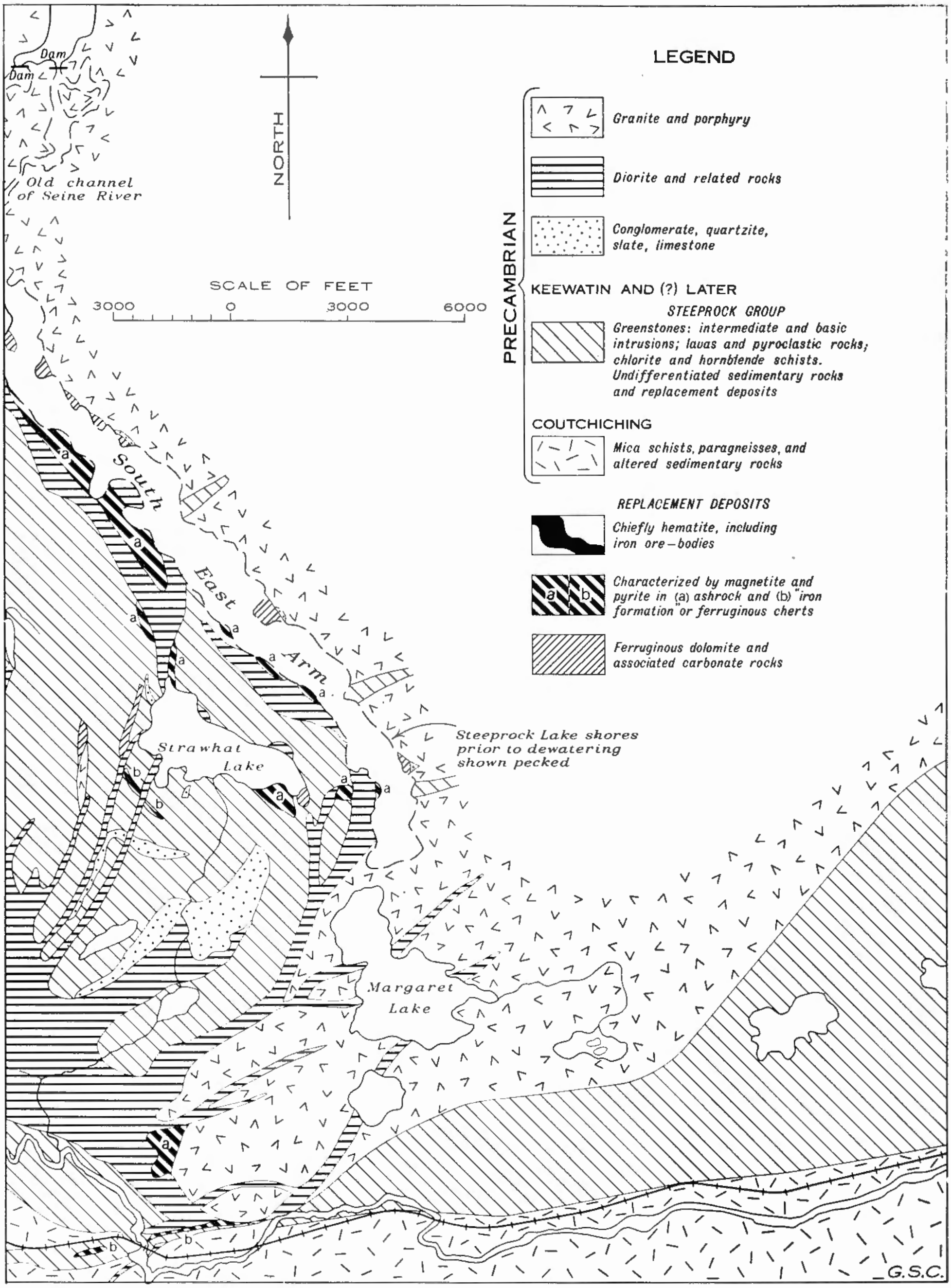


Figure 27. Geology of Steeprock Lake area. (By T. L. Tanton.)



LEGEND
PRECAMBRIAN
Granite and porphyry
Diorite and related rocks
Conglomerate, quartzite, slate, limestone
KEEWATIN AND (?) LATER
STEEPROCK GROUP
Greenstones: intermediate and basic intrusions; lavas and pyroclastic rocks; chlorite and hornblende schists. Undifferentiated sedimentary rocks and replacement deposits
COUTCHICHING
Mica schists, paragneisses, and altered sedimentary rocks
REPLACEMENT DEPOSITS
Chiefly hematite, including iron ore-bodies
Characterized by magnetite and pyrite in (a) ashrock and (b) "iron formation" or ferruginous cherts
Ferruginous dolomite and associated carbonate rocks
NORTH
SCALE OF FEET
3000 0 3000 6000
Dam
Dam
Old channel of Seine River
South
East
Arm
Strawhat Lake
Margaret Lake
Steeprock Lake shores prior to dewatering shown pecked
G.S.C.

The Josephine mine, although smaller, presents features very similar to those at Steeprock Lake. The property is in Michipicoten district, about 8 miles northeast of the Helen mine. The orebody lay beneath the bed of Parks Lake, which has been drained to permit of mining; on the north side it is bounded by the banded silica member of the iron formation. The ore forms a sheet-like body, 5 to 135 feet thick and about 3,200 feet long. The cherty silica had been brecciated, the brecciation becoming more intense toward the south side of the band, and hematite was then introduced, filling the fractures and partly replacing the cherty fragments. Naturally, the proportion of hematite is larger toward the south side, where brecciation was more intense; and toward the south boundary some lenses of very pure hematite have been encountered. Drilling has proved that the ores extend to a depth of at least 1,500 feet. Part of the ore is high-grade, lump hematite, but the bulk of it will require treatment in a gravity separator to get rid of excess silica.

The evidence is clear that the Steep Rock and Josephine deposits have been formed by ascending waters or vapours that have replaced the pre-existing rocks to form bodies of high-grade iron ore. This development has led some geologists to question Collins' original hypothesis, or rather to suggest its modification. Their view is that perhaps the iron carbonate bodies were not formed immediately after the extrusion of the lavas, as Collins supposed, but much later, after the lavas had been folded into their present, steeply inclined attitudes; and that possibly the introduction of iron was a subsequent process, beginning with the formation of iron carbonates and continuing in some places through other stages until pure hematite was deposited. The accuracy of this view must remain for later investigation to determine.

Although only the outstanding examples of the Keewatin iron formations have been described in the previous pages, it should not be forgotten that similar bodies are very numerous throughout at least the southern part of the Shield. Many of these are amenable to beneficiation, and, therefore, form great reserves against the time when the cheaply mined, high-grade ores at present utilized shall approach exhaustion.

Animikie Iron Formations

The Animikie iron formations are not unlike those of the Keewatin, but certain differences present themselves. Commonly, in any large outcrop of the Animikie iron formation the typical "granule texture" appears, which simulates in hand specimen the texture of a fine- to medium-grained sandstone. Also, here and there the regular, even banding passes along the strike into a wavy structure that gives place in turn to disconnected series of cupping bowls or thimbles—the so-called "algal structure."

Animikie iron formation is found in the district running southwest from Port Arthur to the United States boundary. Similar formations are known in the Belcher Islands and Richmond Gulf region of Hudson Bay, and in the band of Proterozoic sediments that strikes north-northwest through the middle of Ungava. A little of it has been reported from Great Slave Lake.

In the area west of Port Arthur no merchantable ore has yet been found, in spite of the fact that this formation on the other side of the International Boundary contains the great deposits of Mesabi district. However, recent drilling holds out some promise that orebodies may yet be found. In the Belcher Islands and Sutton Lake districts there are large deposits of lean ores, some bands of which could be concentrated successfully if conditions warranted, but no deposit of high-grade ore has yet been found.

Within the last 10 years, exploration of the southern end of the band of Proterozoic sediments in Ungava has revealed the presence of large bodies of high-grade iron ore. They have been found approximately on the Quebec-Labrador boundary north of Lake Petitsikapau. Extensive surveys and exploration have been carried on by the Labrador Mining and Exploration Company, which reports that six deposits were discovered during the field seasons of 1936 to 1939. The principal deposit is estimated to contain 2,200,000 tons of good hematite, low in phosphorus, per 100 feet of depth. Four other deposits are said to be of good grade, and one of them is rich in manganese. The sixth deposit is high in silica, but is said to have a large tonnage. The remoteness of these deposits, which will require the construction of 300 miles or more of railway before active development can proceed, makes it seem unlikely that they will become a commercial asset for some years.

Magmatic Segregations

Near Mine Centre, in Rainy Lake district, the rocks are mainly Keewatin lavas intruded by masses of gabbro and anorthosite, and by granite. Along the north shores of Seine Bay and Bad Vermilion Lake there is a long, band-like mass of hornblende-rich gabbro, more or less sheared; and on this, over a distance of 14 miles, occur segregations of titaniferous magnetite up to 100 feet in length. They have the form of steeply dipping, flattened lenses conforming in attitude to the schistosity. Nearly pure titaniferous magnetite forms either the central part or nearly all of each body, and is surrounded by an outer shell of leaner ore that merges outward into the country rock.

In that part of Quebec that lies between Ottawa and the North Atlantic coast numerous bodies of titaniferous magnetite or ilmenite are associated with bodies of gabbro or anorthosite, and apparently are segregations from them. One of the most important is the St. Charles deposit, near the north shore of Saguenay River. The ore, which lies within a very large body of anorthosite, outcrops over an area 700 feet long. One mass of ore measures 320 by 200 feet, another has a length of more than 300 feet, and other large exposures are visible in the immediate neighbourhood.

Titaniferous magnetites of similar origin are also fairly numerous in the region between Ottawa and Georgian Bay.

Other Iron Ores

In the district between Ottawa and Georgian Bay there are iron deposits of at least three types, in addition to the magmatic segregations of titaniferous ore just mentioned, and many of them have been mined on a small scale. Some bodies of hematite or limonite have proved, on mining, to be shallow masses formed by the oxidation of underlying bodies of pyrite. Still others are found in fissures and cavities, and may have been deposited after leaching from the once overlying beds of Palæozoic rocks.

The largest, however, appear to be contact metamorphic types developed along the contacts of granite or diorite with the crystalline limestones and other rocks of the Grenville and Hastings series. They consist of magnetite, intimately associated with hornblende, pyroxene, garnet, feldspar, and in some cases considerable amounts of pyrrhotite and pyrite. The ores are of good grade, low in phosphorus and titanium, and generally in sulphur. The orebodies are small by present standards, however, and occur as successions of rather short, stout lenses; and the ore must either be carefully selected to maintain the grade, or would have to be concentrated to remove impurities. Probably the largest of these properties was the Bessemer mine, in Hastings county, which was operated intermittently from 1902 to 1913.

SULPHUR

The principal source of sulphur on the Shield is iron pyrites or pyrite. During and prior to the last war large amounts of this mineral were mined for the sulphur content—more than 400,000 tons annually in 1917-8—but by 1924 competition from foreign sources had cut the production to some 11,000 tons, and shortly afterwards it ceased. No pyrite has been mined for many years for its sulphur content alone, though considerable amounts have been shipped from the copper mines of northern Quebec as a by-product, principally from the Aldermac mine, closed in October 1943. At Copper Cliff, Ontario, recovery of sulphur dioxide fumes from the smelter yielded the equivalent, in 1942, of some 10,000 tons of sulphur. This process was begun in 1931.

Pyrite deposits occur in three general districts; in eastern Ontario in Hastings and nearby counties, in Michipicoten district, and west of Lake Superior.

The first property to be mined was the old Billings deposit near Brockville. Operations commenced in 1868 and ceased in 1880. The main deposit was a lens about 300 feet long and 20 feet wide, on which a pit was sunk 250 feet. It was composed largely of pyrite, with some quartz, calcite, pyrrhotite, and magnetite.

Several deposits in Hastings county have been extensively mined. Near Sulphide garnetiferous schist is cut by a body of diorite or gabbro, and lenses of pyrite are strung along the contact for a distance of several miles. The principal mass mined was more than 600 feet long and 5 to 22 feet wide. The main impurity was calcite, but some quartz was present. Operations extended from 1904 to 1925.

Near Queensborough an irregular body of felsite intrudes garnetiferous schist, probably a recrystallized greywacke. At the Queensboro or Blakely mine pyrite lenses are on the contact with the felsite and garnetiferous schist. The lenses mined were about 50 feet long and 15 feet wide, and were very high-grade pyrite, the only impurity being thin veinlets of quartz. On the property of the Canadian Sulphur Ore Company lenses of pyrite occur at the contact of a pyritiferous schist with quartzite. The lenses are as much as 25 feet wide and were mined for several years.

In Michipicoten district the main pyrite deposits are the pyritiferous parts of the iron formations already described under "Iron". These range in thickness, in different places, from a few feet to 120 feet, and in composition from siderite thickly sprinkled with pyrite grains to material 90 per cent pyrite. At the top there are usually alternations of pyrite with banded silica; at the bottom the pyrite passes by gradual increase of carbonate into lean ore and then into the pure carbonate. The "range pyrite" is generally contaminated with about 10 per cent of magnetite and pyrrhotite, and with fractional percentages of arsenic, manganese, and zinc. Deposits of this type near Goudreau, Ontario, were mined extensively during the years 1914-9.

At the Helen mine, in the years 1900 to 1918, bodies of loose pyrite sand were encountered in mining the rich limonitic orebody. A considerable tonnage of these pyrite ores was shipped.

The Holdsworth property, in Goudreau district, has features rather different from the ordinary range pyrite. Drilling located two large lenses of pyrite lying on the contact between a green schist on the north and a grey sericite schist to the south. The eastern lens is 1,100 feet long, up to 25 feet wide, and extends to a depth of at least 525 feet. The western lens is 600 feet long, up to 31 feet wide, and at least 490 feet deep. It is pure, clean pyrite, with none of the siderite, magnetite, and pyrrhotite that characterize the "range pyrite".

West of Lake Superior, a pyrite deposit at the east end of Vermilion Lake was mined for many years. It appears to have been a vein, dipping vertically.

Its width at the surface was about 5 feet, but considerably greater widths are reported at greater depths. The principal impurity was a little pyrrhotite.

Numerous other bodies of pyrite are known on the Canadian Shield, but their development must await the time when prices and costs will make it profitable to mine them.

LEAD AND ZINC

A large part of the zinc produced from the Shield comes from the copper-zinc mines of Quebec and Manitoba, particularly the Amulet, Waite, and Normetal group of Quebec, which have yielded 214,468 tons to the end of 1945, and the Flin Flon, Sherritt Gordon, and Mandy group of Manitoba and Saskatchewan, from which 600,878 tons were obtained by the same date.

In Bourlamaque township, Quebec, zinc ore was discovered in 1937 at the Golden Manitou property, and a concentrating mill was completed in 1942. 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 in width. 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 gold and silver. By the end of 1945 the mine yielded 49,065 tons of zinc and 722 tons of lead.

Considerable zinc has been obtained from the Tetreault mine, about 45 miles west of Quebec. Although almost worked out some years ago, it was reopened as a wartime measure from 1942 to 1944. A band of limestone, now largely altered to tremolite, with minor amounts of anorthite, epidote, and garnet, strikes north and dips steeply east. It has been traced 3,000 feet on the surface and ranges in width from a few feet to 100 feet, though bulging in one place to 200 feet. The rocks on each side are paragneisses, much altered quartzites, and other sediments. Masses of sphalerite and galena were found along the west or foot-wall side of the limestone band, and pass upward into low-grade disseminated ore. They varied from less than a foot to more than 50 feet in thickness. The ores were of two types, one mainly sphalerite with minor amounts of other sulphides, the other 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, 1942-4, an additional 6,399 tons of zinc and 1,672 tons of lead were obtained.

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 Ottawa River, near Galetta village, or 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, with minor amounts of other minerals. The vein had an average width of 5 feet, and was followed more than 2,700 feet along the strike and to a depth of more than 1,300 feet.

The New Calumet mine is on Calumet Island in Ottawa River about 60 miles above Ottawa. The orebody is 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 feldspars and pyroxenes. 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 have been made at intervals to mine it, there was no real production until 1943. In the years 1943-5 it yielded 25,068 tons of zinc and 7,748 tons of lead.

Toward the west end of Sudbury basin, strong faults cut the Whitewater series with an east-northeast strike (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 iron pyrites, 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 low values in gold and silver.

About 20 miles north-northwest of the last locality, the Lake Geneva Mining Company operated a small property. Work begun in 1928 was suspended in 1930, and resumed in 1941. The deposit is a vein that strikes northwest and dips at the surface 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 contents of the ore run from 9 to 13 per cent zinc and 3 to 6 per cent lead.

Numerous other deposits of lead and zinc ores have been found on the Canadian Shield, but most of them have proved too small or too lean to be mined profitably.

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 the uses of the others are as yet small. Besides being widely employed in jewellery, the metals are required in the chemical and electrical fields where high resistance to corrosion, erosion, and oxidation are essential. The largest single use is as a catalyst in making nitric and sulphuric acids for munitions plants, and also in certain operations in organic chemistry such as the manufacture of vitamins. They are also becoming widely used in dentistry.

These metals are produced only from the Sudbury ores. Platinum and some rhodium occur in the mineral sperrylite, a platinum diarsenide, which 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 both 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.

From 1920 to 1945, inclusive, the Sudbury ores yielded 2,123,643 ounces platinum and 1,952,089 ounces other metals. 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 will, however, give some idea of the relative proportions in which the various metals occur.

Platinum and palladium have been reported from Rottenstone Lake, in northern Saskatchewan, 80 miles north of Lac la Ronge. There one or more zones of gneiss and associated schist carry pyrrhotite and other sulphides. The occurrence was drilled in 1928 and 1929 by Consolidated Mining and Smelting Company. One 10-foot core assayed $3.50 in platinum and $4.30

in palladium a ton, at prices then prevailing, as well as some copper and nickel. In a second hole, 100 feet from the first, a 25-foot section assayed $2.40 in platinum and $8.60 in palladium a ton, with worthwhile amounts of copper and nickel. Further drilling proved, however, that the mass is only a small lens, carrying some 50,000 tons of ore.

COBALT

Essentially all the cobalt produced from the Shield is obtained from the old silver mines at Cobalt, Ontario. Very large amounts of the metal were obtained when these mines were in full operation, and much was discarded because the market was glutted. For the past 15 years only salvage operations have been carried on by persons leasing the old mines or picking the old dumps. The total gross value of all the ore thus recovered in 1942 was only $750,000. This figure includes, of course, the value of the silver recovered.

A small amount of cobalt has been won from a deposit at Werner Lake, in Cobalt district, Ontario. A body of garnetiferous schist striking approximately east has been replaced locally by sulphides, chiefly cobaltite and some chalcopyrite. The unusual mineral linnaeite, Co_3S_4, has also been reported. Plums of ore up to 20 feet in length and 18 inches wide are surrounded by disseminated ore, the whole forming bodies of which the largest was about 150 feet long and 12 feet wide. The property was operated from 1942 to January 1945, and about 800 tons of concentrates were shipped.

Total Canadian production of cobalt in 1945 was only about 55 tons. Total production since 1904, the first year for which production was recorded, to the end of 1945, has been 17,263 tons. The recent use of the metal in high-speed cutting tools has greatly increased its importance.

ARSENIC

A large amount of arsenic is produced from the Shield, but all of it is a by-product of other mining operations. Large amounts have been produced in the past from the ores of cobalt, and some is still obtained from this source. Crude arsenic is shipped by O'Brien Gold Mines and by Beattie Gold Mines in Quebec, and by the Little Long Lac mine, Thunder Bay district, Ontario.

Total Canadian production of arsenic in 1945 was 1,023 tons, but what proportion of this came from the Shield is not indicated.

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. The outstanding discovery reported is on the Huron claim, about 9 or 10 miles upstream from Pointe du Bois. In one exposure beryl occurs in crystals and crystalline masses across a width of 15 feet. In another, a beryl-bearing zone 20 feet wide has an especially rich band 8 feet wide.

A little beryl has been found in pegmatite dykes around the edge of the La Motte granite mass, which overlies the corner of Villemontel, Figuery, Preissac, and La Motte townships about 10 miles southwest of Amos, Quebec. The crystals range from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches in diameter, and from 1 inch to 4 inches in length. They are, however, widely separated, and the amount present is very low. Any beryl recovered from this district will probably be by-product material from the mining of other substances, such as spodumene.

In the Yellowknife-Beaulieu area of the Northwest Territories dykes of pegmatite are very numerous, and many have been found to carry beryl. Only a small percentage of them has yet been examined, but of these an unusually large number carry beryl in promising quantities. Possibilities seem bright in this area for mining some of these dykes either for beryl alone or together with tantalite-columbite. Beryllium has assumed new importance of late years because, alloyed with copper, it makes springs that can vibrate numberless times without displaying fatigue.

CADMIUM

A little cadmium is obtained as a by-product of zinc production at the Flin Flon mine in Manitoba. About 66 tons were obtained in 1945. Total production to the end of 1945 has been 919 tons. The principal use of the metal is for plating to protect against salt-water corrosion, for which purpose it is much superior to zinc.

CHROMITE

No chromite is at present being produced from the Shield. In the years 1934-7 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 $3\frac{3}{4}$ miles long and $\frac{3}{4}$ mile wide. Masses of disseminated chromite were found in several places, particularly toward 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 has been aroused by the discovery in 1942 of large chromite deposits north of Bird (Oiseau) River, southeastern Manitoba. A great sill-like mass of gabbro intruded into the Precambrian rocks has been differentiated, presumably by gravity, into products ranging from an augitite at the base to a feldspathic quartz diorite at the top. Somewhat below the middle of the sill a band of the rock, paralleling the strike, 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 and 20 per cent Cr_2O_3, but the best chrome-iron ratio is about 1·2 to 1.

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.

Lithium minerals have not been mined commercially in Canada as yet, except for a few hundred tons, mainly of spodumene, that were shipped in 1937 from the Pointe du Bois area of Manitoba. In this area spodumene, lepidolite, and the variety of amblygonite known as montebrasite occur in pegmatite dykes. The ancient volcanic and sedimentary rocks are there intruded by bodies of microcline granite, oligoclase granite, and albite granite. The last, in contrast with the other two, forms only small masses, and the lithium-rich pegmatites seem to be acid differentiates of it, as they are found close to its margins. The lithium minerals appear mainly in the central, quartz-rich parts of the pegmatites.

In the Yellowknife-Beaulieu area of the Northwest Territories, many pegmatite dykes are associated with bodies of muscovite-biotite granite that appears to be of Proterozoic (post-Animikie ?) age. These granite bodies have metamorphosed strongly the sediments they intrude, and the pegmatites are commonly confined to the sediments thus altered. One of these pegmatites, the McDonald body in Buckham Lake area, contains about 30 per cent by weight of spodumene in its central part, which averages 19 feet in thickness and 400 feet in length (Plate XI).

PLATE XI

Spodumene crystals in pegmatite, north end of Buckham Lake, Northwest Territories. Photo by A. W. Jolliffe, Geological Survey (93817).

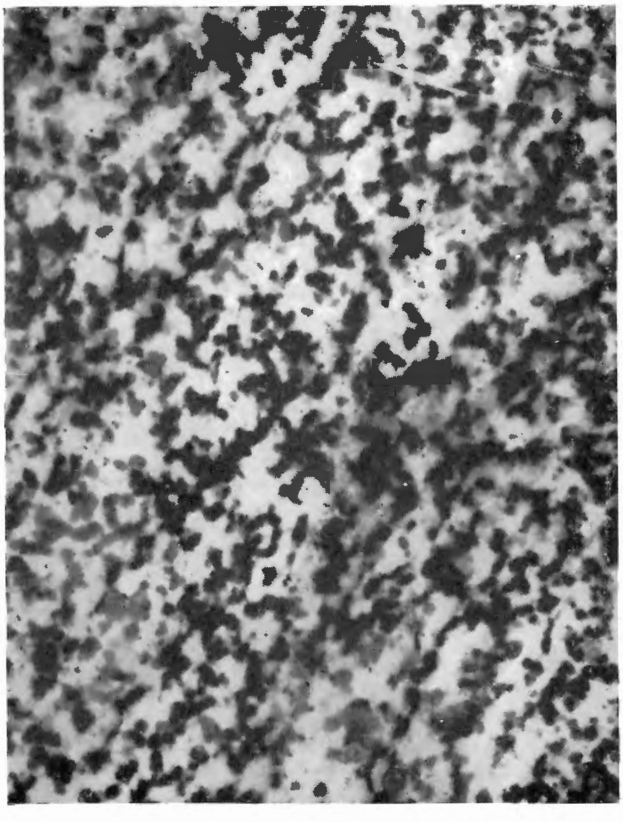
A promising discovery was made in northern Quebec, in 1942, of a pegmatite dyke 23 feet wide carrying about 20 per cent of spodumene apparently distributed uniformly through it. Exploration since that time has indicated that more or less similar dykes occur through La Motte and Lacorne townships for at least 13 miles east and 10 miles southeast of the east end of the La Motte granite body. The spodumene dykes have sharp, tabular, steeply dipping walls. They range from a few feet to 30 feet in width, and can be traced for hundreds of feet. The chief constituents are albite, microcline, quartz, and spodumene, with a little beryl and, rarely, tantalite-columbite. The four chief constituents are present in nearly equal proportions, though the spodumene content varies from dyke to dyke. The general textures are those of very coarse igneous rocks, though there are local segregations where spodumene crystals attain lengths up to 18 inches, or even more.

Lithium is the lightest of the metals, only about half as heavy as water. It is being used increasingly in a wide series of alloys with other elements. The chloride is one of the most hygroscopic inorganic substances, and is utilized as a drying agent in air-conditioning units.

MAGNESIUM

National defence requirements, especially in the aircraft industry, created a tremendous demand for magnesium metal. Accordingly, in 1942, the plant of Dominion Magnesium was brought into production near Renfrew, Ontario. The plant utilizes dolomite beds of the Grenville series, quarried near the plant, and reduced by the ferrosilicon process. Altogether 12,854 tons of metal were turned out by the end of 1945.

PLATE XII



Granules of brucite (stained black) in calcite matrix. Natural size. Photo by M. F. Goudge, Bureau of Mines.

Near Rutherglen, Ontario, 19 miles west of Mattawa, and near Bryson and Wakefield, Quebec, bodies of crystalline limestone of the Grenville series carrying granules of the mineral brucite were discovered by M. F. Goudge of the Bureau of Mines, Ottawa. The bodies of crystalline limestones are surrounded by, and presumably included in, masses of hastingsite syenite; no brucite has as yet been found except in connection with these syenites. The granules of brucite are about the size of grains of wheat, and are present in various proportions up to 36 per cent (Plate XII). 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.

A plant was established at Wakefield, Quebec, in 1942, for mining and extracting the brucite. The rock is calcined, which converts the limestone into lime and the brucite into magnesia (MgO); the lime is slaked with excess of water, and the milk of lime then washed out while the magnesia granules are retained on screens. The clean magnesia is used mainly for refractory products, furnace linings and the like.

Magnesite, the carbonate of magnesium, has been mined for many years from deposits in Grenville and Harrington townships, Quebec, and production has increased rapidly of late years. The magnesite occurs mainly in four localities, and forms lenticular masses several hundred feet in length. These hold varying amounts of dolomite and some bands of disseminated serpentine. The magnesite-dolomite beds, with which are associated quartzites, gneisses, and limestones of the Grenville series, lie close to bodies of pyroxene syenite, and it has been suggested that this association may have some genetic significance.

The magnesite-dolomite mixture is commonly calcined, and is used in bricks or other forms as a refractory material.

MOLYBDENUM

Molybdenum, which is principally used for alloying steel, occurs mainly as the sulphide, molybdenite, a soft, flaky, blue-grey mineral. It has been found in many places on the Shield.

The most outstanding discovery of recent years was made by Dome Exploration Company on Indian Peninsula, Kewagama Lake, in Preissac township, Quebec. Drilling in 1942 established the presence of a large body of disseminated molybdenite, and, under pressure of wartime demand, the property was brought into production in September 1943. A body of mica granite displays numerous pegmatitic and aplitic facies passing into quartz veins. Large numbers of such veins, many of large size, traverse the granite. The quartz veins carry a little feldspar in places, and in others have selvages of mica flakes with some feldspar. In other places they pass into pegmatites. The molybdenite deposit lies between two faults, about 40 feet apart, that strike northwest and dip 40 to 50 degrees northeast (Figure 28). From the hanging-wall fault gently dipping quartz veins 6 inches to a foot wide extend across the granite and are connected by steeply dipping quartz stringers. Near the foot-wall fault the veins increase in number and eventually coalesce to form a solid vein of quartz 12 feet wide in places. Later deformation formed small slips in the quartz and in included fragments of granite.

Undeformed veins carry small amounts of molybdenite in hexagonal plates; but the slip surfaces mentioned are thickly lined with muscovite and fine-grained molybdenite. The run-of-mill ore from this occurrence averaged about 0·45 per cent MoS_2. Mining on it has ceased.

In the southwest corner of Lacorne township, Quebec, and the adjoining corner of Malartic township, deposits of molybdenite known for many years have been worked since 1943. A biotite schist of sedimentary origin has been invaded by thin sills of granite and then by pegmatitic quartz veins carrying molybdenite. The whole assemblage strikes northeast and dips northwest at about 60 degrees, though some veins also dip southeast. Most of the veins average 3 to 4 feet in width. Test samples of the ore ran about 2 per cent molybdenite.

In Renfrew county, Ontario, bodies apparently of contact-metamorphic origin were mined for molybdenite during the war of 1914-8, 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 limestones 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 up to 30 feet. Rich pockets of molybdenite were found in them, but on the whole the grade was low and operations were unprofitable.

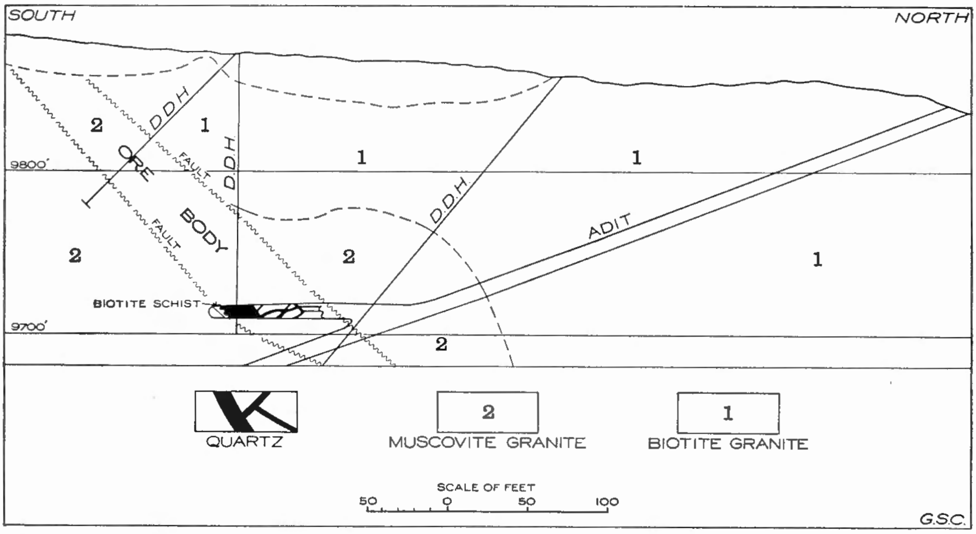


Figure 28. Adit cross-section, Indian molybdenum mine, Preissac township, Quebec. (After G. W. H. Norman.)

A similar occurrence found near Montcerf, 15 miles north of Maniwaki, Quebec, has been mined to some extent during the recent war. A sill-like body of granite-gneiss overlies crystalline limestone of the Grenville series, the contact striking northeast and dipping southeast at a low angle, apparently 25 or 30 degrees. At the contact the 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, might run 1·25 to 1·50 per cent molybdenite, but the general average was much lower.

Much molybdenite has been furnished by a deposit near Quyon, Quebec, called the Moss mine. During the first great war 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 ½ to ¾ of 1 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 who have studied them 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.

RADIUM AND URANIUM

In the spring of 1930 pitchblende, the ore of uranium and radium, was discovered at LaBine Point, at the east end of Great Bear Lake. Since that time other discoveries have been made both in the same general neighbourhood and in the area between Lake Athabaska and Great Bear Lake. The Eldorado mine on Great Bear Lake is, however, the only property that has yet yielded any important amount of pitchblende.

At Eldorado mine the rocks are those of the Echo Bay group of Proterozoic age—thinly banded cherty sediments, bedded tuffs, 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 in thickness 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 the shatter zones of these faults. In the two northernmost faults the ore is found only in the sediments, 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 other 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.

In the years 1933 to 1937 the refinery at Port Hope, Ontario, produced 53·808 grams of radium valued at $1,525,600, and 508,296 pounds of uranium salts valued at $706,500. Figures for later years have not been made public.

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-zinc ores of

Quebec and Manitoba. Production of selenium from these sources in 1945 totalled about 190 tons; of tellurium about 1 ton. Total production from these mines, to the end of 1945, was 2,115 tons of selenium and 98 tons of tellurium.

The use of these elements has increased greatly in the last decade. Selenium is being increasingly utilized for vulcanizing rubber, in the manufacture of high-quality rectifiers for converting alternating into direct current, and for many minor applications. A minute amount of tellurium added to cast iron greatly increases its resistance to abrasion, thus making it more suitable for car wheels, gears, and so on. Tellurium-lead alloys become tougher and stronger when rolled or stretched, so that pipes made of them can be a third thinner than ordinary lead pipes and yet have greater strength. These alloys are also remarkably resistant to corrosion from strong acids, and hence are finding increasing use for tank linings and similar protective materials. One-half of 1 per cent tellurium is reported to double the life of lead in sulphuric acid plants.

TANTALUM AND COLUMBIUM

Neither tantalum nor columbium has been mined in Canada. During the field season of 1943, however, many pegmatite dykes were found by officers of the Geological Survey in the Yellowknife-Beaulieu area of the Northwest Territories, and these contain so much of the mineral tantalite-columbite that a new mining industry may prove practicable.

The pegmatites, which are related to the Late Precambrian granite of the region, are found chiefly in areas of sedimentary rocks of the Yellowknife group much metamorphosed by the heat emanating from these granites; they also cut bodies of older granodiorite and diorite. The pegmatites, as well, carry beryl and lithium-bearing minerals, and have been mentioned under those heads. Near Ross Lake several hundred of these dykes are satellitic to a body of pegmatitic granite, and these display a distinct zoning. Within a mile of the granite the dykes carry few rare-element minerals other than beryl. Between 1 and 2 miles from it, the pegmatites contain most of the rare-element minerals, including the best concentrations of tantalite-columbite. Still farther away spodumene and, in one instance, petalite, become prominent. Only about one dyke in five carries tantalite-columbite; in those that do, the mineral tends to form fairly large crystals, up to several inches in length and 2 inches in diameter.

Small shoots carrying good concentrations of tantalite-columbite have already been found, but unfortunately the distribution is erratic, as in most deposits in pegmatite. Whether sufficient can be found to justify actual mining operation remains for further prospecting to discover.

The composition of the tantalite-columbite varies within wide limits. Some of the specimens carry little tantalum and much columbium; in others the opposite is the case. The high-tantalum ores are much the more valuable, though, oddly enough, columbium metal is worth roughly three times as much as tantalum.

TIN

No tin ores have as yet been found on 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.

TITANIUM

Ilmenite, or titanite of iron, is the principal source of titanium on the Shield. It occurs as magmatic segregations in the anorthosites of southern Quebec, which are found all the way from the lower Ottawa to the North Atlantic coast. Mining of ilmenite has been carried on for many years near St. Urbain, about 9 miles north of Baie St. Paul on the north shore of the St. Lawrence below Quebec. At this locality ilmenite forms a number of bodies in massive anorthosite and 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 the oxide of titanium, rutile, that the ore could be mined for the rutile alone. Ilmenite carries 18 to 25 per cent of titanium, rutile 54 to 59 per cent.

A second important ilmenite occurrence, not now mined, is near Ivry, 67 miles north of Montreal, where a number of outcrops of ore lie in an area 1,100 feet long and about 120 feet wide. Titaniferous magnetites, carrying from 3 to 15 per cent of titanium, are known in a great many places, as near Lake St. John; at Bay of Seven Islands, and on the shores of Seine Bay and Bad Vermilion Lake in Ontario.

Titanium is used chiefly in the manufacture of white paints, on account of its great covering power. It is used to a smaller extent in making ferro-alloys. About 14,000 tons of titanium ores were mined in Canada in 1945.

TUNGSTEN

The principal ore of tungsten on the Shield is scheelite, or calcium tungstate. It is found chiefly in gold ores, and also recently in quartz veins in the Yellowknife-Beaulieu area of the Northwest Territories. No deposit worth mining for its own sake 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 Mines, at whose property perhaps the largest bodies of scheelite were found, erected a mill in which 135 tons of ore were treated daily. Ore from the other mines in Porcupine district was shipped to this mill.

Some tungsten has also been obtained from the deposit on Outpost Islands, Great Slave Lake, which has already been described under gold. The ore, however, is a gold-copper-tungsten-tin complex, and difficulty has been encountered in producing a satisfactory tungsten concentrate. The tungsten mineral here is mainly ferberite, or tungstate of iron, and the ore is said to run about 1 per cent tungsten.

ASBESTOS

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.

A small deposit of asbestos is known on the shore of Rahn Lake in the western part of Bannockburn township, Ontario. A body of highly serpentinized peridotite striking northwest has been traced for some 1,700 feet. A fault along its contact with rhyolite shattered it across a width of 5 or 6 feet, permitting veinlets of asbestos to form in the shattered zone. Several attempts have been made to develop the property, but presumably its small size has been unfavourable to success.

About 3 miles east of Actinolite village, Hastings county, Ontario, there are large bodies of actinolite that were mined, with interruptions, from 1883 to 1927. The mineral in some places appears to be 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 may be an altered crystalline limestone. The mineral was ground, mixed with coal tar, and used for roofing.

APATITE

Apatite, or 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 now produced is a by-product of mica mining and is utilized mainly for the manufacture of phosphorus. Production in 1941, about 2,500 tons, was the largest for many years; in 1942 it was only 1,264 tons.

Almost all the apatite comes from Quebec, between and bordering on Gatineau and Lièvre Rivers, and from a district in Ontario lying north and northeast of Kingston. Crystalline limestones of the Grenville series have been metamorphosed to irregular masses and bands of light green diopside accompanied by calcite, phlogopite, apatite, tourmaline, fluorite, and other minerals. Apatite is found in the pyroxene rock in irregular pockety masses, accompanied by more or less phlogopite. The apatite is always fluor-apatite.

MICA

Most of the mica produced from the Shield is amber mica or phlogopite, and comes from the same areas and the same types of deposits described for apatite. Some of these bodies, like the Lacey mine northwest of Kingston, have been large producers. Production of phlogopite in 1942 was 2,706 tons, an amount nearly double that produced in 1941.

Muscovite, or white mica, is found in small amount in pegmatite dykes. In 1941 an important discovery was made near Eau Claire station 13 miles west of Mattawa, Ontario. Bodies of biotite schist, hornblende gneiss, and hornblende-garnet gneiss, all of which are probably metamorphosed sedimentary rocks of the Grenville series, are surrounded by alaskite granite consisting chiefly of microcline and quartz. Dykes of pegmatite up to 20 feet wide, lenticular in shape and irregular of outline, are fairly numerous in the metamorphosed sediments, and consist mainly of microcline and quartz. Some of them also carry sodic plagioclase, muscovite, biotite, and small amounts of other minerals. The commercial muscovite is found in large crystals, one of them 6 feet by 8 feet. It is reported that commercial muscovite is confined to those dykes that are coarse in grain, contain soda feldspar rather than potash feldspar, and cut across the cleavage of the wall-rocks. Twenty-two tons of muscovite were produced in 1942.

A second body of similar type is found at the Villeneuve mine 20 miles north of Buckingham, Quebec. The pegmatite mass here is at least 150 feet wide and consists of intimately associated microcline and albite with minor amounts of quartz. The mine has not been operated for some years.

FELDSPAR

Feldspar is likewise mined from pegmatite dykes, and most of the production from the Shield comes from the same general areas as that of apatite and mica. There are also many deposits, which have shipped intermittently, throughout Ontario west to Georgian Bay, and in Sudbury district. Most of the feldspar produced is of the high-potash type, though a little high-soda feldspar is also mined. 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 in 1945 was 26,389 tons from Quebec and 3,857 tons from Ontario. Approximately 98 per cent of it is used in glass, pottery, and enamel manufactures. During the war powdered feldspar was used to some extent for smothering incendiary bombs. The feldspar used, an easily fusible variety, melts with the heat of the bomb to cover it with a viscous coat that shuts off access of air.

NEPHELINE SYENITE

A string of nepheline syenite bodies extends from Sebastopol township in Renfrew county westerly almost to the southwest corner of Haliburton county. A small mass is also found in Methuen and Burleigh townships, Peterborough county. These bodies are developed on or close to the contacts of the granite of the region with crystalline limestones, and appear to be differentiates of the granite.

Nepheline syenite is mined in Methuen township, and also in Hastings county near Bancroft village. The rock consists essentially of nepheline and alkali feldspar, with minor amounts of biotite and other basic minerals. It is mined mainly for use in the glass and pottery trades, as it contains 20 to 30 per cent of alumina as opposed to 17 to 20 per cent in feldspar. Likewise its higher content of alkalis reduces the temperatures of melting. Some 61,345 tons were mined in 1945.

CORUNDUM

Corundum occurs as a constituent of the nepheline syenite group of rocks described in the preceding section. This group ranges in composition from alkaline syenites to essexites and more basic types, and also to feldspathic rocks analogous to anorthosite. 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 localized and have been exploited chiefly in Raglan and Carlow townships. 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.

Corundum began to be mined 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 1921, though an effort to revive the industry has lately been made, and 1,317 tons were produced in 1945.

SILICA

Considerable silica is 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. Approximately 1,500,000 tons are thus utilized annually. In addition, these smelters will 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 utilizes 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, parts have also been sold to smelters or manufacturers of ferro-silicon.

The upper third of the Lorrain quartzite formation, the upper part of the Cobalt series, is a very pure quartzite, and has a wide distribution throughout northern Ontario. It has been mined near Sault Ste. Marie for the manufacture of silica brick, and near Killarney, Ontario, for the manufacture of ferro-silicon.

TALC

All the talc produced from the Shield has been from deposits near Madoc, Ontario. The only important producer has been the Henderson mine, operated since 1937 by Canada Talc, Limited. This deposit was discovered in 1900, but for some years operated only 2 months in the year and shipped its products to the United States. In 1907, however, a grinding mill was erected, since when operation has been almost continuous. Some 438,000 tons have been produced to the end of 1945. 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; and within the talc body traces of the bedding planes of the original dolomitic limestone from which the talc is derived are visible. It is probable that the action of solutions from a near-by 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 the talc in general has been of a lower grade.

BARITE

Barite is not mined from the Canadian Shield, except possibly as a by-product. However, there are a number of important occurrences of the mineral.

In eastern Ontario and in districts in Quebec bordering on the lower Ottawa River, barite is a constituent of certain veins of Palæozoic age, but largely developed in Precambrian rocks. These veins, which carry also galena, fluorite, and calcite, in places hold large bodies of nearly pure barite.

In northern Ontario veins of barite are found in several localities. In Cairo township a steeply dipping vein of barite with minor amounts of sphalerite, galena, specularite, and fluorite traverses a body of syenite, and in places is 7 to 15 feet wide. In Yarrow township, similar veins cut Cobalt sediments. In Penhorwood township a vein largely composed of barite, with some calcite, quartz, and fluorite traverses a pegmatite dyke and in places attains a width of 15 feet.

In Port Arthur district barite is an important constituent of some of the silver-bearing veins in the Animikie rocks.

CELESTITE

Celestite, like barite, occurs in eastern Ontario and adjacent parts of Quebec in veins of Palæozoic age, though many of them are found in Precambrian rocks. Much of it was thrown on the waste dumps in the mining of these veins for fluorite near Madoc, Ontario. A deposit in Bagot township, Renfrew county, Ontario, was mined to a small extent in 1920-1, and an attempt to re-open it was made in 1941. The celestite contains much barite, however, and on that account was not found usable.

FLUORITE

Fluorite is the most valuable constituent of the group of veins mentioned in the two preceding sections. These veins, which are 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.

The veins near Madoc occur in two systems, the Moira Lake and Lee-Miller groups. 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 in parallel subsidiary fractures. The Lee-Miller group lies a mile or two to the 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, but the individual descriptions do not so state.

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 the numerous vuggy openings.

Production from these veins has been mainly a wartime effort. In 1906-20 nearly 20,000 tons of fluorite were mined, but before that time and after it until the outbreak of the recent war there was little or no production. In 1940-2 attempts were made to re-open many of the old mines, with the assistance of the Dominion Government, and in the years 1940-5, inclusive, 38,671 tons of fluorspar were recovered.

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 intrusives, and are converted to a greater or less extent to silicate minerals such as feldspar, diopside, scapolite, mica, and similar minerals. 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.

An excellent example of these relations is afforded by a deposit about 7 miles southeast of Perth, Ontario. This body was discovered before 1870 and was worked at intervals, but particularly during the war of 1914-8. A pit some 400 feet long displays a band of graphite-bearing rock carrying 4 to 5 per cent of the mineral paralleling in strike and dip the banding of the surrounding limestone (Figure 29). This band, which strikes east-northeast is narrow and irregular throughout most of its length; but at the northeast end, where the limestone is sharply drag-folded, the graphite band widens to about 40 feet, and the amount of graphite rises to 15 per cent or even more. All the production of the mine was from this thick, high-grade body, which plunged northeast at a high angle.

The most important graphite deposit is the Black Donald mine, situated about 25 miles southwest of Renfrew, Ontario. This body was discovered about 1889, and has been in operation, with some interruptions, from 1895 to the present. 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 is about to roll over into an anticline. The grade of the ore is unusually rich. 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 averages 55 to 65 per cent.

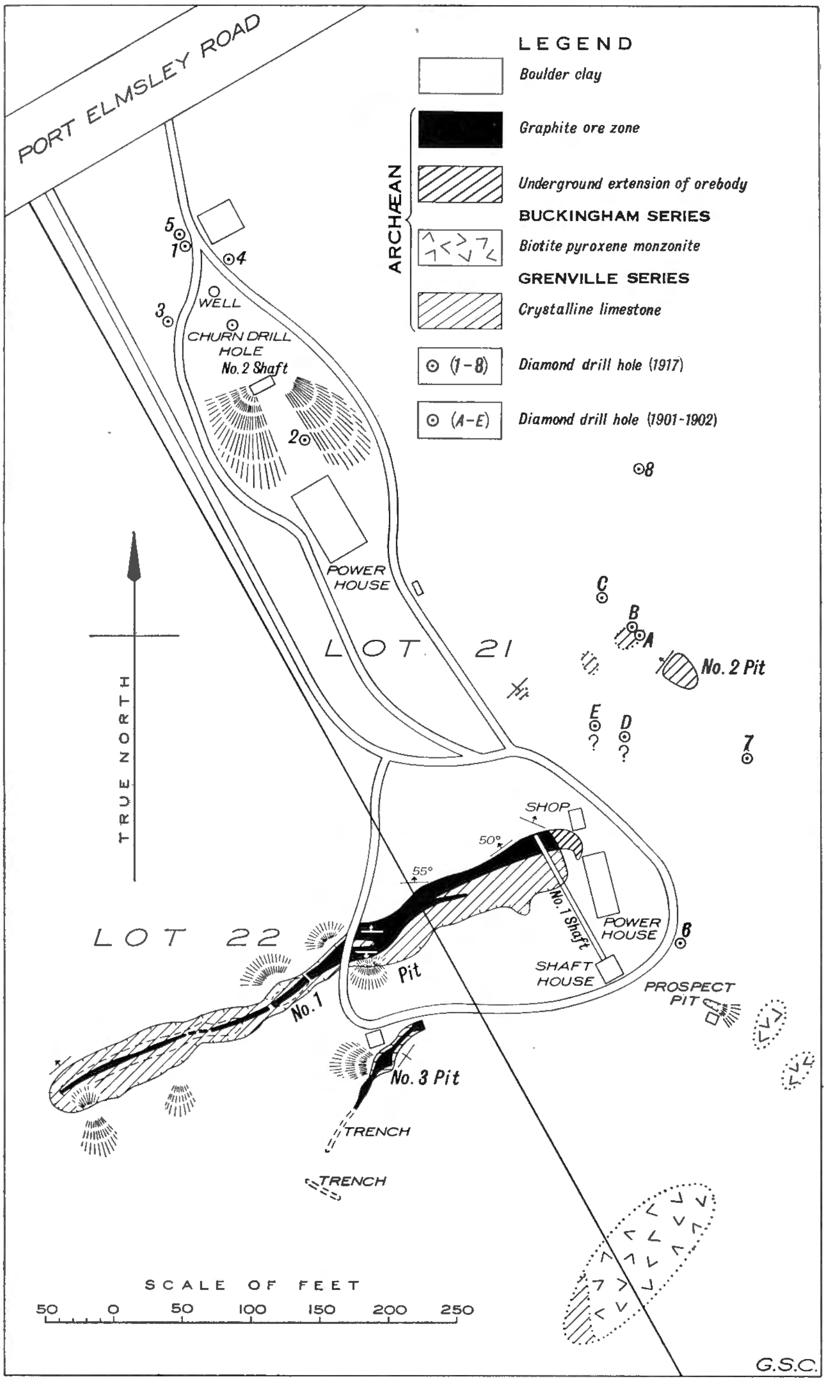


Figure 29. Diagram showing graphite deposits, lots 21 and 22, con. VI, North Elmsley tp., Lanark co., Ontario. (After W. H. Collins.)

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. Only 17 tons were mined in 1942, all of it from River Valley, about 40 miles northwest of North Bay. Since 1942 only 3 tons were mined, in 1944. The Canada Garnet Company also carries on intermittent operations near Labelle, Quebec. The reason for the small production is that Canadian garnet has not yet been found to meet the rather exacting specifications demanded for industrial use.

KAOLIN

Kaolin is found near St. Remi, Amherst township, 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 ridge is separated by valleys from ridges of granite and syenite gneiss. The eastern side of the ridge is massive and unbroken, but the west side, throughout a zone approximately 1,000 feet wide, is shattered almost everywhere by faulting to a friable condition. The shattered zone has been traced at least 7,000 feet.

Within this shattered zone there 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 the quartzite, amounting roughly to two-thirds of the whole mass. There is excellent evidence to show that the kaolin has formed by replacement of the shattered quartzite presumably through the agency of ascending hot liquids or vapours. The average kaolin content of the shattered zone taken as a whole has been estimated to be about 11 per cent.

Nearly 25,000 tons of this material were mined in 1942, but in later years production has fallen off greatly. A by-product of its preparation is washed silica sand suitable for glass making. The kaolin, or china clay, is utilized in the paper, rubber, ceramic, and other industries.

Several other interesting occurrences of kaolin have been discovered in Quebec of recent years. One, near Point Comfort, on Thirty-one-mile Lake, is known to carry high-grade china clay. Other deposits, as yet little explored, are near Brebeuf, on Lake Labelle, and near Chateau Richer.

CHAPTER III

THE APPALACHIAN REGION

(F. J. Alcock)

PHYSICAL FEATURES

The Appalachian region of Canada, sometimes called the Appalachian-Acadian region, comprises the three Maritime Provinces—Nova Scotia, New Brunswick, and Prince Edward Island—and that part of the province of Quebec that lies southeast of "Logan's Line," a thrust fault extending from Lake Champlain northeastward in a gently curving arc to Quebec City and from there down the St. Lawrence. The whole belongs to a larger unit usually referred to as the Appalachian Highlands or the Appalachian Mountain system, which stretches from Alabama in the southwest to Newfoundland in the northeast, a distance of 2,000 miles. This larger region, marked throughout by Palæozoic deformation, is divisible into a number of physiographic provinces that show similar surface characteristics within themselves. The Appalachian region 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 (Mansfield), the White Mountains of New Hampshire, culminating in Mount Washington, 6,293 feet high, and the highlands of Maine.

In Canada the Appalachian region as a whole is an upland dissected by valleys and broken by broader lowland areas developed on belts of weak rocks. It has a long stretch of coast, for the most part irregular in outline and with many deep embayments.

NOVA SCOTIA

Nova Scotia is made up of five upland and as many lowland areas (*See* Figure 30). The former comprise: (1)[1] the large Southern Upland, which embraces the southern and central part of the peninsula and slopes from elevations of about 600 feet southeastward towards the Atlantic Ocean and also southwestward towards the Gulf of Maine; (2) North Mountain, 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 southwest for 120 miles to Brier Island; (3) the Cobequid Mountains, lying north of Minas Basin and stretching for 75 miles across Cumberland county from the head of the Bay of Fundy almost to Northumberland Strait; this region shows broad, rounded summits blending to form a somewhat rolling surface with an average elevation of a little more than 900 feet; (4) the highlands of eastern Pictou and Antigonish counties between New Glasgow and Antigonish and stretching northeastward to Cape George; in the southern part the average elevation is about 800 feet, but near Arisaig it is more nearly 900 feet; (5) the upland belts and northern tableland of Cape Breton Island, where hard, crystalline rocks come to the surface; the northern tableland is the largest of these areas and presents an even, flat-topped surface about 1,200 feet high (Plate XIII).

[1] These numbers correspond with those on the accompanying map, Figure 30.

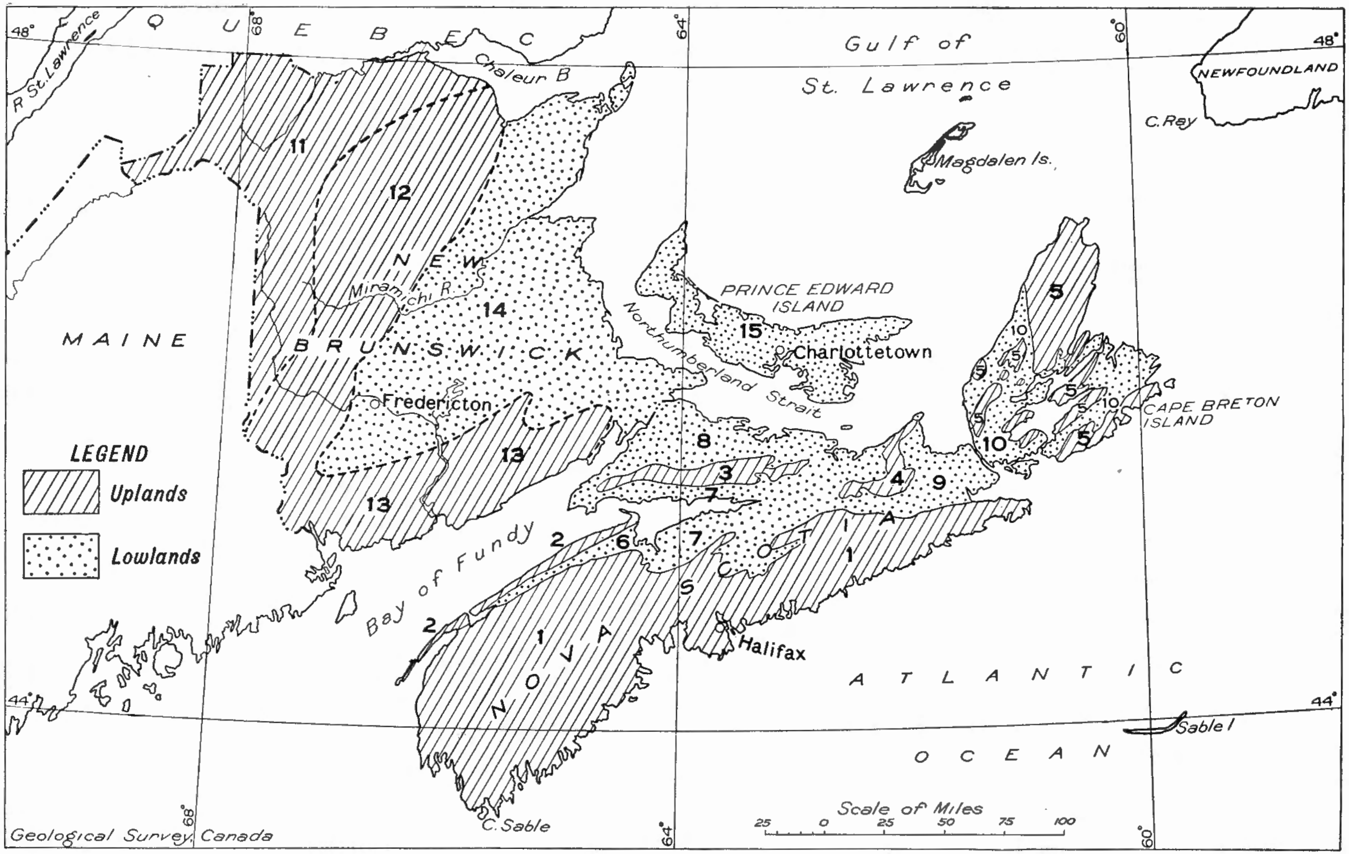


Figure 30. Physical subdivisions of the Maritime Provinces. Nova Scotia: 1, Southern Upland; 2, North Mountain; 3, Cobequid Mountains; 4, Pictou-Antigonish Highlands; 5, Cape Breton Highlands; 6, Annapolis-Cornwallis Valley; 7, Hants-Colchester Lowlands; 8, Cumberland-Pictou Lowlands; 9, Antigonish-Guysborough Lowlands, 10, Cape Breton Lowlands. New Brunswick: 11, Northern Upland; 12, Central Highlands; 13, Southern Highlands; 14, Eastern Plain. Prince Edward Island: 15, outlier of the Eastern Plain of New Brunswick.

The lowlands are underlain by less resistant rocks, such as sandstones, shales, limestone, and gypsum, and show a considerable diversity of elevation and form. They comprise: (6) the Annapolis-Cornwallis Valley, a long, trough-like depression lying between the steep, straight wall of North Mountain and the opposing South Mountain escarpment; (7) the lowlands of Hants and Colchester counties surrounding Minas Basin on the north, east, and south, and merging into Cornwallis Valley on the west; (8) the Cumberland-Pictou area occupying all that part of the isthmus of Chignecto lying north and east of Cobequid Mountains; (9) the lowland of Antigonish and Guysborough counties, which lies south and east of the highlands extending towards Cape George; and (10) the lowlands of Cape Breton Island, areas lying between the upland belts and occupied by undulating country or land-locked lakes.

PLATE XIII

The flat-topped upland surface of northern Cape Breton Island. Photo by J. W. Goldthwait, Geological Survey (31345).

NEW BRUNSWICK AND PRINCE EDWARD ISLAND

New Brunswick falls naturally into four major topographic divisions (*See* Figure 30) whose boundaries, however, in most places are not sharply defined. The first, which may be regarded as the main axis of the province, is known as the Central Highlands, an upland region developed largely on resistant granitic, volcanic, and metamorphic rocks (Plate XIV). It trends northeast through the central part of the province and is made up of ridges and hills most of which have flat summits. Its elevation varies considerably, but much of it has an average height of about 1,000 feet. The highest part is where tributaries of Miramichi, Nipisiguit, and Tobique Rivers take their rise. Here broad summits have a general elevation of about 2,200 feet, with some ridges and peaks rising to still greater heights. For example, Mount Carleton, the highest point in the province, has an elevation of 2,690 feet.

To the northwest of the Central Highlands is a second division, which may be termed the Northern Upland. It stands at an elevation of 800 to 1,000 feet above sea-level and is developed on folded Palæozoic strata. The upland presents a remarkably uniform, flat-topped surface whose regularity is broken only by a few peaks and ridges rising slightly above the general level and by valleys such as those of the St. John and the Restigouche, which are deeply entrenched in it. The Stewart highway from Campbellton to St. Leonard crosses this belt.

PLATE XIV

Serpentine Lake in the Central Highlands of New Brunswick. Photo by C. E. Cairnes, Geological Survey (76695).

The third division, the Eastern Plain, lies to the east of the Central Highlands, and makes up almost one-half of the province. It is a region of low relief, rarely more than 600 feet high, sloping gently to the Gulf of St. Lawrence. Its underlying rocks are mostly flat or gently dipping Carboniferous sediments. Prince Edward Island may be regarded as an outlier of this division, and the Cumberland-Pictou lowland area of Nova Scotia is continuous with it.

The fourth division, termed the Southern Highlands, lies along the Bay of Fundy. It is mainly an upland belt of ridges of which the most important is the flat-topped Caledonia Mountain belt of Albert, Kings, and St. John counties, which reaches a maximum elevation of 1,350 feet southeast of Markhamville. To the southwest, in Charlotte county, the belt merges into the Central Highlands. The region shows considerable topographic diversity and a great variety of rock types. The ridges are composed mainly of hard volcanic and intrusive rocks, whereas minor lowland areas within the belt have been carved from weaker strata.

QUEBEC

In Quebec the Appalachian region is bordered on the northwest by the St. Lawrence Lowlands into which it merges imperceptibly. In fact, considered from the point of view of topography, the lowland belt overlaps the Appalachian

..ogical region. To the southwest the upland region includes three parallel groups of ridges and isolated hills and mountains. These are highest in the

PLATE XV

The summit of Tabletop Mountain, central Gaspe, Quebec, showing surface of Shickshock peneplain. Photo by F. J. Alcock, Geological Survey (58856).

PLATE XVI

Gaspe peneplain, Gaspe Peninsula, Quebec, from south of Restigouche River. Photo by F. J. Alcock, Geological Survey (73511).

south, and decrease in elevation towards the northeast. The highest point is Round Top on Sutton Mountain, elevation 3,175 feet, near the Vermont border.

The most easterly of the three belts is known as the Megantic anticline. It forms part of the International Boundary, and to the northeast passes into Maine. To the west the Stoke Mountain anticline extends as far as Lake St. Francis, where it loses its identity. Still farther west, a little beyond Lake Memphremagog, the third range, the Sutton Mountain anticline, is a continuation of the Green Mountains of Vermont. Between the anticlinal ranges the country varies from 900 to 1,000 feet in elevation, presenting in places a remarkably level surface. To the northeast, it continues as an upland belt of ridges and rolling country cut across by deep valleys such as those of the St. Francis and Chaudière. It decreases in elevation to a point about opposite Quebec City, but farther northeast it rises again and in the central part of Gaspe Peninsula becomes the Shickshock Mountains, with elevations ranging to more than 4,200 feet. The individual members of this range show broad flat summits (Plates XV and XVI), and the range is bordered both to the north and south by another flat-topped upland at a lower level into which the present river valleys are deeply incised. On the north side of the Shickshocks the descent to the lower upland is for the most part abrupt; on the south it is more gradual (*See* Plate XVI). The lower surface slopes off both to the north and to the south, and to the southwest merges with the Northern Upland of New Brunswick.

GEOLOGICAL INVESTIGATION

Geological investigation began in Nova Scotia as early as 1827, when Francis 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 F. 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 at Parrsboro, who became increasingly interested in rocks and minerals, and in 1836 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 another investigator published his first of many works on the geology of his native province. This was J. W. (later Sir William) Dawson, who from 1855 to 1895 was principal and professor of Natural History at McGill University. His well known work, Acadian Geology, went through four editions. Still another important pioneer worker was the Reverend David Honeyman, whose first publication appeared in 1859.

Since Confederation, in 1867, the Geological Survey has carried out investigations in Nova Scotia. Of the earlier Survey workers the two more outstanding names are those of Hugh Fletcher, chiefly noted for his work in Cape Breton Island, and E. R. Faribault, who was mainly concerned with the mapping of the Gold-bearing (Meguma) series. Later detailed studies of local areas have been made by W. A. Bell, M.Y. Williams, F. H. McLearn, G. W. H. Norman, 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 1842, Sir Charles Lyell paid a visit to both Nova Scotia and New Brunswick, with the result that geological research was greatly stimulated. 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 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 he was associated with Bailey in geological investigation and mapping. His list of publications is very long.

With Confederation in 1867 the Geological Survey 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 bed-rock 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 a 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, and F. J. Alcock. 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 had been born at Montreal, but was educated in Scotland and later became keenly interested in geology from 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 26 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 Gaspe Peninsula. In 1843 he mapped a part of its coast and in the following year continued the 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 and asbestos and chromite in southern Quebec, and later of zinc- and lead-bearing veins in central Gaspe, gave an impetus to detailed studies. The work of J. A. Dresser, B. R. MacKay, H. C. Cooke, T. H. Clark, and others in southeastern Quebec, and that of F. J. Alcock in Gaspe Peninsula, for the Geological Survey, together with the investigations of I. W. Jones and his assistants of the Department of Mines of the province of Quebec in these regions, has done much to increase the information available concerning this belt. Outside workers have also made important contributions: the studies of John M. Clarke on the early Devonian strata of eastern Gaspe and those of Charles Schuchert and S. A. Northrop on the Silurian rocks of Port Daniel and Black Cape require special mention.

GEOLOGY

The Appalachian region of Canada is essentially one of Palæozoic rocks, although both older and younger formations are present. The region underwent extensive deformation twice during the Palæozoic, once at the close of Ordovician and again in Devonian time, and both of these disturbances developed northeasterly trending structures. 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. The generalized table (Table III), page 106, shows the geological succession in Nova Scotia, New Brunswick, and southeastern Quebec.

PRECAMBRIAN

The Appalachian region contains several groups of rocks, such as the Green Head, the George River, and the Coldbrook, whose ages are known definitely to be Precambrian, and others such as the Meguma and the Macquereau regarded as Precambrian, but on less satisfactory evidence. Certain granite intrusions of the Southern Highlands of New Brunswick and others in Cape Breton Island are also probably Precambrian, but absolute proof of this has not been established. Other belts of rocks shown on early maps as Precambrian are now either definitely known or else inferred to be of Palæozoic age.

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 near Smithtown on Hammond River to the northeast, a distance of about 40 miles, and inliers, small areas 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 slates, and mica schists and gneisses. 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, which may be of organic origin. These have been described under the name *Archaeozoon acadiense* (Plate XVII) and may represent algal growths.

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

George River Group

The George River Group, present in most of the upland areas of Cape Breton Island, is very similar to the Green Head. 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, commonly schistose; quartzite-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 sediments and the intrusive rocks gives rise to gneissic rocks.

TABLE III

Era	Period	Epoch	Nova Scotia	New Brunswick	Quebec
Mesozoic	Triassic		Annapolis	Quaco; Lepreau	
Palæozoic	Permian				
	Carboniferous	Pennsylvania	Pictou; Morien; Stellarton Cumberland Riversdale — — — — Canso	Clifton Lancaster } Petitcodiac Mispek	Bonaventure
		Mississipian	Windsor Horton	Hopewell Windsor Moncton Albert Memramcook	
	Devonian	Upper Devonian		Perry	Escuminac Fleurant Pirate Cove
		Middle Devonian		Gaspe	Gaspe; Malbaie; Heppel
		Lower Devonian	McAdam Lake; Torbrook; Knoydart	Dalhousie	Grand Grève Bon Ami St. Albans; Dalhousie; Lake Aylmer
	Silurian		Arisaig; Kentville	Chaleur Bay; Mascarene	Chaleur Bay
	Ordovician	Upper Ordovician		Matapedia	Matapedia; Pabos; White Head
		Middle Ordovician	Malignant Cove; Stewart Brook	Tetagouche	Pohenagamooke; Mictaw; Quebec City; Beauceville; Farnham; St. Francis
		Lower Ordovician	Browns Mountain		Levis Sillery
	Cambrian		Boisdale	Saint John	Murphy Creek; Caldwell; Sutton; L'Islet
Proterozoic			Meguma (Gold-bearing)	Coldbrook	Macquereau; Tibbit Hill
Archæan			George River	Green Head	

The age of the George River group is clearly Precambrian. Fossiliferous Cambrian strata flank the Boisdale Hills: where these beds are in contact with the granite the latter shows no sign of intrusive relationship; moreover, the basal Cambrian conglomerate contains boulders of granite and diorite. It is believed, therefore, that in addition to the George River rocks, most at least of the granites of Cape Breton Island are of Precambrian age.

PLATE XVII

Archaeozoon acadiense, possible primitive fossil from the Green Head group, Saint John region, New Brunswick. Photo by A. O. Hayes, Geological Survey (24858).

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, New Brunswick. 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 overlie unconformably beds of the Green Head group, the Coldbrook is regarded as of Late Precambrian or Proterozoic age.

Rocks correlated with the Coldbrook group underlie most of the Caledonian Mountain belt in southeastern New Brunswick. They consist of volcanic flows, tuffs, and breccias of both acid and basic composition, with some associated tuffaceous sediments, phyllites, and conglomerates, the whole cut by stock-like masses of granite and diorite and by basic dykes. Many of the rocks are massive; others are sheared and in places schistose. At Marks Lake, 2 miles northwest of Loch Lomond, a band of conglomerate interbedded with the volcanic rocks is of interest from the fact that it contains boulders of Green Head rocks, white quartz, and massive red granite, suggesting that the Green Head sediments were intruded by granite prior to the Coldbrook eruptions.

Southwest of Saint John a belt of rocks running from Beaver Harbour northeast to Loch Alva consists of rhyolite and basic volcanic rocks intruded by granite and by felsite dykes. The basic members are largely altered to hornblendic rocks, and they are in sharp contact with somewhat similar volcanic rocks of Silurian age that border them. The older assemblage has been correlated with the Coldbrook, but may be older, possibly Green Head.

Meguma Series

The Meguma series, also known as the Gold-bearing series of Nova Scotia, occupies the Southern Upland of that province, extending along the Atlantic coast from Canso to Yarmouth, a distance of 275 miles. It consists of a great thickness of conformable quartzites and slates 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 age of the series was formerly regarded as Lower Cambrian, but it is now generally considered to be Proterozoic. The chief reason for this belief is the lithological similarity of the group to the Precambrian slates and quartzites of Avalon Peninsula, Newfoundland.

The 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 quartzose sandstone or quartzite, in the main feldspathic and micaceous and commonly containing large cubes of pyrite. Interbedded with the quartzites are layers of argillaceous, siliceous, and micaceous slates. The thickness of the Goldenville formation, as measured on Liverpool Bay, Queens county, is in excess of 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 to the east of Halifax. The thickness of the formation as measured on Black River is 11,700 feet.

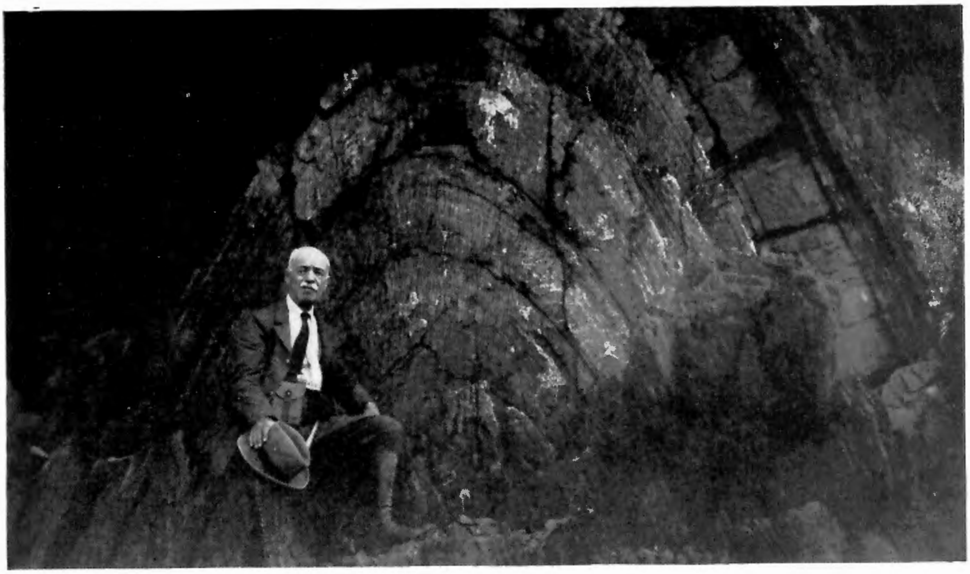
The Meguma series has been closely folded into anticlines and synclines (Plate XVIII) whose axes trend east and west. In addition, there are cross-folds giving rise to a series of domes. On an average the main folds are about 3 miles apart and the domes along the anticlinal axes about 10 to 20 miles apart. The strata are also 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 which reason the strata are referred to commonly as the Gold-bearing series.

Macquereau Group

The Macquereau group extends along the Chaleur Bay coast of Gaspe Peninsula for 15 miles in the Newport-Chandler region. It consists of quartzose sediments and minor amounts of volcanic rocks. The former include arkose-quartzite, slates, red and green shales, quartzose argillites, 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 quite 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.

PLATE XVIII



Folded slates of the Meguma (Gold-bearing) series, Nova Scotia. Photo by E. R. Faribault, Geological Survey (68906).

PALÆOZOIC

Cambrian

Quebec. Cambrian rocks are found in southeastern Quebec, in Gaspe Peninsula, in southern New Brunswick, and in Cape Breton Island, Nova Scotia. In southeastern Quebec most of the rocks of this age are metamorphosed to a greater or less 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 region near the Vermont border a series of Lower Cambrian strata 3,000 to 4,000 feet thick, consisting of slate, quartzite, dolomite, greywacke, and sericite schist, rests on a basement of chlorite schist, known as the Tibbit Hill, which may be Precambrian. Farther south, in Vermont, formations of Lower, Middle, and Upper Cambrian age are all present. 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 times. 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.

The presumably Cambrian rocks of the Thetford-Beauceville region have been described under the name Caldwell group, a succession of nearly pure quartzites, slates, and lavas. They underlie strata that are considered Ordovician. The lower, highly metamorphosed parts of the group, consisting largely of crumpled, silvery, sericite schists, are called the Bennett schists. These also include chlorite schist, phyllites, dark mica schists, and minor amounts of limestone and dolomite. The contact between the schists and the overlying normal well quartzites is a transition zone in which bands of the massive pure zite alternate with layers of fissile schist. The lava members are fine-d, dark green, basaltic types, commonly showing pillow structure. They lie for the most part either at or near the top of the Caldwell quartzite. Associated with them are tuffs, flow breccias, and agglomerates. 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.

At Levis, opposite Quebec City, conglomerates of Lower Ordovician age contain boulders in which are Lower Cambrian fossils, and farther northeast a Lower Cambrian fauna has been collected from pebbles in conglomerates that may be Lower Ordovician or Cambrian, and the same general Lower Cambrian fauna is present in beds on the west shore of the Strait of Belle Isle. Evidently a seaway extended in Cambrian time along the St. Lawrence Valley region into Vermont, but just how continuous deposition was during the period is not known.

In Gaspe 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.

New Brunswick. At Saint John, southern New Brunswick, and in several small areas immediately to the northeast, are beds of the St. John group, which range in age from Lower Cambrian to Lower Ordovician. The following succession has been built up from separate limited sections in the various localities where rocks of the group are exposed, partly through a comparison of the faunas with those of the Cambrian succession in other regions.

TABLE IV

St. John Group

Age	Series	Formation	Faunal zone
Lower Ordovician (Arenig)		Suspension Bridge	*Tetragraptus*
Lower Ordovician or Upper Cambrian (Tremadoc)	Bretonian	Navy Island	*Dictyonema flabelliforme*
Upper Cambrian		Narrows	*Peltura*
			Parabolina
	Johannian	Black Shale Brook	*Olenus*
		Agnostus Cove	*Agnostus pisiformis*
Middle Cambrian	Loch Lomond	Hastings Cove	*Paradoxides matthewi*
		Porter Road	*Paradoxides abenacus*
		Fossil Brook	*Paradoxides eteminicus*
Lower Cambrian	Handfordian	Handford Brook	*Protolenus* and *Beyrichona*
		Glen Falls	
	Etcheminian	Ratcliffe Brook	

The Ratcliffe Brook formation consists of sandstone and conglome and is as much as 200 feet thick. An interesting exposure can be seen rock cut on the river road between Fredericton and Saint John about du of the middle of Catons Island. Here coarse conglomeratic beds containing large granitic boulders rest on rocks of the same material as the boulder, and 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 Handford 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 correlations to be made with Lower Cambrian strata elsewhere in the North Atlantic region, particularly in southeastern Newfoundland and northwest 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 overlaid by grey shales. The succeeding Porter Road formation has two shale members, a lower about 35 feet thick, consisting of dark, hard. heavy bedded, fissile shales abundantly fossiliferous, and an upper, thinly bedded, gritty, finely fissile, black shale from 25 to 75 feet thick. The Hastings Cove formation consists mainly of thinly bedded, black shales 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 former includes the Agnostus Cove formation, consisting of black and grey shales and micaceous grey sandstones 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 shales 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 shales carrying *Dictyonema flabelliforme* and is Upper Cambrian or Lower Ordovician. The youngest formation of the group, consisting of thinly bedded, black, graptolitic shales, outcrops at the upper end of Saint John Harbour, north of Suspension Bridge. The beds contain *Tetragraptus* and *Didymograptus* and are clearly Lower Ordovician.

Nova Scotia. In Cape Breton Island Cambrian rocks are exposed in the Boisdale region on the southeast side of St. Andrew Channel, in a larger belt to the southeast along Mira River and Mira Lake, and in smaller intermediate areas to the northwest of East Bay. The beds range in age from Lower to Upper Cambrian, and present many similarities with those of the St. John group. The Lower Cambrian strata consist of grey shale and slate with some quartzite and conglomerate; red sandstone and red and grey argillite carrying hematite; and greenish grey and some reddish grey argillites. The Middle Cambrian or *Paradoxides* beds are dark grey slates or shales, grey sandstone, and conglomerates, the last occurring at or near the base. The Upper Cambrian rocks are micaceous grey slates, quartzites, hematitic beds, and younger dark grey and black carbonaceous shales and slates with a few thin layers of dark limestone. The beds are overlain by Carboniferous rocks.

Ordovician

In the Appalachian belt of Quebec strata of Lower, Middle, and Upper Ordovician age are known, but in most places fossils are not sufficiently well preserved to permit of exact age determinations. In the long belt from the

Vermont border to the east end of Gaspe 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 Ordovician age. Later the term became a convenient one to include all those early rocks whose exact age was unknown.

In Nova Scotia, Ordovician rocks are known to occur in the Pictou-Antigonish upland. They comprise metamorphosed, sedimentary, volcanic, and intrusive varieties. The Browns Mountain group, consisting of argillites, slates, and greywacke, is regarded, on the evidence of a few fossil linguloids, as of Lower Ordovician age. Locally associated with the sediments 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 New Brunswick, rocks of Middle Ordovician age occur near Bathurst. Stretching to the southwest is a wide belt of sedimentary rocks, with, in places, associated volcanic varieties. Much of this complex may be of Ordovician age. In the southwestern part of the province the Charlotte group is probably of Ordovician age. 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 find any fossils whatever in these rocks.

Lower Ordovician. Logan divided his Quebec group strata at Quebec City into two formations, the Sillery and the Levis. The former is the older and consists of red and green shales, 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. The latter formation 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, forming a belt along the St. Lawrence that may be followed to the eastern end of Gaspe 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 slates with a basal conglomerate and some interbedded impure quartzite or greywacke, overlying unconformably the Cambrian, Caldwell group. In the Beauceville region volcanic tuffs and flows are interbedded with the sediments, and in places the series 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 sediments consisting of shales and limestones overlies Upper Cambrian beds and is followed by strata of Chazy or Middle Ordovician age.

To the northeast of Levis, rocks consisting of red, green, grey, and black slates, quartzites, and conglomerates form a belt in places 20 miles wide. These beds have been correlated with the Sillery, but both younger and older strata may be included. An interesting feature in these rocks is the presence of belts of limestone conglomerates. These occur at various horizons in both the Sillery and the Levis, forming bands from about a foot to more than 100 feet in thickness. 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 to the northeast and Vermont to the southwest. They have been interpreted as the result of local slipping and breaking up of limestones 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.

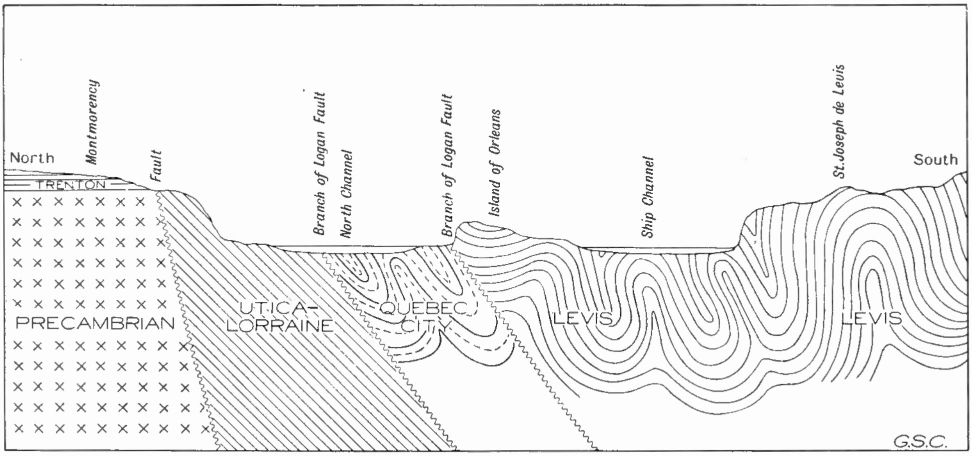


Figure 31. Generalized section across St. Lawrence Valley at Quebec City.

Middle Ordovician. At Quebec City, the Quebec City formation (*See* Figure 31) carries Trenton fossils, and consists of limestone and 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. To the southwest the Beauceville (Farnham) group, mentioned above as possibly Lower Ordovician, may be largely or wholly of Middle Ordovician age. In the Disraeli area the St. Francis group of lavas and impure quartzites 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 what is known as the Pohenagamooke formation are regarded as Middle Ordovician. To the east, in the Matane area, similar rocks have basalt flows 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 Gaspe 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 also 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 dark, 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 argillites, black, dark grey, red, and locally bluish to greenish, quartzose sandstone, arkose, quartzite, and conglomerate. There are also associated igneous rocks, dark volcanic flows, and tuffaceous varieties locally sheared to schists. Both the sedimentary and the volcanic members have supplied pebbles to the succeeding Silurian rocks in the region.

Upper Ordovician. In Matapedia and Restigouche Valleys, at the southwest border of Gaspe Peninsula and farther east on the north side of Chaleur Bay, are sediments 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 limestones are dense, dark grey, and argillaceous, and are associated with argillaceous slates and in many places beds 1 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 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 have associated with them quartzite, grit, and conglomerate beds. Tracadigash Mountain, to the 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 limestones and shales with minor amounts of black shales, sandstones, and basal and intraformational conglomerates, have been described under the name White Head formation, whose beds have yielded a considerable fauna of middle or upper Richmond age. On Grand River west of Percé, grey limestones, shaly limestone, and shales carrying a meagre fauna of late Ordovician age have been termed the Pabos formation. Both of these formations are correlated with the Matapedia.

Fossils regarded as of Utica and Hudson River age have been collected in shales and slates on the St. Lawrence River side of Gaspe, but the extent of these rocks has not been determined.

Silurian

Silurian rocks occur in Nova Scotia in the northern part of the peninsula and southwest of Minas Basin near Kentville. They are present in northern, southern, and west-central New Brunswick. In Quebec they are found in a number of scattered localities in Gaspe Peninsula, and also in the mountainous belt to the southwest.

Nova Scotia. The best section of Silurian strata in Nova Scotia is at Arisaig, where there is an almost continuous exposure, about 2½ miles long, of 3,800 feet of sandstone, calcareous sandstone, and shale 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 considered to be Lower Devonian. The Arisaig beds are highly fossiliferous

Table V

		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	Stonehouse	Indian Point	Edmunds	Ludlow
				West Point		
		Lockport	Moydart	Bouleaux		
			McAdam	Gascons	Dennys	Wenlock
				La Vieille		
		Clinton	Ross Brook	Anse Cascon	Quoddy	
				Clemville		
Lower Silurian	Medinan	Medina-Cataract	Beechhill			Llandovery

Sections on the shore and in the stream valleys show the strata to be crumpled, faulted, and in places overturned. The main structure is that of a syncline broken and faulted along its axis, and this has been complicated by minor folds and faults.

The series is made up of five formations (*See* Table V). The basal Beechhill, 160 to 300 feet thick, is composed of conglomerate, sandstone, and arenaceous shales. The succeeding Ross Brook formation consists of black and grey shales 825 feet thick. The McAdam Lake formation, 1,120 feet thick, consists largely of shales with some sandstones, and carries a bed of oolitic hematite 2 feet thick. The Moydart is made up of 380 feet of grey or bluish grey shales and sandstones, and the Stonehouse of 1,275 feet of grey and greenish grey sandstone, red shale and sandstone, and grey and greenish shales and sandstones. 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.

The Kentville formation, in its type area at Canaan, south of Kentville, consists of fossiliferous, fawn and dark-coloured slates of Silurian age. In the Windsor area this formation is represented by beds of dark green to greenish purple or variegated green and purple argillites. Areas of Silurian rocks are also present in the metamorphic complex of the Cobequid upland. This complex includes altered sediments that may be of Carboniferous age, and some of the granitic intrusive rocks may be of that age also.

Quebec. At Port Daniel and Black Cape, on the north side of Chaleur Bay, are sections showing probably the thickest continuous marine succession of Middle Silurian age in North America, and one of the thickest known anywhere. At Black Cape the rocks outcrop 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, the dip in general being about 60 degrees to the 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 lithologic divisions are recognized in both localities. The following are the formations in descending order, into which the series has been divided, with the thicknesses in the respective areas (*See also* Table V).

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 and 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 shales and sandstones. 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 sandstones and shales and about 500 feet of volcanic rocks. The fauna of the formation is dominantly a brachiopod assemblage.

The Anse Cascon begins with conglomerate and sandstones, which grade up into shales; the shales become increasingly calcareous and grade upward in turn into the hard knobby limestones of the La Vieille formation. The latter contains many fossils, particularly corals; the guide fossil is the large brachiopod, *Stricklandinia gaspiensis*.

The Gascons formation consists of argillaceous, fine-grained sandstones 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 has 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, respectively. Above the upper thick flow is a zone of interbedded sediments and bands of amygdaloidal andesite porphyry. The Indian Point formation of the Port Daniel area consists of muddy, fine-grained, deep green sandstones weathering purplish red, interbedded with more or less local lenses of yellowish limestone. Its fauna is marked by a dominance of pelecypods.

Silurian beds have been found at a considerable number of other areas in Gaspe peninsula, as for example in the Dartmouth River region, the St. John River area, the Mount Albert area, the Mount Alexander area, on Cap Chat and Matane River, and in Matapedia Valley. In almost all of these localities the fossil content of the beds permits of correlations with formations of the Chaleur Bay region. For example, in the Lake Matapedia region the Silurian beds are divided in ascending order into three formations, the Val Brillant, the Sayabec, and the St. Leon. The first of these 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 a number of areas along the Chaleur Bay coast, such as 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 one limb, the western, 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 sediments interbedded with great quantities of volcanic rocks, chiefly rhyolites and andesites, have been described under the name Mascarene group. At Oak Bay the base of the series is a coarse conglomerate known as the Oak Bay formation, which rests unconformably on the Dark Argillite of the Charlotte group. Other sediments include shale, limestone, sandstone, and dense, hard, fine-grained argillitic quartzites locally containing ash material. The volcanic material includes flows, tuffs, breccias, and associated intrusive rocks. The belt is a continuation of one extending from the Eastport area of Maine where sediments 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 Reach on St. John River. On Kingston Peninsula on the opposite side of Long Reach a narrow fringe of Silurian sediments shows corals attached to the ellipsoidal upper surface of a volcanic flow. The latter is, therefore, Silurian as well, and it is probable that most at least of the volcanic rocks that comprise the larger part of the peninsula are of that age also. Silurian sediments occur farther up St. John Valley in the Woodstock and Edmundston-Grand Falls areas.

Devonian

Rocks of Lower Devonian age occur 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, accompanied by the intrusion of granite masses. In the Middle Devonian great thicknesses of clastic sediments accumulated in Gaspe Peninsula, and in Upper Devonian time sedimentation progressed locally in the Chaleur Bay and Bay of Fundy regions.

PLATE XIX

Lower Devonian limestones near Shiphead, Cape Gaspe. Photo by F. J. Alcock, Geological Survey (51490).

Lower Devonian. The best Lower Devonian sections of the Appalachian region of Canada are at the eastern end of Gaspe Peninsula, Quebec, and at Dalhousie, New Brunswick. The former, which are well exposed on the Forillon Peninsula on the northeast side of the mouth of Gaspe Bay, form a thick, orderly succession of southwesterly dipping limestone (Plate XIX) and limy shales unconformable with or overthrust upon Ordovician slates to the northeast. The series has been divided on a lithologic and faunal basis into three formations, the St. Albans, the Bon Ami, and the Grande Grève. The lowest, the St. Albans, consists of compact calcareous shales; these have yielded about fifty species of fossils, more than half of which are found in the lower divisions of the Helderberg series in New York. The succeeding Bon Ami beds consist of magnesian limestones with few fossils and these mostly diminutive forms, all, however, quite distinctly of Helderberg age. The upper formation, the Grande Grève, consists of 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. These Lower Devonian limestones are about 2,000 feet thick. They were described originally by Logan under the name "Gaspe Limestones". Similar beds are exposed at Percé. Here the Mont Joli formation is probably equivalent to the St. Albans, and the Murailles limestone, in its upper part at least, to the Grande Grève. In the Matapedia Valley region, at the western end of Gaspe Peninsula, Lower Devonian shales and argillaceous limestones at least 2,200 feet thick are called the Causapscal formation. They apparently grade up into the sandstones of the Heppel formation of Middle Devonian age. In central Gaspe, Lower Devonian shales and limestones cover wide areas. The beds are folded, faulted, locally intruded by dykes and stocks of porphyry, syenite, and diorite, and mineralized with zinc- and lead-bearing veins. In places associated with the sediments 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 shales carry fossils that, apparently, represent an Onondaga age, and have been described under the name Famine series. Between Chaudière 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 cover a number of areas in northern New Brunswick. They consist of marine sediments, volcanic flows and tuffs interbedded with the sediments, dykes, and volcanic necks, such as that forming Sugarloaf Mountain at Campbellton. In the lower part of the series the sediments are relatively more abundant, whereas in the upper part the volcanic members predominate. The best and most readily accessible section of these rocks is on the shore at Stewarts Cove at Dalhousie (Figure 32). This section belongs to the upper, dominantly volcanic division, but includes a larger proportion of sediments than 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 shales	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 shales	10
9. Limestones and calcareous shales	75
8. Calcareous, sandy shale	20
7. Arenaceous limestone	7
Agglomerate and andesite (with bed 6)	280

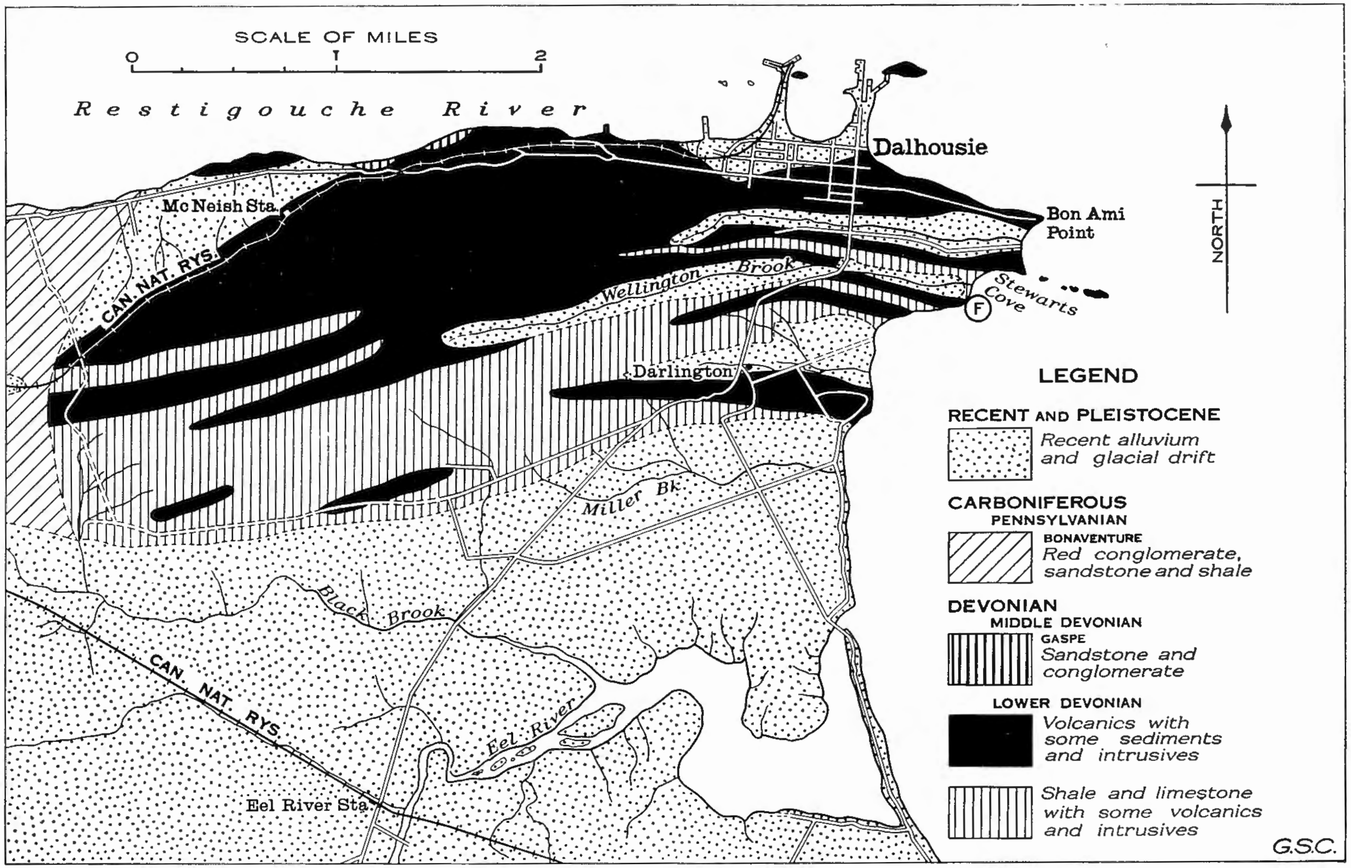


Figure 32. Geology of the Dalhousie region, New Brunswick. (After F. J. Alcock.)

Lower Dalhousie beds	Thickness Feet
5. Hard, grey limestone	10
4. Coarse, yellowish white tuffs	12
3. Hard, grey, arenaceous shale with limestone	40
2. Grey, calcareous shales with limestone	125
1. Silicified limestone with shales	30
Basalt tuff and breccia	30
Basalt	15
Palagonite tuffs	180
Calcareous shales	90

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

In the northern part of the peninsula, to the southwest of Arisaig, fine-grained, red, arenaceous slates and grey sandstones of the Knoydart formation, about 1,000 feet thick and apparently continental in origin, overlie with a marked erosional unconformity Silurian strata of the Arisaig series. The grey sandstone has yielded remains of fish regarded as Lower Devonian.

In the Boisdale region of Cape Breton Island, between East Bay and St. Andrew Channel, the McAdam Lake formation of grey, freshwater arkoses and conglomerates, for the most part steeply dipping, carries plant fragments indicative of a Lower or Middle Devonian age. At one place the sediments have volcanic tuffs associated with them. In the Mabou Highlands and in the Eastern Upland of the Lake Ainslie area are volcanic rocks that are also probably of Lower or Middle Devonian age.

Middle Devonian. Much of the interior of Gaspe Peninsula is underlain by sandstones, conglomerates, and arenaceous shales varying in colour from green and drab to red. The type locality for these rocks is on Gaspe Bay where Logan measured a section 7,036 feet thick. The beds lie above the Gaspe limestones, and Logan gave the name Gaspe sandstones to them. They carry plant remains of the *Psilophyton-Arthrostigma* (*Drepanophycus*) flora and also fish remains. Marine invertebrate fossils have been found in a number of localities, and apparently indicate a Middle Devonian age. 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 Gaspe beds of the lower part of the series 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 Gaspe sandstone beds are not cut by the granitic and syenitic intrusive rocks nor are they mineralized by veins, as are the Lower Devonian beds.

On the north side of Mal Baie, at the eastern end of Gaspe, 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 Gaspe 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 Gaspe sandstones.

Upper Devonian. 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 section between West Maguasha and Escuminac Point (Figure 33). They form a broad syncline pitching north, are underlain to the west by Gaspe sandstone, and are overlain by red Bonaventure conglomerate of Carboniferous age. They have been divided into three formations on a basis of lithology. The lowest, the Pirate Cove formation, consists, at its base, of about 400 feet of coarse, angular-pebble conglomerates 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 $2\frac{1}{4}$ inches thick. This basal zone is overlaid by 210 feet of coarse, angular-pebble conglomerate with salmon-coloured matrix, and this in turn is succeeded by 450 feet of coffee-coloured shales, with occasional green bands, and a conglomerate member 0 to 40 feet thick. The second or Fleurant formation consists of coarse, round-pebble and boulder conglomerate with 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 the low cliff on the shore a third of a mile southeast of Englishman Creek. The upper formation, the Escuminac, consists of grey shales and shaly sandstones, culminating in a 16-foot member made up of reddish beds. This formation is 370 feet thick, and is the one that has yielded the excellent fish fossils (Figure 34) and also 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.

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 Black Harbour south of St. George, and on some of the adjacent islands are areas underlain by beds of red sandstone and conglomerate that are correlated with the Perry conglomerate of Maine.

The beds lie for the most part with low dips and in gentle folds. In places they rest unconformably on the Silurian rocks, and in places are in fault contact against them. The conglomerates contain boulders of the Silurian and pre-Silurian rocks and of the St. George granitic intrusive rocks. 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 Black 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 on the Maine side has yielded an Upper Devonian flora.

Carboniferous

In Quebec, rocks of Carboniferous age outcrop along the shore of Chaleur Bay and on Magdalen Islands in the Gulf of St. Lawrence. In the former region the beds are red conglomerates and sandstones of the Bonaventure formation. They are fresh, and for the most part are undisturbed. Magdalen Islands are composed of folded sedimentary and volcanic rocks of Mississippian age surrounded by flat-lying beds of red sandstone of probable Pennsylvanian age. Over one-half of New Brunswick is underlain by Carboniferous strata, and considerable areas of Nova Scotia are also covered by these rocks. They are the source of the coal, oil, gas, and gypsum of the two provinces. Prince

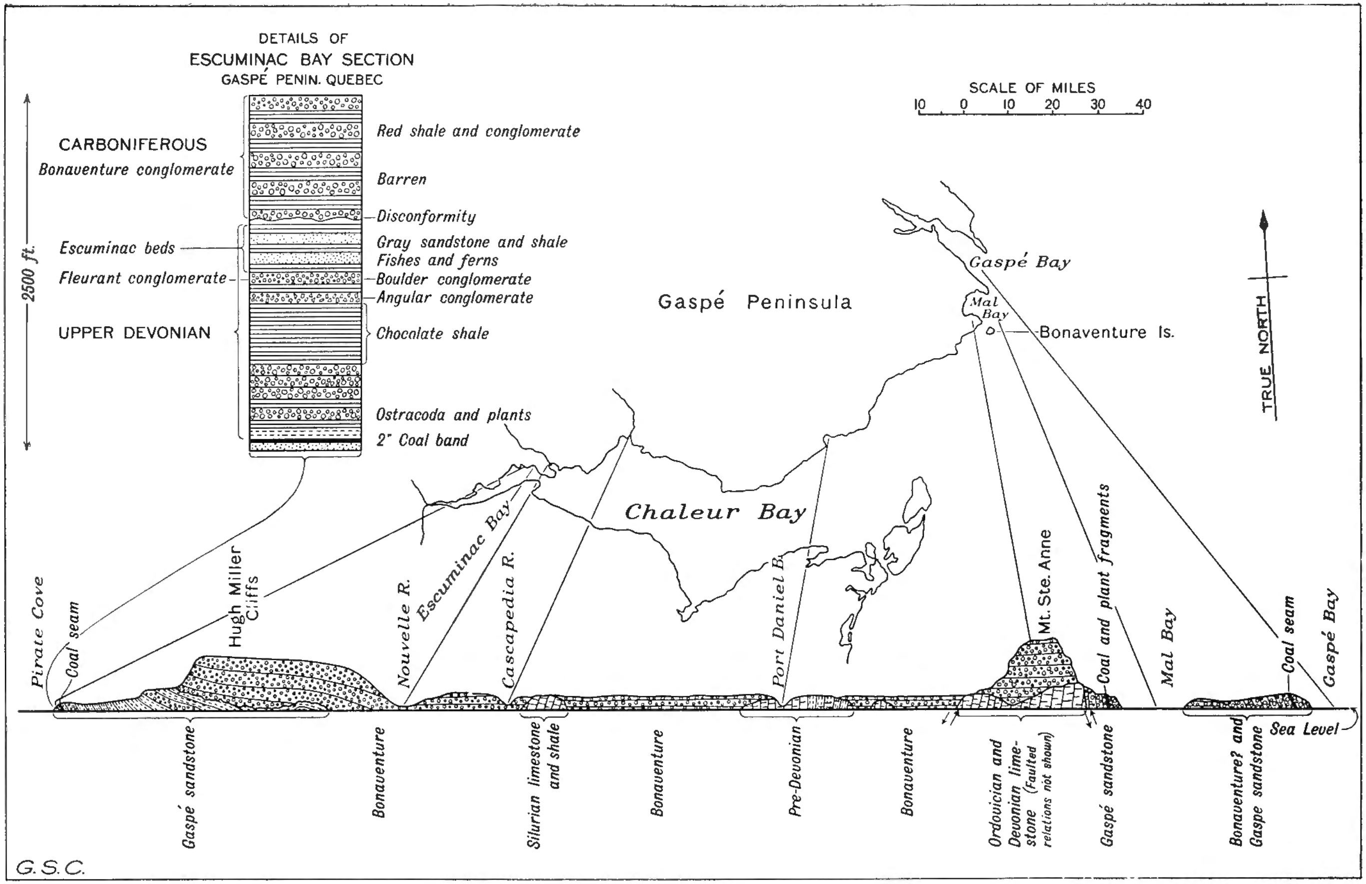
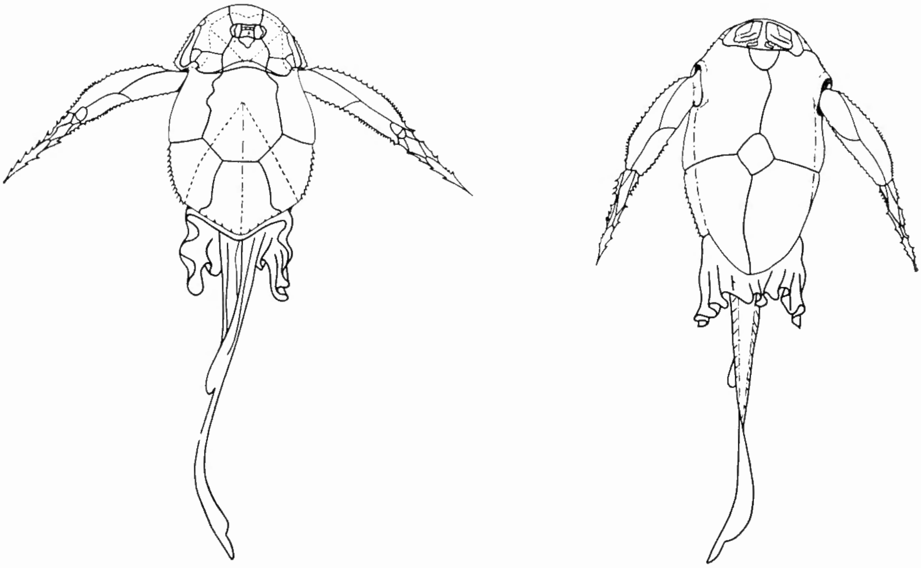


Figure 33. Diagrammatic section near the shore from Escuminac Bay to Gaspe Bay, Quebec. (By F. J. Alcock.)

Edward Island is underlain by gently dipping red beds of late Pennsylvanian or possibly Permian age (Plate XX). Figure 35 shows the succession of formations in some of the more important areas.



Dorsal side ***Ventral side***

Figure 34. Patten's restorations of ***Bothriolepis canadensis*** Whiteaves, an Upper Devonian fish from the Escuminac formation, Escuminac Bay, Quebec.

Mississippian. 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 former is made up of two formations, a lower known as the Horton Bluff, consisting of some 3,400 feet of dark shale, sandstone, and conglomerate, and an upper, the Cheverie, made up of 600 feet of red and grey shales, sandstone, and arkose. The Horton Bluff formation rests unconformably on pre-Carboniferous metamorphic and igneous rocks; it contains plant remains, buried forests, and soils, and has a fauna of ostracod crustaceans and fish remains. The Cheverie rests with angular unconformity on the Horton Bluff, and is succeeded, also unconformably, by the Windsor group of marine sediments. The latter comprise limestone, gypsum, shale, sandstone, and limestone conglomerate, the whole having a thickness of about 1,550 feet. The limestone members are rich in fossils and have yielded one hundred and twenty-seven species, chiefly molluscs and brachiopods.

The Mississippian rocks extend eastward through the lowland belt (9)[1] to the Strait of Canso, and also occupy much of the lowlands of the southwestern part of Cape Breton Island. In the Lake Ainslie area the Horton group includes about 6,000 feet of conformable, dominately clastic sediments containing a meagre flora and fauna. They are intruded by diabase dykes and sills. The succeeding Windsor beds have here a thickness of about 2,000 feet. In the Arisaig region diabase and basalt dykes and stocks intrude red conglomerate, sandstone, and sandy shale of the Mississippian McAras Brook formation, but are apparently older than the limestone of the Ardness formation of Mississippian age.

[1] *See* Figure 30, p. 99.

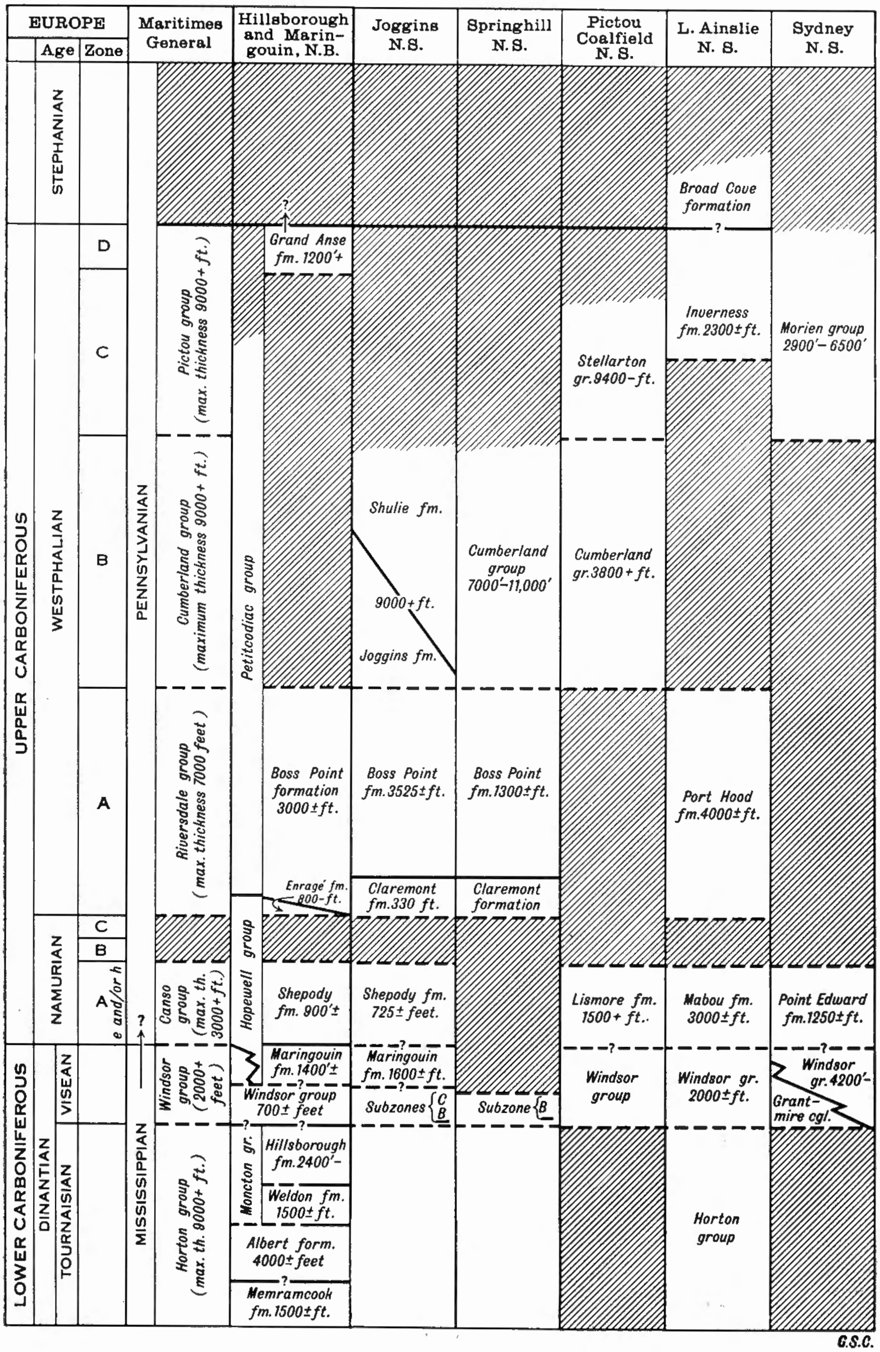


Figure 35. Correlation chart of Carboniferous formations of the Maritime Provinces of Canada. (After W. A. Bell.)

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, and in other areas. In the Hillsborough and Sussex regions the succession begins with the Memramcook formation consisting of red conglomerates, shales, 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 sandstone and limestone layers. These beds were deposited, partly at least, under marine or estuarine conditions; they have yielded a considerable fish fauna and are the source of the oil and gas of the region. They are succeeded, again conformably, by conglomerates and sandstones 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 the Memramcook, Albert, and Moncton strata.

PLATE XX

Keppoch Beach, southeast of Charlottetown, Prince Edward Island, showing gently dipping beds of Pennsylvanian sandstone. Photo by Gordon M. Dallyn, Editor, Canadian Geographical Journal (97160).

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 sandstones and conglomerates of the Hopewell group. In most places the basal Hopewell beds are conformable with those of 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.

In the Plaster Rock area, the Mississippian beds consist of semi-consolidated to well-consolidated coarse conglomerates, sandstones, thin-bedded shales, sandy shales, and shaly and gypsum-bearing strata, with a conglomerate horizon at the top. The beds are nearly everywhere deep red, and have the form of a basin, flat-lying in the centre and with dips on the margin up to 25 degrees. 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 Mississipian sedimentary and volcanic rocks. These consist mainly of red conglomerates and rhyolite, with limestone apparently of younger age. The limestone is Windsor, and the red clastic beds and associated rocks may be Moncton.

Strata of Windsor age occur on Magdalen Islands, Quebec, in the Gulf of St. Lawrence (*See* Figure 44). The oldest beds are limestone, shales, shaly limestone, and gypsum, with interbedded volcanic rocks. The sediments locally contain an abundance of fossils. The volcanic rocks are basaltic, fragmental types, and in places angular bombs are embedded in gypsum, showing that they had fallen into the sea where the gypsum was accumulating. These rocks are locally overlain by a grey sandstone that may also be of Windsor age. All these rocks are folded, and on them rest with angular unconformity red sandstones of probable Pennsylvanian age.

Pennsylvanian. The upper Carboniferous rocks of Nova Scotia have been divided by Bell (*See* Figure 35), on the basis of their flora, into four groups, the Canso, the Riversdale, the Cumberland, and the Pictou. All are wholly non-marine, so far as is known, and in no one area are all four present.

The oldest, the Canso, which may be partly or even wholly Mississippian, consists of red and grey shales overlying the Windsor beds. It contains local thin beds of limestone, and in the Minas basin the strata commonly include thin bands and veinlets of iron carbonate. The beds show abundant ripples, mud-cracks, and rain-prints. There are few recognizable plant remains, but those studied show affinities with Mississippian species. Freshwater shells are also present locally. Canso strata outcrop on the Strait of Canso, in the Mabou area of Cape Breton Island, on the west coast of the same island between Inverness and Cheticamp, in the lower part of the Joggins section, in the Parrsboro area, and elsewhere.

The succeeding Riversdale group is made up of alternating red and grey sandstones and shales, including, locally, a basal conglomerate. In the Parrsboro area it overlies the Canso beds with angular unconformity, and in the Springhill area it underlies the Cumberland group. In other localities both the lower and upper contacts are generally disconformities. The coals of the Port Hood area, Inverness county, and those of Richmond county are in Riversdale strata.

The third or Cumberland group is typically exposed in the Joggins and Springhill coalfields of Cumberland county, and the coals of these areas are in this group. The best section is exposed in the sea-cliffs of Joggins (Plate XXI), where the group shows a thickness of over 9,000 feet of non-marine conglomerate, sandstone, shale, and coal.

The highest group, the Pictou, consists of sandstones, grits, and shales, as much as 9,000 feet thick. The coals of Sydney, Salmon River, Inverness, and Mabou Mines areas of Cape Breton Island, those of the New Glasgow area, Pictou county, and those of 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. In the Springhill area they lie unconformably upon the Cumberland group, and 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 and the Petitcodiac. The former is made up chiefly of red sandstones and shales and, as already mentioned, is probably in part Mississipian. The Petitcodiac group is composed dominantly of only slightly disturbed grey sandstones and grits with pebble conglomerates, and includes beds of Riversdale and Pictou ages.

PLATE XXI

Part of Carboniferous section at Joggins, Nova Scotia. Photo by I. W. Jones, Geological Survey (71625).

In the Hillsborough area the Hopewell group is composed of three formations. The lowest, the Maringouin, possibly of Mississippian age, consists of red shales and sandstones, 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 and may, therefore, be Mississippian. 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 dominantly grey sandstones similar to those of a lower part of the Petitcodiac group. The upper formation of the Petitcodiac group in this area consists of reddish brown sandstone with arkose and pebble conglomerate, and is known as the Grande Anse; its beds overlie the Boss Point 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 identified as those of 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 Gaspe coast.

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

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 (Plate XXII). The strata consist chiefly of coarse conglomerates and sandstones with associated red shales, shaly sandstones, and, locally, limestone. The beds for the most part lie horizontally, but are locally tilted and in places faulted. At two places near Grand River amygdaloidal basaltic flows are associated with the sediments, and near Percé a dyke cutting across the beds is broken by horizontal faults into four parts.

PLATE XXII

View of village of Percé, Percé Rock, and Bonaventure Island, Quebec. Photo by F. J. Alcock, Geological Survey (51473).

To the 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 sandstones, and an upper division of buff sandstones and conglomerates carrying 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 of the same age as the Bonaventure, but were formed in a different basin.

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

MESOZOIC

Triassic

The youngest consolidated rocks in the Appalachian region are of Triassic age and occur in the Bay of Fundy region. They rest unconformably on various Palæozoic and Precambrian formations. In Nova Scotia, red sandstones, shales, and conglomerates of the Annapolis formation underlie the Annapolis-Cornwallis Valley and border both sides of Minas Basin. The sediments 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 conglomerates and sandstones 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 the southwest. At each place the beds dip to the northwest, and are in fault contact with older formations on that side. A few fossil plants and some fish remains serve to correlate the beds with the Newark series of late Triassic age in New England.

PLATE XXIII

Triassic trap at Southern Head, Grand Manan Island, New Brunswick. Photo by F. J. Alcock, Geological Survey (4-3, 1945).

The volcanic rocks that form so much of Grand Manan Island (Plates XXIII and XXIV) are also regarded as of Triassic age, because of their lithologic character and their association with some fresh, red, clastic beds.

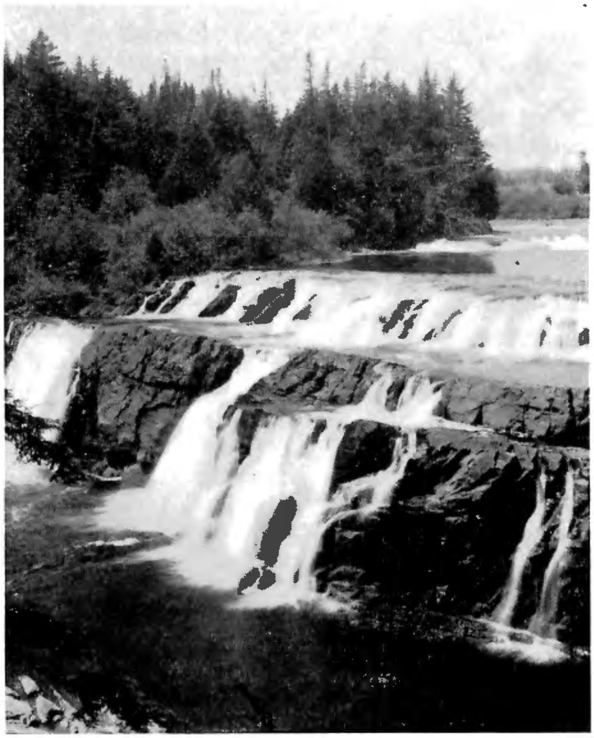
CENOZOIC (?)

In southern Quebec are eight masses of intrusive rocks forming 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 belong to the Appalachian region. The rocks consist of alkalic varieties; they are definitely of post-Lower Devonian age and may be as young as late Tertiary.

GEOLOGICAL HISTORY

The earliest geological event of which there is record is the accumulation in Archæan time of the sediments of the Green Head and George River groups. The great amount of limestone and dolomite in these rocks is evidence that this deposition took place under marine conditions, but the extent of the sea and the source of the material is not known. This period of sedimentation, which was also accompanied by local volcanism, was closed by mountain building movements and granitic intrusion. Succeeding erosion uncovered some of the granite, and was then followed, in Proterozoic time, by a great period of volcanic activity during which the rocks of the Coldbrook group were erupted. These were later intruded, probably in Precambrian time, by granite and associated rocks. Possibly towards the close of the Proterozoic era there accumulated in Nova Scotia another great series of rocks, the Meguma, made up of clastic sediments, some 6 miles thick. These were evidently laid down in a region of differential warping, where a subsiding basin was bordered by rising, mountainous country that supplied the material for the sediments. The basin of accumulation may have been a trough of the sea, or a fluvial depression or depressions on the continent.

PLATE XXIV



Gently sloping beds of Triassic sandstone and conglomerate, at Lepreau Falls, Lepreau River, Lepreau, N.B. Photo by F. J. Alcock, Geological Survey.

With the beginning of the Palæozoic there is more information available from which to draw conclusions concerning the distribution of land and sea during the various epochs. Throughout the Palæozoic most of the larger Appalachian Highland region was a geosynclinal or subsiding belt where sediments continued to be laid down. The source of these sediments was a land mass that lay to the east, an old land known as Appalachia. It occupied the site of the present border of the eastern United States, extending to an unknown distance out into the Atlantic. The southeastern parts of Nova Scotia and of Newfoundland may form parts of the northeastward extension of this ancient land mass. At times, however, this northern or Acadian part of Appalachia was separated from Appalachia proper by seaways connecting the Atlantic with the interior continental sea covering the geosyncline.

Throughout most of the first half of Palæozoic time the St. Lawrence River region was a subsiding trough for the accumulation of sediments. At times this trough was an open seaway connecting the North Atlantic with the interior epicontinental seas; at other times it was merely an embayment of the Atlantic; and at still others it was entirely drained due to the uplift of the region above the sea.

Sedimentation progressed in this trough during much of Cambrian time. At the close of that period uplift with some deformation took place, and is referred to as the Vermont disturbance. During the succeeding Ordovician period sedimentation began again and continued intermittently. Throughout most of the Lower Ordovician epoch the northwest side of the St. Lawrence was a hinge along which vertical movements took place, the northwest side rising and supplying sediments to the sinking trough to the southeast. These movements were marked repeatedly by severe earthquake shocks, the record of which is seen today in the various horizons of limestone conglomerates present in the Ordovician strata. This hinge zone was evidently a fairly steep coastal slope against which the sediments of the trough faded out. Evidence for this is seen at Montmorency Falls northeast of Quebec City where the Precambrian gneiss northwest of the fault zone is overlain by flat-lying Trenton limestone (*See* Figure 31), whereas, immediately in front of the gneiss, Trenton beds of the Quebec City formation are underlain, not directly by the gneiss, but by great thicknesses of pre-Trenton Ordovician strata. Evidently it was not until Middle Ordovician or Trenton time that the sea swept over the region northwest of the St. Lawrence.

Marine sediments of Ordovician age in New Brunswick and Nova Scotia show that at times at least during that period this region lay beneath the sea. It has been postulated by Schuchert that a separate geosynclinal basin, to which the name Acadian has been given, existed here and that it was separated from the St. Lawrence geosyncline by a rising or positive zone termed the New Brunswick geanticline. There is little evidence, however, for such a geanticline or for two quite distinct geosynclinal basins of accumulation.

In late Lower Ordovician time deformation accompanied by granitic intrusion took place in the Arisaig region of Nova Scotia. The Ordovician movements culminated towards the close of the period in what is known as the Taconic revolution, which deformed much of the region southeast of the Logan fault. Evidence of this disturbance is seen in the cleaved and schistose character of the Ordovician rocks as compared with the less altered Silurian strata, in the unconformable relations between the Silurian and Ordovician beds at Lake Matapedia, and the presence of boulders of Ordovician rocks in Silurian conglomerates in northern New Brunswick. North of the Logan line sedimentation was continuous locally, at least, in the lower St. Lawrence region from late Ordovician into Silurian time, with no major break, as is shown by the succession on Anticosti Island. The Taconic orogeny was accompanied apparently by the intrusion of igneous rocks. In the Eastern Townships and in Gaspe are ultrabasic masses that are now partly to completely altered to serpentine. It is probable that most at least of these were intruded at this time.

During early Silurian time the Appalachian region of Canada was above the sea and undergoing erosion, but by the Middle Silurian the sea again covered much of it and for a time even connected with the interior continental sea, which covered much of Ontario and the Interior Plains region of western Canada. Thick deposits of sediments continued, and locally, as in southern New Brunswick, large amounts of volcanic rocks were erupted at the same time. Towards the close of the Silurian period uplift again took place, this time as a broad upwarp raising the region above sea-level. During Lower Devonian time the northern New Brunswick and St. Lawrence regions were once more invaded by the sea, and locally, as in the Chaleur Bay region, the period of deposition thus initiated was also one of great volcanic activity.

At the close of the Lower Devonian epoch, and continuing into Middle Devonian time, earth movements again affected much of the Canadian Appalachian region. This deformation, known as the Shickshockian disturbance, was accompanied by the intrusion of large masses of granite and associated rocks. These granites are exposed over much of the Southern Upland of Nova Scotia and the Central Highlands of New Brunswick.

The Shickshockian deformation, like the Taconic, resulted from thrusts from the southeast, which produced folding and overthrust faulting. The amount of shortening in a northwest direction as a result of these two disturbances was undoubtedly great. It has been mentioned that the Quebec City beds at Quebec are of the same age as the Trenton beds on the opposite side of the Logan fault at adjacent Montmorency Falls. The two sets of Trenton beds are, however, of quite different facies, varying both in lithology and in their fossil content. In New York State outcrops of the Quebec City facies are 50 miles east of the nearest exposures containing the normal Trenton beds. It has been inferred from this that the amount of shortening has been of the order of magnitude of 50 miles and may have been much greater.

During Middle Devonian time great thicknesses of clastic sediments accumulated in Gaspe Peninsula; towards the close of the epoch orogenic movements folded and faulted the beds, a renewal of the earlier Shickshockian movements. In Upper Devonian time deposition occurred in local areas such as the Chaleur Bay and Bay of Fundy regions. By this time some of the granite masses that had been intruded earlier in the period had been unroofed and were undergoing erosion.

By Mississippian time the mountainous topography produced by the Devonian orogeny had been largely destroyed. Much of Nova Scotia and New Brunswick now formed a geosynclinal area bordered on the northwest, in Gaspe and New Brunswick, by an upland and on the southeast by another land mass of which southern Nova Scotia today is a remnant. The floor of this broad depression, commonly referred to as the Fundy basin, was apparently subject to warping and folding, so that deposition in it was quite variable. Positive elements in it, such as the Caledonian and the Cobequid Mountain belts, tended to rise while intervening zones continued to sink, so that sedimentation progressed in local basins. Throughout much of the period the deposits that accumulated were non-marine. During the Windsor stage, however, a sea, an embayment of the Atlantic, swept over the region submerging nearly all of New Brunswick and Nova Scotia. In it limestone, gypsum, and salt accumulated, and on Magdalen Islands in the Gulf of St. Lawrence there was also volcanism, and great quantities of fragmental volcanic material were deposited with the sediments.

Throughout Pennsylvanian time continental deposits again were laid down in subsiding basins in Nova Scotia, with interruptions, however, due to earth movements. At the close of Canso time local orogeny took place, and at the end of Riversdale time there was renewed uplift and broad warping movements. Again in post-Cumberland pre-Pictou time there were further disturbances. These disturbances were accompanied by marked changes in the flora, the two more important being between the Canso and Riversdale and between the Cumberland and Pictou groups. In southern New Brunswick volcanic activity with some intrusions accompanied the deposition of the Mispek strata of probable Canso age. Over much of New Brunswick, however, the Pennsylvanian sediments were deposited not in tectonic basins but as broad uniform sheets of alluvium.

In Triassic time the Bay of Fundy region was a basin surrounded by uplifted country, and into it were brought sediments from all sides. Deposition took place on flood-plains, perhaps as broad alluvial fans, and also in temporary bodies of water. Towards the close of the period of deposition, basalt flows, probably fissure eruptions, accumulated in the North Mountain and Grand Manan regions. Sedimentation was closed or followed by extensive faulting movements. The principal faults were along northeast-southwest lines, with minor ones in a north-south direction, and the resulting fault blocks were tilted uniformly to the northwest. It is possible that this faulting continued into Jurassic time.

As there are no consolidated strata in the Canadian Appalachian region younger than Triassic, any such that may have been deposited must have been removed by subsequent erosion. During most at least of post-Triassic time the country was above the sea and suffering denudation. Available information on this period is limited, therefore, to physiographic data and to that supplied by the unconsolidated deposits of the region.

Reference has already been made to the flat-topped character of the upland surfaces. From almost any high point in the entire region a remarkably even skyline meets the eye in every direction. The flat Shickshock summits and those of the Caledonia Mountains of southern New Brunswick and of the northern upland of Cape Breton Island are particularly striking examples of this feature. These surfaces truncate belts of rocks of varying degrees of hardness, and clearly are parts of an uplifted peneplain, which may have been formed as early as Cretaceous time. It was later uplifted, and following this a second erosion surface was produced in Tertiary time on the areas underlain by softer rocks. The lowland belts of Nova Scotia and New Brunswick and the lower upland surface of Gaspe, known as the Gaspe peneplain to distinguish it from the higher upland or Shickshock peneplain, are parts of this younger erosion surface. This later cycle was in turn terminated by uplift, and the region was carried to elevations much greater than those at which it stands today. It was during this period of uplift, probably in late Pliocene time, that the St. Lawrence River channel was excavated to its present depth.

The high elevation of the region in late Pliocene and early Pleistocene time caused snow and ice to accumulate in the higher areas, with the result that glaciers moved out from the middle of Gaspe, from the Central Highlands of New Brunswick, and from elsewhere. Later the main ice-sheet from its centre in the heart of Labrador Peninsula extended over the entire region, covering even Mount Washington in New Hampshire. Deposits left by the ice include erratics, ground moraines, kames, eskers, and drumlins. The weight of the ice caused the whole region to sink. When the ice finally melted the region rose, but this uplift has not been sufficient to offset the previous depression. The result is that the coastal region still has the features of a drowned topography, with the bottom of St. Lawrence River in places still 1,500 feet below sea-level.

ECONOMIC GEOLOGY

The Appalachian region has a great variety of minerals. The Pennsylvanian rocks contain coal, and Mississippian strata have gypsum, salt, barite, petroleum, natural gas, oil-shale, and albertite. The ultrabasic rocks of the Eastern Townships of Quebec and of Gaspe Peninsula carry asbestos and chromite. Devonian granitic intrusions produced widespread mineralization, giving rise to numerous occurrences of gold, and of iron, copper, zinc, lead, antimony, tungsten, and molybdenum minerals. Bedded iron deposits were formed at several horizons in Palæozoic strata. Manganese has been obtained from ores of several types. Monumental, building, and abrasive stone, rock fertilizer, diatomite, peat, clays, sands, and gravels are other materials that are, or have been, produced.

COAL

Coal is the most important mineral product of the Appalachian region. In 1940 production reached a peak with 7,848,921 tons mined in Nova Scotia and 547,064 in New Brunswick, nearly half the total amount mined in Canada. 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. In normal times the production supplies not only the railways of the area, the local steel industry, 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 36) are those of Sydney and Inverness in Cape Breton Island, Pictou and Cumberland on the Nova Scotian peninsula, and Minto in New Brunswick.

In the Sydney field, coal was exploited more than 200 years ago by the French during the construction of the fortress at Louisburg, and has been mined continuously now for more than a century. At present this field supplies about 75 per cent of the Nova Scotian production. The productive area is a narrow fringe of lowland coast 30 miles long in an east-southeasterly direction, and 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 richest part of the field is directly beneath Sydney Harbour.

The producing beds form part of the Morien group of Pictou age. The series has a maximum thickness of about 6,450 feet, and rests with erosional contact upon strata of the Canso and Windsor groups. It consists of grey and red sandstone, grey and red shale, grey, arkosic grit, with some pebbly conglomerate, and, near the base of the series, some beds of limestone-conglomerate. There are also thin beds of freshwater limestone, commonly carrying *Spirorbis,* and numerous coal seams. The beds are thrown into broad open folds that trend northeasterly to easterly and pitch seawards 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. Those that are worked range for the most part from 4 to 7½ feet in thickness, but thicknesses up to 11 feet have been encountered. The workings extend for more than 3 miles under the sea, and it is believed that the coal-bearing measures extend seaward for another 30 miles.

The coal areas of Inverness county lie on the west coast of Cape Breton Island, forming small detached basins in which the beds dip seawards. In the Mabou Mines and Inverness areas the beds are of Pictou age. Inverness has been largely depleted of its best coal, but at Mabou Mines there is at least one workable coal seam of fair quality. At Port Hood, Chimney Corner, and St. Rose the coal-bearing measures are of Riversdale age. At Port Hood one workable coal seam lies under the water. At Chimney Corner two possible workable seams dip steeply beneath the sea. St. Rose is a small land area containing these same two seams, the area intervening between the two fields being a faulted barren block. In addition to the above areas in Inverness county there are other Cape Breton deposits in Richmond county. These occur inland, and are of Riversdale age. The workings have been on a small scale, and production has been hampered by faults and by the poor quality of the coal.

The Pictou field, covering an area roughly 10 miles long and 3 miles wide surrounding New Glasgow and Stellarton, has been exploited for coal for about 150 years, and up to date has produced more than 40,000,000 tons.

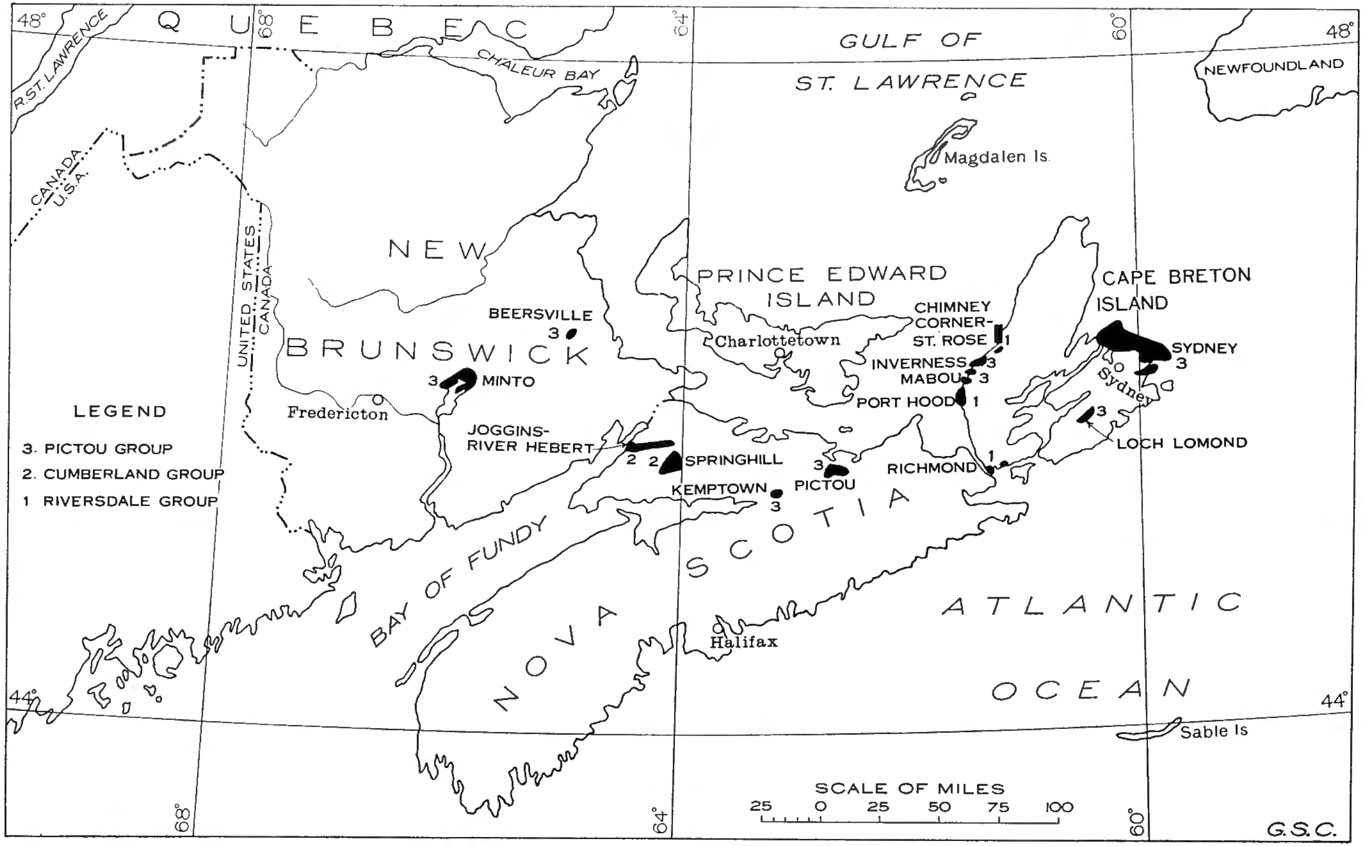


Figure 36. Coalfields of Eastern Canada. (After B. R. MacKay.)

The economically productive measures of the field are known as the Stellarton group and are of Pictou age. They form a triangular shaped 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 a number of 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 these vary greatly in workable thickness and quality within short distances, a feature that makes it difficult to estimate reserves. One seam, the Foord, showed a maximum thickness of 45 feet.

In Cumberland county there are two coal fields, and in both the production is from measures belonging to the Cumberland group. One of the fields is at Springhill, and the other is that of the Joggins-River Hebert area near the head of the Bay of Fundy. The Springhill field is less than 4 miles wide and includes five seams, each 5 to 10 feet thick, in about 800 feet of strata. Both to the north and to the south of the area the seams thin rapidly along the strike and become unworkable. Within the area they dip westward at angles of 20 degrees or more, with no noticeable change at depth. The coals of the Joggins-River Hebert area are slightly lower stratigraphically than those of Springhill, and comprise four seams that locally reach a thickness of 3 feet. They pinch into barren rock within 25 miles of the shore of Chignecto Bay, and most of them were found to thin as they were followed down the dip.

The Minto coal of New Brunswick is in measures of Pictou age that, to a large extent, were deposited as a thin sheet of sediments and not in local, coal-forming basins. There is only a single seam at Minto, but it may cover a much larger area than any of the Nova Scotian seams. The seam is rarely more than 2 feet thick. Over a large area it lies close to the surface, and in places is mined by stripping away the overlying material when this is not more than 15 or 20 feet thick. Elsewhere the seam is worked by shafts to a depth of 125 feet.

ASBESTOS

Canada has the largest production of asbestos of any country in the world, and almost the entire amount comes from the Eastern Townships of Quebec. Mining has been continuous since 1878, and reserves are still very great. In 1880 the value of the output was less than $25,000; in 1920 it amounted to $14,792,201; and in 1943, 467,196 tons were produced with a value of $23,169,505. The asbestos is of the fibrous serpentine 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 Thetford Mines and Black Lake (*See* Figure 37), but other centres are East Broughton, about 25 miles to the northeast, and Asbestos, some 45 miles to the southwest.

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 (*See* Figure 37). Still farther northeast small areas of similar rocks occur near Lake Matapedia and at Mount Albert, Serpentine Mountain, and near Port Daniel, in Gaspe Peninsula, but these areas have produced no commercial fibre. In the Thetford area the peridotite rocks lie mainly within the Cambrian Caldwell group, but also intrude Ordovician Beauceville strata. It is probable that the age of the intrusions is late Ordovician, and that they were introduced at the time of the Taconic orogeny. Small masses of granite and dykes of feldspar are associated with them; these may be differentiates of the basic magma or offshoots of underlying masses of later granite.

The asbestos is of two types, cross fibre and slip fibre. The former occurs in veins with clean-cut walls, the fibres 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 with the fibres more or less matted and lying lengthwise along the planes of slippage.

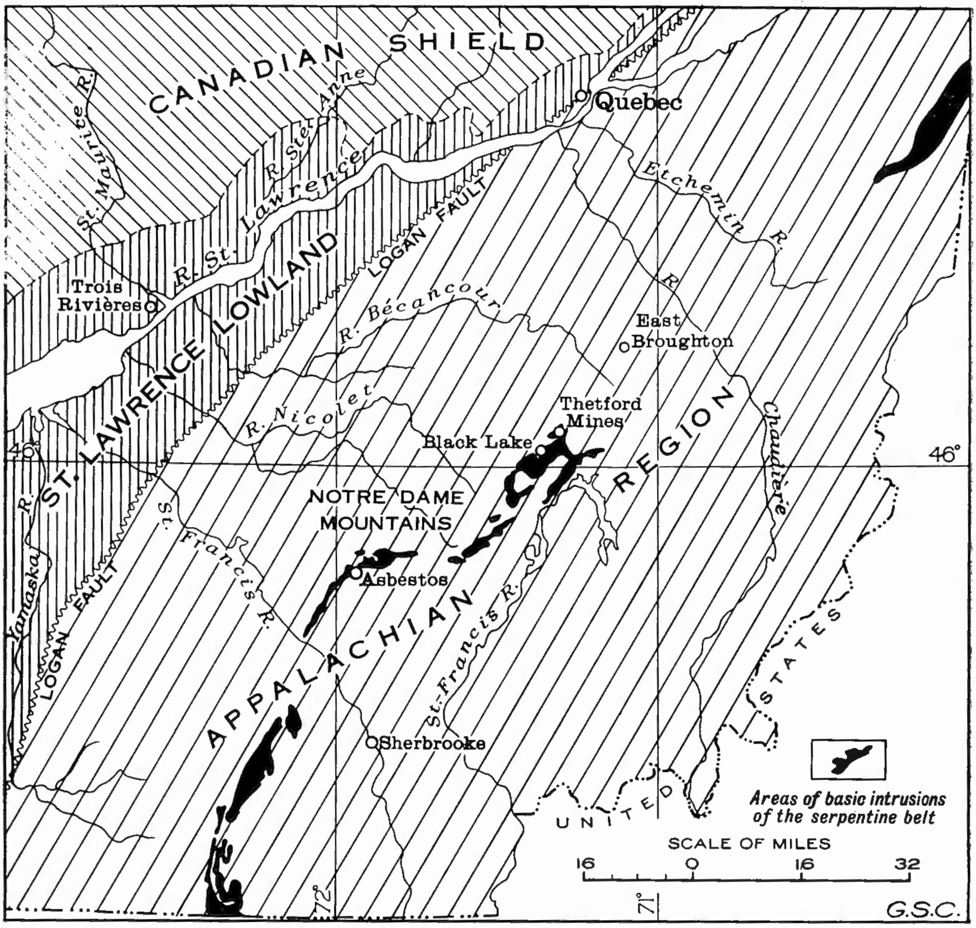


Figure 37. Part of southern Quebec, showing the distribution of rocks of the serpentine belt.

The veins of cross fibre vary in width from a hairline to 3 inches, or very rarely to 4 or 5 inches (Plates XXV and XXVI). That over $\frac{3}{8}$ inch is known as "crude", because it is hand selected and cobbed, whereas shorter material is milled, the rock being crushed, beaten, and screened and the asbestos lifted from the screens by overhead 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 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 rapidly at the edges farthest from the vein into the ordinary partly serpentinized peridotite. 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

PLATE XXV

Serpentinized peridotite at Black Lake, Quebec, showing veins of serpentine whose middle parts consist of asbestos. Photo by F. J. Alcock, Geological Survey (51464).

PLATE XXVI

Asbestos pit and piles of tailings, Black Lake, Quebec. Photo by C. H. Stockwell, Geological Survey (88417).

zone, including the asbestos vein in the middle, is commonly from 6 to 8 times the width of the vein itself (Figure 38).

The veins may also be divided into simple veins and ribbon veins. The latter are found mostly at the Vimy Ridge mine southwest of Black Lake. They are so named because a band or "ribbon" of rock has been sliced along closely spaced, parallel or nearly parallel lines, and the fractures filled with cross fibre asbestos. The separate veinlets commonly average $\frac{1}{8}$ to $\frac{1}{4}$ inch in width, occasionally reaching 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.

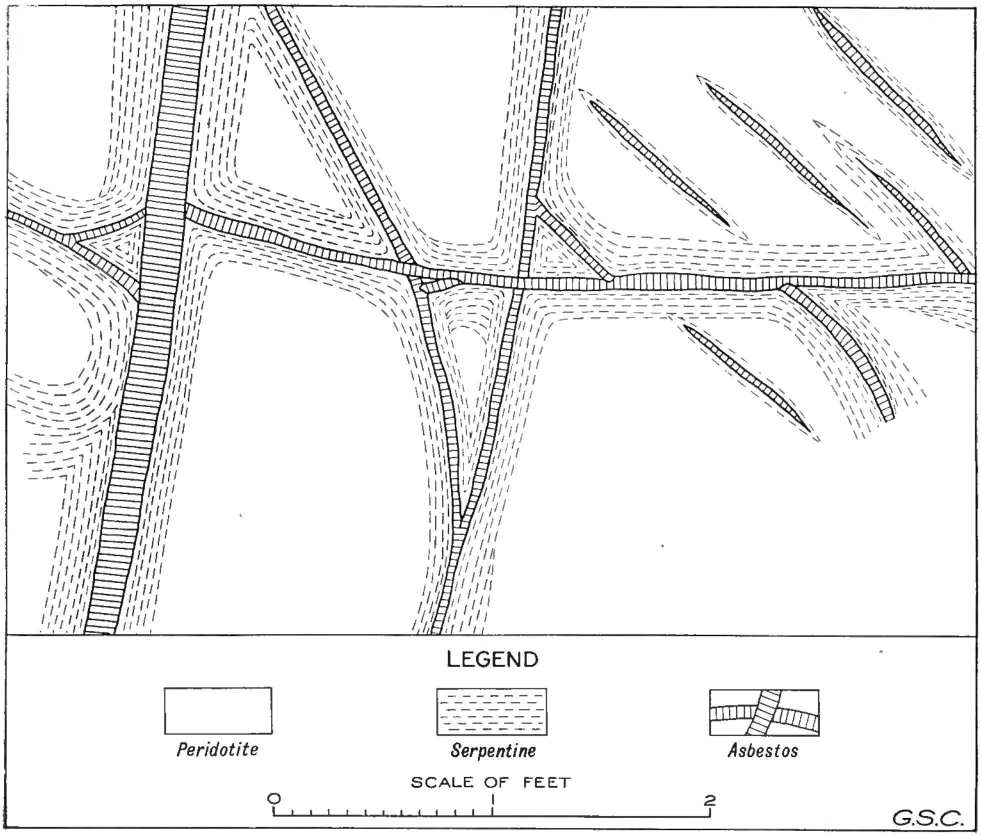


Figure 38. Asbestos and serpentine in peridotite, wall of pit near Standard mine, Black Lake, Quebec.

As already mentioned, it is believed that the injection of the peridotite and pyroxenite rocks took place at the close of the Ordovician period during the Taconic orogeny. It is probable that the rocks were serpentinized originally at a late stage in their consolidation, as a result of reaction between the mineral constituents and associated magmatic water.

Though associated with the peridotite the asbestos is quite 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 was a vein of asbestos 3 feet long and with a maximum width of $\frac{3}{4}$ inch running 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. The presence of magnetite suggests that this alteration took place at high temperatures. From the fault 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 probable that this second period of serpentinization and the production of the asbestos are related to the Devonian orogeny and accompanying intrusions.

CHROMITE

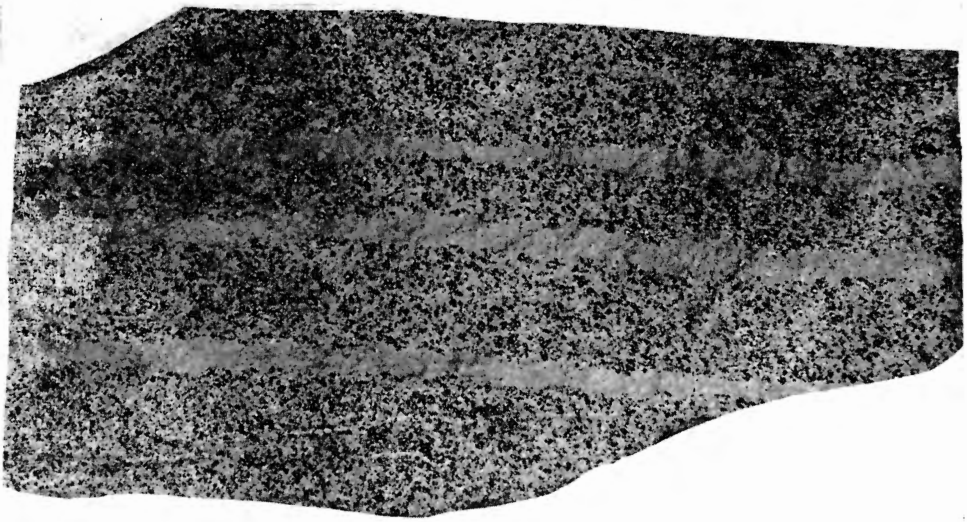
Chromite is associated with the basic intrusive rocks of the Serpentine belt (*See* Figure 373) already referred to in connection with asbestos. The first discovery of the mineral is attributed to Sir William Logan, who is said to have found some loose blocks near Lake Memphremagog in 1842. From 1894 to 1909 there was a steady but small output, but since then mining has been really active only in wartime, the known deposits being too small or too low grade to compete with foreign sources under normal conditions. In 1918 shipments amounted to 15,600 tons of crude ore and 6,400 tons of concentrates. In 1944 total mill capacity of the producing properties was about 750 tons a day, as compared with 200 to 300 tons in 1918. The production has come from the Thetford-Black Lake area, from St. Cyr, situated 30 miles north of Sherbrooke, and from Webster Lake about 12 miles west of that city. The Mount Albert area of central Gaspe is also known to carry small amounts of the mineral.

The serpentinized rocks consist of three main varieties: (1) dunite, or peridotite composed wholly or almost wholly of olivine; (2) peridotite made up of olivine and pyroxene, the latter mineral making up from 5 to 50 per cent of the rock; and (3) 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 XXVII) 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, narrow chromite-bearing zones alternating with layers of barren or nearly barren rock. The tabular deposits vary in size up to 2,000 feet in length and 60 feet in width, but the workable ore may be confined to lenses within them. These deposits have produced 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 may consist of disseminated ore, or of nearly massive chromite, or of a mixture of the two. In the fracture-filling type (Plate XXVIII), short irregular cracks in the rock or spaces between fragments of breccia are filled with nearly massive or heavily disseminated chromite.

The chromite was undoubtedly derived from the magma that produced the basic intrusive rocks. It is probable that partial crystallization took place in a deeper magma chamber, and that differentiation progressed, with chromite and olivine concentrating at the bottom, olivine and pyroxene in the middle, and pyroxene on top. This still mobile mixture of crystals and magma was then intruded into the places now occupied, and the various types were intermixed as a result of the intrusive processes. Final crystallization was probably accompanied by further local differentiation.

Plate XXVII



Specimen from a tabular chromite deposit in dunite, Black Lake area, Quebec. Photo by Bureau of Geology and Topography; scale, ½ natural size (92168).

Plate XXVIII

Specimen of dunite with chromite (black) filling fractures, Black Lake area, Quebec. Photo by Bureau of Geology and Topography; scale, ½ natural size (92167).

SOAPSTONE

Soapstone, or massive fine-grained talc, is associated with the serpentine rocks of the Eastern Townships of Quebec. Most of the production has been from the Thetford region. In 1943 some 12,099 tons of ground talc, valued at $127,343, 1,293 tons of sawn soapstone worth $35,439, and 99 tons of talc crayons, with a value of $19,357, were produced.

The soapstone is an alteration product of serpentinized peridotite dykes that have been intruded into siliceous quartzites or schists. The soapstone bodies commonly lie at the margins of the dykes, and the schists there are 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 the two processes followed each other closely, and that the production of both the asbestos and the talc resulted from injections of solutions from the same source.

GYPSUM

Gypsum occurs in Nova Scotia, in New Brunswick, and on Magdalen Islands in the province of Quebec. The deposits are all in beds belonging to the Windsor group of Mississippian age. 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 series is exposed in a belt around Moncton, and 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 in northwestern Cape Breton. In New Brunswick, production is confined to the Hillsborough area of Albert county. In 1941 Nova Scotia produced 1,395,172 tons valued at $1,517,297, and New Brunswick in the same year produced 56,172 tons. The gypsum and associated anhydrite beds rest on marine Windsor limestone.

In the Windsor area the whole series has an estimated thickness of not less than 1,550 feet. There are here four or five zones of calcium sulphate deposits, 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 shales. The deposits were obviously derived directly by precipitation from sea-water. Deposition probably took place in a series of partly or wholly land-locked basins instead of in the once continuous Windsor sea. The thickness of the deposits suggests that the supply of sea-water must have been replenished repeatedly while the material was being formed.

SALT

Salt is associated with strata of the Windsor group in various places in Nova Scotia and New Brunswick. Large quantities are mined at Malagash on Northumberland Strait; 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, and in the region southwest of Moncton in New Brunswick also cut salt beds. In addition, natural brine springs occur at many places underlain by Windsor beds.

At Malagash, production in 1942 amounted to 50,199 tons valued at $317,798. The Windsor beds there are folded and faulted, and the salt zone apparently immediately succeeds the gypsum. The salt was encountered at a depth of less than 100 feet beneath the surface, and workings have extended to a vertical depth of more than 1,000 feet. There are two main layers of white salt and other zones of reddish coloured salt. Part of the production is from the evaporation of brine produced by leaching the waste material in the mine.

PEAT

Peat is known at many places in the Appalachian region, and a small production comes from bogs in Quebec and at Shippigan in New Brunswick.

PETROLEUM, NATURAL GAS, AND OIL-SHALE

In New Brunswick, the Stony Creek field (Figure 39), situated between Moncton and Hillsborough, supplies these places and other localities in Albert and Westmorland counties with natural gas. The annual production is around 650,000,000 cubic feet, valued at more than $300,000. The same field also produces each year about 25,000 barrels of petroleum.

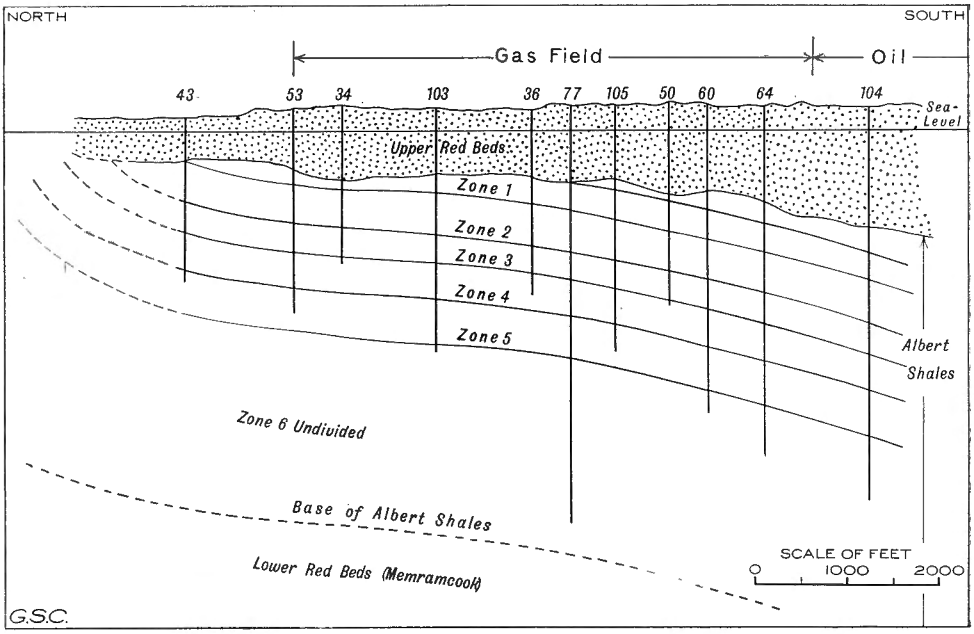


Figure 39. Section across Stony Creek field, New Brunswick. (After J. A. L. Henderson.)

Both the oil and gas come from the Albert formation of Mississippian age. This formation consists largely of shales, but also contains sandstone zones that form the reservoirs for the oil and gas. It outcrops from the valley of the Memramcook on the northeast to the Sussex region on the southwest. In the latter area conglomeratic zones become interbedded with the shales, and still farther southwest sandstones and conglomerates become dominant and evidently represent shore phases of the formation. Elsewhere the Albert shales are concealed by younger Mississippian and Pennsylvanian beds.

The Albert formation locally contains oil-shales, the three localities that have attracted chief attention being Rosevale and Albert Mines in Albert county and Taylor Village in Westmorland county. Extensive diamond-drilling operations were carried out in 1942 on all three of these occurrences, and more than three thousand analyses were made for the oil content. This work has indicated that the material is not rich enough for the oil to be recovered economically.

The Albert beds also contain, locally, a solid hydrocarbon known as albertite. The largest deposit was at Albert Mines. It was discovered in 1851, and mining was carried out 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 the shales. The vein had an irregular strike, a steep dip, and varied in width from nil 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. From it 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.

Gaspe peninsula has attracted attention a number of times as a possible oil field, and holes drilled in the York River region yielded small amounts of petroleum. The oil-bearing zones are in the Gaspe sandstones, in the underlying Gaspe limestones, and at the contact between these two series. No large concentrations of oil have yet been found.

GOLD

Gold has been mined in a large number of districts in Nova Scotia where the deposits are quartz veins, and in the Eastern Townships of Quebec where it was recovered from placers. In addition, the copper-bearing deposits of the latter region have produced some gold.

Gold mining began in Nova Scotia in 1862; the annual production from that date to the present has varied greatly, reaching a high in 1939 with a value of more than $1,000,000. Most of the production has come from the peninsular part of the province where the deposits are in the slates and quartzites of the Meguma or Gold-bearing series. Altogether in the numerous gold districts there are scores of properties that have produced gold.

The deposits are veins that occur for the most part along the bedding of the sediments and are most abundant on the anticlines or domes (Figure 40). They have their greatest width as a rule along the axes of the anticlines, narrowing and in places thinning to nothing on the flanks, thereby forming bodies known as saddle reefs. Some crosscutting veins also occur, and in a few districts form the principal deposits. The minerals associated with the gold-bearing quartz are principally pyrite, arsenopyrite, calcite, and galena. Most of the gold occurs 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 the masses of Devonian granite that intrude the Gold-bearing series.

Gold has also been found in several localities in Cape Breton Island. The rocks consist of altered sediments and intrusions of Precambrian age, but they can in no way be correlated with the Gold-bearing series of the mainland. The gold occurs in quartz veins and also in placer gravels. A small production of gold from both types of deposit was made on Middle River in Victoria county.

Production of placer gold from the Eastern Townships of Quebec has been estimated to be $3,000,000. The first recorded discovery was in 1823, near the mouth of Gilbert River, a tributary of the Chaudière. Mining operations began there in 1847, and as the shallow deposits became exhausted, work was

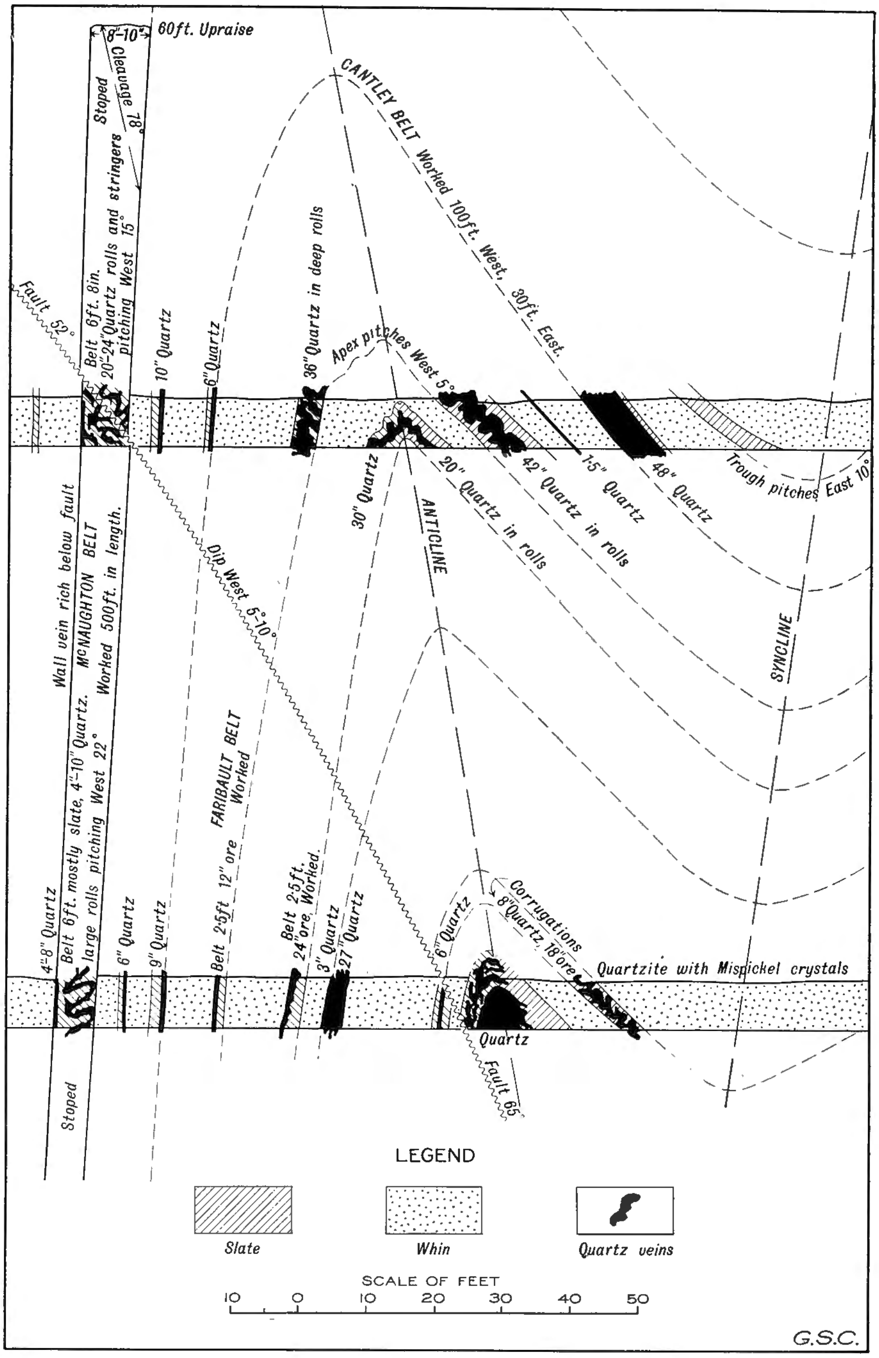


Figure 40. Detailed transverse section of the 280- and 364-foot levels of the Bluenose gold mine, Goldenville, Nova Scotia. (After E. R. Faribault.)

carried up the Chaudière, the Gilbert, and other tributaries, and richer deposits were located in buried channels and benches of pre-glacial streams. The period of 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 obtained were rough and angular, with occasional bits of the vein quartz from which they had been derived still attached, suggesting that they had not travelled far. However, though the region contains many quartz veins, none large enough or rich enough to mine has yet been found.

COPPER

Numerous occurrences of copper minerals are known in New Brunswick and Nova Scotia, but production has been very small. The deposits include a variety of types. At Cape d'Or, Cumberland county, Nova Scotia, native copper occurs in veins and along joints in Triassic diabase, and small quantities have been found also 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 low values in copper and nickel. Secondary copper minerals occur in Carboniferous sandstones 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 beds. Considerable development work was done at Dorchester, and a small amount of copper produced.

The Eastern Townships of Quebec have produced considerable quantities of copper ore. Its presence there was known as early as 1841, and from 1859 to 1866 the region was prospected actively 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 iron pyrites.

The deposits lie within a belt 30 to 40 miles wide and 130 miles long extending northeasterly from the Vermont border to Chaudière River. The belt includes the Sutton Mountain and Stoke Mountain anticlines, 20 to 25 miles apart, both composed largely of schistose sedimentary and igneous rocks of early Palæozoic age. Between them the country is underlain mainly by Palæozoic sedimentary formations. Most of the larger copper deposits lie within or close to one or other of the two schistose anticlinal zones. The following is a brief account of some of the more important properties, beginning at the west.

The Acton mine is on the west of the Sutton Mountain belt near Acton Vale. It produced about 12,000 tons of ore averaging 12 per cent copper. The deposits occurred in three main areas within a length of 720 feet, and lay in a band of cherty limestone, 3 to 70 feet thick, resting on dark slates. 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. Here three bands of slaty schists 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; the production amounted to several thousand tons of ore whose copper content ranged from 14 to 30 per cent.

Between the Sutton Mountain schistose belt and that of Stoke Mountain are copper deposits associated with the basic intrusive rocks of the serpentine belt. The intrusions are of diabase, pyroxenite, and serpentinized peridotite, and form an almost continuous but disconnected series of sill-like masses on the east side of Mississquoi Valley. The copper deposits range 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 minerals. Pyrrhotite also occurs at the Huntingdon and St. Ives mines. The former of these was worked at intervals between 1865 and 1883. The mineralized schistose zone there had a maximum width of 18 feet and a length of 150 feet.

The eastern or Stoke Mountain schistose belt contains many copper showings; a few have supplied large quantities of ore and others smaller amounts. The deposits occur in sericite schist or at the contact of sericite and chlorite schists, the former apparently representing highly altered rhyolites, and the latter metamorphosed andesites.

The most important mine of the belt, and indeed of the entire copper-bearing region, is the Eustis, which, from the time it was first operated soon after its discovery in 1865, until it closed in June 1939, 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 41). They dip southeast, conforming with the schistosity of the country rock. A 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 (Figure 42). The chief sulphide is pyrite, but there is appreciable chalcopyrite in one of the lenses: pyrrhotite is also present and increases with depth.

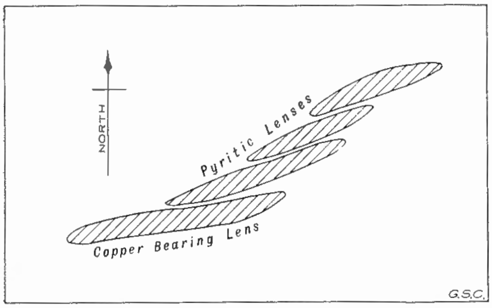


Figure 41. Diagrammatic plan, showing *en échelon* arrangement of sulphide lenses, Eustis mine. (After V. Douglas.)

The Weedon mine, discovered in 1909, lies about 38 miles northeast of the Eustis, and is of the same general type. It is a lenticular mass of pyrite 570 feet long, has a maximum thickness of 40 to 45 feet, and dips at angles of 25 to 60 degrees to the southeast. The ore averages 3·62 per cent copper, 40·74 per cent sulphur, and carries small amounts of zinc, lead, silver, and gold. The Moulton Hill mine is on another deposit of the same general type. The deposits are of replacement origin, and were probably formed during the Devonian period of folding and intrusion.

In 1942 a new discovery was made by the use of detailed geological and geophysical methods near the old Moulton Hill mine. The 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. The ore carries appreciable values in gold and silver.

IRON

The Appalachian region of Canada contains a very large number of iron occurrences, of a variety of types. Some of the deposits have been worked in the past, and a few still have considerable reserves. Many of the showings, however, are so small that they are of geological interest only.

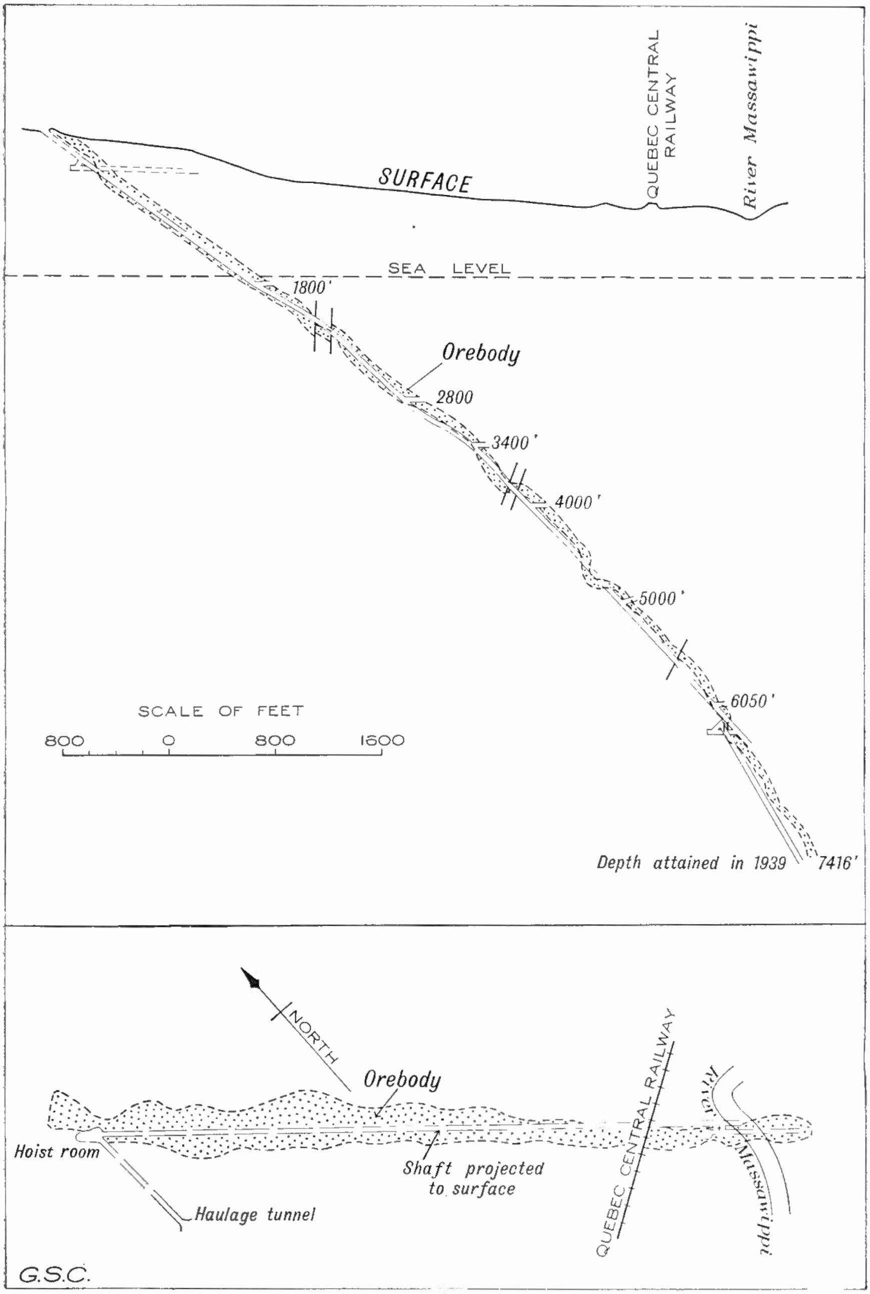


Figure 42. Plan and vertical section through shaft, Eustis mine. (After V. Douglas.)

In southeastern Quebec, narrow zones of magnetite and hematite occur in sedimentary formations of Cambrian or Precambrian age. In New Brunswick, there are important magnetite deposits near Nipisiquit River south of Bathurst. Near Woodstock, in St. John Valley, low-grade, manganiferous hematite is interbedded with Silurian sediments. A blast furnace was erected there as early as 1848, and another in 1863. In Nova Scotia, sedimentary deposits, in places consisting of magnetite, in others of hematite, are associated with Cambrian strata in northeast Cape Breton Island, with Silurian beds in Pictou and Antigonish counties, and in Devonian measures in the Nictaux-Torbrook district of Annapolis county. The Precambrian rocks of Cape Breton Island locally contain masses of magnetite. The region surrounding Minas Basin contains deposits of limonite and siderite, some associated with Windsor limestone. A considerable tonnage of limonite was produced in the Londonderry district.

The Bathurst iron deposits are located on Austin Brook, about 17 miles south of Bathurst. In the years 1910 to 1915 more than 200,000 tons of ore were shipped. Mining was again carried out in 1943, shipments being made by rail to Sydney at a time when, owing to war conditions, it was difficult to get ore from Newfoundland. The Bathurst ore is chiefly magnetite, but some hematite is also present; in places it is well banded. It is associated with quartz porphyry and diabase, of volcanic or intrusive origin, interbedded with or intrusive into sediments of supposed Ordovician age. The ore occurs where the rocks are schistose, and apparently formed as a result of replacement. The largest body of ore forms a well-defined mass dipping at an agle of 45 degrees, and at one place has a breadth at the surface of 105 feet.

In the Nictaux-Torbrook district of Nova Scotia the iron ore is of sedimentary origin, occurring with slates and quartzites of early Devonian age. The beds are folded into a syncline, and, locally, are crumpled, faulted, and sheared. They are also intruded by dykes and masses of gabbro and diorite, and, on the south, they are cut off by a granite batholith. The ore occurrences lie in two nearly parallel zones about a mile apart. The southern has been traced along the strike of the beds 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, with quartz and fine-grained argillaceous material as a cement. The northern zone, which probably represents the same horizon as the above but on the other limb of the syncline, 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.

The limonite and carbonate ores of the Londonderry area lie along a zone of fissuring in a band of conglomerate, sandstone, and shale on the south slope of Cobequid Mountains. The ore has been mined at intervals over a length of 10½ miles. The minerals, which include ankerite, siderite, limonite, and other hydrated oxides of iron in various proportions, occur as lenticular masses of all sizes up to 50 feet or more in width. Mining has been confined to the larger ones. In places the ore consists almost wholly of primary ankerites and other carbonates; in others the carbonates have been altered to limonite and other iron oxides. At one place secondary ores were followed to a depth of 400 feet below the surface.

LEAD AND ZINC

Both Nova Scotia and New Brunswick have numerous small showings of sphalerite and galena, but although development work has been carried out on a large number of properties, there is no production at present.

In southeastern Cape Breton Island a property near Stirling was active for a time as a zinc producer. The deposits are replacements of altered volcanic rocks of Precambrian or early Palæozoic age. The ore zones consist of solid masses of sulphides or of schist with sulphides. The sulphide masses are made up of an intimate mixture of sphalerite, pyrite, chalcopyrite, and galena. One zone of ore ranged up to 35 feet in width and averaged 17 per cent zinc.

Galena occurs 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. Considerable development work was carried out on such a deposit at Leadvale, 12 miles southeast of Truro. The 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 sphalerite and galena. The deposit was formed originally along the contact of limestone of Windsor age and underlying sandstone and shale of the Horton group. Later, the ore zone was extensively broken and sheared by fault movements.

In New Brunswick a sulphide deposit in which sphalerite is the most abundant mineral was discovered near Tetagouche River as a result of tracing blocks of sulphide float back along the direction of glaciation to their source. After finding the material in place the deposit was explored by surface work and diamond drilling. It proved to have a length of more than a mile but a width of less than 30 inches, and in places it is much narrower. The deposit is of replacement origin in schists of supposedly Ordovician age derived from volcanic tuffs.

In central Gaspe a large amount of development work has been carried out on zinc and lead showings, but no production has yet been attempted. The area lies on the north branch of Berry Mountain Brook and 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 Gaspe 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 distances of half a mile. They vary greatly in their mineral content. Post-mineral faulting makes it difficult locally to follow certain veins.

MANGANESE

Oxides of manganese are known at many places in Nova Scotia and New Brunswick (Figure 43). Early attempts at various times to develop the more important occurrences resulted in the production of a total of some 40,000 tons of high-grade material. During the second world war a number of the old properties were re-examined; development work was carried out on a few, but the results were disappointing.

The deposits include a variety of types, of which the more important are: (1) ores associated with Carboniferous sediments, particularly the Windsor limestone; (2) ores filling fissures in pre-Carboniferous rocks; and (3) 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 Magdalen Islands, in the Gulf of St. Lawrence. Deposits of the second type occur at Gowland Mountain and Jordan Mountain in New Brunswick, and at New Ross in Nova Scotia. A considerable deposit of bog ore occurs

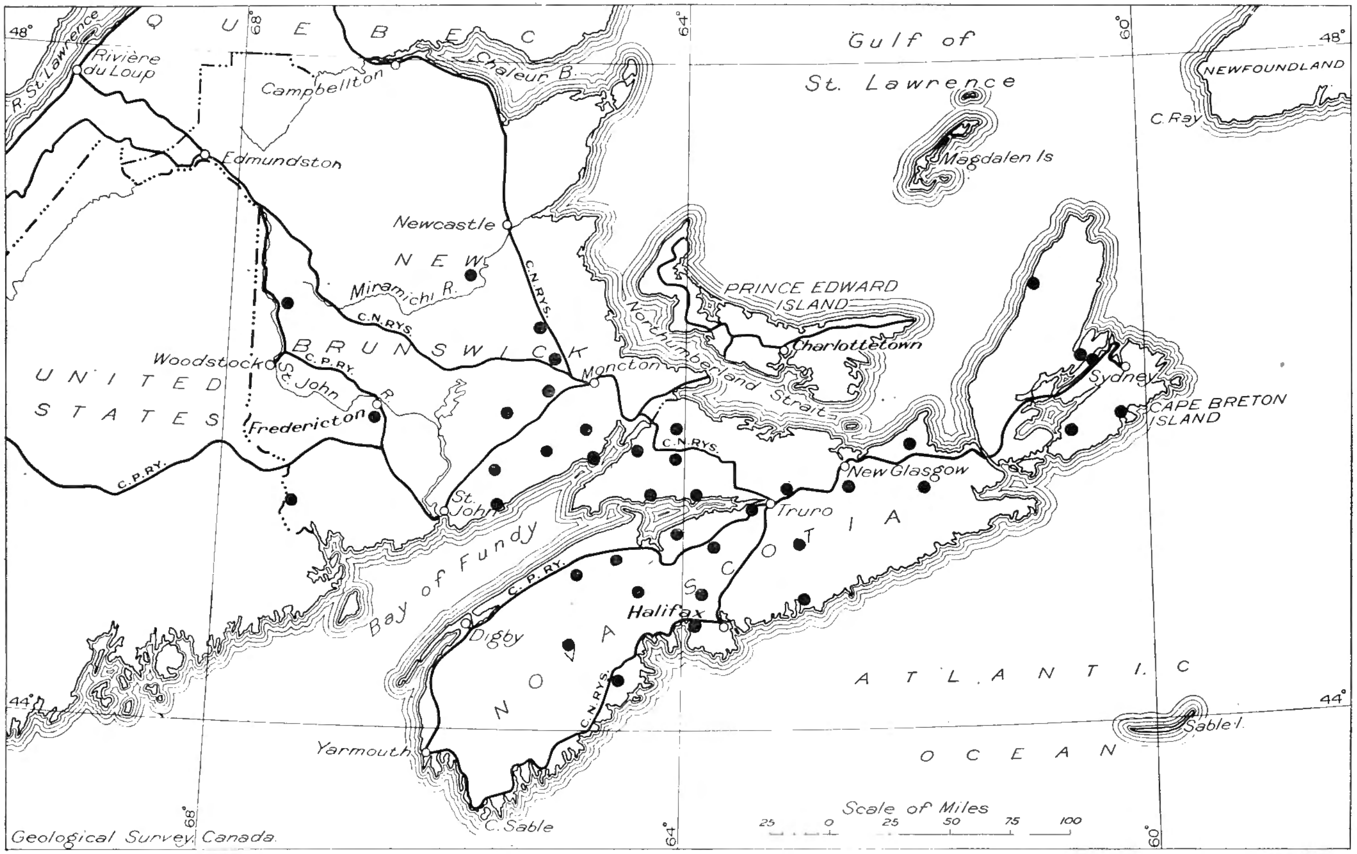


Figure 43. Index map showing location of manganese deposits in New Brunswick and Nova Scotia.

at Dawson Settlement, about 5 miles northwest of Hillsborough, in New Brunswick. There are numerous other, smaller occurrences of bog manganese in the province, many also in Nova Scotia, and some in southeastern Quebec.

The Markhamville deposit was worked between the years 1862 and 1895, and more than 23,000 tons of ore were shipped. The material consisted of crystalline and massive pyrolusite and manganite with some psilomelane, and occurred in masses and pockets along bedding planes and joints in low-dipping Windsor limestone. Considerable quantities were also found at 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 occurred at the top of the limestone, which is overlain by Pennsylvanian sandstone and conglomerate. At Shepody Mountain 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 schists, 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.

At Tennycape, Hants county, Nova Scotia, the ore, which was mainly pyrolusite, occurred near the base of a thick zone of Windsor limestone dipping about 40 degrees to the south. The underlying rocks are sandstones, and between the sandstone and the limestone is an 8-foot bed of limy shale. Near the contact with the shale the limestone is brecciated and the best ore occurred here as nodules and masses. One mass yielded 1,000 tons of good ore.

On Magdalen Islands (Figure 44), manganese oxides occur as masses of float in the soil, and in Windsor limestone beds near the contact with overlying red sandstones of probable Pennsylvanian age.

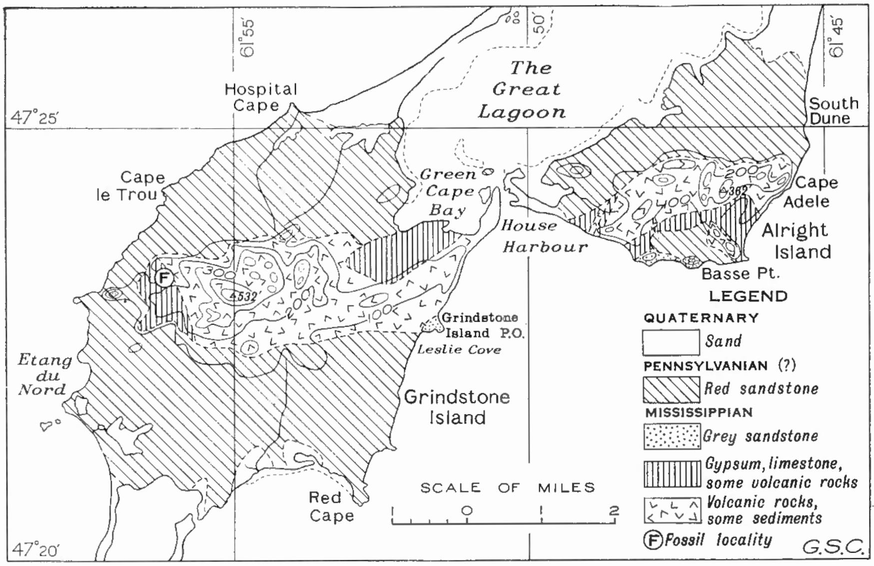


Figure 44. Grindstone and Alright Islands, Magdalen Islands. (By F. J. Alcock.)

The deposits at Gowland Mountain near Elgin and at Jordan Mountain near Sussex, New Brunswick, occur in fractures in rocks of Precambrian age. The original source of the material is believed to be the Precambrian volcanic rocks, but the concentration was effected by surface solutions. Development work has shown that the deposits are shallow.

At New Ross, in the northern corner of Lunenburg county, Nova Scotia, the deposits are lenticular veins lying in faults or crushed zones 25 to 100 feet wide in Devonian granite. The veins vary in width from a few inches to more than 5 feet. The best ore is solid black pyrolusite, but manganite and psilomelane, with calcite, barite, iron oxides, and country rock as gangue material, form less valuable ore.

BUILDING AND ORNAMENTAL STONE, ETC.

In Nova Scotia, New Brunswick, and southern Quebec are large areas of granite that in many places are of a suitable grain and colour for both structural and monumental purposes. With the granites may be included certain basic igneous rocks such as gabbro, diorite, and diabase, commonly known to the trade as "black granite". The region that has attracted most attention in this regard is around the town of St. George in Charlotte county, New Brunswick. From the large number of quarries there, some in red granite, others in black, a considerable production of stone has been recorded. At present a small but steady amount of the black rock is produced at Digdeguash Lake for monumental purposes. Grey granite for monument bases is taken from the Spoon Island quarries in the St. John Valley near Hampstead. In Quebec, granite for building stone is obtained at Stanstead.

Crystalline limestone and dolomite occur at several places in New Brunswick and Nova Scotia. At Saint John crystalline carbonate rocks of the Green Head group are quarried for use as a soil conditioner and for structural purposes. Silurian crystalline limestone is found at L'Etang and on Frye Island south of St. George.

Carboniferous sandstones have furnished considerable amounts of very satisfactory building stone. The Miramichi quarries near Newcastle, those of Chaleur Bay east of Bathurst, and a considerable number in that part of Nova Scotia and New Brunswick lying between the head of Chignecto Bay and Northumberland Strait are among the most important.

GRINDSTONES, ETC.

A small but steady production of grindstones and scythestones is maintained from quarries near Stonehaven on Chaleur Bay between Bathurst and Caraquet. The rocks are fine-grained, even-textured sandstones of the Clifton formation of Pennsylvanian (Pictou) age.

SODIUM SULPHATE

Sodium sulphate is known to be present in the Weldon area, Albert county, New Brunswick, 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. Many millions of tons of the material appear to be 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. The more important deposits in New Brunswick are at Pollet and McNair Lakes near Mechanic Settlement in Kings county, and Flood Lake, 16 miles southeast of Sussex; in Nova Scotia there are deposits near New Annan, Digby Neck, and elsewhere.

BARITE

Nova Scotia has supplied most of the barite produced in Canada, and contains the country's largest known reserves. In 1940 a deposit discovered in the Pembroke-Walton area of Hants county, near Minas Basin, has been proved by drilling to contain more than 3,000,000 tons, one of the largest known barite deposits in the world. Production began there in 1941, and 6,000 tons were shipped in that year; the amount produced in 1944 was 114,147 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 are sandstones and argillites 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 movements 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.

Prior to the discovery of the Walton deposit the chief production of barite 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 the veins have widths varying from 8 to 18 feet, and locally have smaller veins parallel with them. Though the vein material is largely barite, it contains, in places, considerable calcite and fluorite. Barite-bearing veins occur also at North Cheticamp, 40 miles north of Lake Ainslie. Near Five Islands, on the north side of Minas Basin, still other barite deposits occur in a brecciated zone traversing folded slates and sandstones of Carboniferous or earlier age.

ANTIMONY

Antimony, in the form of stibnite and native antimony, has been produced at Lake George, York county, New Brunswick; at West Gore, Hants county, Nova Scotia; and at South Ham in southeastern Quebec. At Lake George, which lies about 25 miles west of Fredericton, the deposits are veins cutting Palæozoic shales and quartzites in the neighbourhood of intrusive masses of diabase and Devonian granite. The gangue mineral is quartz; the chief ore mineral is stibnite, but native antimony is present in the upper parts of the veins.

At West Gore the deposits are also veins, which here cut beds of the Meguma or Gold-bearing series. There are three nearly parallel veins 700 to 1,000 feet apart, the largest of which has been traced for more than 1,200 feet. The ore occurs as lenticular masses in the veins. At South Ham native antimony, with subordinate amounts of stibnite, occurs as flakes along cleavage planes in slaty and schistose rock at its contact with a basic intrusion.

TUNGSTEN

In the Moose River district of Halifax county, Nova Scotia, narrow quartz veins in folded sediments of the Meguma or Gold-bearing series carry scheelite. Arsenopyrite and tourmaline are accompanying minerals. At Waverley, in the same county, scheelite-bearing veins occur along bedding planes of the Meguma sediments.

In New Brunswick, about 25 miles northwest of Boistown, near the junction of Burnt Hill Brook with the Southwest Miramichi, a large number of small quartz veins carry wolframite, molybdenite, and cassiterite. Exploratory work has been carried out on the property at intervals, but the amount of the valuable minerals is small. The veins cut Palæozoic sediments metamorphosed by an adjacent granitic intrusive mass.

CHAPTER IV

THE ST. LAWRENCE LOWLANDS

(J. F. Caley)

PHYSICAL FEATURES

The St. Lawrence Lowlands (Figure 45) are plain-like areas bordering the Canadian Shield on the south and extending northeasterly from Lake Huron and the head of Lake Erie to Anticosti Island. They may be divided for descriptive purposes into three parts, each of which is floored by unfolded Palæozoic rocks.

The most westerly of these divisions includes Manitoulin Island and the part of southwestern Ontario that fronts on Lakes Erie and Ontario and lies west of the Frontenac axis, a projection of the Canadian Shield that crosses the St. Lawrence between Kingston and Brockville. This division is broken into two parts by the Niagara escarpment, a prominent physiographic feature that extends westward from Niagara River (Plate XXIX) to Hamilton and passes from there northwestward, forming Saugeen Peninsula and controlling the longer dimension of Manitoulin Island. In the south, the escarpment presents an abrupt rise of 250 to 300 feet, but to the north it forms part of a narrow belt of rapidly rising land that attains an elevation of 1,700 feet, almost 1,000 feet above the lower land stretching east and southeast to Lake Ontario. The escarpment is the result of erosion acting upon a region of simple structure and normal alternation of resistant and easily eroded strata. East of the escarpment, the land rises gently northward from the level of Lake Ontario, 246 feet, to a maximum height of about 1,000 feet above the sea. At several places east of Lake Simcoe, the north boundary of this area is marked by an escarpment with an abrupt drop of 50 to 100 feet to the Precambrian rocks of the Canadian Shield. West of the Niagara escarpment the ground rises northward from the level of Lake Erie, 572 feet, and attains a maximum elevation of about 1,700 feet in the district southwest of Collingwood. The surface throughout this area is rolling, but of low relief.

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 Ottawa and St. Lawrence Rivers, and straddles the St. Lawrence to Quebec City, below which it extends a short distance along the north shore. East of the St. Lawrence the division is bounded by the "Logan's line", a fault or fault zone that marks the northwestern border of the folded and hilly Appalachian region. To the north of Ottawa and St. Lawrence Rivers the Palæozoic formations of the Lowlands are either faulted against or overlap upon the crystalline Precambrian rocks of the Canadian Shield. Within this division of the Lowlands the land nowhere rises more than 500 feet above the sea, except for a few isolated hills of intrusive igneous rock that penetrates 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 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.

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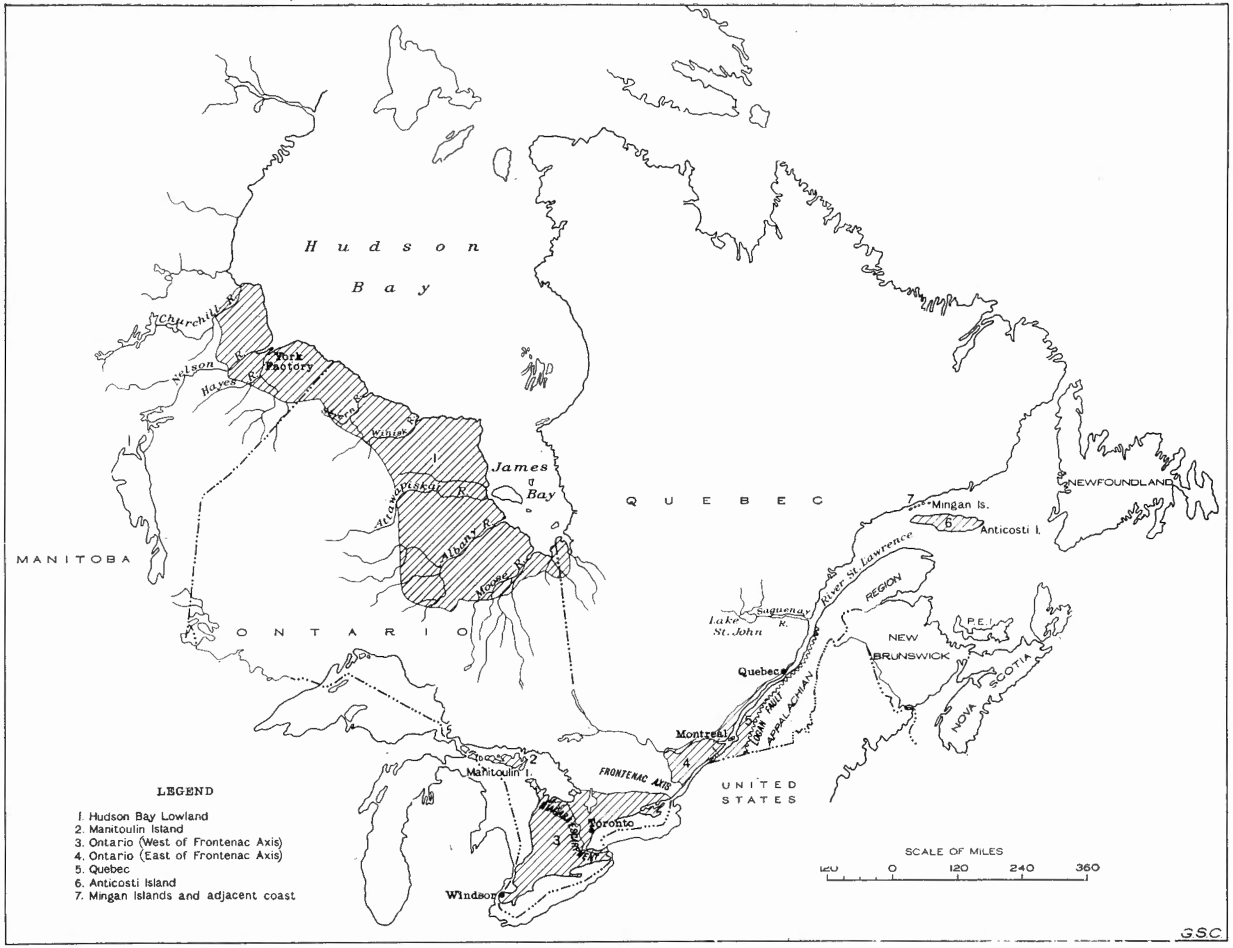

Figure 45. Hudson Bay and St. Lawrence Lowlands.

View of Niagara escarpment at Niagara Falls, showing American Falls, New York, in foreground and Horseshoe Falls, Ontario, in background. Photo by permission Royal Canadian Air Force (A.2106-50).

Anticosti Island is about 125 miles long, with a maximum width of about 35 miles. It is a partly submerged, southerly dipping cuesta, with an escarpment facing north and the higher land near the north coast. Terraces occur on both north and south sides of the island: those on the north are generally narrow, whereas on the south side some are several miles wide. More than a score of such terraces are known, the highest more than 400 feet above the sea. Most of them, even the highest, are covered with gravel, apparently of beach origin.

Mingan Islands fringe the Quebec coast north of Anticosti for a distance of about 60 miles. They are twenty-two in number, fifteen of fair size and the others small. The regional dip of the strata forming these islands is southward, resulting in steep cliffs along their north sides. Some of the islands carry accumulations of gravel both at and above sea-level.

HISTORICAL REVIEW

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. Here 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.

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.

Such was the discovery and beginning of settlement by the white man in the St. Lawrence Lowlands. Today this area, the oldest settled part of Canada, constitutes a first ranking industrial and agricultural region (Plate XXX). It forms a narrow fringe along the southern border of Quebec and Ontario extending from the Gulf of St. Lawrence to the Great Lakes. Roughly half of the total population of the Dominion lives within the area of the St. Lawrence Lowlands.

Serious attempts to study the geological history of the area commenced in the early 1820's. 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, and drew attention to the occurrence of gold in the drift of the Eastern Townships. 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 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.

Agricultural area in the St. Lawrence Lowland just east of the Niagara escarpment, Brampton, Ontario. By permission Royal Canadian Air Force (R.A. 21-10).

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 stretching 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 the Mingan Islands. He also investigated either side of Ottawa River from Pembroke to Grenville, and examined the north shore of the St. Lawrence 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 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. F. 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 the Ontario formations.

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. Here, 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 contributions 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. Detailed studies have also been made by M. A. Fritz, W. S. Dyer, J. C. Sproule, W. A. Johnston, J. F. Caley, G. P. Crombie, E. W. Shaw, H. C. Laird, C. S. Evans, J. S. Stewart, E. M. Kindle, and others.

TABLE VI

Time			Strata						
				St. Lawrence Lowlands					
				Ontario					
Period	Epoch	Sub-epoch	Hudson Bay Lowland	Manitoulin Island	West of Frontenac axis	East of Frontenac axis	Quebec	Anticosti Island	Mingan Islands and adjacent coast
Tertiary									
Cretaceous	Lower Cretaceous or Upper Jurassic		Mattagami				Monteregian		
Devonian	Upper Devonian		Long Rapids		Kettle Point		Intrusions		
	Middle Devonian		Williams Island Abitibi River		Hamilton Norfolk				
	Lower Devonian		Moose River Sextant		Pre-Norfolk Oriskany		Oriskany Helderberg		
Silurian	Upper Silurian (Cayugan)				Bertie-Akron Salina				
	Middle Silurian (Niagaran)		Attawapiskat Ekwan River	Lockport	Guelph Lockport Rochester Clinton			Chicotte Jupiter	
	Lower Silurian (Alexandrian)		Severn River Port Nelson	Medina	Medina (Medina-Cataract)			Gun River Becscie	

		Gamachian						Ellis Bay	
	Upper Ordovician	Richmond	Shammattawa Nelson River	Kagawong Meaford	Queenston Meaford	Queenston Russell	Queenston "Waynes-ville"	Vauréal English Head	
		Lorraine		Wekwemi-kongsing	Dundas	Carlsbad	"Lorraine"		
	Middle and Lower Ordovician	Gloucester and Colling-wood (Utica)		Sheguiandah Collingwood	Blue Mountain Collingwood	Billings Eastview	Gloucester Collingwood	Macasty	
Ordovician		Trenton		Trenton	Cobourg Trenton	Ottawa	Cobourg Sherman Falls Hull Rockland		
		Black River			Leray Lowville Pamelia		Leray Lowville Pamelia		
		Chazy				St. Martin Rockcliffe	Aylmer		Mingan
		Beekman-town				Oxford March	Beauharnois Theresa(?)		Romaine
Cambrian or Ordo-vician						Nepean	Potsdam		
Cambrian	Upper Cambrian								

GEOLOGY

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 of these seas, parts of the region were either flooded or emerged before others. The result is 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; Ontario and Quebec, east of the Frontenac axis; and Anticosti and the Mingan Islands (*See* Table VI).

ONTARIO PENINSULA AND MANITOULIN ISLAND

Stratigraphy

The region west of the Frontenac axis (Figures 46 and 47) is underlain by marine sedimentary strata of Ordovician, Silurian, and Devonian ages. These rocks rest upon the uneven surface of the Precambrian basement complex that outcrops to the north as part of the Canadian Shield. The sediments have a maximum known thickness of about 4,280 feet, of which 1,654 feet are Ordovician, 1,554 feet are Silurian, and 1,072 feet are Devonian strata. These rocks have been divided into about twenty formations varying in thickness from 20 to nearly 1,500 feet.

The oldest exposed rocks were formed in Black River time (*See* Table VI) and are represented by limestone strata with, locally, a basal sandstone and shale, carrying the fauna of successive Pamelia, Lowville, and Leray zones. These are overlain by limestones of the Trenton and Cobourg formations, the whole attaining a thickness of 550 feet in the Lake Simcoe district, about 72 feet on Manitoulin Island, and 890 feet in a well drilled in South Marysburg township, Prince Edward county (*See* Tables VII and VIII).

The Trenton sea seems to have withdrawn from at least the northern part of the area, as disconformable relations between the Cobourg limestone, of upper Trenton age, and the succeeding Collingwood shale are in evidence both on Manitoulin Island and in the Georgian Bay district. 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 the black bituminous Collingwood shales, replete with fossils, notably graptolites and trilobites, and ranging in thickness from 30 feet on Georgian Bay to 60 feet on Manitoulin Island. This deposit is overlain by the Blue Mountain formation consisting of soft, bluish grey shale, sparingly fossiliferous and about 120 feet thick. On Manitoulin, contemporaneous sediments of the Sheguiandah formation are about 100 feet thick. The Blue Mountain is succeeded conformably by the Dundas formation, a series of grey shales with occasional thin limestone beds, and attaining a maximum thickness of about 250 feet. Fossils are abundant, particularly in certain zones. Bryozoa and brachiopods are among the chief diagnostic forms. On Manitoulin the correlative of the Dundas is called the Wekwemikongsing formation, and has a thickness upwards of 75 feet. The next overlying formation is the Meaford, consisting of about 150 feet of shales similar to those of the Dundas, but becoming appreciably more calcareous toward the top. This formation contains both coral and bryozoan reefs, and the general assemblage of fossils indicates a Richmond age. The youngest Ordovician

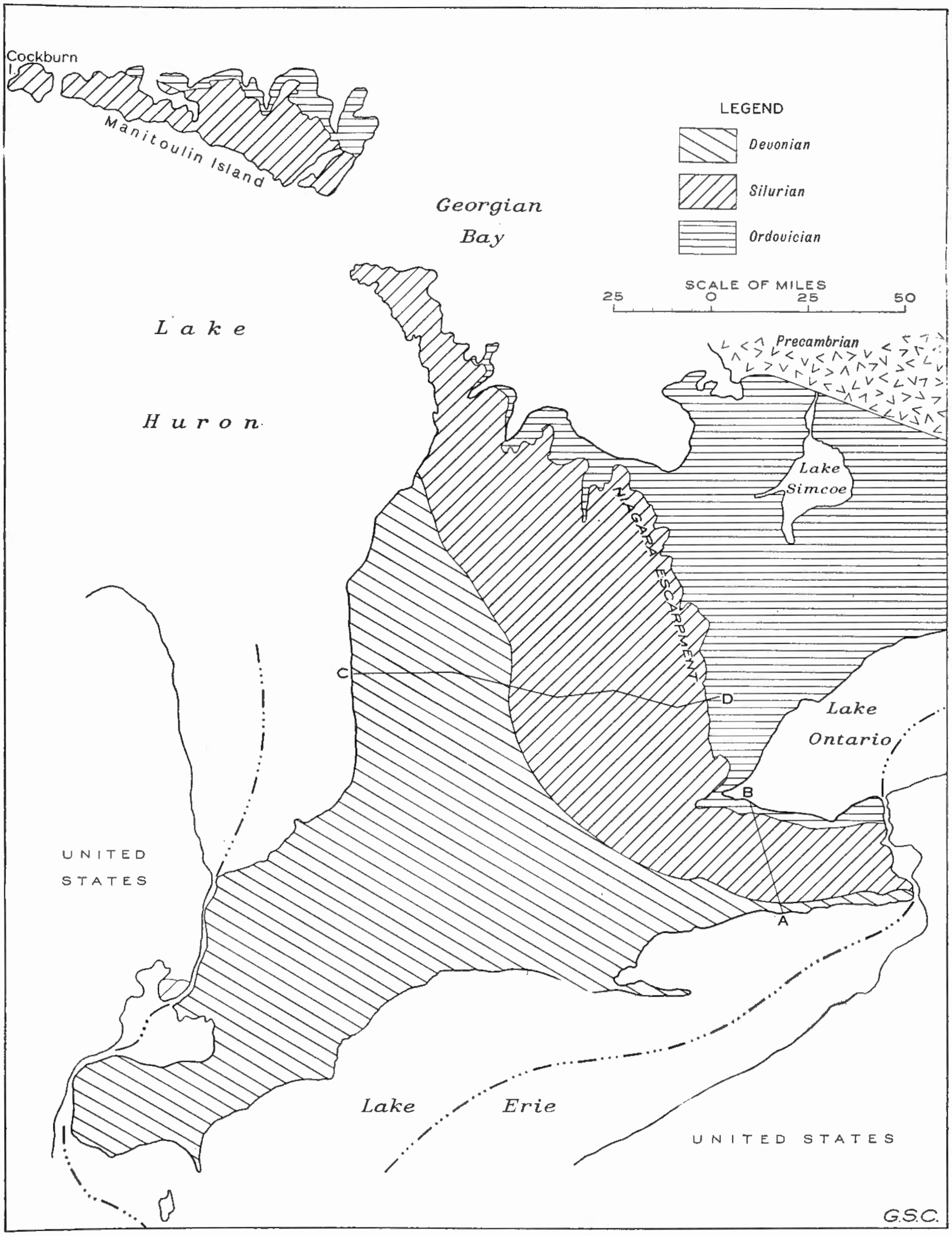

Figure 46. General geology of Ontario Peninsula.

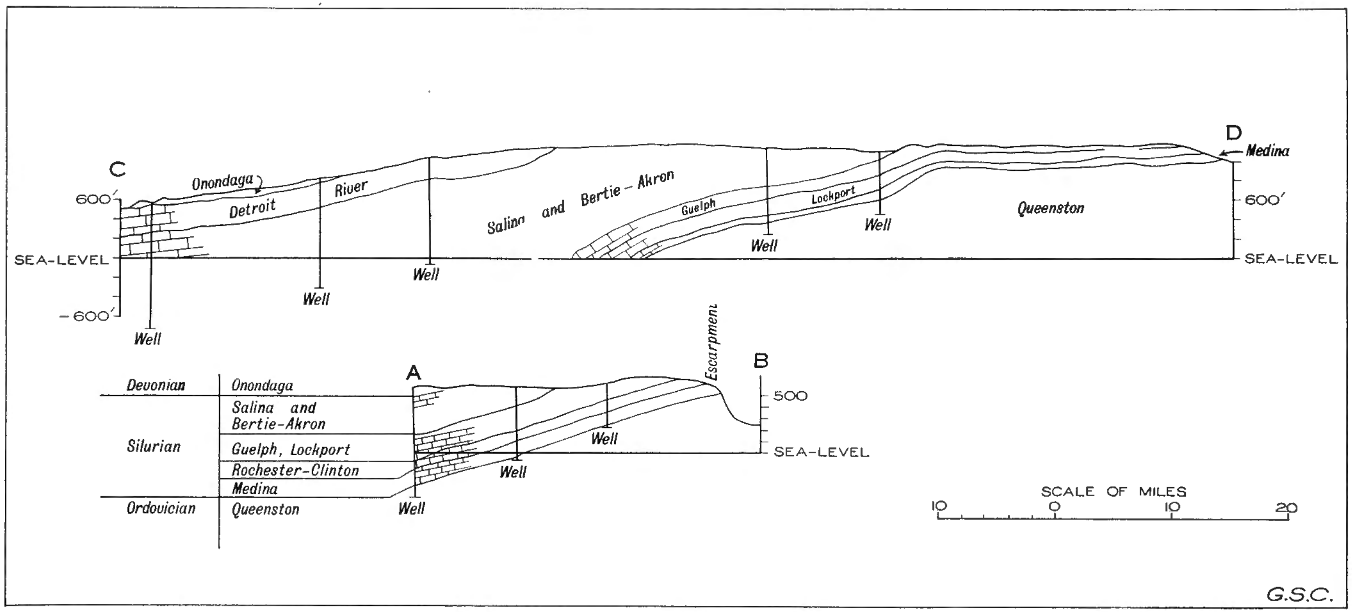

Figure 47. Ontario Peninsula, sections A-B and C-D. (*See* Figure 46.) (After M. Y. Williams.)

rocks are represented by the Queenston formation, consisting of red shale perhaps in part of deltaic origin (Plate XXXI). Except for a few ostracods, no fossils have been found in this shale. In the Meaford-Owen Sound district, grey fossiliferous shale and limestone beds are interbedded with the red rock, but on Manitoulin Island the red shale is entirely replaced by grey limestone and shale (Kagawong formation) enclosing a Richmond fauna. Wells in the southern part of the region show a maximum of 963 feet of Queenston beds; on Manitoulin the Kagawong is about 85 feet thick.

TABLE VII

Ontario Peninsula

Period	Formation	Description	Thickness
			Feet
Devonian	Kettle Point	Black shale	280+
	Hamilton	Grey shale	330
	Norfolk {Delaware, Onondaga(?)}	Limestone with some chert and, in places, sand	240
	Pre-Norfolk {Detroit River, Sylvania}	Dolomite; limestone; chert; sand	640
	Oriskany	Grey sandstone	20
Silurian	Bertie-Akron	Buff dolomite	395
	Salina	Brown dolomite; grey, limy shale; gypsum; salt	1,438
	Guelph	Buff dolomite	500 (Guelph and Lockport)
	Lockport	Buff and light grey dolomite	
	Rochester	Dark grey shale and calcareous shale	71
	Clinton	Light grey dolomite	35
	Medina	Red and grey shale; red sandstone; grey sandstone; grey dolomite	140
Ordovician	Queenston	Red shale; some grey shale and limestone in Saugeen Peninsula	963
	Meaford	Grey shale and limestone	418 (Meaford and Dundas)
	Dundas	Grey shale with thin, limy bands	
	Blue Mountain	Grey shale	120
	Collingwood	Black shale; some limestone bands	30
	Cobourg	Grey, argillaceous limestone	550 (Cobourg to Pamelia)
	Trenton	Grey limestone	
	Leray	Limestone	
	Lowville	Limestone	
	Pamelia	Basal formation of limestone, sandstone, red and green shale with embedded sand grains	

TABLE VIII

Manitoulin Island

Period	Formation	Member	Description	Thickness
				Feet
Silurian	Lockport		Dolomite	230+
	Medina	Wingfield	Green shale	22
		Dyer Bay	Green, shaly dolomite	25
		Cabot Head	Red and green shale	57
		Manitoulin	Dolomite or magnesian limestone	60
Ordovician	Kagawong		Dolomitic and arenaceous limestone; some grey shale	85+
	Meaford		Argillaceous limestone	53
	Wekwemikongsing		Grey shale with thin limestone bands	75+
	Sheguiandah		Grey and brown salt shale	100+
	Collingwood		Black, bituminous shale	60
	Cobourg / Trenton		Impure grey limestone	72+

PLATE XXXI

Contact between Ordovician Queenston shale and overlying Silurian Whirlpool sandstone (*See* Figure 48), on Credit River at Cataract, Ontario. Photo by J. F. Caley, Geological Survey (84274).

At the close of Richmond (Upper Ordovician) time the Ordovician sea withdrew from this region, initiating a period of erosion.

The oldest Silurian strata consist of a variable group of rocks included under the term Medina formation. They occur from Niagara River to Manitoulin Island, but vary in lithology from place to place. The initial Silurian deposit is grey, Whirlpool sandstone (*See* Plate XXXI), 25 to 30 feet thick, extending from Niagara Peninsula almost to Georgian Bay, where it disappears. Above is the Manitoulin member, represented in Niagara Peninsula by about 30 feet of grey shale. Northward it becomes increasingly calcareous until on Manitoulin Island it consists of 60 feet of dolomite that rests directly on Ordovician strata (Kagawong formation). The upper member of the Medina is known as the Cabot Head; on Niagara River it comprises about 60 feet of red and green shale, shaly limestone, and red (Grimsby) and grey (Thorold) sandstone. On Saugeen Peninsula, north of Colpoy Bay, these beds are represented by about 90 feet of green and red shale, with two thin zones of grey dolomite known respectively as the Dyer Bay and St. Edmund Lentilles. On Manitoulin Island the Cabot Head shale is restricted to about 57 feet of red and green shale; it is overlain by 25 feet of green Dyer Bay shaly dolomite followed by 22 feet of green Wingfield shale. The presence of the bryozoan *Helopora fragilis* determines the enclosing beds as of Cabot Head age.

The Medina is succeeded, along Niagara River, by the Middle Silurian, Clinton formation, consisting chiefly of light grey, dolomitic limestone with some grey shale, the whole about 35 feet thick. It thins rapidly to the west and north, disappearing in Elgin county. In Niagara Peninsula the Clinton is overlain by the Rochester formation, consisting of medium to dark grey shale. This is about 71 feet thick at Niagara Falls, and is present throughout the southwestern part of the Ontario Peninsula. It thins northward, disappearing at about the latitude of Hamilton.

Following Rochester time, the entire Ontario Peninsula and Manitoulin Island remained beneath the sea during the period of deposition of the succeeding Lockport and Guelph formations. The Lockport formation consists of grey dolomite (Plate XXXII). It is about 80 feet thick at Niagara River, more than 160 feet thick in Saugeen Peninsula, and at least 230 feet thick on Manitoulin Island. In the southern part of Ontario Peninsula, the Lockport rests upon Rochester shale. In Saugeen Peninsula and on Manitoulin Island it rests directly upon the Lower Silurian Medina formation, the intervening Rochester and Clinton having pinched out before these northern localities are reached. In the south, the Lockport is overlain by the Guelph formation, consisting of buff and grey dolomite, 150 feet thick in the vicinity of Niagara Falls, 135 feet thick at Dundas, and perhaps 60 feet thick in Lambton county. At Elora, in Wellington county, about 82 feet of the Guelph is exposed, but no Guelph beds have been identified on Manitoulin Island, although the formation may once have been present there. The Guelph fauna is characterized by an abundance of pelecypods of the genus *Megalomus,* the occurrence of edentulate brachiopods of the family Trimerellidae, and a great variety of gastropods.

The great gorge of Niagara River 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 falls and their recession are the result of the erosive power of water falling over nearly flat-lying sedimentary strata of varying hardness. The stratigraphic succession at the falls consists, in descending order, of Lockport dolomite, 78 feet thick; Rochester shale, 65 feet; Clinton limestone and shale, 22 feet; Medina shale and sandstone, 119 feet; and the soft Queenston shale in which the river bed is cut. The Clinton limestone forms a ledge about 15 feet above the level of the river at the foot of the falls, the underlying formations all being 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 Clinton limestone (Figure 48). 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 softer Medina shale and sandstone, and is effected by the action of boulders and stones carried by the currents. Removal of the Lockport dolomite and Clinton limestone by undermining results in the maintainance of a vertical falls as recession proceeds.

PLATE XXXII

"Flowerpots" of Middle Silurian (Niagaran) dolomite, Flowerpot Island, Georgian Bay National Park. Photo by J. F. Caley, Geological Survey (84284).

In the region between Lakes Huron and Erie, the Guelph dolomite is overlain by Upper Silurian (Cayugan) strata. It is probable that at the close of Middle Silurian (Niagaran) time the Lockport sea gradually withdrew from the north, and advanced in New York State. This had the effect in Ontario of exposing the tops of many of the reef-formed, positive relief features on the sea floor, giving rise to a number of intermittently connected lagoons.

The lowest member of the Upper Silurian succession is the Salina formation, consisting of dolomite, shaly dolomite, limy shale, and shale, with extensive beds of salt and gypsum, the whole ranging in thickness from 300 to more than 1,400 feet. Beds of salt as much as 200 feet thick are known, and an aggregate thickness of 540 feet has been penetrated in one well. No fossils have yet been found in the formation.

The Salina is succeeded by the Bertie-Akron beds, the uppermost Silurian strata in Ontario. They consist of grey to brownish, dense dolomite with, in Niagara Peninsula, some dark, compact, calcareous shale. The shale disappears westward until, west of Woodstock, the formation is entirely dolomite. The Bertie-Akron varies in thickness from 35 feet, in Niagara peninsula, to 395 feet, in Essex county.

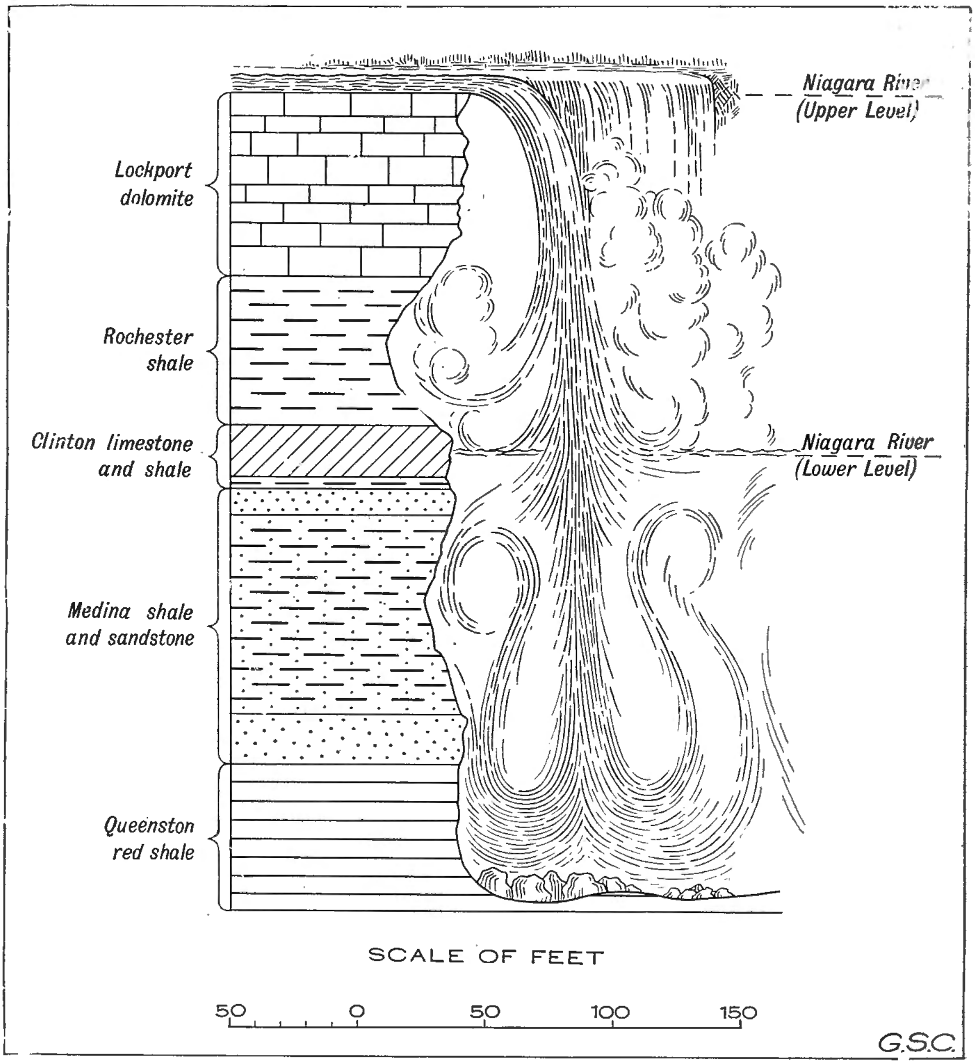

Figure 48. Section of formations at Niagara Falls.

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, in Lower Devonian time.

In Niagara Peninsula, the earliest Devonian rocks are represented by the Oriskany sandstone, which rests upon the eroded surface of the Silurian beds. This sandstone was itself subjected to erosion, so that it is patchy in distribution and is nowhere more than 20 feet thick. The contained fauna is characterized by a preponderance of brachiopods, and these determine the Lower Devonian age of the deposit.

West of Niagara Peninsula the Oriskany has not been identified, and the Silurian rocks are there succeeded by a series of limestone, dolomitic limestone, and dolomite with varying quantities of chert in the lower part. Sandstone beds as much as 60 feet thick are present locally between 110 and 172 feet above the top of the Silurian, and the base of the group is commonly sandy with small amounts of glauconite. This assemblage is known in Michigan and Ohio as the Detroit River group, the sandstone being designated the Sylvania sandstone. The Detroit River and Sylvania together comprise the pre-Norfolk strata of southwestern Ontario. Their aggregate thickness is variable, ranging from about 140 feet in Woodhouse township to 650 feet in Sandwich township. Overlying the pre-Norfolk, perhaps disconformably, is the Norfolk formation (Delaware and (?) Onondaga) consisting of grey limestone commonly with some chert and in places with sand at the base. Its thickness ranges from about 70 to more than 200 feet. The lower part of the Norfolk contains middle or upper Onondaga fossils, the upper part fossils of Delaware age, but the two parts are lithologically similar.

The stratigraphic position of the Detroit River group with reference to the Onondaga of western New York is not certainly known. It has long been thought that these rocks lay beneath the Onondaga. However, recent work in Michigan throws some doubt upon this interpretation, and further work in Ontario may indicate that the rocks containing the typical lower Onondaga fauna underlie rather than overlie the Detroit River group.

The Norfolk is succeeded by the Hamilton formation consisting chiefly of grey, calcareous shale, but including thin zones of limestone, commonly at the top and within the upper part of the formation. The thickness varies from 140 to 330 feet. Although some grey, shaly limestone may be present at the base of the formation, the change from limestone (Norfolk) to the soft Hamilton shale is generally sharp enough to suggest the possibility of a break in sedimentation at this horizon. The Hamilton is abundantly fossiliferous, with brachiopods, bryozoa, corals, and pelecypods especially numerous.

The Hamilton is succeeded by the black shales of the Kettle Point (Huron) formation. This is the youngest consolidated rock in the area, and occupies the centre of the broad regional syncline of southwestern Ontario. At Kettle Point the formation is characterized by spherical concretions known as "kettles"; its maximum known thickness is about 280 feet. Fossils are not plentiful, but the known fauna comprises the brachiopod *Lingula,* some annelid jaws, and fish scales. A small flora is also present, small, amber-coloured, spherical spore cases referred to *Protosalvinia huronensis* being numerous in some beds.

The entire area has been glaciated, and bedrock is covered by a mantle of drift, consisting of boulder clay, sand, gravel, and clay, which varies from a few feet to several hundred feet in thickness.

OTTAWA-ST. LAWRENCE REGION

Stratigraphy

The central part of the St. Lawrence Lowlands extends east from the Frontenac axis (Plate XXXIII) to a short distance below Quebec city. As in the western part, this section 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 is about 2,200 feet, but in Quebec at least 10,000 feet of Palæozoic rock is known (*See* Tables IX and X).

PLATE XXXIII

View of the Thousand Islands, St. Lawrence River, forming part of the Frontenac axis of Precambrian rocks, separating areas of the Palæozoic, St. Lawrence Lowland (*See* Figure 45). Photo by permission Royal Canadian Air Force (H.A.22.13).

Table IX

Ontario (East of Frontenac Axis)

Period	Sub-epoch	Formation	Description	Thickness
				Feet
Ordovician	Richmond	Queenston Russell	Red shale, grey shale, and heavy dolomite	100
	Lorraine	Carlsbad	Grey shale and dolomitic bands	600
	Gloucester and Collingwood (Utica)	Billings Eastview	Black, bituminous shale Dark limestone and brown shale	250+
	Trenton and Black River	Ottawa	Limestone with sand, shale, and dolomite at the base	700
	Chazy	St. Martin Rockcliffe	Limestone and shale Shale and sandstone	200
	Beekmantown	Oxford March	Dolomite Dolomite and sandstone	350
Ordovician or Cambrian		Nepean	Sandstone	0–280

Table X[1]

Quebec

Period	Sub-epoch	Formation	Description	Thickness
				Feet
Tertiary or earlier		Monteregian intrusions		
Ordovician	Richmond	Queenston 'Waynesville'	Red and grey shale Grey shale	1,500+ 239
	Lorraine	Lorraine	Grey shale	3,340+
	(Utica)	Gloucester Collingwood	Shale Black shale	200–1,500
	Trenton	Cobourg Sherman Fall Hull Rockland	Grey limestone Limestone Limestone Limestone	800
	Black River	Leray Lowville Pamelia	Limestone Limestone Dolomite	50
	Chazy	Aylmer	Limestone Sandstone	300
	Beekmantown	Beauharnois Theresa(?)	Dolomite Dolomite and sandstone	1,060
Cambrian or (?) Ordovician		Potsdam	Sandstone	0–1,696

[1] Adopted from Geology of Quebec, vol. II, p. 253; pub. by Quebec Dept. of Mines, 1944.

The varying extent, direction of advance, and the local oscillations of the several seas that invaded this area during Palæozoic time have produced both lateral and vertical differences in the accumulated sediments. Formations of more or less local extent have thus been recognized. These have been given local names, as in Table VI.

The earliest sediments are represented in Quebec by the Potsdam sandstone, accumulated perhaps in late Cambrian time, on the undulating Precambrian surface. The sandstone varies greatly in thickness from place to place, ranging from nil to about 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 region, and constitutes the basis for assigning a Cambrian age to the rock. *Climatichnites* and *Protichnites,* thought to be trails of invertebrate animals, and the burrow *Scolithus* have been observed in many outcrops.

After Potsdam time, the sea drained from Quebec. The beds (Theresa (?)) at the base of the Ordovician are composed of rounded and frosted sand grains, whereas the Potsdam is composed mainly of angular grains.

In Ontario the Precambrian surface 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 is also of that age.

The Potsdam-Nepean strata are succeeded by beds of Beekmantown age, commencing with a sandy phase and ending with dolomite. They comprise two formations each with different names in both 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 Beekmantown age is indicated by the enclosed marine fauna.

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 300 feet in Quebec.

At the end of Chazy time the sea again withdrew, probably in the direction from whence it came, and after what is thought to have been a relatively short period of emergence, the sea again encroached, 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 strata (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, chiefly on fossil evidence (*See* Table X).

Trenton time may have been succeeded, in Ontario, by a short period of non-deposition, but otherwise the sea appears to have remained over 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 the contemporaneous deposits are entirely shale, and reach a maximum thickness of 1,500 feet. They comprise the Collingwood and Gloucester formations, and are considered to be of Utica age.

Succeeding the Utica is the Lorrain, represented in Ontario by the Carlsbad formation. The latter consists of grey shale with dolomite bands and carries a fauna of post-Utica age. In Quebec, Lorraine strata consist of shales with subordinate amounts of limestone and sandstone. A measured thickness of

2,274 feet is present on Nicolet River, and a boring south of the St. Lawrence penetrates for 3,340 feet in grey shales probably of Lorraine age. This succession has not been subdivided.

The Lorraine is overlain by strata of Richmond age. In Ontario these consist of dolomite (Russell formation) overlain by typical red Queenston shale, the whole about 100 feet thick. In Quebec the sequence begins with the Waynesville grey shale, separable from the underlying Lorraine only on palæontological evidence and attaining a thickness of 239 feet on Nicolet River. Overlying the Waynesville are blue and red barren shales, commonly referred to the Queenston formation and at least 1,500 feet thick.

During Queenston time the sea had already begun to withdraw, and except during part of the Lower Devonian epoch the St. Lawrence region appears to have remained a land area until Pleistocene time.

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 rocks. The blocks are from Precambrian granite and gneiss, Potsdam sandstone, the several Ordovician limestones, and Devonian limestone. Fossils collected from some of these 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 well over 1,000 feet above the surrounding plain, the others to heights of 600 to 700 feet. Their respective names are Mount Royal, St. Bruno, St. Hilaire, Rougemont, Johnson, Yamaska, Shefford, and Brome. The last three intrude the folded and faulted Palæozoic rocks east of the Logan fault, and are, therefore, within the Appalachian region previously described.

The hills are circular or oval in outline, each only a few square miles in area and rising abruptly above the level of the surrounding land. 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 remaining 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 OF QUEBEC

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.

TABLE XI[1]

Anticosti Island

Period	Epoch	Formation	Description	Thickness
				Feet
Silurian	Niagaran	Chicotte	Crinoidal and reef limestone	73
		Jupiter	Limestone and shale	653
	Anticostian (Alexandrian)	Gun River	Alternating limestone and shale	308
		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
	Richmondian (Richmond)	Vauréal	Interbedded limestone and shale	730
		English Head	Limestone and shale	228
	(Utica)	Macasty	Black shale	?

TABLE XII[2]

Mingan Islands and Adjacent Coast

Period	Sub-epoch	Formation	Description	Thickness
				Feet
Ordovician	Chazy	Mingan	Limestone, shale, and sandstone	135+
	Beekmantown	Romaine	Dolomite with some shale	262+

Anticosti Island was visited in 1856 by Richardson, who collected many fossils later to be identified by Billings. The report on the Geology of Canada, 1863, contains the result of Logan's observations on the island. In later years several descriptions of the geology of Anticosti have appeared, and in 1927 the most comprehensive report, by Twenhofel, was published.

Both Ordovician and Silurian systems are represented on Anticosti. The oldest beds are those of the Macasty, black, bituminous shale. This has not been seen in place, but occurs as loose blocks thrown up by the waves along the north shore of the island. The blocks enclose fossil graptolites and trilobites indicating a Utica age for the rock.

1 Adapted from Twenhofel, W. H.: Geology of Anticosti Island; Geol. Surv., Canada, Mem. 154 (1928).
2 Twenhofel, W. H.: Geology of the Mingan Islands; Geol. Soc. Am., Special Paper No. 11, 1938.

The oldest exposed formations represent a continuous series 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 Vauréal. Fossils are fairly numerous and are of Richmond age.

The Vauréal formation is overlain by about 200 feet of rock consisting predominantly of limestone, but containing also some beds of sandstone and even one bed of quartz pebble conglomerate. This is the Ellis Bay formation. It encloses a fauna, over 80 per cent of whose species do not pass into the next succeeding formation. Although the fauna has a decided Richmond aspect the assemblages are not known elsewhere in America, and certain species bear a close resemblance to Silurian forms.

The Ellis Bay is succeeded by the Becscie formation, which has at its base a limestone conglomerate, indicating possible unconformable relations. The conglomerate is succeeded by limestone with shale partings, the whole about 200 feet thick. About twenty-eight faunal species persist into this formation from underlying Ellis Bay strata, and these forms, together with the introduction of some thirty new species, comprise the Becscie fauna. This fauna indicates a Silurian age of about the time of the Cataract (Medina) formation of Ontario.

Overlying the Becscie is about 308 feet of alternating limestone and shale comprising the Gun River formation. These rocks show evidence of shallow water deposition. The enclosed fauna indicates a time from about Medina to Clinton.

The Gun River is succeeded by about 650 feet of limestone and shale of the Jupiter formation, which carries a fauna of Clinton age. Overlying it is the Chicotte formation consisting of 73 feet of crinoidal and reef limestone. Corals form an important element of the Chicotte fauna, which is correlated with the Rochester and lower part of the Lockport formations, and is, therefore, Niagaran in age.

The Anticosti section is one of the most interesting in North America, as the Ellis Bay beds bridge in large part the gap that in most 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."

The rocks of the Mingan Islands and adjacent coast of Quebec were examined by Richardson as early as 1857. The islands were later visited by Logan and Schuchert, and in 1938 Twenhofel published the results of previous visits made by him in 1909, 1929, and 1933.

The exposed rocks belong to the Ordovician system and have been divided into two formations, the Romaine and Mingan of Beekmantown and Chazy age respectively. The Romaine formation consists of thick-bedded dolomite containing some chert and reaching a thickness of about 262 feet. A sparse fauna of about thirty-seven recognized species indicate an Upper Beekmantown age. The Mingan formation is separated from the underlying Romaine by an unconformity, and consists of a basal sandstone succeeded by limestone with some shale. The total thickness is more than 135 feet. A fauna of one hundred and eleven species has so far been described, fifty-three of which are not known elsewhere. A Chazy age is, however, indicated (*See* Tables VI and XII).

ECONOMIC GEOLOGY

The principal economic products of the Palæozoic formations in the St. Lawrence Lowlands are of the non-metallic type. The more important of these are natural gas and oil, salt, gypsum, structural materials, and fluorite.

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 basal Ordovician limestones.

NATURAL GAS AND OIL

The commercial gas and oil fields are all in the Ontario Peninsula (Figure 49) and lie almost entirely 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 Georgian Bay, but so far no field of commercial importance has been discovered there. In general, the gas and oil fields are separate, and yield from different geological zones. Exceptions are the Dawn and Dover fields, each of which yields both gas and oil.

The first gas field was discovered in Essex county about 1889, and is still productive, though on a small scale. Production of natural gas in Ontario in 1945 was approximately 7,200,000 M cubic feet and had a retail value of about $4,837,585. The gas fields are concentrated mainly in Niagara Peninsula in the east and in Middlesex, Lambton, Kent, and Essex counties in the west. In Niagara Peninsula the commercially productive formations are all of Silurian age, chief among which are the Whirlpool and Grimsby sandstones and the Clinton limestone. West of London the productive zones are in the Guelph and Salina formations (Silurian), except in the Dover field, which yields from the Trenton formation (Ordovician). Porosity appears to be the chief factor controlling accumulation. Important also are anticlines and domes. Positive relief features on the Guelph formation produced by growth of reefs are also important locally. The Dover field is of special interest in that it is synclinal in structure. It is thought that accumulation there is possibly due to lack of water in the reservoir rock.

The oil industry in Ontario began in 1858 with development of tarry seepages long known to occur along Black Creek near the village of Oil Springs. Drilling commenced in 1861, and many flowing wells were quickly brought in. Initial flows of 2,000 and 5,000 barrels a day were not uncommon, and one well is reported to have flowed 7,500 barrels a day. Drilling soon spread to the Petrolia district, and this area is still the chief productive region in Ontario. Total production of oil in Ontario in 1945 was about 113,325 barrels, of which 65,007 barrels came from the Oil Springs and Petrolia fields.

All commercially productive fields are in the southwestern part of the peninsula. Main production is from the Norfolk formation (Devonian) at depths of 380 to 500 feet below the surface. Smaller yields are from the Salina and Guelph formations (Silurian), and from the Trenton formation (Ordovician) in the Dover field. The Trenton has also yielded small quantities of oil in the Georgian Bay district and on Manitoulin Island. In addition, a few barrels annually are recovered from the Whirlpool sandstone (Silurian) in Niagara Peninsula. At all productive horizons, except that of the Trenton, the oil has accumulated in local anticlines and domes. The Dover field produces from a syncline, due to the almost complete absence of water.

SALT

Production of salt in 1945 was 578,697 short tons, valued at $2,920,973. This was obtained from the southwestern part of Ontario Peninsula (Figure 50) and represents 86·5 per cent of the total Canadian output for that year. The salt is produced by evaporation of artificial brine.

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

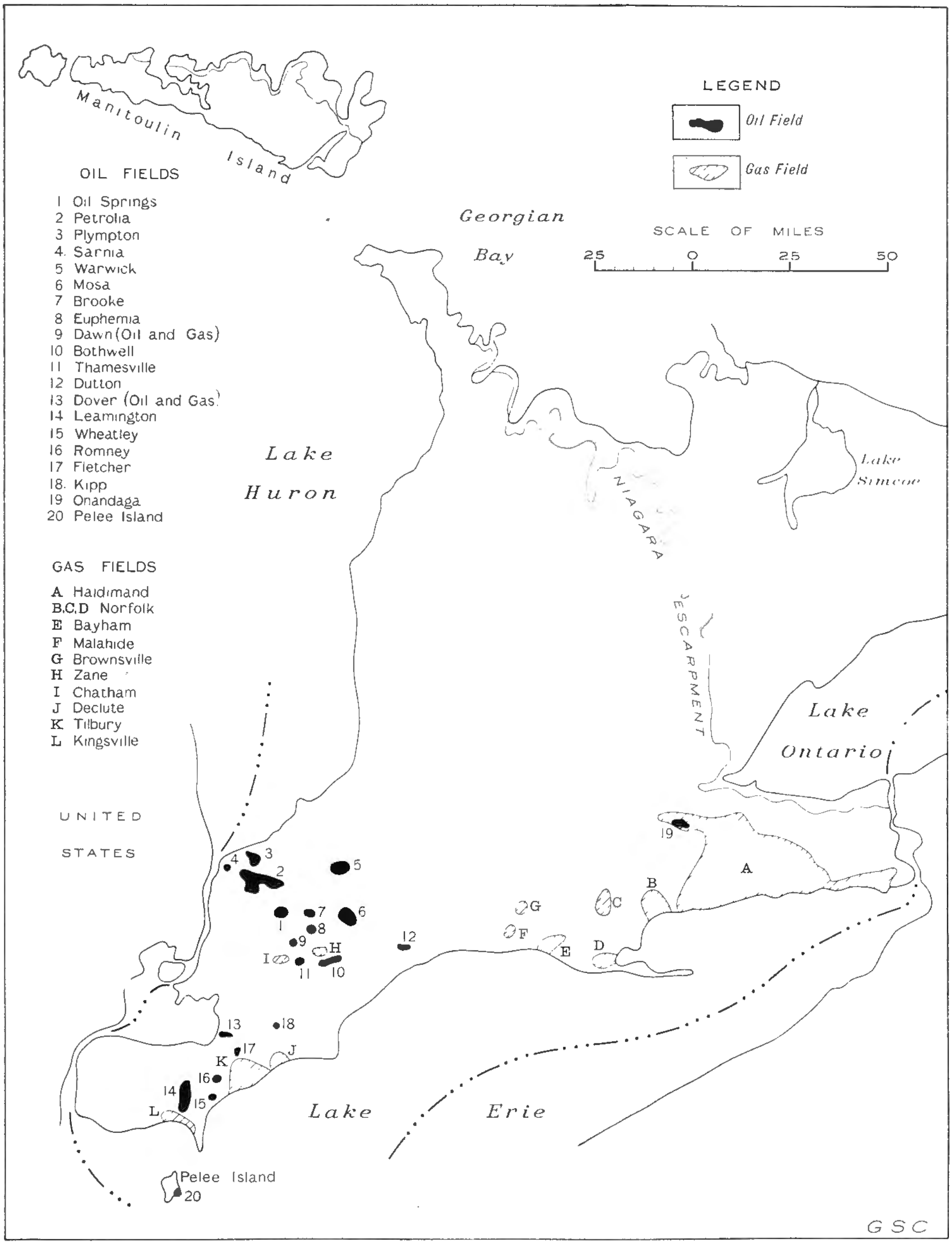

Figure 49. Oil and gas fields, Ontario Peninsula.

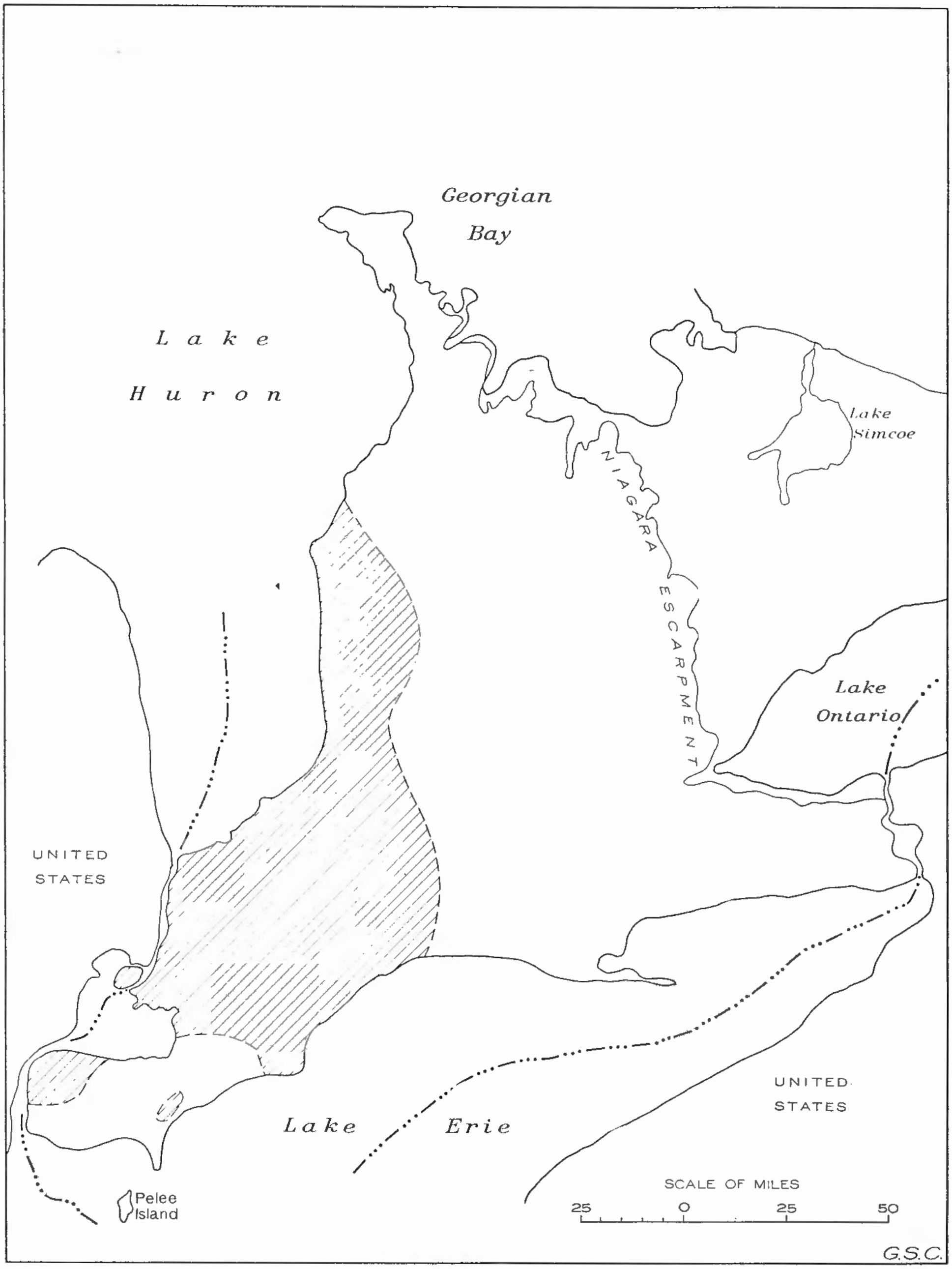

Figure 50. Approximate area underlain by salt, Ontario Peninsula.

north side of Maitland River a short distance above the 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, parts of Dover, Harwich, Camden Gore, Raleigh, Chatham, and Romney townships in Kent county, and Sandwich and part of Anderdon townships in Essex county. The salt does not form a continuous sheet or bed beneath this large area, a number of wells having 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 from 5 to 295 feet in thickness, and their aggregate known thickness reaches a maximum of 593 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 within 100 feet of the base of the formation.

Toward the close of Niagaran time the Lockport sea gradually receded, and a partly isolated basin was formed over much of southwestern Ontario. This basin underwent desiccation, with resultant formation of beds of gypsum and salt. These precipitates were interbedded with muds, products of the erosion of older Silurian beds exposed in the surrounding, uplifted 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 will take 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 so on.

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 1945 the Ontario output was 92,174 tons, valued at $385,516. This was about 11 per cent of the total Canadian production for that year.

The entire output is from Grand River Valley, where Seneca, Oneida, and North Cayuga are the most important townships for workable gypsum deposits. The deposits are lenticular in form, and occur at different horizons within the Salina formation. Individual deposits as much as 11 feet thick are known. At present mining is carried on by the Canadian Gypsum Company, Limited, at Hagersville, and by Gypsum, Lime and Alabastine, Canada, Limited, at Caledonia.

FLUORITE

Fluorite has been obtained in economic quantity from veins in Black River (Ordovician) limestone in Madoc township, Ontario. The width of the vein material ranges from 2 inches to 8 feet, the chief associated minerals being barite and calcite.

Fluorite also occurs in cavities in Devonian dolomite at Amherstburg, Essex county, and in Lockport (Silurian) dolomite at Niagara Falls. These occurrences are small, and of mineralogical interest only.

LEAD AND ZINC

Lead- and zinc-bearing veins in Lanark county, Ontario, near Carleton Place, intersect Ordovician strata and are, therefore, of Ordovician or later age. Associated with these minerals is a little pyrite and chalcopyrite. The gangue is commonly calcite. These occurrences are of interest as furnishing evidence regarding 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.

STRUCTURAL MATERIALS

The concentration of population within the St. Lawrence Lowlands creates a substantial demand for structural materials. It is, therefore, fortunate that the region is underlain by almost undisturbed Palæozoic rocks, the limestones, shales, and sandstones of which furnish ample supplies for structural needs.

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 formation is the most widely used, although the Medina, Cabot Head shale also possesses 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.

CHAPTER V

THE HUDSON BAY LOWLAND

(J. F. Caley)

PHYSICAL FEATURES

The Hudson Bay Lowland is the plain that borders James Bay on the south and west and extends along Hudson Bay to Churchill River in Manitoba (*See* Figure 45). West of James Bay it averages about 200 miles in width, but farther northwest narrows to less than 100 miles. Its seaward slope in Moose River basin is about 3½ feet a mile. This lowland area is bordered on the south and west by the Canadian Shield, and occupies an area of about 125,000 square miles.

Most of Hudson Bay Lowland is floored by almost flat-lying, Palæozic strata of Ordovician, Silurian, and Devonian ages. In addition, two relatively small remnants of Upper Jurassic or Lower Cretaceous beds are exposed at the southern margin (*See* Table VI).

The most prominent topographic feature in the Moose River basin is the low escarpment at the southern boundary of the coastal plain. It is most conspicuous where cut by Missinaibi, Opazatika, and Mattagami Rivers, where it marks the northern limit of Precambrian exposures. From Abitibi River eastward, however, the escarpment diverges to the southeast, whereas the Precambrian-Palæozoic contact trends northeasterly toward James Bay.

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

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 to the south of Hudson Bay. However, during the 100 years following the establishment in 1670 of the Hudson's Bay Company[1], several of the Company's men, notably Henry Kelsey, Anthony Hendy, and Mathew Cocking, travelled some of the waterways between the bay and 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 the Hudson's Bay Company were amalgamated under the name of the latter.

[1] Events leading up to the inauguration of this company are recorded in an earlier part of this volume.

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 respective 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), W. S. Dobs (1905), and M. B. Baker (1911). 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 himself.

More recently, detailed studies have been made on 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 Dyer and A. R. Crozier, on the Onakawana lignite field.

GEOLOGY

TABLE XIII

Hudson Bay Lowland

Period	Formation	Description	Thickness
			Feet
Lower Cretaceous or Upper Jurassic	Mattagami	Fire-clay and lignite	138
Devonian	Long Rapids	Petroliferous, black and grey shale	50
	Williams Island	Limestone and calcareous shale	87
	Abitibi River	Grey, fossiliferous limestone	65
	Moose River	Limestone and gypsum	50
	Sextant	Arkose; clay; sandstone	50
Silurian	Attawapiskat	Limestone; coral reef	85
	Ekwan River	Limestone; some cherty dolomite	100
	Severn River	Limestone	75
	Port Nelson	Limestone	35
Ordovician	Shammattawa	Limestone	80
	Nelson River	Limestone	70

The oldest sedimentary rocks are of Ordovician age (*See* Table XIII). The main body, at the northern part of the lowland area, outcrops along Nelson and Drowning Rivers. 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 used to be correlated with the Ordovician rocks of Lake Timiskaming and with Trenton limestone of the Lake Winnipeg region. Due, however, to the recognition of a recurrence of certain Trenton species in the Richmond, it is now known that the Liskeard formation at Lake Timiskaming is Richmond in age and not Trenton as was formerly thought, and it is probable that the Nelson River formation is of the same age and correctly correlated with the Liskeard. The fauna of the Shammattawa formation determines its Richmond age, and correlates it with the Stony Mountain formation of the Lake Winnipeg region.

The Silurian rocks of the Hudson Bay region are well exposed along Severn, Winisk, Ekwan, and Attawapiskat Rivers. 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 limestone of Manitoba.

The Port Nelson is succeeded by the Severn River, a formation about 75 feet thick, composed of limestone and carrying 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 basin.

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 represents about the time of the lower or middle Lockport limestone, and the coral reef about that of the upper Lockport: both are, therefore, Niagaran (Middle Silurian) in age.

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 a diamond-drill core from a well located near the axis of the broad synclinal region of the Moose River basin in which the Mesozoic remnants are preserved. This core shows the Devonian rocks resting directly on the Precambrian.

The age of the lowest Palaeozoic rocks in the well, those of the Moose River formation, is not certainly known, but a Lower Devonian marine flora has been obtained from some of the exposed beds.

At Sextant Rapids, on Abitibi River, the Moose River formation is only 50 feet thick, and is underlain by about 50 feet of soft, unindurated, grey, pink, and green arkose, and grey sandstone and shale of the Sextant formation (*See* Table XIII). Marine plants from the grey shales and sandstone near the foot of Sextant Rapids indicate a Lower Devonian age for the formation.

The Moose River formation is succeeded by about 37 feet of buff limestone known as the Abitibi River formation. These strata have been correlated with the Onondaga of southwestern Ontario and New York, but Lower as well as Upper Devonian elements have been recognized.

The Abitibi River formation is overlain by the Williams Island formation, consisting of about 149 feet of massive grey shale, succeeded by 32 feet of red, gypsiferous shale, the whole capped by 120 feet of porous and cavernous limestone. 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, with about the same number of each. The formation is thought to represent about the time of the Hamilton of New York.

TABLE XIV

Hudson Bay Lowland (Drill Core)

Period	Formation	Description	Thickness
			Feet
Lower Cretaceous or Upper Jurassic	Mattagami	Fire-clay, lignite, and lignite clay	132
		Light grey and green, plastic clay	38
Devonian	Long Rapids	Greenish grey shale and bituminous shale	285
	Williams Island	Porous and cavernous limestone	120
		Red gypsiferous shale and gypsum	32
		Massive grey shale	149
	Abitibi River	Buff limestone	37
	Moose River	Limestone breccia, porous limestone, and grey shale	63
		Interbedded shale and limestone with gypsum or selenite veins	59
		Arenaceous limestone, calcareous sandstone, red sandstone, and coarse grit	32
Precambrian		Weathered syenitic gneiss; granite-gneiss	30
		Weathered, pink granite-gneiss	3

Succeeding the Williams Island formation is about 285 feet of greenish grey, brownish, and dark grey to black, bituminous shale comprising the Long Rapids formation. The only fossils found in the exposed dark shale are spores referred to *Protosalvinia (Sporangites) huronensis*. Their presence, together with the lithological similarity of the two formations, indicates a correlation with the Kettle Point shales of Lake Huron. These shales are of Upper Devonian age, and are correlated with the Genesee of New York and with part of the Antrim formation of Michigan.

The Mesozoic rocks of the Hudson Bay region are termed the Mattagami formation. It comprises two facies, a lower one consisting of light grey, brown, red, and buff-coloured, fine-grained, plastic fire-clay, and an upper one of dark grey to black fire-clay and brown, micaceous sand with seams of argillaceous lignite. The total thickness, as indicated by diamond drilling, is about 170 feet. 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 toward a Kootenay age (Lower Cretaceous).

ECONOMIC GEOLOGY

Extensive deposits of gypsum are known to occur in the Moose River formation at several localities in the Moose River basin. The mineral outcrops on Moose River, where 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 deposits of economic interest are known to 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 Upper Jurassic or Lower Cretaceous age, and lie at an average depth of about 65 feet below the surface. They occur in two main seams separated by a clay parting. The lower seam has a fairly uniform thickness of 14 to 22 feet throughout the middle and eastern part 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 much greater variation in thickness. In places, part or all of this seam has been eroded, 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.

CHAPTER VI

THE INTERIOR PLAINS

(*G. S. Hume*)

INTRODUCTION

The Interior Plains occupy that part of Western Canada between the Precambrian Shield on the east and the Cordilleran area on the west. 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: (1) the southwest quarter of Manitoba; (2) the southern half to two-thirds of Saskatchewan; (3) all of Alberta, with the exception of a narrow belt of mountains and foothills in the southwest and a small area of Precambrian rocks in the northeast; (4) the northeastern corner of British Columbia; and (5) the Mackenzie lowlands of the Northwest Territories. Altogether 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 XXXIV) bordered on the north by park lands with poplar groves (Plate XXXV), which, in turn, merge farther north into more heavily timbered areas of poplar and evergreen forests. Still farther north, in the Mackenzie lowlands, the Plains extend into the Arctic regions and scantily timbered and barren lands. The area within the Northwest Territories extends west and northwest from the border of the Precambrian Shield at the Fort Fitzgerald-Fort Smith rapids on Slave River. It includes the basin of Great Slave Lake west of the North Arm and west to South Nahanni and lower Liard Rivers. Northward it includes most of the basin of Great Bear Lake, and where it reaches the Arctic coast has a width of about 325 miles west from Darnley Bay to Mackenzie Bay at the west edge of the Mackenzie delta.

The eastern boundary of the Interior Plains is the junction with the Canadian Shield, and follows a broadly curving northwesterly course from southeastern Manitoba, through Lake Winnipeg to the western end of Lake Athabaska, and thence in fairly direct line through Great Slave and Great Bear Lakes to the Arctic coast. Along this eastern edge the region either merges into the Canadian Shield without any noticeable topographical 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 (*See* Figure 53), the Interior Plains merge with the Foothills of the Rocky Mountains for 1,000 miles to Liard River in northern British Columbia. Farther north their boundary swings northerly along the west side of the Liard to Mackenzie River, beyond which the main ranges of mountains are west of the Mackenzie, but east of it the Plains are interrupted by the Franklin Mountains. These consist of the Franklin Range, which begins north of Willowlake River and ends north of Great Bear River and south of Fort Good Hope, and the Norman Range, which begins at Bear Rock at the mouth of Great Bear River and ends in the vicinity of Sans Sault Rapids on Mackenzie River. South of Wrigley the Mackenzie cuts through a narrow mountain ridge, which is the northward continuation of Camsell Range on the southwest to Rock-by-the-Rivers-Side on the northeast, but elsewhere

PLATE XXXIV

Prairie lands of southern Alberta in Twin River area. Photo by G. S. Hume, Geological Survey (G.S.H. 1-10, 45).

PLATE XXXV

Park lands in Battle River Valley, near Donalda, Alberta. Photo by G. S. Hume, Geological Survey (79369).

throughout its entire length flows through a lowland underlain by gently inclined strata. To the north this lowland occupies the lower parts of Peel, Arctic Red, an Ramparts Rivers, and its southern boundary is a westward-trending range that extends from Carcajou and Imperial Rivers to the east edge of Peel River plateau near the junction of Snake and Peel Rivers. Beyond this the west boundary of the Plains is the east edge of Richardson Mountains to the Arctic coast.

PHYSICAL FEATURES

DRAINAGE

The drainage of the Interior Plains is largely controlled by the regional northeast slope from an elevation of about 4,000 feet on the eastern edge of the Foothills to 500 feet in the Manitoba Lowland, a relatively narrow fringe of glacial-lake deposits bordering the Precambrian Shield. In the Manitoba Lowland the drainage is northward into Lake Winnipeg, but, except for Milk River in Alberta and a few small streams in southern Saskatchewan that drain south to Milk and Missouri Rivers, the drainage of the Plains is northeastward through the Saskatchewan River system into Hudson Bay, and northward through the Athabaska and Peace River systems into Mackenzie River and thence to the Arctic Ocean. All the larger drainage courses and many of the smaller ones are cut well below the plains level, in places as much as 200 or 300 feet, and occupy wide valleys mostly with steep banks and flat, bottom lands. In many areas, also, particularly in the southern Plains, valleys that once contained large streams are now dry, or are occupied only by minor streams in wet seasons or by the remnants of former lakes, now largely alkaline and without outward drainage. In many other parts of the southern Interior Plains alkaline lakes fill shallow depressions below the prairie level and are completely surrounded by slightly higher lands. In dry periods these lakes either dry completely, leaving white alkaline flats from which the salts are scattered by winds over the adjoining uplands in white dust storms, or they dry in part, leaving a white salt fringe as a rim around the lake shores.

INTERSTREAM AREAS

In the interstream areas, especially in the south, a large part of the Interior Plains is flat or gently undulating. In these areas in Alberta irrigation projects are turning semi-arid grazing lands into rich agricultural districts, and tree growth is changing the physical aspects of the former grass lands. In other interstream areas large moraines have been deposited in belts of variable width within which irregular hills and ridges, mostly well rounded and with moderate relief, present an irregular topography in comparison with other prairie lands. In still other areas there are extensive sand deposits, partly blown into dunes and nearly everywhere supporting a growth of scrubby bush.

RELIEF

The contrast in relief between the prairie level and the rather deeply incised river valleys is still further increased by the presence of a considerable number of flat-topped hills or mesas that are erosion remnants of a much higher plateau level. Most of these carry a thin mantle of glacial materials deposited as the continental ice-sheet receded, but some, as for example Cypress Hills in southeastern Alberta and southwestern Saskatchewan, lay above the ice-level and were not glaciated in their higher parts. Other than the Cypress Hills, which rise above 4,000 feet, there are Hand, Neutral (Plate XXXVI), and Misty Hills of southern Alberta; Swan Hills and Caribou Mountains of northern Alberta; Horn Mountains north of the west end of Great Slave Lake in the Northwest Territories; Wood and Moose Mountains in southern Saskatchewan; Turtle Mountain in southern Manitoba; and many others of less height and area.

PLATE XXXVI

Neutral Hills, north of Veteran, Alberta. Photo by G. S. Hume, Geological Survey (86008).

ESCARPMENTS

In addition to these various hills, the prairie level is, in the south, interrupted by two eastward-facing escarpments. The more easterly and more prominent, known as the Manitoba escarpment, faces the Manitoba Lowland, and rises abruptly 500 to 1,000 feet above it. The escarpment face has been dissected by erosion, and is cut by several wide valleys. Viewed from the east it appears as groups of hills known, from south to north, as Pembina, Riding Mountain, Duck, Porcupine, and Pasquia, but their tops are in reality only the level of the second prairie steppe.

The second escarpment, known as the Missouri Couteau, is in southwestern Saskatchewan, and forms the eastern boundary of Wood Mountain Plateau and a northwest extension from it. The rise is 200 to 500 feet, but as there is an equal drop to the west, the escarpment does not represent a rise from one prairie level to another as does the Manitoba escarpment. It disappears to the northwest, but in the south is locally a prominent feature.

"BADLAND" TOPOGRAPHY

A few places in the central Plains are featured by what is known as "badland" topography (Plate XXXVII). This is developed as a result of easy erosion of soft beds, overlain usually by more resistant sandstones or shales. The land becomes deeply dissected by sharp valleys between knobs or hills of variable size, heights, and shapes, almost entirely devoid of vegetation. Fantastic land forms develop, but, though spectacular, they do not occupy large areas. In Alberta they are present along Red Deer River Valley from Drumheller to and beyond Steveville, and along Milk River in the southern part of the province. 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. None of these is extensive.

PLATE XXXVII

Badlands on Red Deer River, east of Steveville, Alberta. Photo by C. M. Sternberg, Geological Survey (81536).

Thus, although the name "plains" suggests a level tableland there are many irregularities of topography both as deeply dissected river valleys and as prominent hills rising well above the prairie level. The rolling grass lands of the south give place to the bush lands of the north, and in the far north to forests, muskegs, and barren, frozen ground, with many groups of large lakes, and the physical features of the Interior Plains as a whole are more diverse than uniform.

PREVIOUS GEOLOGICAL WORK

Geological information relating to the southern Plains of Western Canada dates back to the Palliser expedition of 1859 and the reports by Hector. In 1874, George M. Dawson, as geologist for the North American Boundary Commission, studied the country along the 49th parallel. In 1881, under the auspices of the Geological Survey, Dawson, with R. G. McConnell as assistant, examined the region in the vicinity of Bow and Belly (Oldman) Rivers from the Rocky Mountains east almost to the Saskatchewan boundary and north from the International Boundary to Calgary. McConnell spent the winter of 1881-82 in Calgary, and the work of the previous summer was continued by him independently in 1882. In 1883 Dawson again visited the area for about a month. This early work by Dawson and McConnell laid the foundation for subsequent investigations on the southern Plains. In 1887 Warren Upham studied glacial Lake Agassiz in Manitoba, and in 1887 to 1889 J. B. Tyrrell, with D. B. Dowling as assistant, traversed northwestern Manitoba, including the area in the vicinity of Lakes Winnipeg and Winnipegosis. This was the beginning in Western Canada of Dowling's work that was to continue until his retirement in 1925, and to be especially significant in relation to the development of coal and artesian water resources and to a less extent those of oil and natural gas.

In the far north information has been relatively scanty, and explorations have been confined to the main stream courses or to investigations in the mountain groups within or adjoining the Interior Plains. In 1789 Alexander Mackenzie made his memorable journey from Fort Chipewyan on Lake Athabaska to the mouth of Mackenzie River and back to Fort Chipewyan, a distance of 3,000 miles, which he covered in 102 days. His journal contains much accurate and valuable information. From 1799 to 1810 David Thompson made the first complete survey of Athabaska River, and a monument on the Athabaska at Jasper now commemorates his exploits. In 1888 William Ogilvie, for the Department of the Interior, made the first good map of Mackenzie River, having crossed from the Yukon by way of Rat River, a tributary of the Peel. He ascended the Mackenzie to Great Slave Lake and Slave River to Lake Athabaska. In 1891 he also ascended Liard and Fort Nelson Rivers, crossing to Fort St. John on Peace River. In 1879 George M. Dawson and R. G. McConnell examined the Peace River country along the South Pine to Dunvegan on Peace River. From thence they travelled across country to Athabaska Landing and from there to Edmonton. In 1887 R. G. McConnell descended Liard River to Fort Simpson, a trip made under great difficulties, and in 1888 descended the Mackenzie to Fort McPherson on Peel River. McConnell was one of the first to make accurate observations of the geology and possible oil resources of the Mackenzie basin. In 1888-89 he examined the country between Athabaska and Peace Rivers north to Great Slave Lake. In 1902 Charles Camsell examined the salt springs south of Fort Smith, and crossed to Peace River. This was followed in 1905 by exploration and mapping of the Peel and Wind River basins. In 1907 Joseph Keele descended Gravel (Keele) River to its junction with the Mackenzie. From 1913 to his retirement in 1945 S. C. Ells made extensive investigations of the bituminous sands of the Athabaska and of the more general region in their vicinity. During the years 1920 to 1923 several parties of the Geological Survey, under M. Y. Williams, E. J. Whittaker, A. E. Cameron, and G. S. Hume, investigated the Mackenzie River basin, where exploratory wells that led to the discovery of the Norman Wells oil field were being drilled. These reports were greatly augmented by explorations under the direction of T. A. Link for the Canol project during the years 1942-4.

Many investigations, in addition to those mentioned above, have been made since 1900 on various parts of the Interior Plains by members of the Geological Survey and of the geological staff of the University of Alberta, and, particularly in the last few years, much information concerning the sub-surface stratigraphy and structure has been made available by companies drilling in search of oil.

GEOLOGY

The Interior Plains are underlain by sedimentary rocks of Palæozoic, Mesozoic, and Cenozoic ages resting on a Precambrian erosional surface of variable relief. They are largely drift covered, but beneath the glacial debris and glacial-lake deposits the bedrock has a regional southwest dip, mostly so gentle that the beds appear to be almost flat. For this reason the younger strata mostly conceal the older beds except where the latter reach the surface along the margin of the Precambrian Shield or are upthrust by faults in the western foothills and mountains. Thus the older beds are known only from their outcrops on the east and west margins of the Plains and from well borings that have penetrated them, largely in the search for oil and gas, whereas the youngest rocks have been subjected to erosion and occur now as isolated remnants of former, much more extensive deposits, the removal of which has revealed other slightly older strata that they previously concealed.

CAMBRIAN

The oldest Palæozoic strata, the Cambrian (Figure 51), are not known to occur in Manitoba either as outcrops or in borings. The age of some sandstone beds filling irregularities in the Precambrian floor below fossiliferous Ordovician beds is not definitely known, but is believed to be Ordovician also. Near Ogema, in south-central Saskatchewan south of Regina, a deep well reaching the Precambrian at a depth of 9,400 feet encountered about 800 feet of sandstones, in part glauconitic, that may be wholly or in part Cambrian, overlain by 500 to 600 feet of limestones and dolomites of possible Ordovician age. Cambrian strata are known to occur across southern Alberta, where shales and dolomites were drilled in the Commonwealth-Milk River well, northeast of the town of Milk River, and in the California Standard Princess No. 1 well, which reached the Precambrian at a depth of 6,147 feet. The extent of the Cambrian under northern Alberta and northern Saskatchewan is unknown. It is presumed that the Montreal-Alberta well at Wainwright reached Cambrian strata, and limy shales of this age are believed to lie below a white and red quartz sand at a depth of 4,150 feet in Vermilion Consolidated No. 15 well, southeast of Vermilion. Cambrian beds, however, are not present along the edge of the Palæozoic outcrops in northern Alberta to the west of Lake Athabaska, nor in wells drilled to the Precambrian at Fort McMurray in search of salt; nor have they been observed along the eastern edge of the Palæozoic sediments where these are in contact with the Precambrian on the north arm of Great Slave Lake. A thick succession of Cambrian shales, dolomites, and limestones is, however, known in the eastern mountains of southern Alberta, and beds of similar age have been recognized in Mackenzie and Franklin Mountains in the Northwest Territories.

ORDOVICIAN

Strata of Upper Ordovician age flank the Precambrian rocks of the Canadian Shield to the west, northwest, and south of Lake Winnipeg. In the southern part they have been subdivided into three formations, consisting of the Winnipeg formation of mainly sandstone, succeeded by the Red River formation of limestone and dolomite, overlain, in turn, by the Stony Mountain formation of limestone, dolomite, and red shale. Together these formations comprise less than 800 feet of strata, the basal, sandstone beds resting on and filling inequalities in the Precambrian surface. They thin westwards beneath the Plains; are doubtfully present in the extreme southwest; and, so far as known, do not occur in the northern plains of Alberta. In the eastern Rocky Mountains early and late Ordovician strata are present, and certain shales encountered in the Commonwealth-Milk River well of southern Alberta contained ostracods that may be of Ordovician age. Ordovician shales and dolomites with gypsum occur along the west side of the north arm of Great Slave Lake and from there northward along the western margin of the Shield to Great Bear Lake, but are doubtfully present west of Mackenzie River Valley in Mackenzie Mountains.

SILURIAN

Middle Silurian (Niagaran) strata of the Stonewall formation, less than 450 feet thick, are known in Manitoba west of Lake Winnipeg, and similar beds

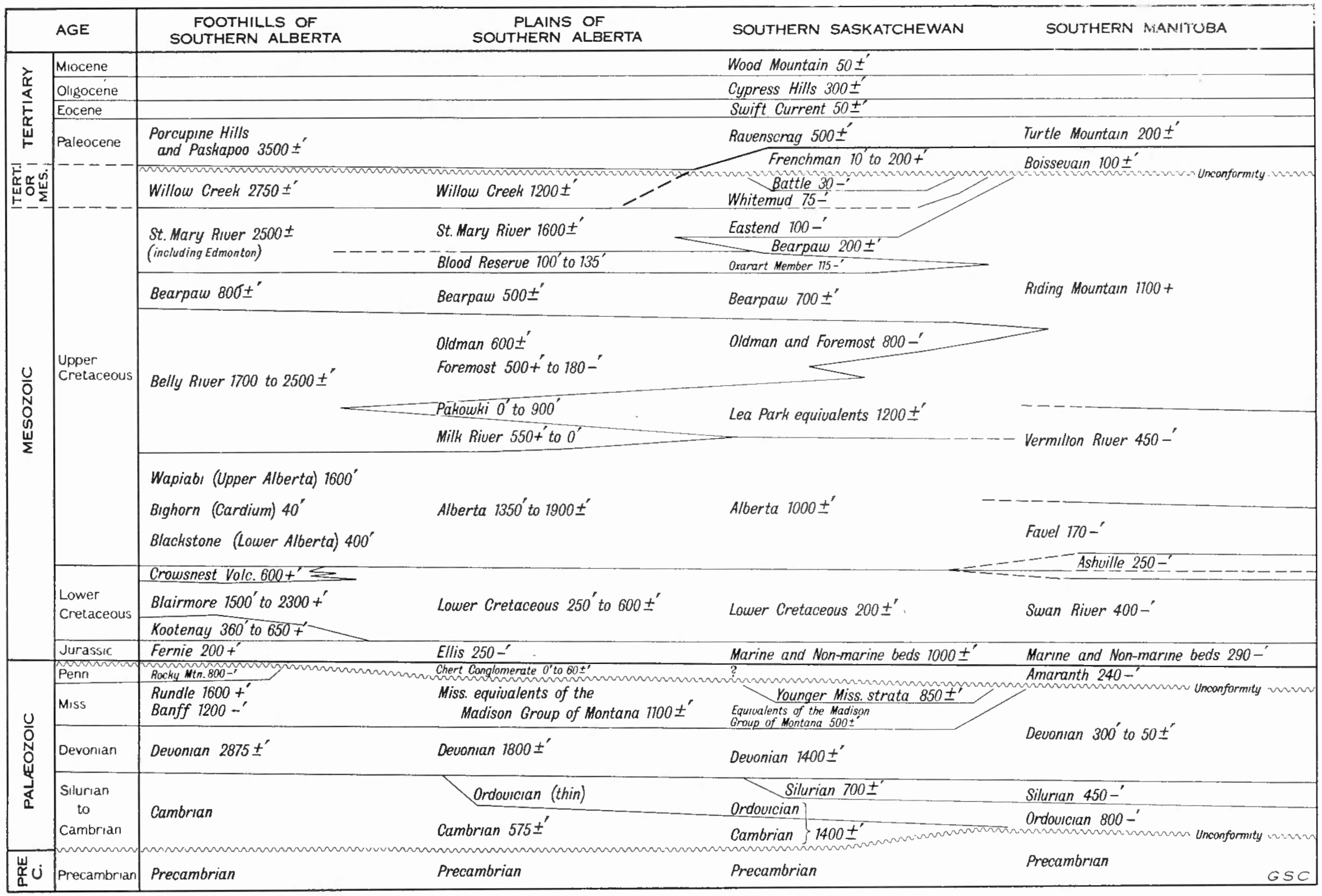

Figure 51. Correlation chart across southern Interior Plains of Canada.

revealed by drilling in southern Saskatchewan may be of the same age. The formation consists largely of dolomite or dolomitic limestone, with, locally, salt and gypsum beds. Strata of this age have not been identified in the southwestern Plains, and probably are not present. In the Fort McMurray area of northern Alberta Silurian beds are present locally, and the lower part of Peace River Valley contains gypsum beds of this age. Dolomitic strata are associated with salt beds west of Fort Smith, and are considered to be Silurian, and limestones and dolomites of Silurian age presumably underlie most, if not all, of the Mackenzie lowlands, outcropping both on the east and west margins, and are present in the Windy Point well drilled on the north shore of Great Slave Lake toward the west end of the West Arm.

DEVONIAN

Devonian strata underlie all of the Interior Plains, but consist entirely of Middle and Upper Devonian limestone and dolomite, interbedded with shale and containing some thick beds of anhydrite and salt. In Manitoba, west of the fringe of Silurian outcrops, there are extensive exposures of Devonian beds on Lakes Manitoba and Winnipegosis. Also in northern Alberta, at Fort McMurray and in the lower valley of Peace River, Upper Devonian beds outcrop, but no Middle or Lower Devonian beds are present. Farther north, however, Middle Devonian limestones and dolomites have been found in the vicinity of Great Slave Lake, Northwest Territories, and except where overlain by Cretaceous strata occupy a belt of considerable but as yet unknown width along the entire course of Mackenzie Valley. In ascending order are the Pine Point limestone, Presqu'ile dolomite, and Slave Point limestone. The Upper Devonian Simpson shales are exposed on Mackenzie River above Fort Simpson and also on Hay River. The overlying Hay River shales outcrop on the same river below its falls and are overlain by Hay River limestones.

Devonian beds, mostly of limestone and dolomite, but with some shale, have been encountered in the Plains in every well drilled deep enough to reach them. In southern Alberta the division is threefold, with dolomitic limestones and dolomites comprising the lowest division, anhydrite in an intermediate zone, and shale and dolomitic limestones, containing Upper Devonian fossils, in the upper division. In east-central Alberta salt has been encountered below 1,000 to 1,500 feet of limestones and dolomites of Devonian age. The relationships of the salt beds in east-central Alberta, the anhydrite beds of southern Alberta, and the salt and anhydrite beds encountered in the Palæozoic rocks of southern Saskatchewan are unknown, but it is presumed both Silurian and Devonian deposits may be present. The salt beds at Fort McMurray have been considered to be Silurian, but there is no positive proof of their age.

MISSISSIPPIAN AND LATER PALÆOZOIC

Mississippian beds overlying the Devonian are restricted on the Plains to southern Saskatchewan and southern Alberta (*See* Figure 51), with a fringe of unknown width along the east edge of the Foothills. In southwestern Alberta the youngest Mississippian strata are limestones correlated with the Rundle formation of Banff. They overlie limy shales of the Banff formation, and are correlated with the Madison group of Montana. In the southern Plains the top of the Mississippian is an erosion surface, but there are still younger Mississippian beds in southern Saskatchewan, revealed by the drilling of deep wells. In the Williston basin, which extends north from North Dakota and northeastern Montana into southern Saskatchewan, the typical massive limestones of the Madison group are continued upward into earthy limestones, and anhydritic limestones with red and variegated shales. In west-central Montana, where these beds are absent, red calcareous sands overlie the Madison disconformably, but to the east, in the Williston basin, there is a gradual merging upward into sandy limestones, overlain by typical marine limestones and shales, in turn overlain by black organic shales alternating with continental deposits containing plant fragments and even thin coal seams. These are overlain by the youngest Palæozoic beds of the area, namely dolomitic sandstones, anhydrite, and red and variegated shales. The fauna from the uppermost beds show Pennsylvanian elements, though the beds are mainly, if not wholly, of Chester (Mississippian) age.

Elsewhere in the Interior Plains area of Canada there are no known Pennsylvanian or Permian rocks, although late Palæozoic strata have been recognized in the eastern Cordilleran region as far north as, and on, Liard River. It is believed, therefore, that Mississippian and possibly Pennsylvanian formations occur under younger strata in the southwest part of the Northwest Territories adjoining lower Liard River, but no Carboniferous rocks are known elsewhere in the Mackenzie River basin.

In certain areas of southern Alberta a regolith overlies Mississippian strata, and is either a chert conglomerate or a conglomerate containing chert, green clay, and other clastic materials. In east-central Alberta, where it overlies Devonian limestone, the regolith is quite widespread. In a few places it consists only of non-calcareous, green and red, argillaceous materials, but in other areas sand is present in considerable amount, and the thickness of the detrital material may be as much as 100 feet, or even more in exceptional instances. In central-western Saskatchewan a gas-bearing sand below Lower Cretaceous beds may belong to this regolith. The age of the detrital material may be either late Palæozoic or early Mesozoic, but the material itself is derived from the weathering of Palæozoic rocks. In southern Manitoba, the Amaranth formation, described mostly from well samples, lies between known Devonian and Jurassic strata, but its precise age is uncertain. The beds are a succession of red shales with gypsum, with a maximum known thickness of 240 feet.

TRIASSIC

Rocks definitely identified as Triassic are known only from the northwestern part of the central Plains, where they have been encountered in a deep well drilled near Pouce Coupé, Alberta. The Triassic beds of this area are entirely marine, consisting of siltstones, calcareous shales, and arenaceous limestones. It is probable that strata of this age underlie the western and northern parts of the Plains in northeastern British Columbia, as well as a small area in northwestern Alberta. They thin out eastward, presumably due to erosion prior to Jurassic deposition, and are not present where the top of the Palæozoic is exposed on Peace River at Vermilion Chutes.

JURASSIC

Jurassic rocks overlie the Triassic, where present, or rest on Palæozoic formations. They are known in southern Manitoba, in southern Saskatchewan, in southern and western Alberta along the west edge of the Interior Plains, and in northeast British Columbia (*See* Figure 51). In the west and southwest the Jurassic is entirely marine, consisting mostly of dark shales with limestone bands in the lower part and brown ribboned sandstones in the upper part. In the southern Alberta plains the sediments, as encountered by drilling, are mainly green shales with some sands, although limestone beds are also present. These are 250 feet or less thick, and are believed to correspond with the Ellis formation of Montana. In southern Saskatchewan and Manitoba information is again based wholly on the study of samples from a few deep wells. Part of the Jurassic strata there may consist of red shales, but grey shales predominate and limestone beds may be present. The contained fossils indicate an intermixture of marine and non-marine beds, whose aggregate thickness is quite variable, but commonly does not exceed a few hundred feet. The extent of the Jurassic beds northward in these provinces is not known, but it is doubtful if marine strata persist far north of Swan River in Manitoba.

CRETACEOUS AND PALEOCENE

The Cretaceous period, following the Jurassic, was one of widespread deposition in the Interior Plains, and conditions of sedimentation were highly variable even at the same time in different areas. In southwestern Alberta the period began under widespread continental conditions with the deposition of clastic materials, sands and shales with coal. This condition was maintained through Lower Cretaceous time, ending with local deposition of volcanic breccia, which in the beginning was mingled with the continental material. To the north, in northwestern Alberta and northeastern British Columbia, and extending into northeastern Alberta and south to southern Saskatchewan, Lower Cretaceous marine beds alternate with the non-marine deposits. The sea in which these marine beds were laid down obviously existed to the north and east of the area of southwestern Alberta that received only continental deposits, but marine Lower Cretaceous beds are not known to have extended into northern Manitoba, although they are present in the south interbedded with non-marine strata of the Swan River group. A considerable part of the marine Lower Cretaceous is composed of shales, and these alternate with non-marine beds of sands and shales in which coal seams occur.

In southeastern Alberta and in southern Saskatchewan beds of Lower Cretaceous age are deeply buried below the surface, and are only known where penetrated by deep boreholes. They include the partly non-marine and probably partly marine shales and sandstones referred to in the literature as the "varicoloured" beds. Their exact age has not been determined, but they have been tentatively correlated with the Blairmore of southwestern Alberta. Some at least partly marine dark shales and sandstones overlying the "varicoloured" beds in southern Saskatchewan have also been referred to the Lower Cretaceous. To the east, on the Manitoba escarpment, it is probable that some part of the partly marine and partly non-marine sandstones, shales, and clays of the Swan River group, and possibly a part of the marine shales of the Ashville formation, are of Lower Cretaceous age.

Farther north in Athabaska River Valley in the vicinity of Fort McMurray the westerly non-marine sandstones of the McMurray formation (the "Tar sands") have been placed in the Lower Cretaceous and correlated with either the Kootenay or lower part of the Blairmore formation of southwestern Alberta, the latest correlation being with lower Blairmore. The McMurray is overlain by the Fort St. John group, including the marine shales and sandstones of the Clearwater formation, the marine and non-marine sandstones and rare coaly layers of the Grand Rapids formation, and possibly, at the top, the dark marine "Pelican shale". To the northwest of Fort McMurray and lower Athabaska Valley, and in the lower or eastern part of Peace Valley, the succession is much the same. At the base and penetrated in boreholes is sandstone, probably comparable with the McMurray sands on Athabaska River. Above are the marine shales of the Loon River formation, occupying a stratigraphic position similar to that of the Clearwater of the Athabaska section. Higher, the partly marine and partly non-marine sandstone, shale, and one known coaly layer of the Peace River formation resemble the beds of the Grand Rapids formation, and the marine dark shales of the Shaftesbury recall the "Pelican shale" of the Athabaska section. The section from the base of the Loon River to the top of the Shaftesbury has been included in the Fort St. John group. The faunas of the Fort St. John group, particularly the *Beaudanticeras affine* and *Gastroplites* faunas, have been dated late Lower Cretaceous, and the beds containing them correlated with the upper part of the Blairmore group and possibly the base of the Alberta group in southwestern Alberta. Some doubt of the Lower Cretaceous age of the top of the Fort St. John group, including the Shaftesbury formation, has, however, been expressed. The shales of the Meander formation, possibly of Lower Cretaceous age, occur in Hay River Valley.

At the beginning of Upper Cretaceous time continental conditions disappeared, and thick marine deposits accumulated everywhere over the area of the Plains. For the most part these are dark shales, but in the northwestern Plains the oldest Upper Cretaceous deposits are sands, in part alternating with shales. The sea that deposited these sediments lasted much longer in the east than in the west, and, in consequence, when continental conditions again began in the west, marine deposits were still accumulating in the east and continued to do so almost to the end of Upper Cretaceous time. These conditions are illustrated for the southern Plains by Figure 51. In the west the early Upper Cretaceous comprises about 1,700 to 2,000 feet of marine, Alberta shales of Colorado age, succeeded by a few hundred feet of marine shales of Montana age. Farther north in Smoky and Peace Valleys the Upper Cretaceous apparently begins with the sandstones, shales, and thin, rare coal seams of the Dunvegan formation. These are overlain by the marine shales and rare sandstones of the Smoky group, the equivalent of the Alberta group in the south. To the southeast, in Athabaska Valley, the marine shales of the La Biche formation include beds equivalent to those of the Alberta and Smoky groups, but may extend a little higher stratigraphically. Farther east, in the Manitoba escarpment, beds equivalent to the Alberta group include the marine shales, calcareous shales, and rare limestones of the Favel formation and a part of the marine shales of the Vermilion River formation.

The beds of the Alberta group are overlain by Belly River sandstones and shales (*See* Figure 51). In the west these contain coal seams and are entirely non-marine, but to the east and northeast they wedge out and become interfingered with marine shales and sands. Thus in the southern plains of Alberta the non-marine equivalent of the Belly River beds of the Foothills, represented by the Milk River, Foremost, and Oldman formations, are intercalated above the Milk River by a westerly thinning wedge of marine, Pakowki shales. Still farther east, in southern Saskatchewan, the Milk River formation of non-marine sandstones and shales wedges out, and the overlying, marine Pakowki beds give place to the much thicker series of marine shales of the Lea Park, which rest directly on the Alberta shales and are very similar to them lithologically. The succeeding Foremost and Oldman continental beds are here thinning rapidly to the east, and disappear somewhere in the western part of southern Manitoba, east of which point almost the entire Upper Cretaceous section is marine, and consists dominantly of shales. The marine succession in southern Manitoba has been subdivided lithologically into four formations, namely the Ashville, which may be in part lower Cretaceous, succeeded by the Favel, Vermilion River, and Riding Mountain formations. The Riding Mountain is much the thickest of these (*See* Figure 51) and except around Turtle Mountain, in southernmost Manitoba, is everywhere exposed to erosion. It includes equivalents of the upper Lea Park of Saskatchewan as well as those of the continental, Oldman and Foremost formations and the succeeding marine beds of the Bearpaw formation of more westerly areas.

Throughout southern Saskatchewan and Alberta, and in southwestern Alberta, the Belly River beds or their equivalents are overlain by marine shales of the Bearpaw formation, which attains a thickness of more than 700 feet and contains a number of sandstone members. Marine sedimentation lasted longer in the east than in the west, and the Blood Reserve sandstone, which overlies the Bearpaw of southern Alberta, has recently been correlated with the Oxarart sandstone member of the Bearpaw of the Cypress Lake area in southwestern Saskatchewan. In the Cypress Hills the Oxarart sandstone is overlain by as much as 200 feet more of marine Bearpaw shales, and these are now believed to represent the time equivalents of the basal, brackish water, oyster-bearing beds of the St. Mary River formation, which overlies the Blood Reserve sandstone in southern and southwestern Alberta (*See* Figure 51).

Northward along the east edge of the Foothills the Bearpaw marine shales of the south become less typically marine, and contain yellow and reddish sandstones. In some areas thin coal seams are present in beds considered Bearpaw equivalents. Apparently this represents a near shore phase of sedimentation, and north of Highwood River the recognition of the Bearpaw becomes difficult, and the underlying, non-marine, Belly River beds, with a thick coal seam near the top in Turner Valley and more southerly areas, is continued upward into the non-marine sandstones and shales of the Edmonton formation. In the Drumheller area of Alberta, where the Edmonton is well exposed and consists of 1,224 feet of white, bentonitic sandstones and shales with coal, there is an erosional disconformity at its top. To the southwest these late Upper Cretaceous beds are overlain by non-marine Paleocene sandstones and shales of the Paskapoo formation, with a basal conglomeratic sandstone containing cobbles up to 6 inches in diameter. Along the eastern edge of the Foothills north of Bow River difficulty has been experienced in dividing the non-marine succession into the various component parts recognized farther south. In the Mountain Park and Cadomin areas of Alberta the non-marine beds are said to be 12,000 to 14,000 feet thick, and although the upper part is regarded as Paleocene, its point of separation from the Cretaceous below is still uncertain. The basal Paleocene conglomeratic sandstone has been traced southward along the east edge of the Foothills from Bow River to Willow Creek. On Bow River it rests on Edmonton strata, but due to northward bevelling, progressively higher beds appear to the south below it. Thus, as the Edmonton formation is traced southward it becomes thicker with the addition of younger beds, and south of Highwood River it is known as the St. Mary River formation. In addition, still younger beds appear between the St. Mary River formation and the Paleocene conglomeratic sandstone These are the Willow Creek beds consisting mainly of red shales, but including also green shales and sandstones (*See* Figure 51). The Willow Creek beds contain freshwater fossils whose age is indefinite, but hitherto have been regarded as probably Paleocene. The stratigraphic relationships, however, seem to indicate that the Willow Creek formation may be Cretaceous. In the Porcupine Hills of southwest Alberta, west of Nanton and Claresholm, a thick succession of sandstones and shales of the Porcupine Hills formation, with a basal conglomeratic sandstone, is probably the southward equivalent of the Paskapoo formation.

It has already been indicated that marine conditions persisted longer in the east than in the west, and that the brackish, lower part of the St. Mary River formation of southern Alberta may be the time equivalent of part of the upper Bearpaw in the Cypress Hills area of southwestern Saskatchewan. Above the Bearpaw marine beds in the Cypress Hills are sandy beds with carbonaceous materials and thin coal seams that comprise the Eastend formation (*See* Figure 51). The division between the Eastend and Bearpaw formations, however, is drawn arbitrarily, as some sandy members formerly included in the Eastend have been described recently as part of the Bearpaw. Also, the upper contact of the Eastend formation is transitional into white, feldspathic sandstones of the Whitemud formation. Bentonitic shales and sands formerly included in the top of the Whitemud formation have been separated in the Cypress Hills area into the Battle formation, and seem to indicate a marked change in sedimentary conditions, particularly in the prevalence of volcanic activity as revealed by the presence of bentonite. The deposition of the Battle formation, however, was followed by a period of erosion, which in places removed both it and part or all of the Whitemud formation. This period of erosion in the east appears to correspond with that in the west at the base of the Paskapoo formation, but in the east still younger Cretaceous beds, represented by the Frenchman formation (formerly Lower Ravenscrag) apparently of Lance age and containing a *Triceratops* vertebrate fauna, succeed the period of erosion, and in the east end of the Cypress Hills grade upwards into the Ravenscrag (formerly Upper Ravenscag) formation of non-marine Paleocene beds. The division between the Frenchman and Ravenscrag formations is placed at the base of a coal-bearing succession of beds.

Considerable diversity of opinion has marked attempts to correlate the various formations of eastern and western areas. Formerly the lower part of the Edmonton formation was correlated with the Eastend and the upper part with the Whitemud, as the Edmonton in the Gleichen area of southwestern Alberta contains a volcanic ash bed, which with bentonite in the formation indicated a period of volcanic activity. Furnival, however, correlates the lower part of the St. Mary River (or Edmonton) with the upper part of the Bearpaw of the Cypress Hills area and the upper or freshwater part of the St. Mary River with the Eastend formation. He also tentatively correlates the Willow Creek beds of southwestern Alberta with the Whitemud formation[1]. It is presumed that the Battle formation was not included in this correlation, and it is thus assumed that sedimentation in the east may still have been in progress when it had ceased in the west. In the west the division between the Cretaceous and the Paleocene is represented by an erosional disconformity at the base of the Paskapoo, but in the east the sedimentation appears to have been continuous from late Cretaceous into Paleocene time, as indicated by continuous deposition of continental sandstones and shales. In a general way the Ravenscrag, as re-defined by Furnival, correlates with the Paskapoo of Alberta and with similar non-marine sandstones that occur in southern Manitoba and are there known as the Turtle Mountain formation.

Overlying the Upper Cretaceous marine shale succession, or Riding Mountain beds, in Manitoba is a sandstone known as the Boissevain. Its exact correlation with the Cypress Hills succession is not definitely known, but it may be Frenchman or older. It is overlain by Paleocene, Turtle Mountain beds.

In the north and northwest, in Smoky, Wapiti, and Peace Valleys, the marine shales and sandstones of the Smoky group are succeeded by the non-marine sandstones, shales, and coal seams of the Wapiti formation. In their lower part they are apparently equivalent to the Belly River of the south, but may extend much higher stratigraphically.

In the northwest beds of both Lower and Upper Cretaceous age occur in the valleys of Fort Nelson and Liard Rivers.

In the far north strata of Cretaceous age are found on the west and north shores of Great Bear Lake, including the shores of Keith, Smith, and Dease Arms. They comprise shales and sandstones.

EOCENE AND LATER TERTIARY

Upper Cretaceous and Paleocene strata form the bedrock over most of the southern Interior Plains exclusive of the Palæozoic exposures in the Manitoba lowlands and in northern Alberta. There are, however, a few localities where

[1] In the summer of 1946 C. M. Sternberg, Geological Survey, collected *Triceratops* from Upper Edmonton beds of the Red Deer River area, southwest of Big Valley. This fossil has been considered to be confined to beds of Lance age, and formerly has only been found in the Frenchman formation of southern Saskatchewan.

younger beds are present. In the Swift Current area, north of the Cypress Hills in Saskatchewan, about 50 feet of conglomeratic sandstones and sandstones are, on the basis of contained vertebrate fauna, of late Eocene age. These beds are overlain by other conglomerates and sandstones believed to be the same as those that cap the Cypress Hills and are there known as the Cypress Hills formation of Oligocene age. At the east end of Cypress Hills they have an elevation of 3,375 feet, but at the west end lie above an elevation of 4,400 feet. They rest disconformably on various older formations, indicating a considerable period of erosion prior to their deposition. Their thickness probably does not exceed 300 feet. Similar beds are found in the Hand Hills of southeastern Alberta and in the Swan Hills of northern Alberta. In the Wood Mountain area of southern Saskatchewan the plateau is capped by gravels that contain a Miocene vertebrate fauna. The gravels are mostly unconsolidated, but in places have a calcareous cement and are associated with some sands.

At a number of widely separated localities in southern Alberta deposits of gravel, consisting mostly of quartzite pebbles, occur in the river valleys. These are the Saskatchewan gravels. On North Saskatchewan River at Edmonton and in many other areas these pebbles are of quartzites, chert, and arkose. They are well rounded, and so smooth that they have a peculiar, greasy appearance. In the Edmonton area they rest on bedrock in deposits as much as 50 or more feet thick. In places the gravel contains some sand, fragments of fossil wood, and ironstone pebbles. In southern Alberta, so far as known, they are confined to the river valleys, but in the area north of Red Deer to Edmonton there are many deposits on the upland slopes, or on the sides of small stream valleys far removed from any major watercourse. The gravels, undoubtedly derived from the west, were thus widely distributed, presumably by stream action, but their age is unknown except that they are pre-glacial and younger than the bedrock on which they rest. It is assumed, therefore, that they are Tertiary deposits.

GLACIAL DEPOSITS

Except for the top of the Cypress Hills and a small area near Rockglen in southern Saskatchewan the Interior Plains have been glaciated by ice-sheets that originated to the northeast in northern Canada. In southern Saskatchewan at least three till sheets and two series of interglacial deposits have been recognized, whereas in southern Alberta there are, so far as known, only two till sheets of the continental glaciation, and one series of interglacial beds. The older of these two continental ice-sheets is thought to have extended much the farther southwest, and the later sheet is presumed to have coalesced with the ice from the mountains leaving deposits that are found beyond the Foothills as far east as Calgary.

Interglacial deposits on Bow River in southern Alberta are as much as 30 feet thick, and consist of loess, or wind-blown silt, and alluvial flood-plain deposits of fine silt and clay with small seams of lignite. The glacial deposits have formed moraines, eskers, and outwash material of sand and gravel, as well as glacial-lake silts deposited in bodies of water of various sizes that were dammed by the ice. The most extensive of the lake deposits are those of glacial Lake Agassiz, and form the rich, flat farming lands of the Manitoba Lowland. The main drainage channels of the Plains existed prior to the Glacial period, but to a considerable extent these channels were, at one time or another, dammed by glacial ice and lakes were temporarily formed. Subsequently, on the retreat of the ice, many of these old drainage channels were again re-occupied by the major streams, but in other instances new stream channels were cut due to the diversion of the water. The large amount of water formed by the melting of the ice also accounted for some large streams at that time in valleys where there is none now. These valleys are commonly wide and deep, but may be occupied by alkaline lakes, the remnants of former, much larger bodies of fresh water. In size the valleys now appear as wholly out of proportion to the present drainage requirements. Relief was further accentuated by the accumulation of morainic materials along the margins of the slowly retreating ice-sheets. In places this drift is as much as 500 feet, or more, thick, but generally, except in the moraines, it is much thinner. These glacial features, together with the hills that are former remnants of a much higher surface, give the southern Plains their present characteristic appearance of rolling lands and northwest-trending ridges, and break the monotony of what would otherwise be a somewhat featureless topography.

STRUCTURAL GEOLOGY

The strata of the central Plains have been remarkably little disturbed except by regional warpings of the earth's crust. In general there is a low southwest dip away from the margin of the Precambrian Shield, but locally broad, gentle folds are present. Some of these folds are undoubtedly due to compression, but others are thought to be the result of deposition and compaction of sediments laid down on an erosional surface of considerable relief. Two such widespread erosional surfaces are known to have been formed during the geological history of the Plains, and others of minor importance may be present.

EROSIONAL SURFACES

The first of the major erosional surfaces was that existing on the Precambrian rocks when the earliest Palæozoic strata were being laid down. There is reason to believe that the relief on this surface was as much as or even greater than the present relief of the Precambrian Shield. The second erosional surface developed at the close of Palæozoic time, and previous to the deposition of the Mesozoic sediments. Undoubtedly erosion was accentuated by a broad warping of the Palæozoic strata, and areas such as that of the Sweet Grass arch in southern Alberta were uplifted at that time. It is well known that the close of Palæozoic time was marked by great diastrophism in eastern North America, but in the west the disturbances were relatively slight, and the major mountain-building deformation came much later. Very little information is available on the relief that developed on the Palæozoic erosion surface, but knobs 100 feet or more high are known to have been left, and very much larger ones may be present. In Alberta, late Palæozoic erosion resulted in a general bevelling from south to northeast and perhaps as much as 2,000 feet of Palæozoic sediments now present in southern Alberta were removed from more northerly areas. The area of the Sweet Grass arch was broadly warped at that time, but it appears that on it the slope of the strata as a whole must have been southwest as the younger strata were preserved in the south and removed from northeast areas. In this area at present the slope of the strata and of the buried Palæozoic surface is to the north, but this may have been brought about by the intrusion of igneous plugs that now form three buttes in Montana a short distance south of the International Boundary. These intrusions disturbed Mesozoic strata, and hence are younger than the late Palæozoic erosion surface. In Saskatchewan also, east of the Regina area and extending northwest into Alberta south of Lloydminster, there seems to have been an erosional plateau of Palæozoic strata. This formed a barrier for the early Mesozoic seas, and hence separated Manitoba from western Saskatchewan and Alberta.

STRUCTURAL AND STRATIGRAPHIC TRAPS

Sediments laid down on an erosion surface of considerable relief have a depositional dip due to the fact that the strata as they are formed lap against the sides of any feature that projects above their general level. As the areas of low relief become filled with sediment the amount of depositional dip tends to decrease, but when the sediments become sufficiently thick to pass over the top of any higher part of the former erosion surface, such as a knob or ridge, there is a tendency for the knob or ridge to become the locus of an arch. This is the result of shrinkage in volume and hence in thickness due to compaction and consolidation. Obviously, if the sedimentary material is uniform in character the amount of arching that will result from the complete burial of any erosional knob or ridge will be dependent on its relief. There is also the tendency for the amount of arching to become progressively less upwards, and, finally, if sufficient depth of burial occurs the effect of the arching disappears. Sands compact much less than muds, which, when deposited, are very loosely coherent, but on compression may change into hard shales. Sand bodies in a shale sequence, therefore, may have the same effect of arching the sediments laid down over them as do the irregularities on an erosional surface. These arched beds are structural traps for oil and gas.

In the compaction of sediments certain organic materials may be changed to oil and gas. Squeezing during compaction causes these, as well as the water in the sediments, to move into the parts where compaction is less. As sands compact to a much less extent than muds, the common consequence of compression is for fluids and gases to move to the more porous sands. In the compaction also the shales become relatively impervious, so that lenticular sand bodies surrounded by shales that prevent further migration become reservoir rocks for gas, oil, and water arranged according to their specific gravities relative to the attitude of the sand body itself. These are the stratigraphic traps that are now becoming recognized as an important source of oil and gas. Sands are important features in sedimentation because, as already stated, their porosity on compaction may be adequate for the retention of petroliferous deposits.

The effect of erosional surfaces may have a marked influence in the formation of structural traps for oil and gas in limestones or dolomites. If the erosional surface is on limestone, as it is in the central Plains, the weathering of the surface causes leaching, and the circulation of ground water may develop pore space in the limestones at some distance below the surface. Also the change from limestone to dolomite, with consequent shrinkage in volume, may be of great significance in creating a porous reservoir rock. It has been noted time and again that reservoir beds in limestones are related to former erosion surfaces, although all limestone reservoirs are not necessarily associated with unconformities.

FOLDS

In addition to local structural traps for oil and gas on the Plains, there are also broad folds brought about by compression. The Sweet Grass arch in southern Alberta is one of the most prominent of these. It has a width, from Medicine Hat on its east flank to McLeod on its west flank, of about 125 miles, and on it are smaller flexures, at least in the Mesozoic rocks. It plunges to the north and loses its identity south of Red Deer River.

West of the Sweet Grass arch and east of the Foothills, Mesozoic strata occupy the basal part of a broad trough known as the Alberta syncline. This extends northwesterly from the International Boundary almost to Peace River, a distance of about 500 miles. It is largely filled with Tertiary strata, and hence is a noticeable feature of any geological map. It is possible, though, that the trough is quite superficial and that for part of the area from Highwood to Bow Rivers it does not exist as a broad fold in the underlying Palæozoic rocks. Farther north little information is available. Drilling in the area east of the north end of Turner Valley shows that the surface of the Palæozoic limestone has a regional southwest dip to the edge of the Foothills, and, if any syncline is present, it is under the fault plate that is overthrust from the Foothills onto the west edge of the Plains. To the south of Calgary, however, the stratigraphic relationships are such that there is reason to believe that the syncline involves the pre-Mesozoic formations.

The southwest dip, apparent along the east edge of the Alberta syncline across central Alberta, is interrupted in the vicinity of the Saskatchewan boundary, near Lloydminster, by a reversal of dip to the east. It is not known whether this structure is due to folding as the result of compression, or is the result of deposition over a broad elevated part of the Palæozoic erosion surface.

BASINS OF DEPOSITION

It is apparent from the study of the Plains that some areas received considerably more sediments even in Palæozoic time than did other areas, and that sedimentation continued in these basins of deposition when it had apparently ceased elsewhere. These basins probably existed from Precambrian time. One such is present in southern Saskatchewan, and is the extension of the Williston basin of North Dakota and northeast Montana. Another appears to have existed in east-central Alberta where there is an unusually thick section of Devonian and older rocks, even though the younger Devonian beds, present farther south, were removed by erosion prior to Mesozoic deposition. In contrast with the basin in southern Saskatchewan, which contains Tertiary strata, and, therefore, is readily discernible at the surface, the central Alberta basin has no surface expression. It is suspected, however, that in this area there may be some relationship between the basin and a thickness of 400 to 1,000 feet of rock salt that was found by drilling and is either of Silurian or, more probably, Devonian age.

ECONOMIC GEOLOGY

The weathering of the sedimentary bedrock and the glacial materials that cover the southern Interior Plains made this a rich agricultural area, but the lack of intrusive rocks precludes, in general, the occurrence of metalliferous deposits. Lead-zinc deposits do, however, occur in sedimentary Devonian strata south of Great Slave Lake. The Saskatchewan gravels, particularly in the Edmonton area, contain some placer gold, and the weathering and erosion of these beds along North Saskatchewan River Valley has allowed a lean concentration of fine gold in the bars of the river. These have been worked sporadically, but are of relatively small importance.

The mineral wealth of the Plains is confined to non-metallic substances found in sedimentary strata. The most important of these are the fuels—coal, oil, and gas. However, common salt, sodium sulphate, and gypsum are locally important.

COAL

The coal-bearing beds of the southern Interior Plains are in the Belly River and Edmonton (St. Mary River) beds of Alberta and the Ravenscrag beds of Saskatchewan.

Belly River coal occurs in the following thirteen areas in southern and central Alberta: Brooks, Empress, Lethbridge, Magrath, Milk River, Pakan, Pakowki, Redcliff, Rochester, Steveville, Taber, Wainwright, and Westlock. In the Empress, Pakan, Steveville, and Wainwright areas the coal seams are small and are not being mined. Edmonton coal is also present in the Westlock area, but at present only Belly River coal is mined.

Edmonton coal is mined from the following fourteen areas in Alberta: Ardley, Big Valley, Camrose, Carbon, Castor, Champion, Drumheller, Edmonton, Gleichen, Pembina, Sheerness, Tofield, Wetaskiwin, and Whitecourt.

TABLE XV

PRODUCTION TABLE

—	1943		1944	
	Tons	$	Tons	$
Coal—				
Alberta (Plains only)	3,414,581	10,689,194	3,160,155	11,136,348
Saskatchewan	1,665,972	2,432,249	1,390,155	2,037,212
Manitoba	999	2,964	....	....
	Bbls.		Bbls.	
Petroleum—				
Alberta (Plains only)	221,851	....	462,412	....
Saskatchewan	....	....	....	....
Manitoba	....	....	....	....
	M cu. ft.			
Natural gas—				
Alberta (Plains only)	10,866,508	....	11,896,753	....
Saskatchewan	138,235	13,823	....	....
Manitoba	....	....	....	....
	Tons		Tons	
Salt (sodium chloride)—				
Alberta	18,700	324,147	24,151	352,133
Saskatchewan	....	....	....	....
Manitoba	27,275	486,000	28,150	387,500
Sodium sulphate—				
Alberta	....	....	....	....
Saskatchewan	87,297	854,152	98,188	1,004,054
Manitoba	....	....	....	....
Gypsum—				
Alberta	....	....	....	....
Saskatchewan	....	....	....	....
Manitoba	35,180	236,710	37,768	378,965
Clay and clay products (brick, tile, etc.)—				
Alberta	....	1,010,094	....	1,118,349
Saskatchewan	....	293,050	....	290,732
Manitoba	....	132,452	....	189,115
	Bbls.		Bbls	
Cement—				
Alberta (Plains only)	....	....	....	....
Saskatchewan	....	....	....	....
Manitoba	792,392	1,497,445	866,186	1,697,277
	Tons		Tons	
Building stone—				
Alberta	13,032	47,490	12,755	47,100
Saskatchewan	....	....	....	....
Manitoba	36,887	46,132	33,796	51,464

In addition to the above there are several areas in the Peace River district where coal occurs in the equivalents of the Belly River-Edmonton sequence of beds.

Most of the coal in the Plains areas of Alberta is sub-bituminous in rank, but in the Lethbridge and Magrath areas the coal is higher grade bituminous.

All the coal seams are flat-lying. In the Edmonton formation there are fourteen seams varying from 1 foot to a maximum of 20 feet in thickness. In Red Deer River Valley, where Edmonton strata outcrop in the Ardley, Big Valley, Carbon, and Drumheller coal fields, the formation is 1,224 feet thick and the aggregate thickness of coal seams is 62 feet.

Lethbridge is the most important mining area for Belly River coal. The upper 85 feet of the formation are there coal-bearing, but only one seam is extensively worked. It varies from 3 feet to 5 feet 6 inches in thickness.

At Taber, where the coal is strip-mined, a seam about 4 feet thick occurs near the top of the Foremost formation, which is stratigraphically about 380 feet below the top of the coal-bearing beds at Lethbridge. The seams of coal in the Milk River and Redcliff areas are in the Foremost formation. The coal in the Brooks area is in Bow River Valley at Eyremore, and is in upper Belly River beds. It has been strip-mined on a valley bench, and mined by a shaft 150 feet deep on the upland.

NATURAL GAS

Petroleum and natural gas are closely associated in origin, and, under similar conditions, in mode of accumulation. Petroleum is always associated with some natural gas in the earth reservoirs, but, because of the greater mobility of gas when subjected to earth compressive forces, there are many occurrences of natural gas without any evidence of the presence of petroleum.

Viking-Kinsella Area

The greatest developed reserve of natural gas on the Plains is in the Viking-Kinsella area of east-central Alberta (Figure 52). In a few wells a small amount of distillate has been found on the down-dip side of the gas area, which has given rise to the hope that an oil field may also be found in this area and for which the search is still being continued. Mostly, however, the gas is dry, that is, it contains no light volatile liquids.

Gas was discovered in the Viking field north of the town of Viking in 1914, and the area now developed by the drilling of twenty-six wells of which eighteen are producing, comprises about 34 sections of proved land, that is 21,760 acres. The original pressure of these wells, which are about 2,200 feet deep, was 733 pounds, and in 1944, after a production of 55,000,000 M cubic feet, the pressure was 520 pounds. In 1945 there were eighteen wells. The gas was piped to Edmonton in 1923, and supplies a number of small towns en route. In 1940 the pipe-line was extended to the Kinsella field to the northeast of Viking, and in 1946 it was further extended from the gas main at Poe, 50 miles southeast of Edmonton, to Red Deer by way of Camrose, Wetaskiwin, Ponoka, and Lacombe. This branch line is 98·5 miles long, and is connected to various towns by smaller lines.

The gas occurs in the Viking sand, which is in Upper Cretaceous marine shales about 140 feet above the Lower Cretaceous non-marine beds. The sand is widespread, varying from a few feet to 20 feet in thickness. Apparently the porosity of the reservoir rock and its thickness is more important in relation to production than is the position of the well in relation to the structure.

The first well was drilled in the Kinsella gas field in 1930, and from 1932 to 1944, eighteen more wells were completed, proving a gas area 7 miles long by 5 miles wide, representing more than 20,000 acres. In 1946 five more wells were drilled in the gas area. In addition, an extensive drilling program has been undertaken in the adjoining areas. Seventeen wells have been drilled, of which ten have been successful. The proved area, which trends northwest, is now more than 30 miles long by about 15 miles wide, representing about 275,000 acres, including the Kinsella field. The initial open flow of individual wells was large, as much as 20,000 M cubic feet, and only one of those drilled by Northwestern Utilities was less than 7,000 M cubic feet a day, with most of the wells over 10,000 M cubic feet.

Wainwright-Fabyan Area

In the Wainwright-Fabyan area (*See* Figure 52) the Viking gas horizon is composed of sandy shale, but wells in it yield 1,000 M to 3,000 M cubic feet of gas a day. Gas from Fabyan is piped 8 miles to Wainwright.

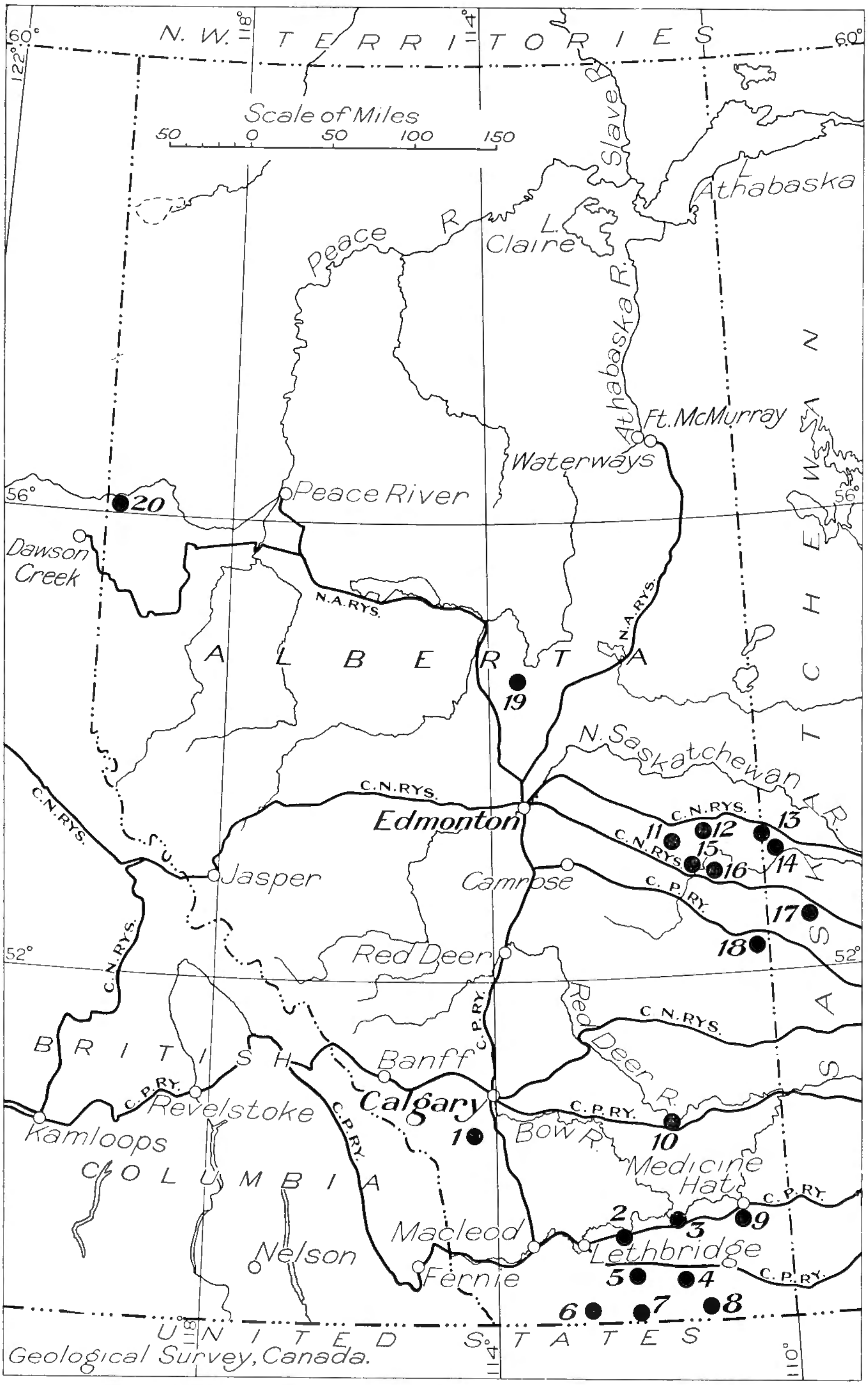

Figure 52. Index map of oil and gas fields of Alberta and western Saskatchewan. 1, Turner Valley; 2, Taber; 3, Bow Island; 4, Foremost; 5, Conrad; 6, Del Bonita-Twin River; 7, Red Coulée; 8, Pinhorn; 9, Medicine Hat; 10, Princess-Brooks; 11, Viking-Kinsella; 12, Vermilion; 13, Lloydminster; 14, Lone Rock; 15, Fabyan; 16, Wainwright; 17, Unity; 18, Provost; 19, Athabaska; 20, Pouce Coupé.

East of Wainwright and in the vicinity of the Alberta-Saskatchewan boundary the Viking horizon is mostly too shaly to produce gas, but in Saskatchewan, in an area southwest of Unity, a sand at about the same stratigraphic position has been found to be gas-bearing. Gas has now been piped into Unity from this field, a distance of about 5 miles. The volume of production apparently is dependent on the thickness and porosity of the sand, and varies from a few thousand to 3,500 M cubic feet initial open flow daily.

Provost Area

Drilling in 1946 in the area south of Provost in east-central Alberta near the Saskatchewan boundary has given further proof of the wide extent of the Viking sand. There is reason to believe, however, that this sand is developed locally rather than as a continuous body. Drilling of the first well south of Provost revealed the presence of gas in the Viking sand, but the well was completed as an oil well in a sand at the top of the Lower Cretaceous beds. Number 2 well, drilled a mile north and half a mile west of Number 1 well, gave a drill-stem test indicating about 1,800 M cubic feet in the Viking sand, but the well is being deepened to test lower formations. Number 3 well, about a quarter mile north of Number 1, was completed in the Viking sand with an open flow of 4,700 M cubic feet, and Number 4 well, about 5 miles east of Number 1, also completed as a gas well in the Viking sand, gave an open flow of 2,100 M cubic feet a day. Thus another large gas area has been opened in Alberta.

Vermilion-Lloydminster Area

In the Vermilion-Lloydminster area (*See* Figure 52) gas occurs in a sand at the top of the Lower Cretaceous and in other sands somewhat lower stratigraphically. Gas was discovered near Lloydminster in 1934 in a sand 260 feet below the top of the Lower Cretaceous, but subsequent wells have developed gas flows in the sand at the top of the Lower Cretaceous. Heavy asphaltic oil with some gas has also been produced in this area from a sand 165 feet below the top of the Lower Cretaceous. In the Vermilion area the gas field that supplies the town is about 10 miles to the southeast. Gas is found both in the sand at the upper contact and in Lower Cretaceous beds, but, apparently, in a different sand than that which produces heavy oil in the Borradaile field, 6 miles east of Vermilion. Ordinarily in the Borradaile field only sufficient gas is present with the oil to pump the wells, and the sand in which these occur is about 130 to 140 feet below the top of the Lower Cretaceous non-marine beds.

Southern Alberta Gas Fields

Bow Island Field. In southern Alberta there are the developed gas fields of Bow Island, Foremost, Brooks, and Medicine Hat, as well as many other individual wells containing gas in quantity (*See* Figure 52). A large undeveloped gas reserve is undoubtedly present in the Princess area where an oil field is producing from Devonian limestones. Apparently, however, the most prolific gas horizon in this area is in the basal Lower Cretaceous sand, although other sands also carry gas.

The Bow Island gas field was discovered in 1909, and after the drilling of several wells, a 16-inch gas main was built to Calgary in 1912, a distance of 110 miles. In all twenty-eight wells were drilled to a depth of 2,200 feet on the upland or about 1,900 feet in Oldman River Valley. By 1919 the field was showing signs of exhaustion after the withdrawal of 28,000,000 M cubic feet of an estimated original gas content of 45,000,000 M cubic feet. In 1930 operations were commenced to re-pressure the field with Turner Valley gas, and by 1939, 13,250,000 M cubic feet had been injected for storage, and the pressure had increased from 256 to 565 pounds. The original rock pressure of the field was 745 pounds.

The gas in the Bow Island field occurs in an Upper Cretaceous sand about 360 feet above the top of the Lower Cretaceous in the deep, Imperial Burdette No. 1 well, but this interval to the top of the Lower Cretaceous increases to approximately 500 feet in the Taber area. In the Bow Island field the gas was in pay streaks, not all equally porous, in a sand about 30 feet thick and commonly overlain by a fine pebble zone.

Foremost Field. The Foremost gas field lies 30 miles south of the Bow Island field. It was discovered in 1916, but development dates from 1923. In 1927 there were six productive gas wells, although several others had been drilled. The gas horizon is apparently the Bow Island sand, and although it is thought to occur in an east-west fold, there is no south closure. The sand, however, is lenticular southward up the flank of the Sweet Grass arch. Drilling in 1946 has greatly extended this field to the south and southeast in the area west of Pakowki Lake. The gas area is presently under development and the indicated gas reserve is very large.

A 10-inch pipe-line was built in 1923 to join the Foremost field with the 16-inch Calgary line at Burdett. With the discovery of large quantities of gas in Turner Valley in 1924 this field has only been drawn on in emergencies.

Brooks Area

The Brooks gas field is small, with a few wells of low yield producing from a depth of about 1,250 feet in a sandy zone said to be in the Milk River formation. There is no structure in the Brooks field other than the regional dip of the strata of about 25 feet to the mile. Eight wells supply the town of Brooks. The supply of gas from the Brooks field has barely been adequate for the needs of the town. However, a new well drilled 7 miles northeast of Brooks in 1946 has been completed in the basal Cretaceous sand with an open flow of 23,000 M cubic feet and a small show of light oil. Further drilling is to be done in the hope of finding oil down the flank of the structure to the northeast. Thus adequate gas is now available for Brooks when the situation warrants the building of the necessary pipe-line. The Brooks discovery in the basal Lower Cretaceous sand is further proof of the widespread gas potentialities of the Brooks-Princess-Steveville area.

Medicine Hat Field

The Medicine Hat gas field, at the town of the same name, is the oldest in Alberta. Gas was found in a water well drilled in 1890, and this subsequently led to the development of the gas field. Two gas zones occur; the upper zone, at a depth of 650 feet, is probably the same as the producing sand at Brooks, and the lower, at about 1,100 to 1,200 feet, is 250 to 300 feet below the base of the Milk River formation in Upper Cretaceous sandy shales. The gas field covers an area of about 72 square miles in and close to the cities of Medicine Hat and Redcliff, and the gas rights on four townships are reserved for the use of these communities. More than seventy wells have been drilled to 1945 with open flows of 1,000,000 to more than 4,000,000 cubic feet a day. Gas is used both for domestic and industrial purposes.

Pinhorn Area

In 1943 McColl-Frontenac Oil Company drilled a well in the Pinhorn area close to the International Boundary southeast of Foremost. Tests showed 4,850 M cubic feet a day of gas in the basal Lower Cretaceous, 6,000 M cubic feet a day in the Jurassic, and 5,000 M cubic feet a day in the top of the Mississippian limestone. In 1944 a second well was drilled about a mile north of the first, but yielded only minor flows of gas and shows of oil with water, and was abandoned. In 1946, however, four wells were completed in an area 12 to 16 miles north of the original discovery. The first well obtained an open flow of 46,000 to 48,000 M cubic feet in the Bow Island sand; the second, $1\frac{1}{2}$ miles to the southwest, obtained 8,000 M cubic feet a day; the third, 3 miles northwest of the first, indicated a major gas well on drill-stem test, whereas the fourth, 5 miles east and slightly north of the third, was a dry hole. Subsequent wells, however, have shown that this area is probably an extension of the Foremost gas field as already indicated. Thus, regardless of its ultimate yield a large new gas area has been discovered with an additional, apparently somewhat smaller, field discovered in 1943 and within $1\frac{1}{2}$ miles of the International Boundary.

Miscellaneous Alberta Production

The prevalence of gas in Alberta has made it possible to obtain small supplies for local use. At the Dominion Experimental Station at Suffield the Department of National Defence has drilled several wells for fuel. The flows of gas are less than 500 M cubic feet, and the gas zone is that of the Medicine Hat producing sand. In other areas individual gas wells have given supplies that, mostly, only have been used locally. An exception to this was the Range (Rogers Imperial) No. 1 well drilled close to the International Boundary south of Foremost. This well obtained gas on the basal Lower Cretaceous sand, in the Ellis (Jurassic), and in the top of the Palæozoic limestone. The combined flow was about 45,000 M cubic feet, but the gas from the limestone was high in sulphur and was plugged. Gas from the other sands in the well was piped to Montana to join the pipe-line from the Whitlash field to Great Falls, and between the years 1930 and 1939 about 1,300,000 M cubic feet were exported. At Wetaskiwin, south of Edmonton, a well 1,200 feet deep was used to supply a hotel, and at the Provincial Asylum at Ponoka gas from shallow wells was used for some time. At the town of Athabaska 100 miles north of Edmonton six shallow wells, about 350 feet deep, were drilled in 1913-4, and gas from them was used locally until exhausted. In 1943 Deca No. 2 well, drilled 6 miles southwest of the town, obtained 19,000 M cubic feet of gas at a depth of 1,684 feet in the Grand Rapids formation. This gas has now been piped to supply the town of Athabaska. Also at Pouce Coupé, close to the British Columbia boundary, Bonanza Royalties No. 1 well, drilled to a depth of 2,173 feet, obtained an open flow of about 5,000 M cubic feet of gas, but there is no present market for it.

Saskatchewan Gas Fields

In Saskatchewan, gas has been produced for local use at Lloydminster, Unity, and Kamsack. The first gas well at Lloydminster was drilled in 1934, and gave a flow of 16,750 M cubic feet at a depth of 1,970 feet, from a Lower Cretaceous sand. This well became flooded with water, and was abandoned in 1938, but other gas wells south of the town continue to provide supplies needed in this community. The development of gas at Unity is quite recent, and only during the past summer (1945) has this supply been piped to the town. The gas comes from two sands, an upper one at a depth of about 1,650 feet, and considered to be at about the Viking sand horizon, and a deeper one at a depth of 2,050 feet in the Lower Cretaceous directly above the Palæozoic limestone. Some large wells have been obtained and drilling is being continued.

In the Kamsack area of Saskatchewan near the Manitoba border more than fifty shallow wells, around 200 feet deep, have been drilled for small gas flows in brown shale. The initial pressure was about 35 pounds and, as would be expected, rapid exhaustion occurs. The gas has been used in the town of Kamsack.

Southwestern Manitoba

In southwestern Manitoba shallow wells of 150 to 300 feet in depth have produced sufficient gas from Upper Cretaceous marine shales to supply farm-houses, but no gas fields have been developed.

PETROLEUM

The search for petroleum on the Plains has been extensive in the last few years, and several fields have been developed. Among the older fields are Red Coulée and Wainwright, and the newer fields[1] are Taber and West Taber (Barnwell), Conrad, Princess, Vermilion, and Lloydminster. Recently there has been a considerable program of drilling in southern Saskatchewan, with negative results. A number of oil wells have been drilled in Saskatchewan at Lloydminster and the producing area has been greatly extended in 1946. Previously the main production of this field was in Alberta, but this has increased considerably in 1946, mainly from Saskatchewan. Other than this there is no oil production in Saskatchewan, and none in Manitoba.

Red Coulée Field

The Red Coulée field (*See* Figure 52) was discovered in 1929 and abandoned in 1944. Production came from seven wells drilled close to the International Boundary on a small "nose" on the Sweet Grass arch. The producing horizon was a sand in the lower part of the Lower Cretaceous at a depth of about 2,500 feet. All wells were pumped. Production during the life of the field was 328,711 barrels.

Taber and West Taber (Barnwell) Fields

The Taber field (*See* Figure 52) was discovered in 1942, although one well, Plains No. 2, had obtained some oil in this area in a well drilled in 1937. The field occupies about 280 acres, and was proved by seven wells. Production comes from a bar sand about 470 feet below the top of the Lower Cretaceous, and all wells are pumped.

In 1944 a new oil field, south of Barnwell and a few miles west of Taber, was found to be productive from the Taber sand. Only four wells had been drilled in it at the end of 1946, but two other wells south of the main field gave a small production. Up to the end of 1945 the production of Taber and West Taber was 427,210 barrels.

Conrad Field

In 1944, also, an important discovery was made at Conrad, about 20 miles southeast of Taber. Production there comes from sand in the Ellis (Jurassic) beds at a depth of approximately 3,100 feet below the plateau level, or 2,950 feet in depth where the wells are in the bottom of Etzikom Coulée. The oil has a gravity of about 26 degrees. The sand is lenticular, wedging out above shale against the northward plunging Palæozoic rocks of the Sweet Grass arch. Also it is not equally porous, and on the edge of the field is tight and unproductive. At the end of 1944 there were three productive wells in this area. An additional seventeen successful completions were made in 1945, and a pipe-line has been laid to connect the field with Conrad station, a distance of 3 miles. One new well was drilled in 1946. The field as presently developed is 2¼ miles long, with a maximum width of 1 mile. Initial production of the wells on the pump was 50 to better than 100 barrels a day and in midsummer 1946 seventeen wells were averaging slightly more than 1,000 barrels each a month.

[1] For additional data on new fields *See* note on page 219.

Princess Field

Between the years 1939 and 1942 several wells were drilled in the Princess field, 125 miles east of Calgary, and one of these, Standard Princess No. 2, obtained some oil in the upper part of the Mississippian limestone. In 1944 a well was drilled as an offset to Princess No. 2 and at a depth of 3,965 to 3,982 feet oil of 34·5 degree gravity was found in Devonian dolomite. The top of the productive zone is 345 feet below the top of the Devonian and 50 feet below the top of a limestone and dolomite that underlies a succession of anhydrite beds. This is the first well to produce oil from Devonian beds in the central Plains. Additional drilling in 1945 enlarged the area to five wells on a 40-acre spacing program, and the field now appears to be incapable of further expansion. The size of the field is thus relatively small, and some water is present with the oil in a few of the wells. The discovery, however, is important as indicating the type of structure that may be found in this area, and drilling has already indicated other possible productive fields in younger strata, in the weathered debris on top of the Mississippian and in the upper Mississippian beds, in the basal Lower Cretaceous sand, and in the Upper Cretaceous Bow Island sand.

Vermilion-Lloydminster Area

In east-central Alberta the Vermilion and Lloydminster fields (*See* Figure 52) are producing oil of 14 to 15 degrees gravity for railway fuel. The discovery well in the Vermilion area is 6 miles east of the town and 1 mile south of Borradaile station, and was completed in 1939. Production was obtained in forty-eight wells, although considerably more than this have been drilled in the adjoining areas and in outlining the field. The production is from a sand about 130 to 140 feet below the top of the Lower Cretaceous at a depth of 1,800 to 1,850 feet. The oil as produced is partly emulsified with water and contains considerable fine silt. Cleaning is done in a Petreco (electrical dehydrating) unit, and the production in 1945 was 238,358 barrels. Individual wells produce 10 to 35 barrels a day on the pump.

The Lloydminster field is spread over a wide area in Alberta and Saskatchewan, and may consist of more than one continuous pool. Production per well is somewhat better than at Vermilion and is mainly from a sand 165 feet below the top of the Lower Cretaceous although two other sands also have produced oil. The structure is relatively flat, and, as at Vermilion, the oil has to be cleaned. By the close of 1945 there were eleven producing wells in Alberta and three in Saskatchewan. In 1946, however, the field was greatly expanded, particularly in Saskatchewan, about 4 miles south of Lloydminster on both sides of the 4th meridian. Production was somewhat retarded by lack of marketing facilities, and considerable oil on the Saskatchewan side was placed in open pit storage. Late in 1946 a site was bought for an asphalt plant and plans are under way for its erection. This outlet, together with the oil being bought by the Canadian National Railways for fuel, will undoubtedly stimulate interest, and the prospects are considered excellent for further expansion. In 1946 an area 6 miles west of Lloydminster was extended to the north by a well that may open up a new pool. Also, drilling 15 miles southeast of Lloydminster at Lone Rock has established the presence of both oil and gas, and may also indicate a new pool. The limits of none of these pools are yet established.

Wainwright Area

In the Wainwright area (*See* Figure 52) oil was discovered in 1923, but production did not begin until about 1926. Several wells scattered over a considerable area were drilled, and a few of these were found to be productive in a sand about 140 feet below the top of the Lower Cretaceous. The production of the field, mainly from seven wells, to the end of 1945 was 223,025 barrels. The oil has a gravity of 18 to 21 A.P.I.

BITUMINOUS SANDS

Bituminous sands of Lower Cretaceous age outcrop on Athabaska River and its tributaries in the Fort McMurray area of Alberta. They are readily accessible and have been extensively studied where they outcrop for 118 miles along Athabaska River both above and below Fort McMurray and on many tributary streams (*See* Figure 52).

The sands in which the bitumen occurs are approximately 180 to 250 feet thick, but the thickness and grade of deposit available for exploitation are highly variable. Some of the sand may carry as much as 17 to 19 per cent of bitumen by weight, but most of it is lower grade with interbedded streaks of shale and lean material. The amount of overburden covering the deposits is an important consideration in evaluating commercial possibilities of any local area and this, too, is highly variable, with only limited known areas of rich material under light cover.

In the Mildred-Ruth Lakes area, on the west side of Athabaska River opposite the mouth of Steepbank River, 22 miles north of Fort McMurray, diamond drilling in 1946 by the Dominion Government, who during the war sponsored the operations of Abasand Oils, Limited, has established the presence of a rich bituminous sand area with interstratified bitumen beds. These bitumen beds, varying from a few inches to 21 feet thick, with an aggregate maximum thickness of 57 feet in one hole, have been found in thirty-three holes of seventy-three drilled on $\frac{1}{8}$- to $\frac{1}{4}$-mile spacing in an area of about 3 square miles, which is considered to contain more than 500,000,000 barrels of bitumen. In 120 acres close to a possible plant site the rich bituminous sands with bitumen beds have an average thickness of 188 feet, overlain by 47 feet of overburden, and contain more than 50,000,000 barrels of bitumen, which is sufficient to supply 10,000 barrels a day to a plant for 15 years. The deposit is sufficiently rich to warrant commercial operations when these are considered feasible.

Many attempts have been made to work the bituminous sands by strip mining and extraction of the bitumen content. For a few years the International Bitumen Company operated at Bitumont, 50 miles down Athabaska River from Fort McMurray. This deposit, which is rich and rather soft in comparison with some others, has now been taken over by Oil Sands, Limited, supported financially by the Alberta Government. The present plant has not yet reached the production stage.

In the Fort McMurray area, on Horse River, the Abasand Company has been active for the past 15 years. During that time experiments have been carried on with different plant designs and by various methods to find an economical means of extraction. In 1943 and 1944, owing to the scarcity of oil products during the war, the Abasand operations were financially supported by the Dominion Government. A new plant was built after the former one had burned down, but unfortunately, when the new plant was ready to go on continuous operation to determine actual operating costs, it also burned down. No new plant has been built. The method of extraction used is: washing with warm water to obtain the bitumen from the sand, and the dilution of the recovered bitumen with lighter oil products to settle out the contained silt. A small topping plant is used to recover the oil used as a diluent and to make such diluent as is necessary from the raw bitumen. The Oil Sands method at Bitumont is different in that although hot water is used in separation, no diluent is used.

The products that can be made from the bitumen are dependent on the refining process used. Asphalt of high quality for roofing or for road paving is the main constituent. If very expensive refinery processes are adopted, however, a range of products from aviation gasoline to tar residuum can be manufactured. The problem of the use of the vast quantities of "tar sands" available is economic. The bitumen can be extracted and products can be made from it, but cheap methods of operating are essential if the products are to be marketed in competition with similar products obtained from oil produced from oil fields in the usual way.

SALT

Salt production is confined to the Waterways area of Alberta, 300 miles north of Edmonton, and the Neepawa area of Manitoba. At Waterways the salt beds, 200 feet thick, are remarkably pure and underlie 200 feet of gypsum and anhydrite beds, in turn underlying limestones containing Upper Devonian fossils. The top of the salt deposit in the first salt well drilled at Waterways in 1936 was at a depth of 694 feet. Below the bottom of the salt, at 893 feet, are more gypsum and anhydrite beds to a depth of 898 feet, where drilling was discontinued.

In 1937 a salt evaporation plant was built at Waterways. Coal brought from the Edmonton area is used as fuel. A 6-inch production well was drilled 170 feet into the salt and production began late in 1937, but the first shipment was not made until early in 1938. In 1939 another well was drilled, and 211 feet of salt was penetrated. The top of the gypsum-anhydrite beds was reached at 525 feet, the top of the salt at 723 feet, the bottom of the salt at 934 feet, and the hole was discontinued at 952 feet in the lower gypsum-anhydrite-dolomitic beds.

Various grades of salt both for human and animal consumption are made at the Waterways plant, and production in 1944 was 24,151 tons.

Thick salt beds are known to occur in east-central Alberta and west-central Saskatchewan. In Vermilion Consolidated No. 15 well, drilled in 1944, 12 miles southeast of Vermilion, a salt deposit 422 feet thick was encountered between depths of 3,481 and 3,903 feet. This salt contained a few thin bands of shale and, in the bottom, some thin bands of anhydrite and dolomite were present. The age of the salt is thought to be Devonian. Similar salt beds have been encountered in deep wells in Alberta at Wainwright, Provost, and at Elk Point north of North Saskatchewan River. The first or Number 1 well at Elk Point reached the top of the salt beds at a depth of 2,775 feet, and drilled an aggregate thickness of 750 feet of salt in three beds, of which the thickest was about 400 feet. A gas well with an open flow of 3,000 M cubic feet a day at a depth of 1,305 to 1,320 feet in the Lower Cretaceous has been completed close to the salt well. In Number 2 well, drilled 7 miles northwest of Number 1, an aggregate thickness of about 1,000 feet of salt-bearing beds was drilled. In Saskatchewan similar salt beds have been drilled south of Unity, at Davidson, and in southern Saskatchewan. Thus the salt beds cover many thousands of square miles, and may extend from the Wainwright-Vermilion-Elk Point area to the Waterways deposits, 300 miles north of Edmonton.

The Neepawa salt deposit in Manitoba was discovered by a well completed in 1913 at a depth of 1,742 feet. In 1931 the Neepawa Salt Company, a subsidiary of Canadian Industries, Limited, was formed, and in 1932 commenced operations by pumping out brine, which rises in the well to within 200 feet of the surface, and evaporating it to obtain salt. In 1942 another well 2,000 feet west of the first one found salt zones between depths of 1,162 and 1,445 feet. The original plant produced only coarse grades of salt, but in 1940 a new plant was built, capable of producing 100 tons a day, and making coarse, table, and dairy salt as well as compressed blocks for livestock use. Estevan coal is used in the evaporation process.

No salt is at present being produced in Saskatchewan. In drilling a well at Simpson a salt brine was encountered at a depth of 3,435 feet. A small salt plant was built in 1933, but only operated for 2 years, in which time 774 tons of salt were produced. In 1942 a deep well near Radville encountered 240 feet of rock salt between depths of 7,602 and 7,842 feet, but no attempt has been made to utilize this.

SODIUM SULPHATE

Sodium sulphate deposits result from the evaporation of alkaline lake waters, and form hard beds of crystalline salts usually mixed with impurities in the form of mud. The salts are gathered from the lake and put through a purification plant before being shipped to the market.

Saskatchewan is the only province shipping sodium sulphate at present. The material is largely used in the Kraft Paper Mills of Ontario and Quebec and the copper-nickel refinery at Sudbury, Ontario. Small amounts are used in the glass and textile industries.

There are many deposits of sodium sulphate in Saskatchewan, and plants are situated at Bishopric, Alsask, Ormiston, Oban, and Gladmar. The two largest operators are the Horseshoe Lake Mining Company, with plant at Ormiston, and Natural Sodium Products, Limited, with plants at Bishopric and Alsask.

GYPSUM

Gypsum for commercial purposes is mined in Manitoba only. Gypsum beds outcrop near Gypsumville in the vicinity of Lake Martin, Manitoba, and are quarried. The exposed area is about 4½ square miles. Operations began in 1900, and have been continuous since that time. The material is blasted from a face about 15 feet high, loaded into cars, and shipped to a plant at Winnipeg where it is processed into various kinds of gypsum products. Since 1928 Gypsum Lime and Alabastine Canada, Limited, have worked these deposits.

In 1929 Western Gypsum Products, Limited, started to mine gypsum a mile south of Amaranth, 40 miles north of Portage la Prairie, on the west side of Lake Manitoba. The gypsum bed is 38 feet thick, and is reached by a shaft 130 feet deep. The processing mill is in Winnipeg.

CLAY AND CLAY PRODUCTS

In Alberta the clay products industry largely centres at Medicine Hat where cheap natural gas is available for fuel. The clays, however, are obtained by selective mining in the Eastend and Willows area of Saskatchewan. The products made are stoneware, sewer-pipe, pottery, and tableware. At Claybank, Saskatchewan, a plant uses plastic refractory clays obtained by selective mining of the Upper Cretaceous Whitemud beds (Plate XXXVIII).

Glacial clays have been used in a number of areas on the Plains for the making of brick. Mostly, however, these clays are rather unsatisfactory for this purpose.

CEMENT

On the Plains the only operating cement plant is that of Canada Cement Company at Fort Whyte, close to Winnipeg, Manitoba. The limestone for this cement plant is quarried on Lake Manitoba and mixed with clay obtained not far from the plant.

In Alberta the main cement plant is at Exshaw in the Foothills west of Calgary.

PLATE XXXVIII

Exposures of pottery clay, Willows, Saskatchewan. Photo by N. B. Davis, Bureau of Mines.

PLATE XXXIX

Building stone quarry and kilns at Garson (Tyndall), Manitoba. Photo by M. F. Goudge, Bureau of Mines.

BENTONITE

Bentonite from near Drumheller, Alberta, has been used in the manufacture of drilling mud for oil wells. In Manitoba bentonite has been obtained from a deposit near Morden and used in foundries and for bleaching in oil refining.

BUILDING STONE

The Ordovician limestone of Tyndall and Garson, Manitoba, has been used extensively for building (Plate XXXIX). It is a mottled grey to buff stone. The Paskapoo sandstone at Calgary and elsewhere is also suitable for building purposes.

LEAD AND ZINC

On the south shore of Great Slave Lake at Pine Point west of Fort Resolution five deposits containing galena and sphalerite have been found in relatively flat-lying dolomites of the Middle Devonian Presqu'ile formation. The dolomite is commonly quite massive and cavernous, but thin beds are present. On the north shore of Great Slave Lake at Windy Point this dolomite yields copious oil seepages, and small quantities of bitumen are reported in brownish dolomites associated with the mineral deposits. At one locality about 4 miles from the mineral deposits a pyrobitumen resembling albertite has been found in irregular chunks in the cavernous dolomite.

Occurrences of lead-zinc minerals have been found in an area 15 miles from east to west and 10 miles from north to south in the Pine Point area, but the five main deposits occur in an area 1 mile long by ½ mile wide. Three of these deposits are roughly circular and about 250 feet in diameter; the fourth is elliptical, about 900 feet by 200 feet; and the fifth measures 125 by 80 feet. Drilling has shown that the deposits are superficial, having a depth up to 75 to 100 feet, but becoming lower in grade in the deeper parts. Some of the ore contains more than 30 per cent lead and more than 20 per cent zinc, and the richer parts occur at a depth of 10 to 45 feet.

The beds in which the ore occurs lie in a broad syncline that, locally, has been somewhat folded and fractured. The deposits are along two lines, which are considered the shattered axes of low, local anticlines in which jointing is prominent. Sink holes surround some of the deposits, but others show no surface expression. Lead and zinc minerals occur in greater or less amounts throughout the deposits, but beds of nearly barren material may be interstratified with others containing a high mineral content. It seems obvious, therefore, that the deposits are of the replacement type, but the origin of the galena and sphalerite is obscure. Silver is present only in insignificant amounts.

NOTE. Since this volume was forwarded for printing the Leduc oil field, 20 miles southwest of Edmonton, has been discovered, and to date (October 1947) has eleven productive wells. The discovery well was completed at a depth of 5,066 feet, the reservoir beds being dolomites of Devonian age. This discovery is the most important since that of Turner Valley, gives promise of becoming a major field, and greatly increases the prospect of discovering additional fields in the Plains.

CHAPTER VII

THE CORDILLERAN REGION

(*C. S. Lord, C. O. Hage,* and *J. S. Stewart*)[1]

GENERAL STATEMENT

The Cordilleran region in Canada embraces the mountainous belt of country, some 500 miles wide, that borders the Pacific Ocean. It is part of a great mountain system that extends along the Pacific border of the continent. In Canada the region includes Yukon and most of British Columbia, as well as a western part of Alberta and 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 Great 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, from south to north, lies a little west of Calgary, in southern Alberta, and close to Hudson Hope on Peace River; it passes through the southeast corner of Yukon, crosses to the east side of Mackenzie River about 50 miles below Fort Simpson, crosses Bear River, and re-crosses to the west side of Mackenzie River near Fort Good Hope; thence it reaches the Arctic coast at the west edge of the Mackenzie River delta.

Except in the far north, the Cordilleran region is largely a forested country, but the more mountainous areas everywhere project well above timberline. In the southern interior are wide stretches of grass-covered or sparsely wooded hills and valleys. The region has contributed about one-quarter of all mineral wealth produced in Canada, outstanding mineral products being copper, gold, lead, silver, zinc, coal, natural gas, and petroleum. In British Columbia, the principal mineral province of the region, mining in 1945 contributed 12·5 per cent of the value of all Canadian production.

PHYSICAL FEATURES

The Cordilleran region includes three northwesterly trending physiographic sub-provinces: (*a*) a western system of mountains; (*b*) a central system of plateaux and mountains; and (*c*) an eastern system of mainly mountains (*See* Figure 53).

WESTERN SYSTEM

The western system includes the St. Elias, Coast, Cascade, and Vancouver Island Mountains. The St. Elias Mountains occupy an area in the extreme northwest corner of British Columbia and adjacent, southwestern Yukon. They are the highest in Canada, extremely rugged, and in large part covered by an ice-field. The elevation of Mount Logan (*See* Plate I) the highest peak in Canada, is 19,850 feet, and other peaks exceed 15,000 feet.

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[1] C. S. Lord prepared various introductory sections, and is responsible for the general geology of the Western Cordillera, the section on metalliferous deposits, and miscellaneous non-metallic deposits. C. O. Hage and J. S. Stewart are responsible for the geology of the Eastern Cordillera, and sections on coal and petroleum and natural gas.

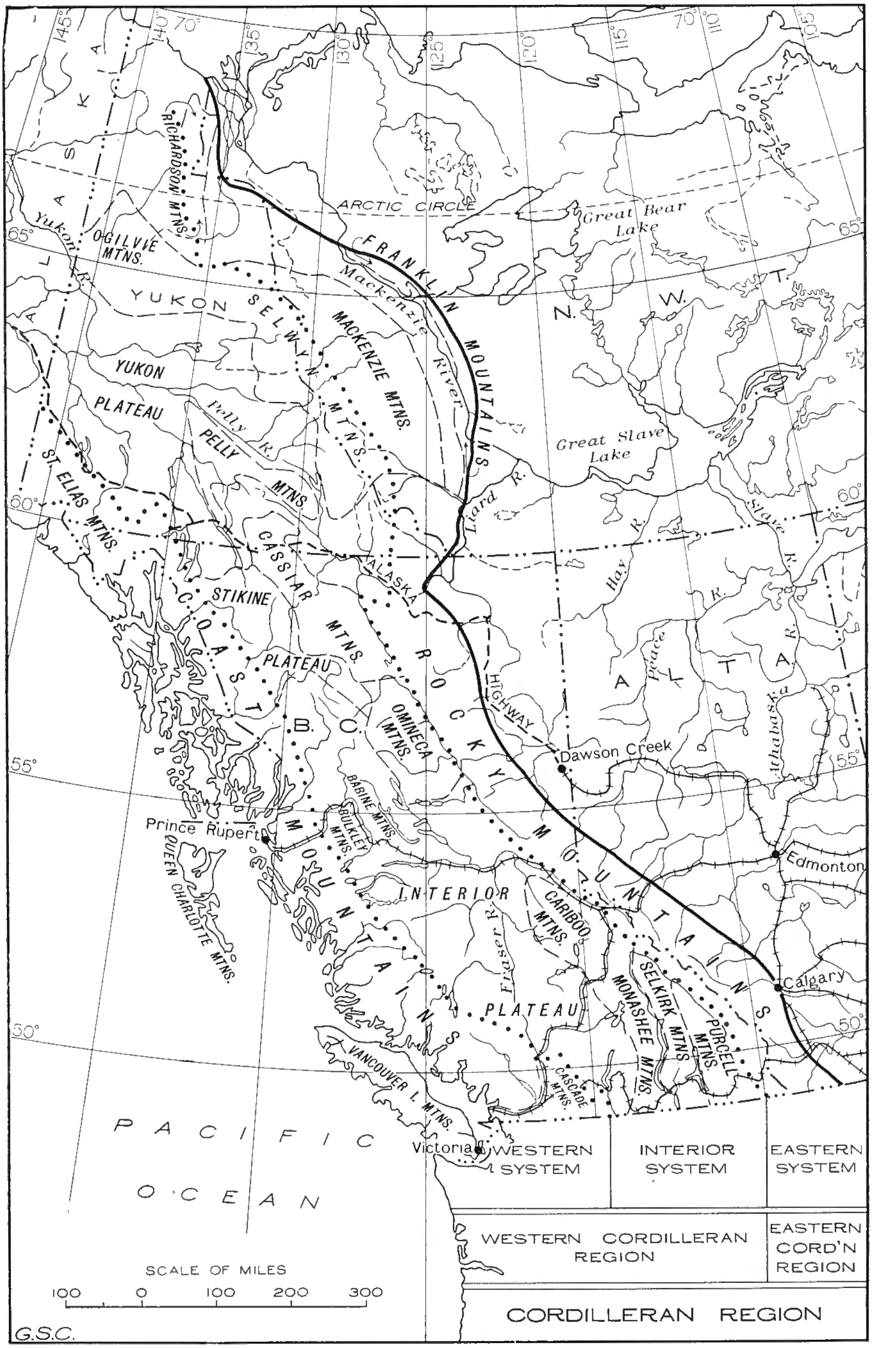


Figure 53. Physical divisions of the Cordilleran region.

The Coast Mountains occupy 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 an almost unbroken succession of bare, rugged peaks and saw-toothed ridges rising to elevations from 7,000 to more than 13,000 feet (Plates XL and XLI). Alpine glaciers and ice-fields are common, and in a few places in the northern half of the range valley glaciers extend to sea-level. The range is crossed by a number of deep river valleys, and its western margin is penetrated by numerous, long, narrow fiords continued inland by deep U-shaped valleys.

The Cascade Mountains project into Canada from the State of Washington and are more than 100 miles wide where they cross the border. They lie on the east side of lower Fraser River Valley, which separates them from 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 7,500 and 8,500 feet; they are fully as rugged as those of the adjacent Coast Mountains, and, like them, hold many alpine glaciers.

Mountains occupy most of Vancouver Island and culminate, in the central part, in peaks 5,000 to 7,000 feet or more above sea-level. The western side of the island, like the western side of the Coast Mountains, is characterized by an intricate set of fiords and by heavily timbered rocky slopes that rise abruptly from the sea to heights of several thousand feet. A lowland as much as 10 miles wide borders the east coast.

CENTRAL SYSTEM

The central system, composed of dissected plateaux and scattered mountain ranges, occupies a belt that averages more than 200 miles wide and extends southeast from the Alaska Boundary at Yukon River to the southern boundary of British Columbia at Okanagan River. In Yukon it includes the Yukon Plateau and Ogilvie, Selwyn, Pelly, and other mountains. In British Columbia north of latitude 54 and 55 degrees it includes Cassiar and Omineca Mountains, Babine and Bulkley Mountains, and Stikine Plateau. In the southern part of the province it comprises the Interior Plateau and Cariboo, Monashee, Selkirk, and Purcell Mountains.

Yukon Plateau in Canada includes much of the drainage basin of Yukon River and, commencing in northern British Columbia near Atlin and Teslin Lakes, extends northwestward through Yukon and thence westward into Alaska. It has been deeply dissected by a drainage system whose main channels are several thousand feet deep, and the once gently rolling upland has been broken into a series of high, flat-topped hills and ridges. Ogilvie and Selwyn Mountains border it on the north and northeast respectively, and to the southeast the plateau ends against Pelly Mountains.

Little is known about Ogilvie and Selwyn Mountains. The former, with bordering peaks as high as 7,000 feet, extend easterly from the Alaska boundary, near latitude 65 degrees, for 150 miles. There they join Selwyn Mountains, which form the northeast rim of the Yukon Plateau and stretch nearly 400 miles southeasterly to end in low country east of Frances River near latitude 61 degrees. Selwyn Mountains rise from the plateau along an irregular front, and are broken into groups of mountains by broad valleys and other depressions. Probably a few peaks are more than 10,000 feet above sea-level, and many rise to elevations in excess of 7,000 feet. Selwyn Mountains are bordered on the northeast by the Mackenzie Mountains of the eastern physiographic subprovince.

PLATE XL

View of Coast Mountains, Skeena River, British Columbia. Photo by permission Royal Canadian Air Force (B.A.11.37).

PLATE XLI

View of Coast Mountains on west side of Klinaklini River, British Columbia. Photo by permission Royal Canadian Air Force (A.2830-76).

Pelly Mountains form a triangular area in the southern part of the Yukon Plateau, with corners near Teslin Lake, Frances Lake, and Pelly River at longitude 135 degrees. They include Glenlyon, Pelly, and Big Salmon Ranges, and rise from adjacent plateau areas through border areas characterized by long, smooth-topped spurs and dissected tablelands. The highest peaks of the main unit, the rugged Pelly Range, may be more than 8,000 feet above sea-level, and hold a few small alpine glaciers.

Cassiar and Omineca Mountains constitute a continuous belt stretching 450 miles northwesterly from near Takla Lake into Yukon, and extending 50 to 75 miles west from Finlay and Parsnip Rivers. These mountains comprise a great number of ranges separated by broad, transverse and longitudinal valleys several thousand feet deep. The higher peaks and ridges range in elevation from 6,000 feet to more than 8,000 feet. Permanent ice is confined to rather small, scattered, alpine glaciers.

Babine and Bulkley Mountains and their northerly extensions occupy an area of more than 20,000 square miles, bounded on the east by Cassiar and Omineca Mountains, on the south by the Interior Plateau, on the west by the Coast Mountains, and on the north by Stikine Plateau. Bulkley and Babine Mountains lie on either side of the northwesterly trending Bulkley-upper Skeena Valley. They comprise many individual mountains or mountain groups isolated by wide low areas or great valleys. Most peaks are highly dissected, and some rise more than 7,500 feet above the valleys.

Stikine Plateau occupies much of the drainage basin of Stikine River east of the Coast Mountains: on the north it joins Yukon Plateau between Atlin and Teslin Lakes, and elsewhere is bounded by the northerly extensions of Babine and Bulkley Mountains or by Omineca and Cassiar Mountains. Its gently undulating surface averages 4,000 feet or more above sea-level, and is dissected into a number of smaller plateaux by the larger stream and river valleys.

The Interior Plateau stretches from Bulkley, Babine, and Omineca Mountains approximately 500 miles southeasterly to the International Boundary. At its north end it extends from the Coast Mountains 200 miles east to the Rocky Mountains. Towards the south it becomes progressively restricted by Cascade Mountains, on the west, and by Cariboo and Monashee Mountains, on the east, and at the Boundary near Okanagan and Kettle Rivers is less than 50 miles wide. This great plateau region, with a general elevation of 3,000 to 4,000 feet (Plate XLII), is composed of a succession of plateau surfaces interrupted by the deeply cut valleys of a drainage system whose main channels lie 1,000 feet or more below the remnants of the upland surface.

Cariboo, Monashee, Selkirk, and Purcell Mountains form a mountain group within a triangular area between the Interior Plateau on the west and the Rocky Mountain Trench on the east: the apex is in the big bend of Fraser River, and the base at the International Boundary. The various members of the group are separated by deep valleys or trenches trending northward and northwestward. Selkirk Mountains are exceedingly rugged, with summits rising to elevations of 11,000 feet and more above sea-level.

EASTERN SYSTEM

The eastern system includes 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 trough that extends northwesterly from the International Boundary nearly to the southern boundary of Yukon, and includes alined parts of Kootenay, Columbia, Fraser, Parsnip, and Finlay Rivers. The boundary between these systems is less well defined beyond the northern

View, looking northwest, from Williams Lake over an area of the Interior Plateau, British Columbia Photo by permission Royal Canadian Air Force (A1934.35).

end of the trench: it enters Yukon near longitude 126 degrees, extends northerly into Northwest Territories, and swings to the northwest between Selwyn Mountains on the southwest and Mackenzie Mountains on the northeast to re-enter Yukon near latitude 65 degrees, and thence proceeds northwesterly on a sinuous course to pass west of Richardson Mountains and enter Alaska near latitude 69 degrees.

Richardson Mountains form a straight wall 175 miles long extending northerly from Peel River near longitude 136 degrees nearly to the Arctic coastal plain west of Mackenzie River delta. 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 much narrower belt of steep-sided ridges, the flat tops of which lie mainly below 4,000 feet. No cirques or other evidence of alpine glaciation has been found in aerial photographs of even the highest peaks.

Mackenzie Mountains occupy a broad crescentic area, convex towards the northeast, stretching 425 miles southeasterly from south of Peel River near longitude 134 degrees nearly to Liard River at latitude 61 degrees. Their maximum width exceeds 100 miles. They are distinguished from Selwyn Mountains, which adjoin them on the southwest, not by any abrupt topographic boundary, but by absence of intrusions, conspicuous stratification, and more youthful topography. On the north and northeast they rise abruptly from the Mackenzie River lowland. In the main they comprise a compact mass of conspicuously layered, northwesterly trending ridges topped by peaks that commonly rise to elevations of more than 7,000 feet, and in some places are reported to exceed elevations of 9,000 to 10,000 feet. Small alpine glaciers are widespread. 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.

Peel Plateau is a great triangular terrace occupying the angle between the east front of Richardson Mountains and the north front of Mackenzie Mountains. Its northeastern edge is in part a scarp rising 200 to 1,000 feet above the Plains region. The major rivers traversing the plateau, such as the Peel and Arctic Red, are deeply entrenched in the otherwise rather flat, glaciated, upland surface.

Throughout most of their length Franklin Mountains lie a short distance east of and parallel with Mackenzie River. They extend from Fort Good Hope more than 400 miles southeasterly to the mouth of South Nahanni River and average less than 30 miles wide. They include, from north to south, Norman, Franklin, Camsell, and Nahanni Ranges, each comprising a number of parallel north to northwesterly trending ridges. In places they reach heights of 5,000 feet.

The Rocky Mountains form the eastern front of the Cordilleran region in British Columbia. Here they rise sharply from the comparatively flat Plains region, through a Foothills belt, to peaks reaching elevations of 10,000 to nearly 13,000 feet. These mountains, with their eastern foothills, have a maximum width of about 100 miles, and extend from the International Boundary at longitude 114 degrees 850 miles northwesterly to Liard River. At their northwest end they are separated from Selwyn and Mackenzie Mountains by a distance of more than 100 miles. They have been carved from a thick series of sedimentary strata of rather simple structure, and the resultant layering, visible from great distances, at once distinguishes them from most other mountains in British Columbia (Plate XLIII). They consist of a series of overlapping ranges that trend northwest and, on the whole, have precipitous eastern faces and much less steep western slopes. Individual ranges are broken or terminated by deep cross-valleys, and the whole mountain mass is crossed by several deep depressions having comparatively low heights at the divides.

View of Rocky Mountains south of Banff, Alberta, showing bedding of Palæozoic sedimentary rocks, and Mount Assiniboine, elevation 11,870 feet. Photo by permission Royal Canadian Air Force (CA 114-23).

EARLY GEOLOGICAL WORK

Geological exploration in the Cordilleran region by the Geological Survey dates from 1871. In that year the province of British Columbia became part of the Dominion, and the Geological Survey agreed to extend its services to the province and to maintain them there. 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 coal fields. A report on this work was published in 1872, accompanied by a map of Vancouver Island coal fields on a scale of 1 inch to 10 miles. This was the first geological map of any part of British Columbia.

A first need of the province and other parts of the Cordilleran region was for geological exploration, and this task was pursued enthusiastically by a limited staff of geologists from 1871 to about 1908. Besides his exploratory trip of 1871, Selwyn made in 1875 an exploration from the mouth of the Fraser to the junction of Smoky and Peace Rivers, thus completing the first geological traverse of the mountainous belt of western Canada. 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 first to describe, the Yukon: 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 a decade before the discovery of the spectacular placer deposits of Klondike River. Dawson's principal field, however, lay in the Interior Plateau region of central 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.

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.

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, recently Deputy Minister of the 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. Their reports, only in part mentioned here, contain, in addition to geological data, a wealth of information on topography, natural history, and resources of every kind pertaining to the regions examined. A number of the journeys that they completed showed, incidentally, a proficiency of pioneer travel not likely to be again equalled in the history of the Survey. In general, the results of their geological work were portrayed on maps on a scale of 8 miles to the inch, the topographic bases in most cases having been made by the geologists themselves.

As the broad general features of the physiography and geology became fairly well known through explorations, the need for more detailed work became evident. A scale of 1 inch to 4 miles was found suitable. Dawson completed the field work for his Kamloops sheet on this scale as early as 1890. The adjoining Shuswap map-area, in which work was commenced by him in the same year, was completed by James McEvoy by 1896. By 1900 R. W. Brock had completed work on the area covered by the West Kootenay Sheet, work commenced by McConnell in 1894.

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. Map scales of 1 inch to 1 mile, or of even larger, came into general use. A. P. Low, appointed Director of the Survey in 1906, at once realized that geologists with specialized training were required for this work, and by setting higher standards for qualifications of new appointees, may be said to have initiated the present period of detailed geological surveys.

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, Charles Camsell at Hedley and in 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 his many contributions on the coalfields and coal resources of the Cordillera.

International Boundary surveys provided excellent opportunities of studying geological sections across the Cordillera. A memoir entitled "Geology of the North American Cordillera at the Forty-Ninth Parallel" was published by R. A. Daly as a result of his field work between 1901 and 1906. In the north,

D. D. Cairnes examined the geology along the Yukon-Alaska boundary between Yukon and Porcupine Rivers during 1911 and 1912. This work was part of a co-operative agreement with the United States Geological Survey whereby the latter organization undertook the study of the boundary region north of Porcupine River. In the following year Cairnes examined an area adjacent to the same boundary on upper White River.

Since about 1910 many other workers have been assigned by the Geological Survey to the Cordilleran region. Both detailed investigations of mining camps and more general mapping on a scale of 1 inch to 4 miles have been carried on more or less continuously to the present. Even today considerably less than one-quarter of British Columbia and Yukon are geologically mapped according to modern standards.

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, Mackenzie, and Richardson Mountains, and is thus co-extensive with the western and central physiographic sub-provinces; the Eastern Cordilleran region includes the above-mentioned mountains, extends east to the Interior Plains, and is co-extensive with the eastern physiographic sub-province.

The Western Cordilleran region is one of great geological complexity. 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 Proterozoic and late Mesozoic to early Tertiary time are outstanding. During the latter 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 the parallel intrusive bodies such as the Coast and Cassiar-Omineca batholiths. These strata are intensely folded, even locally overturned, and dips commonly exceed 45 degrees. Some are schistose, and it may be that they have been more highly folded and sheared in the vicinity of the batholiths. In many places the axial planes of the overturned folds dip towards the southwest as though formed by a thrust from the southwest. The Tertiary deposits include vast areas of only slightly disturbed volcanic rocks. Faults are widespread throughout the region and both normal and reverse types have been recognized. They trend in many directions and in places appear to have broken the terrain into separate blocks, with unrelated structures. Great thrust faults, such as the Pinchi fault in the Takla area and others in the Nelson area, 500 miles to the southeast, seem to have been developed by thrusting towards the interior of the continent. 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, and Mesozoic sediments, 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.

Western Cordillera

SEDIMENTARY AND VOLCANIC ROCKS

Precambrian

The oldest known rocks of the Western Cordilleran region of Yukon and British Columbia are of Proterozoic age. In British Columbia they outcrop only within a belt that parallels and lies mainly west of the Rocky Mountain Trench and tapers northwesterly from a width of about 120 miles at the International Boundary to end, so far as is known, near latitude 58 degrees. The rocks of this belt have been examined in most detail in the area between Kootenay Lake and the valley of Kootenay and Columbia Rivers, where they underlie most of the Purcell and large parts of Selkirk Mountains. North of the "Big Bend" of Columbia River they are presumed to underlie wide areas of relatively unexplored country. Still farther north they reappear as a narrow band near Teslin Lake on the Yukon-British Columbia boundary and outcrop in extensive though highly irregular areas throughout much of southwestern Yukon. The Proterozoic assemblage includes variously deformed and metamorphosed, shallow to deep water sediments and lesser amounts of volcanic and, possibly, deep-seated igneous rocks. In parts of southeastern British Columbia, where exposed thicknesses of as much as 75,000 feet have been recorded, they have been subdivided into two great unconformable systems, the older known as Purcell, and the latter as Windermere. Elsewhere no satisfactory division has been made, and nowhere have basal Proterozoic rocks been recognized.

Recent field work has shown that large areas of schistose and gneissic rocks, classed as Precambrian by early workers, are wholly or in part of Palæozoic or even Mesozoic age. The term "Shuswap series" was at one time applied to some 4,000 square miles of schists, crystalline limestones, gneisses, and massive granitoid rocks lying between Shuswap Lake and the International Boundary in southeastern British Columbia. Although originally thought to be of Archæan (pre-Beltian) age recent work has shown that Shuswap rocks represent merely a condition of metamorphism and are of no particular age: in places they are now known to include formations of Proterozoic, Palæozoic, and even early Mesozoic ages. It is entirely probable that further work within the little known Proterozoic belt extending northwesterly from the "Big Bend" of Columbia River will reveal appreciable areas of similarly highly altered Palæozoic rocks. In Yukon, highly altered rocks placed within the Yukon group, and at one time thought to be all of Precambrian age, are now known to include, in places, formations of both Precambrian and later ages.

The Proterozoic sediments are overlain in different districts by Palæozoic formations varying in age from Lower Cambrian upwards, but in most places the unconformity is not marked by noticeable angular discordance.

A large part of Yukon Plateau is occupied by altered sedimentary and volcanic rocks of the Yukon group, including quartzites, quartzose mica schists and their gneissic phases, crystalline limestone, and greenstone. These are accompanied by bodies of deformed intrusive rocks, now altered to sericite and other schists, and gneissic granite, which, though younger than the Yukon group strata, are of uncertain age. Certain members of the group have been definitely established as Precambrian in Alaska, and doubtless some of these members extend into Yukon. However, no definite dating has been possible throughout most of Yukon, and various areas of so-called Yukon group rocks have been correlated on a basis of lithology, pronounced metamorphism, and apparent lack of fossils. Although originally thought to be all of Precambrian age, recent work has shown that some are altered Palæozoic rocks, and it has been considered best in recent years to class them as probably of Precambrian and Palæozoic age.

To the southeast, in the Cariboo district of British Columbia, the Precambrian rocks are known as the Cariboo series, and have been divided into three conformable sedimentary formations known as the Richfield, Barkerville, and Pleasant Valley. This series consists mainly of quartzite, limestone, and argillite with minor proportions of volcanic rocks and schists. The exposed thickness probably exceeds 15,000 feet, and the base has not been seen. The strata are folded, and the folds plunge to the north and disappear beneath younger strata before reaching Fraser River. The gold-quartz veins of the Barkerville region occur in the upper part of the Richfield formation. The Pleasant Valley or uppermost formation of the Cariboo series is apparently overlain conformably in one locality by fossiliferous Lower Cambrian limestone and argillite, suggesting a Proterozoic age for the Cariboo series. The latter is separated from the next youngest strata, the Mississippian, Slide Mountain group, by an angular unconformity.

In southeastern British Columbia Proterozoic sediments occupy a belt some 60 to 100 miles wide, mainly west of the Rocky Mountains, and in an area now occupied by Selkirk and Purcell Mountains. These rocks are of Purcell (Early Proterozoic) and Windermere (Late Proterozoic) ages. A great many basic sills and dykes, including those known as the Purcell intrusives, occur throughout the Purcell and Windermere systems.

The sediments formed in Purcell time consist of a conformable succession of formations with a maximum recorded total thickness of about 45,000 feet. Although there are no breaks in the succession and similar rock types occur throughout, it has been possible to subdivide the system lithologically into recognizable formations. These comprise a Lower Purcell and an Upper Purcell sedimentary series, intercalated at or near the top of the lower series, in the Cranbrook area, with basic, altered extrusive rocks known as the Purcell lavas, and intruded, particularly in the lower formations of this series, by thick sills and multiple sills of dioritic composition, possibly related to the Purcell lavas and referred to in reports as the Purcell intrusives.

The Lower Purcell series comprises, from its base up: the Fort Steele formation, 7,000+ feet thick, composed of white quartzite, banded, grey argillite and quartzite, black, limy argillite, and grey-green, dolomitic argillite; the Aldridge formation, 16,000 feet of grey, rusty weathering argillite and argillaceous quartzite; the Creston formation, consisting of 6,300 feet of green, purple, and white, argillaceous quartzite; the Kitchener formation, 6,000+ feet of green, grey, and purple, buff weathering, dolomitic argillite; and the Siyeh formation, 1,000-2,000 feet of highly coloured argillite and dolomitic argillite.

The Upper Purcell series is most generally subdivided into two formations: a lower, or Dutch Creek formation, comprising 4,000 feet or more of laminated argillite, magnesian limestone, and argillite; and an upper, Mount Nelson formation, consisting of some 3,000 feet of beds very similar to those of the Dutch Creek.

The formations of the Purcell system are, as a whole, remarkably fresh. They were laid down in shallow standing water in a slowly sinking seaway at least 10,000 square miles in area, and ripple-marks and crossbedding are common in the Cranbrook and Nelson areas. The presence of mud-cracks throughout the series in these areas shows that the surface of deposition was exposed to sun and air at frequent intervals.

The Windermere system was laid down on an eroded surface of folded Purcell strata. The erosion surface dips westerly, so that west of a line extending northerly from the south end of Kootenay Lake the Purcell strata pass beneath a thick, steeply dipping mantle of Windermere rocks. The angular discordance between the two great systems seldom reaches 45 degrees, indicating that the pre-Windermere folding was broad and open. Windermere rocks, with a maximum recorded total thickness of about 22,000 feet, include conglomerate, slate, coarse-grained quartzite, limestone, greenstone, schist, and paragneiss.

The basal formation, known as the Toby conglomerate, ranges in thickness from 50 feet to more than 2,000 feet and contains, amongst fragments of Purcell rocks, pebbles and fragments of orthoclase that suggest a granitic intrusive rock as a source of at least some of the sediments. Near the International Boundary, west of Kootenay Lake, the Toby conglomerate is mainly overlain by, but partly interbedded with, the Irene Volcanic formation consisting essentially of fine-grained, sheared greenstone or hornblende schist. Elsewhere to the north, however, the Toby is overlain conformably by the Horsethief Creek series, about 6,000 feet thick, composed of green, argillaceous quartzite, blue-grey limestone, arkose, and pebble conglomerate. This is succeeded by the Hamill series, 7,500 to 10,000 feet thick, consisting largely of grey, green, and white, siliceous quartzite, and separated from younger strata by a prominent band or bands of magnesian limestone of the Badshot formation, 100 to 250 feet thick, which conformably overlies the Hamill and forms a splendid horizon marker. The succeeding Lardeau series, the uppermost member of the Windermere system, has an exposed maximum thickness in Lardeau area, northwest of Kootenay Lake, of 15,000 feet. It is composed of argillite, slate, quartzite, and limestone, with some basic igneous bands of doubtful origin. These rocks are commonly metamorphosed to schists of various types, to crystalline limestone, and to gneisses. Near the International Boundary the equivalent of the Hamill and, probably, part of the Horsethief Creek series of the north is taken by the Three Sisters, Quartzite Range, and Reno formations, and these in turn are overlain conformably by the Pend-d'Oreille series of phyllite, argillaceous quartzite, and limestone, corresponding stratigraphically to the more widespread Lardeau series.

In the general vicinity of Kootenay and Slocan Lakes Windermere strata have been severely metamorphosed and intimately invaded by granitic and pegmatitic bodies and are locally so granitized as to be distinguished from granitic intrusions with difficulty. Parts of this highly metamorphosed terrain were formerly included with the Shuswap series. Erosion due to uplift without marked tilting or folding preceded early Cambrian deposition. Along the Rocky Mountain Trench fossiliferous Lower Cambrian beds rest in different places on quite different horizons of the Windermere rocks. In places there is a slight angular unconformity at the base of the Cambrian.

Palæozoic

The record of the Palæozoic is fragmentary. Probably the greater part of the Western Cordilleran region was a land area exposed to erosion in Cambrian time and, south of about latitude 56 degrees, remained so until the Carboniferous period. At least partial submergence in British Columbia and Yukon, north of this latitude, is indicated by widely scattered occurrences of post-Cambrian and pre-Carboniferous fossiliferous strata. During the Carboniferous and Permian periods apparently nearly the whole of the Western Cordilleran region lay beneath the sea, and great thicknesses of sedimentary and volcanic material accumulated. Wide areas of almost unexplored country in eastern Yukon are presumed to be underlain chiefly by Palæozoic strata, but may also contain rocks of Mesozoic and Precambrian age. In northern

British Columbia, where exposed strata are thought to represent much of Palæozoic time, no important break in deposition or record of orogenic disturbance has been recognized. In a number of localities sedimentation and vulcanism probably proceeded more or less continuously from late Palæozoic into early Mesozoic time, but in places an interval of uplift and erosion without marked tilting or folding may have intervened.

Cambrian sedimentary strata are known only on the Yukon-Alaska boundary near latitude 65 degrees, in the Cariboo district of British Columbia, and in southeastern British Columbia on either side of the Rocky Mountain trench. All these localities lie close to the northeastern and eastern edge of the Western Cordilleran region, and may indicate the approximate southwestern and western limits of the Cambrian sea, which was an important feature of the Eastern Cordilleran region. Middle and Upper Cambrian fossils occur in calcareous strata on the Yukon-Alaska boundary. At one locality in the Cariboo district Lower Cambrian limestone and argillite apparently overlie Proterozoic rocks conformably. Lower, Middle, and Upper Cambrian sedimentary formations outcrop here and there, in southeastern British Columbia east of Kootenay Lake and in the vicinity of Golden. The Lower Cambrian Cranbrook and Eager formations rest without marked angular discordance on an erosion surface that truncates both early and late Proterozoic strata.

Known occurrences of post-Cambrian and pre-Carboniferous strata in northern British Columbia and Yukon are too widely scattered and too little studied to provide a reliable picture of their former extent and general character. More detailed work may show sedimentary rocks of this age to be rather extensively developed within the basins drained by Stikine and Dease Rivers. Silurian and Devonian formations are suspected to occur beneath Carboniferous and Permian strata in the Stikine River area. Probable Silurian fossils have been found in the Dease series of chert, quartzite, limestone, and argillite near Dease Lake, and several thousand feet of sedimentary rocks underlie the fossiliferous beds. Permian fossils have also been found in this series, which, so far as known, comprises an essentially conformable assemblage of sediments representing much of Palæozoic time. Ordovician graptolites have been found in black shales associated with similar rocks near the mouth of Dease River. Upper Ordovician graptolites are also recorded from shale, cherty argillite, and chert on upper Ross River in Yukon, about 275 miles north of Dease Lake, suggesting the former presence of a rather extensive early Palæozoic sea in southeastern Yukon and northern British Columbia. Fossiliferous Cambrian to Devonian limestones and dolomites are known on the Yukon-Alaska boundary about 25 miles north of Yukon River. On Donjek River, in southwestern Yukon, are exposures of a group of schist, phyllite, and limestone, the latter containing Devonian fossils at its base. This group may contain Carboniferous strata in its upper part. Farther south, near Slims River, limestone and chert are overlain by Silurian limestone and overlie rocks correlated with the Yukon group.

In the Purcell Mountains of southeastern British Columbia, the Mount Forster formation has been tentatively placed in the Devonian. It is composed chiefly of shale, with thin limestone interbeds, and has a maximum thickness of 600 feet. The basal beds rest with apparent conformity on Brisco strata of Lower Silurian age. No fossils have yet been found in this formation, but the lithologic change from underlying Brisco beds is abrupt, whereas the Mount Forster appears to merge upward into the overlying Starbird formation of Upper Devonian age.

The Starbird formation is essentially calcareous, and grades from shale and arenaceous limestone at the base to limestone at the top. A complete section is not available, but one more than 230 feet thick was measured where a collection of fossils was obtained. The fauna is apparently peculiar to the locality, but is definitely Devonian and is placed in the Upper Devonian.

The great thickness of sedimentary and volcanic strata that accumulated in marine waters over much of British Columbia and Yukon during Carboniferous and Permian time are now exposed in relatively small, isolated, greatly deformed patches and northwesterly trending troughs. One group of such exposures lies within a great triangle in the southern interior of British Columbia, with its base on the International Boundary from Chilliwack to Greenwood and its apex a short distance north of Omineca River. Another group of these exposures extends northwesterly from upper Stikine River through Dease Lake and Atlin districts into southwestern Yukon. Other exposures of these rocks have been mapped east of the British Columbia-Alaska boundary between Stikine and Taku Rivers. Rocks of this general age, originally described in southern British Columbia as the Cache Creek group, have in other localities been given such names as Dease, Slide Mountain, Bridge River, Hozameen, and Chilliwack groups. All are remarkably alike in lithology and structure wherever examined, and include limestone, chert, quartzite, argillite, greenstone, and derived schists. The limestones, commonly massive, are particularly abundant in the Permian, and in many places schists predominate in the vicinity of the batholiths. The non-calcareous sediments consist of beds of quartzite or of chert, ½ inch to 6 inches thick, commonly minutely crumpled, and separated by black, lustrous, carbonaceous argillite. In many places the partings have a slaty cleavage and have been partly metamorphosed to graphite or to mica. The greenstones comprise altered sills, flows, volcanic fragmental material, and minor intrusions.

In the Upper White River district of southwestern Yukon a conformable succession of limestone, chert, shale, sandstone, and conglomerate is intimately associated with andesite, basalt, and related pyroclastic rocks. The assemblage includes members ranging in age from Carboniferous to Cretaceous, and apparently represents a long period of continuous sedimentation and intermittent volcanism wherein palæontological evidence is the only satisfactory means of differentiating Mesozoic and late Palæozoic formations.

To the northeast, in the Mayo area, just north of Macmillan River, an extensive Carboniferous fauna has been found, and about 45 miles east of Dawson fossils of Ordovician or, more probably, later Palæozoic age occur in an argillite-sandstone-conglomerate series. Both these occurrences of late Palæozoic strata lie near the southwestern edge of a great unexplored area provisionally designated merely as "undivided Palæozoic" and suggest rather extensive tracts of late Palæozoic rocks within that terrain.

The Dease series in the Dease-Stikine area consists of 15,000 feet of thin-bedded chert, quartzite, limestone, and argillite with minor greenstone and derived schists, and is capped by massive Permian limestone. As previously stated, there are no apparent unconformities or marked changes in lithology throughout the series although beds ranging from Ordovician to Permian may be represented. In the Stikine area the series is reported to be separated from overlying Triassic sedimentary and volcanic formations by a pronounced unconformity, but in the Eagle-McDame area no unconformity was found, and the upper part of the series that may be in part Triassic could not be distinguished lithologically from the lower sediments.

The Carboniferous and Permian rocks elsewhere in northern British Columbia include 10,000 feet or more of limestone, chert, argillite, greenstone, and derived schists, the limestone being particularly abundant in the Permian. In the Cariboo district they are called Slide Mountain series, which has been divided into four members; namely, the basal Guyet conglomerate, the Greenberry limestone, the Waverly basic lavas and breccias, and, at the top, the Antler argillite and chert. The Slide Mountain series overlies the Precambrian and Cambrian strata unconformably. Fossiliferous Permian boulders are found in Triassic conglomerate near Zymoetz River, indicating that uplift and erosion there intervened between late Palæozoic and early Mesozoic deposition. In the general vicinity of Takla Lake, 140 miles to the northeast, a period of uplift and erosion without marked tilting or folding may have extended from Permian to Upper Triassic time.

In southern British Columbia Carboniferous and Permian strata are exposed mainly east of the Coast Range and on Vancouver Island. At Buttle Lake, near the centre of the island, limestone interlayered with andesitic and basaltic flows, tuffs, and breccias contains Permian bryozoa. The considerable thickness of volcanic rocks and other sediments lying stratigraphically below the limestone may be Pennsylvanian or older. Triassic lavas and fragmental rocks overlie the limestone. As yet no horizon has been defined as marking a break between Palæozoic and Mesozoic formations, and it seems probable that volcanic activity was more or less continuous, unbroken by any important erosion interval. On the eastern side of the Coast Range, between the International Boundary and Thompson River, Cache Creek intercalated sedimentary and volcanic rocks may be as much as 20,000 feet thick; their deposition probably was followed by an interval of uplift and erosion extending to Upper Triassic time. In the Slocan and Lardeau areas, near the east edge of the late Palæozoic exposures in southern British Columbia, the Upper Carboniferous and Triassic strata of the Milford group show no evidence of any interruption of sedimentation at the close of Palæozoic time. This group is composed mainly of slate, argillite, chert, cherty greenstone, and limestone, and the late Palæozoic members are separable from the Mesozoic members only where fossil evidence is available.

Mesozoic

Mesozoic deposits are known to range in age from Upper Triassic to Upper Cretaceous. Strata of Lower and Middle Triassic age have not been definitely recognized in the Western Cordilleran region, but they may be present because, as already stated, deposition was apparently continuous, in some areas, from late Palæozoic well into Mesozoic time. It seems probable that Triassic and Jurassic volcanic and sedimentary strata originally overlay much of the Western Cordilleran region in British Columbia and at least the southwestern half of that region in Yukon. Subsequently, however, they have been removed by erosion from vast areas now occupied by the Coast and Cassiar-Omineca batholiths and related intrusions, and in the Interior Plateau of southern British Columbia have been buried by widespread Tertiary lavas. Except in a few places there is little evidence of orogenic movements or an erosion interval intervening between Triassic and Jurassic formations, and in the main the rather scant palæontological evidence has proved the most satisfactory means of separating the strata of these periods. Similar difficulties have been experienced in separating Jurassic strata from the predominately sedimentary formations of Lower Cretaceous age, and on the geological map of Canada considerable Lower Cretaceous and some Triassic rocks are included with those of Jurassic age. However, in a few widely separate areas, ranging from southern British Columbia to the Yukon, an unconformity has been recognized near the base of the Cretaceous system. Lower Cretaceous sandstone, shale, and conglomerate with minor volcanic members and a few coal seams occur within a narrow belt along the east edge of the southern part of the Coast Range and as minor areas on Vancouver and Queen Charlotte Islands. Other Lower Cretaceous strata are probably widespread in the Hazelton group between the Coast and Cassiar-

Omineca batholiths north of the Jasper-Prince Rupert line of the Canadian National Railway, but, except locally, where diagnostic fossils have been found, have not been satisfactorily separated from Jurassic beds. Cretaceous formations of both sedimentary and volcanic origin are found with the older Mesozoic rocks of the Yukon and Lewes River basins in southern Yukon. Sedimentary rocks of marine and continental origin alternate throughout the Upper Triassic-Lower Cretaceous section showing successive occupations and withdrawals of the seas of the past from different parts of the region. Limestone is common in the Upper Triassic, coal and plant remains occur at a few horizons within the Jurassic of northern British Columbia and Yukon, and continental sedimentary rocks with coal seams and plant remains comprise much of the Lower Cretaceous strata, indicating a progressive change from dominantly marine conditions in the Upper Triassic to essentially continental conditions in Lower Cretaceous time. Upper Cretaceous rocks occur in a few widely scattered localities. They are mainly continental conglomerates, sandstones, and shales, and were probably formed in local basins. Mountain building marked the close of the Mesozoic era and extended into early Tertiary time. With this disturbance marine waters disappeared for all time from most of the Western Cordilleran region.

Upper Triassic limestone, greywackes, sandstones, and argillites of the Lewes River series occupy scattered northerly and northwesterly trending troughs in the Lewes and Teslin River basins of southern Yukon. This series is about 4,400 feet thick near Lake Laberge on Lewes River. Various relations have been noted between the Lewes River strata and the overlying Laberge series of Jurassic age: in part the two series are structurally conformable although in places separated by a period of erosion, and in part they are separated by an angular unconformity.

Upper Triassic rocks occupy a belt about 230 miles long lying east of the Coast Range batholith between Taku and Unuk Rivers. They include perhaps 5,000 feet of interbedded limestone, argillite, greywacke, conglomerate, tuff, breccia, and andesite, and are overlain unconformably by Jurassic volcanic and sedimentary strata. Similar Upper Triassic strata are found near Takla Lake, 250 miles to the southeast, and may possibly underlie parts of the little-known intervening area provisionally classified as mainly Jurassic.

The Vancouver group of northern Vancouver Island consists of a great and, so far as known, conformable succession of volcanic and sedimentary rocks. The volcanic rocks, including flows and fragmental types, form the large part of the group, but limestone and other sediments are interbedded with them in places. Fossil shells indicate that although part of the group is undoubtedly Triassic it may also include Jurassic strata. A sharp angular unconformity separates it from overlying Lower Cretaceous sedimentary beds.

Triassic formations in the southern interior of British Columbia occupy a western belt between Tatlayoko and Harrison Lakes, wide areas in the vicinity of Nicola and Kamloops Lakes and Princeton, and an eastern area near Slocan and Kootenay Lakes. In the Tyaughton Lake area of the western belt the Noel and Pioneer formations and the Hurley group succeed each other conformably and include argillite, tuff, andesites, conglomerate, and limestone. The Hurley group contains Triassic fossils and is overlain, probably conformably, by the Tyaughton group of mainly, if not entirely, Upper Triassic age. The Tyaughton group is a distinctive lithological assemblage of marine formations consisting of interbedded sandstone, shale, grit, conglomerate, and limestone. It is overlain conformably by Lower Jurassic rocks. Upper Triassic rocks of the Princeton and Nicola areas include the Tulameen and Nicola groups of mainly andesitic and basaltic lavas, with local accumulations of argillite and limestone. In the Slocan area, as already mentioned, some Triassic sediments are included with the Milford group. The Milford group is overlain, probably unconformably, by the Kaslo series, which is, in turn, disconformably overlain by the Slocan series of probable late Triassic age. The Kaslo series includes abundant andesitic volcanic rocks, whereas the marine Slocan series, with a basal conglomerate, is made up of slate, argillite, quartzite, limestone, and tuffaceous sediments.

The most widely exposed Mesozoic formations in the Western Cordilleran region are of Jurassic and early Cretaceous ages. In southern Yukon they occupy the greater part of the Mesozoic syncline drained by upper Yukon, Lewes, and Teslin Rivers, and are there assigned to the Laberge series and Older Volcanics. They have been traced southerly into British Columbia through the Atlin region, and thence southeasterly through northern British Columbia for some 700 miles to Quesnel Lake, through a belt that broadens to a maximum width of about 150 miles and occupies much of the country between the Coast and Omineca-Cassiar batholiths. Within this vast region of northern and central British Columbia they have been assigned various names such as McLeod series in the Dease-Stikine area, Hazelton group and Skeena formation in central British Columbia, and Quesnel River group in the Cariboo district. Much smaller areas of Jurassic strata are assigned to the Maude and Yakoun formations on Queen Charlotte Islands, and to the Taylor, Eldorado, Ladner, and Agassiz formations in the Bridge River and lower Fraser Valley areas of southern British Columbia.

The Laberge series of Yukon is an interlayered assemblage of conglomerate, greywacke, tuff, arkose, sandstone, argillite, and coal. It may be as much as 10,000 feet thick in the Whitehorse area. Some beds contain both shell fragments and plant remains. The series contains Lower and Middle Jurassic members, and is overlain conformably by the Tantalus conglomerate, sandstone, shale, and coal of presumably early Lower Cretaceous age. Andesite, basalt, and related tuff and breccia of the Older Volcanics of the Whitehorse and Atlin areas are thought to be mainly contemporaneous with the Laberge beds.

The Hazelton group is widespread from Portland Canal to Prince George. In the Smithers and Hazelton areas, where some of the most recent work has been done, it is a conformable succession, possibly 10,000 feet thick, of interbedded sandstone, greywacke, argillite, conglomerate, tuff, breccia, andesite, and basalt, ranging in age from pre-Middle Jurassic to Lower Cretaceous, and includes what have been called the Hazelton group and the Skeena formation or series. The assemblage was subdivided locally into three volcanic units separated by two sedimentary units, but this subdivision was not possible where diagnostic fossils were not found or where the sedimentary units are missing. Both marine and continental strata are present, and coal is found associated with continental strata throughout the Hazelton group, although the best coal appears to occur in rocks of Blairmore (Lower Cretaceous) age. These continental, coal-bearing members of the Hazelton group have hitherto been thought to comprise the Skeena formation or series and to overlie the Hazelton group conformably, according to some geologists, or unconformably according to others. Recent studies indicate that no satisfactory stratigraphic division can be made, and that continental strata comparable with the Skeena appear at various horizons in the Hazelton group. Northwest of Takla Lake equivalent strata are separated from overlying Upper Cretaceous continental rocks by an erosion interval with or without angular discordance. There is a general similarity of the Quesnel River and McLeod series to the Hazelton group, although the McLeod series contains a basal conglomerate in places and has been reported to rest unconformably on Upper Triassic limestone of the Thibert series.

In the Queen Charlotte Islands, the Lower Jurassic Maude formation of argillite, sandstone, and tuff grades upwards into the Yakoun basalts, agglomerates, and tuffs. The combined thickness of the two formations may reach

15,000 feet. They were folded, intruded by granitic stocks, and exposed to erosion before being buried by the Cretaceous formations of the Queen Charlotte series.

Although patches of Lower and Middle Jurassic sediments occur in the Tyaughton area of the Bridge River district the earliest widespread Jurassic rocks are those of the Taylor group of probable Middle or Upper Jurassic age. It includes several thousand feet of conglomerate, sandstone, and shale of deltaic estuarine origin. A heavy basal conglomerate suggests a considerable interval of erosion between it and underlying formations. The Eldorado group is a structurally conformable, locally disconformable, succession of Upper Jurassic and Lower Cretaceous sedimentary rocks. Although some difficulty has been experienced in separating the Jurassic and Cretaceous strata of this group, the latter contain more sandy and tuffaceous material and locally a coarse basal conglomerate with many granitic pebbles. The Eldorado beds are overlain, with apparent structural conformity, by late Lower or early Upper Cretaceous volcanic strata of the Leckie group.

At Harrison Lake, in the Hope area, the Upper Jurassic sedimentary rocks of the Agassiz group, with a basal conglomerate 3,000 feet thick, rest unconformably on Middle and Upper Jurassic volcanic and sedimentary strata. The Agassiz conglomerate evidently marks a considerable erosional interval, probably in Upper Jurassic time. Nearby, resting unconformably on early Upper Jurassic beds, are 5,000 feet of conglomerates, sandstones, and shales containing marine, early Lower Cretaceous fossils.

The Hutshi and Mount Nansen groups, presumably of Cretaceous age, occupy rather extensive tracts in the Laberge and Carmacks areas of Yukon. They include andesite, basalt, and associated pyroclastic rocks and minor sedimentary beds. They are thought to be separated from the older, coal-bearing Tantalus formation, of probable early Lower Cretaceous age, by an angular unconformity.

On Queen Charlotte Islands the Haida coal-bearing formation of late Lower Cretaceous age grades abruptly upwards into the Honna and Skidegate formations of Upper Cretaceous age. These formations have an aggregate thickness of about 9,000 feet and represent sediments that accumulated rapidly in shallow water. They make up the Queen Charlotte series.

Small areas of sandstone, shale, and conglomerate of continental origin and presumably of Upper Cretaceous age occur in the Hazelton-Smithers and Dease-Stikine areas. In the latter area they overlie Jurassic rocks unconformably.

Lower Cretaceous conglomerate, sandstone, and shale, with thin coal seams, have been found in scattered localities on northern Vancouver Island. On the southeastern part of the island Upper Cretaceous time is represented by about 10,000 feet of similar, coal-bearing sediments of the Nanaimo series.

A narrow, discontinuous belt of Lower Cretaceous continental and marine rocks extends from the International Boundary at Similkameen River northwesterly along the east flank of the Coast Range for nearly 300 miles to the Chilko Lake area. In the southeast part of the belt the assemblage is more than 10,000 feet thick, and includes the Dewdney Creek and Jackass Mountain marine sedimentary groups and the continental Pasayten arkose, greywacke, and shale with plant remains, as well as other volcanic and sedimentary groups. A volcanic assemblage of late Lower Cretaceous age contains a basal agglomerate with fragments of granitic rocks, suggesting a period of uplift and erosion in late Jurassic or early Cretaceous time. Near Chilko Lake, crossbedded arkose, sandstone, and shale, with carbonized plant fragments, contain diagnostic Lower

Cretaceous marine shells, and overlie Triassic beds without any marked unconformity. Comparable beds of the Jackass Mountain group are found along Fraser River between Boston Bar and Lillooet. In the Bridge River area the Leckie group, comprising more than 10,000 feet of fragmental volcanic rocks, rests conformably on the Eldorado sediments. Fossil plants found in carbonaceous beds in the volcanic rocks indicate a late Lower or early Upper Cretaceous age.

Tertiary

Tertiary time represents most of the Cenozoic era. Orogenic movements and uplift at the close of Mesozoic time probably acted to some extent throughout much of the Cordilleran region. In the adjoining Eastern Cordilleran region the Rocky Mountains were formed and in the Western Cordillera Cretaceous strata were folded and faulted to various degrees, and the Coast Range was brought into being through an uplift sufficiently gradual to enable various rivers to maintain westerly courses across it. Local freshwater basins of sedimentation appeared here and there from time to time throughout the Tertiary, and local accumulations of marine sediments formed near the present coastline. Vulcanism was more or less active from Eocene time on, although it appears to have reached a climax in the Miocene or Pliocene, and then to have gradually waned. The volcanic rocks are mainly basalitic and andesitic lavas and related pyroclastic materials. In general the Tertiary strata rest with a definite angular unconformity on the older rocks, and early Tertiary formations lie in open folds whereas later Tertiary beds are nearly horizontal. In Yukon they occur as irregular isolated areas lying mainly within two northwesterly trending belts. One of the belts extends from near Carmacks, at the mouth of Lewes River, to the Alaska boundary, and the other lies along the northeast flank of St. Elias Mountains. In northern British Columbia one area, in part of Quaternary age, extends north from Telegraph Creek, on Stikine River, for about 80 miles, and another floors the Rocky Mountain Trench for perhaps 150 miles along Finlay and Fox Rivers. In the southern interior of British Columbia they attain thicknesses of some thousands of feet and mask much of the older terrain in a belt 150 miles wide extending 350 miles southeasterly from Babine Lake to Kamloops Lake, and thence southeast to the International Boundary they occupy smaller scattered areas. Other occurrences are known on Queen Charlotte Islands and at the mouth of Fraser River.

Age determinations of Tertiary strata have not proved entirely satisfactory, and revisions have been, and doubtless will be, necessary from time to time. Angular discordances have been recognized within the Tertiary succession in many areas, but the precise ages of the various periods of disturbance represented are commonly in doubt, and a satisfactory account of Tertiary history is hardly possible at present.

In the Carmacks and Ogilvie areas in Yukon the basal Tertiary rocks comprise small areas of partly consolidated conglomerate, sandstone, shale, and tuff, with plant remains and seams of lignite. They are of very early Tertiary age, and have been correlated with the Kenai series of Alaska. In part they occupy a northwesterly trending basin, perhaps 120 miles long, that parallels Yukon River east of the Yukon-Alaska boundary. The Carmacks volcanic rocks, mainly andesitic lavas, conformably overlie the basal sedimentary series and have an exposed thickness of at least 2,500 feet. All these early Tertiary rocks, with dips ranging up to 20 degrees, are separated by an angular unconformity from the undisturbed basaltic and andesitic lavas and pyroclastic rocks of the Selkirk series, the extrusion of which commenced in very late Tertiary or in Pleistocene time and did not cease until perhaps only a few thousand years ago.

In central British Columbia, in the general vicinity of the Prince Rupert line of the Canadian National Railway, small areas of Paleocene or Upper Cretaceous sedimentary rocks have been identified between Hazelton and Vanderhoof. They comprise several hundred feet of sandstone, shale, conglomerate, and lignitic coal. Comparable rocks have been called the Sifton formation along Finlay and Fox rivers in the Rocky Mountain Trench. In the Fort Fraser area somewhat similar strata of possible upper Oligocene or lower Miocene age dip at angles up to 30 degrees and are overlain by 2,000 feet of nearly horizontal basalts, andesites, and other volcanic rocks. These horizontal lavas are thus probably of Miocene or Pliocene age or both. Similar flat-lying lavas, commonly referred to as the "Plateau basalts", cover much of the older rocks within the vast area extending southeasterly to Kamloops Lake and North Thompson River.

Paleocene or early Eocene clastic strata of the Burrard formation, with a thickness of at least 2,000 feet, occur in the vicinity of Vancouver. The beds, apparently, were formed on an alluvial plain at the western base of the Coast Range. Sedimentation was interrupted for an interval, but recommenced in late Oligocene or early Miocene time when 1,500 feet or more of clastic sediments of the Kitsilano formation were laid down. These two groups of strata are in large part of freshwater origin, but formed near a seacoast, and the upper formation is probably partly marine. On southern Vancouver Island an extensive area is occupied by the Metchosin volcanics, possibly 7,500 feet thick, of late Eocene age. These rocks were folded and subjected to erosion before the Sooke sandstones and conglomerates of middle Tertiary age were laid down upon them. Possibly the disturbance took place at the time deposition temporarily ceased near Vancouver, and presumably at a time when orogenic movements affected much or all of the Cordilleran region, as in various districts in the interior earlier Tertiary sediments and volcanic rocks are considerably more disturbed than younger Tertiary formations. The interval of deformation, which was accompanied by local plutonic and presumably volcanic activity, perhaps took place in Oligocene time.

One of the best sections of Tertiary rocks of the southern interior of the province is found in Okanagan Valley close to the International Boundary. Here the Springbrook formation, perhaps of Paleocene age, and composed of soils, alluvium, talus, stream and lake deposits, and tuff, rests on a pre-Tertiary rock surface of steep relief. These strata accumulated in the valleys and are overlain by and to some extent interlayered with the andesites, basalts, and pyroclastic rocks of the Marron formation, which buried the valleys and reached a thickness of more than 4,000 feet. The White Lake formation, consisting mainly of lake and stream deposits with coal, was deposited on the Marron strata from which most of their materials were derived. They are locally as steep as 65 degrees and 4,000 feet or more thick. Their age is probably late Eocene, but they may be somewhat younger. The White Lake strata are overlain unconformably by beds of more gently dipping andesitic breccia and agglomerate, which are succeeded upwards by agglomerate and conglomerate. The youngest conglomerate beds are horizontal and of pre-Pleistocene age. On North Thompson River, 150 miles to the north, a coal-bearing formation of conglomerate, sandstone, and shale of early Tertiary age occupies valleys, as does the Springbrook formation. Fossil flora collected from the coal-bearing assemblage include many Kenai forms. Its preserved thickness is several thousand feet, and it is capped, in places with angular unconformity, by andesitic and basaltic lavas of presumably Miocene or Pliocene age or both. Similar lavas, as already stated, occupy wide areas in a great tract extending northwesterly to Babine Lake in the Fort Fraser area. The strata, although locally tilted, are for the most part approximately horizontal. In the Princeton area of southwestern British Columbia andesite and basalt is interlayered with sedimentary rocks comprising conglomerate, sandstone, shale, and coal, which accumulated in lake basins during a period of vulcanism in Oligocene or Miocene time. This assemblage of volcanic and sedimentary strata is overlain unconformably by flat-lying black basalts of Miocene or later age.

Quaternary

Latest Cenozoic time is known as Quaternary, and is subdivided into Pleistocene and Recent epochs. During Pleistocene time the Western Cordilleran region, except for a large area in the Yukon River basin and, possibly, some of the higher mountain peaks, was covered by the Cordilleran ice-sheet. The ice probably accumulated in the mountains and moved out from them in many directions. As a result of the ice movement most of the deeply weathered, Tertiary surface was removed, and, especially in some of the larger valleys, underlying fresh bedrock was deeply eroded. The notable exception was the preservation of the weathered Tertiary surface in the unglaciated district in Yukon. In places there is evidence of more than one advance of the ice. Near Vancouver, Pleistocene deposits are more than 1,000 feet thick, and consist of at least two sheets of boulder clay separated by stratified sands and clays. The boulder clays were laid down by different ice-sheets separated in time by an interglacial period during which the sands and clays were deposited. Other deposits of boulder clay occur throughout the glaciated region, and marine and lake sediments were deposited at the margin of the glacier or in englacial lakes. Since Pleistocene time the ice has disappeared from the region with the outstanding exception of the many retreating glaciers and ice-fields that still persist in the Coast Range and St. Elias Mountains. With the recession of the ice came a general re-elevation of the land, which has left former marine beaches standing several hundred feet above present sea-level. Existing streams have cut into and re-transported the glacial deposits, which now appear as post-glacial sands, gravels, and silts in many of the present valleys.

The widespread vulcanism of the Tertiary period persisted, on a greatly reduced scale, into Pleistocene and Recent times, the last eruptions probably taking place within the past few thousand years. Even today, hot springs, considered to be a phase of the dying vulcanism, are rather widely distributed throughout the Cordilleran region. In Yukon, in addition to very young lavas such as those of the Selkirk series, are deposits of loose white volcanic ash throughout the southwestern half of the territory. They are as much as 100 feet thick on the northeast face of St. Elias Mountains, but thin rapidly away from this centre, and elsewhere are commonly a foot or less in thickness. The ash lies at or close to the surface, growing vegetation commonly being rooted in it. The Tuya and similar lavas and cinder cones of Dease Lake and Stikine River areas include members of very late Tertiary, Pleistocene, and Recent ages. Some of this activity probably took place in quite recent time; Hoodoo Mountain, on Iskut River, may, for example, still be active and capable of further eruptions. Recent lavas occur in several places along the coast, as on islands in Mathieson Channel where stratified tuffs and flows of a maximum thickness of 1,000 feet rest on glaciated batholithic rocks and on till. Recent volcanic deposits in the southern part of the province include lavas of the Garibaldi district, ash beds in the Bridge River area, and andesitic lava on North Thompson River.

INTRUSIVE ROCKS

Intrusive rocks are common throughout most of the Western Cordilleran region, but considerable areas of them are capped by Tertiary lavas. The intrusions vary widely in size, age, and composition, although granitic bodies of Mesozoic age are by far the most abundant and include the Coast batholith, which ranks among the world's largest. They are of particular interest in that they were derived from the same deep-seated source or sources as the metallic mineral deposits of the region. In general they have not been greatly affected by the compressive stresses that crumpled the associated strata, and well-developed gneissic phases are not common.

No granitic rocks of proved Precambrian age have been recognized in British Columbia or Yukon. However, feldspar pebbles in the basal Windermere rocks of southeastern British Columbia suggest the presence of an Early Proterozoic or older granitic intrusion. The quartz diorite Purcell sills in the same district have been mapped as of early Proterozoic age, but may be younger. Gneissic granite that cuts rocks of the Yukon group is possibly in part of Precambrian age, but it may be much younger.

So far as known only minor intrusions occurred in Palæozoic time. An example is the Proserpine sills and dykes of quartz porphyry, felsite, and aplite that cut Precambrian rocks of the Cariboo district but are not known to intrude Mississippian strata.

The Coast batholith is the largest of the Mesozoic intrusions. It forms the core of the Coast Range and extends northwesterly about 1,100 miles from the northern part of the State of Washington to Yukon. Its width averages more than 50 miles and locally exceeds 125 miles. Flanking it for many miles on either side are smaller, related intrusive masses that, with the rocks of the main batholith, comprise what is commonly known as the Coast intrusions. In southern British Columbia the batholith curves towards the east and is linked with the presumably related Nelson batholith of Kootenay district by other intervening intrusions. The Coast intrusions range in composition from granite to gabbro, but are mainly of granodiorite and quartz diorite. The batholith is a composite of an unknown number of phases that were emplaced as successive irruptions over a long period of time, and, presumably, the numerous satellitic bodies are likewise of more than one age. The younger phases commonly show sharp intrusive contacts against older phases, and in many localities the batholithic rocks cut Lower Cretaceous sediments that contain pebbles of earlier batholithic rocks. It has been suggested that in northern British Columbia the more acid phases are most common towards the interior of the batholith. In the southern part of the province, however, the eastern intrusions, such as the Nelson batholith, are more acid and contain a greater proportion of granite than those nearer the coast.

Determinations of the ages of the Coast intrusions are, in general, confined to phases appearing along the eastern border of the batholith or in the presumably related satellitic intrusions lying on either flank. Phases developed only in the interior or coastal parts of the main batholith, where they cannot be compared directly with fossiliferous strata, might be of appreciably older or younger ages. Although most of the intrusive rocks are acknowledged to be not older than late Jurassic, gneissic granite of possible pre-Jurassic age has been reported from the Topley area, and other possible pre-Jurassic granitic bodies are suggested by the occurrence of granitic pebbles in Jurassic strata in the Whitehorse, Laberge, Stikine, and Britannia areas. On Queen Charlotte Islands intrusive rocks correlated with the Coast batholith cut early Upper Jurassic formations and are overlain by late Lower Cretaceous formations. In the Hope area granitic rocks of comparable age cut Middle Jurassic strata and appear to be the source of granitic detritus in early Lower Cretaceous conglomerate. Nearby, in the Princeton area, rocks ranging from granite to gabbro, and representing several periods of intrusion, cut Upper Triassic strata and are in part older than late Lower Cretaceous formations that hold their derived pebbles. At

Ashcroft, granite that intruded early Upper Triassic rocks is overlain unconformably by late Middle or very early Upper Jurassic strata. Intrusions cutting Lower Cretaceous beds have been found along the east side of the batholith in many places in British Columbia and somewhat east of the batholith in the Laberge and Carmacks areas in Yukon. In the Bridge River district the batholith cuts a formation of late Lower or early Upper Cretaceous age. A small satellite stock has intruded probable Upper Cretaceous rocks in the Houston area and may be of Tertiary age. Near Vancouver the batholith was emplaced and unroofed before Paleocene or early Eocene time when it was buried by the Burrard formation. In a number of localities relatively fresh phases of the intrusions cut late Mesozoic phases and are thought, but not proved, to be of Tertiary age. In summary the available evidence indicates that most of the Coast intrusions are not older than late Jurassic or younger than earliest Tertiary, and that the main mass is post-Lower Cretaceous in age.

The intrusive rocks of south-central British Columbia are most extensively developed in the region between Kootenay and Okanagan Lakes. Much of this great area is occupied by a complex of batholithic rocks referable chiefly to one great period of intrusion and correlated with the Nelson (West Kootenay) batholith. Associated with but cutting this batholith, are bodies of younger intrusives. Elsewhere in Selkirk and Purcell Mountains are a number of large stock-shaped bodies of granitic rocks, some of batholithic proportions, which for the most part resemble members of the Nelson batholith but may include later intrusions. Much granitic material in this general part of the province appears as banded, or gneissic and pegmatitic, granitic rocks closely associated with and partly replacing Precambrian and later strata. This assemblage has been referred to as the Shuswap granitic and gneissic rocks, which are now, in large part at least, correlated with the Nelson batholith. The various members of the Nelson batholith are granite, and grade into one another as if they represent nearly, if not quite, continuous irruption that doubtless occupied a considerable interval of time. They cut the Slocan series and are, therefore, of post-Triassic age. No other direct evidence of age is available, but it is generally conceded, on indirect evidence, that the age of the batholith is almost certainly Cretaceous and may well be late Cretaceous.

The Cassiar-Omineca batholith, with a probable length of more than 500 miles, extends northwesterly from near Takla Lake through northern British Columbia and well into Yukon. It is only partly explored and is not known to have been completely unroofed. Where observed its width ranges up to about 25 miles. Smaller related bodies are numerous along its western margin. Near its southern end and in the vicinity of the Yukon-British Columbia border intrusions are abundant within belts that appear to connect it with the composite Coast batholith. Recorded phases range in composition from granite to diorite and, locally, more basic rocks, although granodiorite is probably the most abundant. These rocks commonly grade into one another and are not known to represent more than one continuous period of intrusion. Near Takla Lake the batholithic rocks cut Jurassic strata that are thought to be conformable with other Jurassic strata of early Upper Jurassic age. They also appear to have been the source of pebbles found in early Upper Cretaceous conglomerate. Thus, so far as known, the main Cassiar-Omineca batholith is of Upper Jurassic or Lower Cretaceous age.

Intrusive, stock-like, tabular, and irregular bodies of serpentinized dunite, peridotite, pyroxenite, and gabbro are found in southern Yukon, in Dease Lake and Takla areas of northern and central British Columbia, and in Bridge River, Hope, Princeton, and other areas of the southwestern part of the province. The largest are more than 100 square miles in area, but most of them are much smaller. They are commonly considered to be early phases of the Mesozoic batholithic intrusions and to be of Jurassic age.

In addition to some of the batholithic rocks, the age of which is known only to be post-Lower Cretaceous, and which may, therefore, be of early Tertiary age, are widespread dykes, stocks, and other larger intrusive bodies of more or less definite early Tertiary age. They include rhyolite, granophyre, quartz porphyry, and medium- to fine-grained granite, syenite, monzonite, and quartz diorite. A number are of distinctly alkaline composition. Porphyritic textures are common. A few bodies exceed 15 miles in maximum dimensions. In various localities they cut pre-Tertiary granitic bodies, or early Tertiary strata, or closely resemble and are presumably related to Tertiary volcanic rocks. Such bodies are found in the Ogilvie, Carmacks, and Whitehorse areas of Yukon, along the Prince Rupert line of the Canadian National Railway, northwest of Takla Lake, and on Vancouver Island. Others occur in the interior of southern British Columbia, where they include the Kuskanax batholith, the Rossland alkali granite and syenite, the monzonite stocks of Franklin mining camp, and Coryell and Beaverdell batholiths and other intrusions of Kettle River and Okanagan Lake areas.

Eastern Cordillera

GEOLOGY

In the Eastern Cordillera the rocks are almost entirely of sedimentary origin (Figure 54). Rocks of igneous origin occur in limited areas in the south, and sills and flows are of some importance as horizon markers.

Proterozoic

Proterozoic (Late Precambrian) rocks (*See* Figure 54) are exposed for the greater length of the Rocky Mountains, and along the Rocky Mountain Trench, which forms the boundary between the Eastern and Western Cordillera. In the Northwest Territories, also, sedimentary beds thought to be of Proterozoic age underlie strata of known Cambrian age in the Cap Mountain region of Franklin Mountains and in Mackenzie Mountains.

Proterozoic rocks have their greatest exposed width in the vicinity of the International Boundary. In the Clarke Range on the east these rocks are known as the Lewis series, which has been subdivided into eight formations with an aggregate thickness of 13,720 feet. From oldest to youngest the formations are the Waterton, Altyn, Appekunny, Grinnell, Siyeh, Purcell lavas, Sheppard, and Kintla. They succeed one another with apparent conformity, and are composed chiefly of siliceous dolomites and argillites with lesser amounts of quartzite. These Proterozoic rocks are chiefly water-laid sediments, but include one important sheet of extrusive basaltic lava that extends across the southern Rocky Mountains into the eastern part of the Purcell Range. In the Lewis series it forms conspicuous cliffs, and may be seen contouring the mountains through several miles of continuous exposure. It preserves a conformable position between the Siyeh and Sheppard formations, and maintains a fairly even thickness of 260 to 350 feet. This lava occurs in the Clarke Range near Waterton Lakes, and extends westward along the International Boundary into the Western Cordillera. Some fine-grained diorite sills a few feet thick occur in the Lewis series at a considerable interval above the basaltic flows. The Proterozoic age of the Lewis series is assumed from its stratigraphic position unconformably beneath Middle Cambrian sediments and the presence, in the Altyn formation, of formless, chitinous plates and films that indicate early forms of life.

ERA	PERIOD	EPOCH	ROCKY MOUNTAINS			
			SOUTHWESTERN AREA	SOUTHEASTERN AREA	BANFF AREA	JASPER AREA
CENOZOIC	TERTIARY	Eocene		*Kishinena*		
		Paleocene				
MESOZOIC	CRETACEOUS	Upper Cretaceous — *Montana*				
		Upper Cretaceous — *Colorado*		*Crowsnest*		
		Lower Cretaceous		*Blairmore*		*Blairmore*
				Kootenay	*Kootenay*	*Nikanassin*
	JURASSIC			*Fernie*	*Fernie*	*Fernie*
	TRIASSIC	Upper				?
		Middle				
		Lower		*Spray River*	*Spray River*	*Spray River*
PALÆOZOIC	PERMIAN					
	CARBONIFEROUS	Pennsylvanian		*Rocky Mountain*	*Rocky Mountain*	*Rocky Mountain*
		Mississippian		*Rundle*	*Rundle*	*Rundle*
				Banff	*Banff*	*Banff*
	DEVONIAN	Upper	?	*Exshaw*	*Exshaw*	*Exshaw*
				Minnewanka	*Minnewanka*	*Minnewanka*
		Middle	*Harrogate*	?	?	?
	SILURIAN		*Brisco*	*Unnamed*		
	ORDOVICIAN	Upper	*Beaverfoot* *Wonah*			
		Lower	*Glenogle* *Goodsir*		*Sawback*	*Present*
	CAMBRIAN	Upper	*Goodsir* *Ottertail* *Chancellor* *Sherbrooke* *Paget* *Bosworth* *Arctomys* *Pika*		*Sawback*	*Unnamed*
		Middle	*Eldon* *Stephen* *Cathedral* *Ptarmigan*	*Unnamed*	*Ghost R.* *Castle Mtn.* *Present*	?
		Lower	*Mt. Whyte* *St. Piran* *Fort Mountain*		?	*Quartzite* ?
LATE PRECAMBRIAN — PROTEROZOIC (BELTIAN)	WINDERMERE	(Not subdivided)	*Horsethief Creek* *(Hector and Corral Creek)* *Toby*	*Not present*	*Unexposed*	?
	PURCELL	Upper Purcell	*Mt. Nelson* *Dutch Cr.*: *Roosville*, *Phillips*, *Gateway*	*Kintla* *Sheppard*	*Unexposed*	*Jasper*
		Lower Purcell	*Purcell lava* *Siyeh* *Kitchener* *Creston* *Aldridge* *Fort Steele*	*Purcell lava* *Siyeh* *Grinnell* *Appekunny* *Altyn* *Waterton*	*Unexposed*	*Jasper*

Figure 54. Correlation chart of formations for Rocky Mountains and Foothills.

FOOTHILLS				
CROWSNEST PASS AREA	TURNER VALLEY AREA	ATHABASKA RIVER AREA	PEACE RIVER AREA	LIARD RIVER AREA
Porcupine Hills	*Paskapoo*	*Paskapoo*		
Willow Creek *St. Mary River*	*Edmonton*	*Brazeau*	*Wapiti*	
Bearpaw	*Bearpaw*			
Belly River	*Belly River*			*Unnamed shale and sandstone*
Alberta: *Wapiabi*	*Alberta*: *Wapiabi*	*Alberta*: *Wapiabi*	*Smoky*	
Alberta: *Bighorn*	*Alberta*: *Bighorn*	*Alberta*: *Bighorn*		
Alberta: *Blackstone*	*Alberta*: *Blackstone*	*Alberta*: *Blackstone*		
Crowsnest			*Dunvegan*	*Fort Nelson*
Blairmore	*Blairmore*	*Blairmore*: *Mountain Park*	*Fort St. John*: *Cruiser* *Goodrich* *Hasler* *Gates* *Moosebar*	*Lepine* *Scatter* *Garbutt*
		Blairmore: *Luscar*	*Bullhead*	
		Blairmore: *Cadomin*		
Kootenay	*Kootenay*	*Nikanassin*		?
Fernie	*Fernie*	*Fernie*	*Fernie*	
			Schooler Creek	
				Toad
		Spray River		*Grayling*
			Unnamed	*Unnamed*
Unexposed	?	?	*Unnamed*	*Unnamed*
	Rundle	*Rundle*		
	Banff	*Banff*		
	Unexposed	*Minnewanka*	*Unexposed*	*Unexposed*
		?		
		Unexposed		

G.S.C.

The Lewis series is practically identical in petrography and succession with the Purcell series on the other side of the Rocky Mountain Trench, and is always correlated with it. The Purcell series is, however, overlain unconformably by the Windermere series, also of Proterozoic age, which is apparently absent in the Clarke Range where the Lewis is overlain by Middle Cambrian strata.

Rocks of Precambrian age occur at the headwaters of Bow River near Lake Louise. The lowest beds exposed belong to the Corral Creek formation, and consist of quartzite, sandstone, and shale with a total thickness of 1,320 feet. They are overlain by the Hector formation, composed of grey, green, and purple shales, interbedded with conglomerate, and having an aggregate thickness of 1,390 feet. These formations are assumed to be of Precambrian age from the fact that they are separated by an unconformity from the overlying *Olenellus* zone of Lower Cambrian age.

In the Jasper Park region rocks of Precambrian age form the base of thrust-fault blocks. They have been named the Jasper series by Allan, Rutherford, and Warren, and the Miette series, in Mount Robson Park, by Walcott. The rocks consist of argillites, slates, quartzites, breccias, and conglomerates. Their aggregate thickness is unknown, but probably amounts to several thousand feet. The Jasper series is overlain by quartzites believed to be of Lower Cambrian age.

In the Finlay Forks area of British Columbia, at the headwaters of Peace River, the Misinchinka schists represent the oldest rocks. They consist of a thick succession of finely laminated mica schists, and have been tentatively placed in the Precambrian because of their stratigraphic position, their intensely metamorphosed condition, and their lithologic resemblance to schists elsewhere of Beltian (Proterozoic) age. No attempt has been made to correlate Proterozoic formations in the different areas where they are exposed. Lacking fossils, the other criteria commonly employed for correlation are only useful in a general way.

Palæozoic

Cambrian

Sedimentary rocks of Cambrian age are almost as extensive as the Eastern Cordillera region itself (*See* Figure 54), but fluctuations of the sea during the period caused wide differences in the type and thickness of sediments in various places. 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 Lower Cambrian sea was restricted in size. In the Clarke Range, near the International Boundary, Middle Cambrian beds, as already noted, rest on the Proterozoic, so that, if Lower Cambrian sediments ever were laid down there, they were subsequently removed by erosion. In the vicinity of the Canadian Pacific Railway, at the headwaters of Bow River, some 3,700 feet of sediments, composed of conglomerate, sandstone, and shale, have been definitely assigned to the Lower Cambrian on fossil evidence.

Farther north, in the vicinity of Mount Robson on the Canadian National Railway, the Lower Cambrian is represented by quartzitic sandstone, siliceous shales, and limestones with a total thickness of about 3,900 feet. Elsewhere to the north, on Peace River and in Franklin and Mackenzie Mountains, sedimentary beds have been assigned to the Lower Cambrian on scanty and questionable fossil evidence, and, commonly, on lithology and stratigraphic position.

The Middle Cambrian sea was more widespread, and probably extended the full length of the Eastern Cordillera. At the south, in the Clarke Range, the epoch is represented by quartzites, sandstones, and shales with some limestone at the top, and the total thickness of beds is about 500 feet. In the vicinity of the headwaters of Bow River the Middle Cambrian beds are chiefly limestone and have a total thickness of nearly 5,000 feet. In the Mount Robson region massive, arenaceous limestones predominate, and the total thickness of Middle Cambrian strata is estimated to be 6,200 feet.

Middle Cambrian strata have not been recognized in Peace River Valley, but may include part or all of more than 4,000 feet of beds composed of quartzites and shales whose age has not been determined but whose stratigraphic position indicates that they are pre-Devonian.

In the Northwest Territories Middle Cambrian shales and sandstones at least 200 feet thick have been identified from contained fossils in Franklin Mountains near Fort Norman and in Mackenzie Mountains.

Upper Cambrian rocks are much more restricted in distribution than those of Middle Cambrian age. They are absent at the 49th parallel, but are well represented in the vicinity of Kicking Horse Pass on the Canadian Pacific Railway, and are also represented, though less fully, at Mount Robson on the Canadian National Railway. The Bow River-Kicking Horse Pass section is composed largely of limestones and shales with a total thickness of nearly 10,000 feet. In the Mount Robson region the Upper Cambrian is again made up of shale and limestone with a thickness of about 2,100 feet. Farther north, on Peace River and in the Northwest Territories, Upper Cambrian strata may be present, but have not been certainly identified.

The Cambrian succession of formations appears to be complete along the two routes of the main lines of the Canadian National and Canadian Pacific Railways. On Mount Robson and in the vicinity no well-defined lithological break separates Ordovician and Cambrian strata, nor is there any sharp change in the faunas, so that it will require careful collecting and detailed study to determine the position of the contact.

Ordovician

On Mount Robson itself the strata definitely recognized as Upper Cambrian are succeeded by some 3,000 feet of thin-bedded limestones. These beds are arenaceous near the top, and weather into massive forms in cliff sections. Fossils in the lower part indicate a basal Ordovician age.

The boundary between Upper Cambrian and Ordovician strata is also hard to define where the main line of the Canadian Pacific Railway crosses the Rocky Mountains. There massive Upper Cambrian limestones of the Ottertail formation are conformably overlain by some 6,000 feet of chert, cherty limestone, shale, and slate of the Goodsir formation; but the basal Goodsir beds are now known to carry Upper Cambrian fossils, and not far above the base lowermost Ordovician fossils have been found. The Goodsir formation is overlain by about 1,700 feet of black and brown shales containing Ordovician graptolites.

In Beaverfoot Mountains, near Golden, British Columbia, the Glenogle shales of Lower Ordovician age contain graptolites, and are overlain by the Beaverfoot formation of Upper Ordovician age. The basal Beaverfoot beds comprise 150 feet of quartzite. This is overlain by some 700 feet of arenaceous shale, succeeded by quartzite and shale of small but undetermined thickness. The upper part of the Beaverfoot consists of 900 feet of limestone.

In southeastern British Columbia the early Ordovician graptolitic shales of the Glenogle formation are overlain by 167 feet of quartzite and sandstone of the Wonah formation (*See* Figure 54). These beds are thought to rest on an eroded surface of graptolitic shales, and in places on the underlying Goodsir formation. Although no discordance in dip is observable a considerable erosional interval seems to be represented. No fossils have been found in the Wonah, but the formation is overlain by magnesian limestone of late Upper Ordovician (Richmond) age, so it is thought that the Wonah beds may be early Richmond.

In the Northwest Territories no strata of Ordovician age have been recognized in Franklin Mountains, nor by the recent geological work and well drilling in Mackenzie River Valley. North of Fort Norman, however, a deep well penetrated a section of evaporites over 2,000 feet in thickness. This series contains some thick beds of rock salt of a high degree of purity, as evidenced by drill cores. No fossils have been found in these saline deposits nor in the associated sediments. They overlie strata of Middle Cambrian age, and underlie beds of Silurian age. Until more definite correlation is possible, this evaporite series could be placed anywhere in the sequence from Upper Cambrian to Lower Silurian.

On Peel River dark shales carrying graptolites are apparently of early Ordovician age.

In Mackenzie Mountains, Ordovician limestones of Richmond age are reported from the headwaters of Gravel River. In fact it appears that the Richmond sea spread across all of northern Canada. Fossils of Richmond age have been collected from the Arctic regions and in northern Ontario, Manitoba, and north of Great Slave Lake in the Northwest Territories.

Silurian

The submergence of the Eastern Cordilleran region in late Ordovician time continued into that of the Silurian period, and sediments of this age occur at intervals from the International Boundary in the south to Franklin and Mackenzie Mountains in the north.

Silurian rocks may be represented in the Clarke Range, near the International Boundary, by some unfossiliferous beds that underlie strata of Devonian age, but in general the Silurian beds, as those of Ordovician age, have been largely removed by erosion.

In the Windermere region of southeastern British Columbia both late Ordovician and early Silurian sediments are present. The change is transitional, however, and no accurate lithological separation can be made. The Silurian is here represented by the Brisco formation, composed of thin-bedded, magnesian limestones 1,000 to 1,200 feet thick.

Along the main line of the Canadian Pacific Railway, where Kicking Horse River cuts the Beaverfoot Range, the Brisco formation is represented by some of the Halysites beds of early authors. On Sinclair Mountain the formation consists of dark, finely arenaceous and magnesian limestones, with some black shales. The total estimated thickness of these beds is 1,200 feet.

Middle Silurian limestones occur along the Alaska Highway in the front ranges of the Rocky Mountains west of Fort Nelson. They rest on sandstones that are tentatively referred to as Cambrian. The beds immediately overlying them are of Middle Devonian age.

No Silurian has been recognized in the Jasper Park region where the Canadian National Railway crosses the Rockies; nor is there any record of Silurian strata where the headwaters of Peace River cross the Rocky Mountains.

Silurian rocks are widely distributed in the Northwest Territories, and good sections are exposed in Franklin and Mackenzie Mountains and in Mackenzie River Valley. In the geological exploration and deep-well drilling for and since the Canol Project development, the Silurian strata in Mackenzie-Carcajou basin are all included in the Ronning group, which is composed of hard, dense, dolomitic limestones interbedded with anhydrite and green shale, and has an aggregate thickness of about 1,500 feet.

The Ronning group is overlain by about 435 feet of brecciated dolomite with some gypsum. The age of this breccia is uncertain, but it is underlain by Silurian beds and overlain by Middle Devonian strata.

Devonian

Early Devonian time was apparently marked by a general withdrawal of the sea from the Rocky Mountain region, as no strata of Lower Devonian age have been recognized.

Limestones and shales of Middle Devonian age, as much as 2,000 feet thick, are widespread in the Mackenzie River region. This sea also extended westward into the Rocky Mountain region of the Alaska Highway where Middle Devonian limestones of undetermined thickness occur west of Fort Nelson.

In Peace and Pine River Valleys the Middle Devonian rocks are mainly massive limestones, with exposed sections up to 2,000 feet thick.

In the Jasper Park region of Alberta Devonian limestones constitute the thickest and most extensive formations. They rest on Cambrian or Ordovician beds.

To the south, one of the best exposed and most easily accessible sections of Devonian rocks is north of Bow River between Exshaw and Kananaskis, on the Canadian Pacific Railway. It comprises the Fairholme and overlying Palliser formations, which, together, have also been referred to as the Minnewanka formation. The Fairholme consists of black, dolomitic limestone in the lower part and light grey dolomite in the upper part, with a total thickness of about 1,420 feet. The basal beds of the formation rest on arenaceous dolomites thought to be of Cambrian age. Although the Fairholme contains abundant fossils they are poorly preserved and their age cannot be more closely defined than Devonian. However, the formation is overlain by Upper Devonian strata and was quite probably laid down in the Middle Devonian sea that spread northward. The succeeding, Palliser formation is composed essentially of grey weathering, dolomitic limestone, and is particularly resistant to erosion. It has a thickness of about 790 feet. On Athabaska River and vicinity the apparent equivalents of the Minnewanka succession farther south are divisible into three units, comprising a lower and upper series of limestone and dolomite strata separated by about 500 feet of chiefly thin-bedded calcareous shale carrying fossils of Upper Devonian age.

In the Clarke Range, near the southeastern edge of the Canadian Rockies, the Devonian strata of Windsor Mountain and possibly older rocks are included in an unnamed series of beds some 1,450 feet thick. They consist mainly of limestones and dolomites, but include three intervening shale members. Fossils of Upper or Middle Devonian age have been found in beds near the middle of the series.

In Mackenzie River Valley the Upper Devonian deposits are widespread, and are composed of shale, limestone, and sandstone. In the southern part, the total thickness of beds is less than 1,000 feet, but in the northern part, where shales prevail, nearly 3,000 feet of beds are present in places.

The Rocky Mountain and Mackenzie River regions were, therefore, more or less continuously submerged during Middle and Upper Devonian time.

Carboniferous

Carboniferous strata were laid down with apparent conformity on Devonian beds throughout the Rocky Mountain region, but are absent along Mackenzie River Valley. In the Crowsnest Pass and at Banff the period is represented by the Banff, Rundle, and Rocky Mountain formations, the first two of Mississippian age, and the last a Pennsylvanian formation.

The Banff formation is composed mainly of shaly, cherty limestone and limy shales, and is 1,200 to 1,400 feet thick. At its base is a thin but persistent band of chiefly black shale variously referred to as the Exshaw shale or Exshaw formation, and which is uncertainly of late Devonian or early Mississippian age. Fossil evidence from its type locality in the Banff area near Exshaw has indicated a Devonian age, but the contact relations indicate a much closer association with the overlying Mississippian beds. Also, similar widespread black shale within the same stratigraphic interval is known to be early Mississippian, though this may be a higher shale than that at the type Exshaw locality.

Overlying the Banff is the Rundle formation, consisting largely of grey, cherty limestone. In Crowsnest Pass the Rundle has a thickness of 5,300 feet, whereas to the east in the vicinity of Blairmore it is only 1,600 feet thick. To the north in the Banff area the Rundle has a thickness of 2,400 feet, but in the Jasper Park region it is not more than 1,000 feet thick. The Rundle formation lies conformably on the Banff, and grades imperceptibly into it. Recent investigations indicate that it is entirely of Mississippian age.

The Rundle is overlain with apparent conformity by the Rocky Mountain formation, consisting of quartzite, chert, and sandy dolomite of Pennsylvanian age. This series of beds varies greatly in thickness, apparently due to subsequent erosion. In Crowsnest Pass the thickness is given as 350 to 800 feet; in the Banff area it is 2,400 feet thick; but southeast of Banff, at Moose Mountain, the formation is missing.

To the north, in the Jasper Park region, the same threefold division of the Carboniferous can be made, but the thickness of the formations is much less. Mississippian strata are generally less than 1,500 feet thick, and those of Pennsylvanian age about 500 feet.

In Peace River Valley the Carboniferous is represented by limestone and quartzite of both Mississippian and Pennsylvanian ages, and of undetermined thickness. Argillites and limestones of Mississippian age have been observed along the Alaska Highway in the vicinity of Liard River.

The Banff and Rundle formations extend east beyond the limits of the Rocky Mountains and Foothills, but the Rocky Mountain formation is rarely found beyond the eastern ranges. Where it is missing the top of the Rundle formation becomes an erosion surface, as in the Foothills and region to the east.

Permian

Strata of Permian age have been recognized on Liard and Peace Rivers. An occurrence on Beaver River, a tributary of the Liard, some 50 miles above Fort Liard, consists largely of chert, with thin layers of shale. The chert is overlain by calcareous sandstone containing marine fossils. The total thickness of beds definitely assigned to the Permian is only 150 feet, but they are underlain by some 1,600 feet of calcareous sandstones and shales, the age of which may be Upper Pennsylvanian or Permian.

The Peace River occurrence is located above Hudson Hope where the Permian strata are exposed in the core of a tightly folded and faulted anticline south of the river. The beds are of marine origin, and consist of calcareous sand, marl, and limestone with a total thickness of 415 feet. The extent of this Permian sea is not definitely known.

Mesozoic

Triassic

Marine strata of Triassic age are distributed throughout the entire length of the Rocky Mountains, and rest with apparent conformity on the Palæozoic rocks. To the south the eastern margin of Triassic sediments follows closely the eastern ranges of the Rockies, but north of Athabaska River Triassic strata extended some distance east of the mountain front.

In the vicinity of Banff the Triassic beds consist of calcareous shale, argillaceous limestone, and dolomite of the Spray River formation (*See* Figure 54). This formation is generally divisible into a lower, dark grey member, composed of laminated, calcareous and sandy shales, and argillaceous limestone of Lower Triassic age, and an upper member of light grey limestone with sandy beds and darker shale bands of Middle Triassic age. The line of demarcation, however, between Lower and Middle Triassic sediments has not been defined. The total thickness of the Spray River group of beds is about 1,650 feet in the vicinity of Banff, where the formation rests on Rocky Mountain quartzite.

The continuity of Triassic strata southward is uncertain. None is recognized in the Turner Valley oil field, and although beds have been correlated with the Spray River in Crowsnest Pass on lithology, fossil evidence is lacking.

Northward, near Cadomin on a tributary of Athabaska River, the two members of the Spray River formation are exposed, but are thinner, and here the basal beds rest on the Rundle formation of Mississippian age. In the Jasper Park region both members of the Spray River outcrop in several places, and in one section the uppermost beds are overlain by gypsum and other evaporites, and the gypsum is immediately overlain by Jurassic shales. On Mowitch Creek, to the north of Athabaska River, the gypsum is overlain by some 480 feet of light grey limestone, which in turn is overlain by Jurassic beds.

In the Peace River section of the Rockies, the Triassic is represented by the Schooler Creek formation (*See* Figure 54). This is a cliff-forming group of beds more than 2,500 feet thick and composed of fine calcareous sandstone, grading to arenaceous limestone. The formation is divisible into two members, a lower, light grey, slightly carbonaceous and arenaceous member of Upper and possibly also Middle Triassic age, and an upper, dark, carbonaceous member of Upper Triassic age.

To the east, near where the Alberta-British Columbia boundary crosses Peace River, red beds and gypsum penetrated in a deep well have been correlated with the Triassic on the basis of lithology and stratigraphic sequence, but farther east the Triassic is absent.

North of Peace River and to the west of the Alaska Highway the Schooler Creek formation has been traced as far as Prophet River. From Halfway Valley northward it is known to be underlain by the marine shales, siltstones, sandstones, and limestones of the Toad formation, from which fossils of early Middle Triassic age have been collected. This formation may extend south of the Halfway, but has not yet been satisfactorily identified there.

In the western part of Tetsa Valley the highest Triassic beds are the massive, calcareous sandstones and limestones of the Liard formation, corresponding to the lower part of the Schooler Creek formation in the south. It is underlain by the Toad formation. In the same valley and to the east, near mile-posts 375 to 377, Alaska Highway, all or most of the Liard has disappeared, and the Toad is the highest Triassic formation and is overlain by dark shale, possibly of Lower Cretaceous age.

On Liard River the Triassic is exposed from the Rapids of the Drowned to beyond the mouth of Toad River. In the west the Toad formation is overlain by the Liard formation, but in the east the Liard is absent and the Toad is the highest Triassic formation. The Toad formation of Liard River carries two marine faunas, one of late Lower and one of early Middle Triassic age, and is underlain by the marine grey shales, with some ripple-marked sandstones, of the early Lower Triassic Grayling formation. This basal formation possibly extends far to the south, but has not yet been recognized there.

The Grayling is 600 to 1,000 feet thick. Eight miles southwest of the mouth of Toad River the Liard formation is more than 600 feet thick, and the Toad 1,800 feet. At the mouth of Toad River the Toad formation is about 800 feet thick.

Farther north, along the Alaska boundary north of Porcupine River, are wo known occurrences of Upper Triassic rocks. No Triassic has been recognized in Mackenzie River Valley or Mackenzie Mountains, and in many places Cretaceous rocks rest directly on Devonian strata. During this long interval there was ample time to remove any late Palæozoic or Triassic sediments if such had been deposited in this region.

Jurassic

Marine Jurassic sediments can be traced continuously along the eastern ranges of the Rocky Mountains and Foothills from the International Boundary northward to beyond Peace River, but are apparently absent on Liard River and in the Mackenzie River region. Jurassic strata are reported from Richardson Mountains west of Aklavik, and from Firth River farther west. The northern part of the Rocky Mountains and Mackenzie River basin were probably land masses during this period.

The Jurassic in the vicinity of the International Boundary is represented by the Fernie formation. This name has been carried northward to include all Jurassic strata (*See* Figure 54), and has thereby acquired the significance of a group as it includes strata of various divisions of Jurassic time, ranging from early Lower to middle Upper Jurassic. The Fernie is typically composed of dark marine shales with a few thin limestone and sandstone beds, and at the base, in many places, phosphatic limestone.

South of Bow River the Jurassic seas spread eastward over the Plains. The thickness of the Fernie is difficult to estimate because of lack of continuous exposed sections and the tendency of the abundant shaly beds to crumple and fold easily. Further, the succession apparently follows the general tendency of formations of the Rocky Mountains to thin rapidly to the east. In the vicinity of Blairmore in Crowsnest Pass it is about 800 feet thick, whereas to the west, at Corbin, thicknesses of 2,800 to 3,000 feet have been estimated. Thicknesses elsewhere include: Turner Valley oil field, less than 200 feet; Banff, 1,600 feet; and Mountain Park, southwest of Edmonton, 1,500 feet. Jurassic shales are known to occur in the Foothills of the Peace River region, but have not been studied, and they have been traced northward along the Alaska Highway as far as Sikanni Chief River.

Lower Cretaceous

The Lower Cretaceous epoch began with a broad uplift of the southeastern Cordillera, causing the sea to withdraw, and leaving the region a land mass. Continental deposits of Lower Cretaceous age continued, however, to be laid down from the International Boundary to and beyond Peace River. North of Athabaska River, marine beds appear in the Lower Cretaceous series and at Peace River fully half of the strata are marine. At Liard River and northward to the Arctic in Mackenzie River Valley the Lower Cretaceous is entirely composed of marine sediments.

In the Crowsnest Pass region the Lower Cretaceous is represented by the Kootenay formation and the Blairmore group. The Kootenay rests with structural conformity on the Fernie and apparently grades into it. The strata are composed of sandstones, sandy shales, and conglomerates, with numerous coal seams, many of which are mined. In the western Crowsnest Pass the sediments are coarse, and together with the associated coal seams attain a thickness 3,000 to 4,000 feet. To the east these beds become finer grained and thin to 500 feet or less. South of Bow River the Kootenay formation contains all the commercial coal, and the seams can be traced some distance north of the river. The Kootenay formation is overlain by the Blairmore group, the base of which is marked by the persistent Cadomin conglomerate that extends continuously along the Foothills belt to somewhere north of Athabaska River (*See* Figure 54). The Blairmore strata comprise a series of freshwater sediments, from 1,200 to 3,000 feet thick, composed of alternating sandstone and shale with some thin argillaceous limestones near the base. These sediments, like those of the Kootenay, become thinner and finer grained from west to east. This decreasing coarseness of sediments suggests a high land mass to the west. A conglomerate bed in the upper part of the Blairmore group is composed partly of porphyry pebbles, and suggests that an intrusive mass had been unroofed before the close of the Lower Cretaceous epoch.

In the Crowsnest Pass region the Blairmore group is overlain by bedded tuffs and agglomerates of the Crowsnest formation, which has a maximum thickness of 1,150 feet. This deposit covers a limited area of about 800 square miles.

On Brazeau River the Lower Cretaceous has been subdivided into four formations. These, in ascending order, are the Nikanassin, Cadomin, Luscar, and Mountain Park. The upper part of the Nikanassin is correlated with an upper part of the Kootenay of the southern Foothills, and is composed of quartzitic sandstone and shale some 900 feet thick. The formation is largely of freshwater origin, but some marine beds occur at the base. The Cadomin, Luscar, and Mountain Park formations are the equivalent of the Blairmore group. The Cadomin is a persistent conglomerate band, but is rarely more than 25 feet thick.

The Luscar is composed of shale, sandstone, and coal, and has a total thickness of 2,000 feet. The coal seams in this formation are commercially important, and are mined at many places between North Saskatchewan and Peace Rivers. The Mountain Park formation is composed of hard, ridge-forming, green sandstones. It is some 825 feet thick on Brazeau River, but thins rapidly northward. On Athabaska River it has lost its ridge-forming character, and if present has not been separated from the underlying Luscar formation.

In the Peace River region the Lower Cretaceous is represented by the Bullhead group, overlain by the Fort St. John group (*See* Figure 54). The former has not yet been satisfactorily divided. In the eastern part of the Peace River Foothills two divisions, the Dunlevy and overlying Gething formations, have been recognized. The Dunlevy is some 3,000 feet thick, and is composed of sandstone and shale. Some of the sandstones are coarse and conglomeratic and others are quartzitic; the lower beds are marine and may be partly of late Jurassic age. The Gething formation is correlated with the Luscar. It consists of sandstone and shale with coal seams, and has an aggregate thickness of about 1,400 feet. The Bullhead group thins northward and loses its identity about midway between Peace and Liard Rivers.

The Fort St. John group of Peace River Valley has been divided into five formations. Beginning with the oldest these are the Moosebar, Gates, Hasler, Goodrich, and Cruiser. The group as a whole is composed of shales and sandstones, largely if not entirely of marine origin, and has a total thickness of about 4,000 feet.

On Liard River the Lower Cretaceous is represented, in ascending order, by the Garbutt, Scatter, and Lepine formations composed of sandstones and shales, entirely of marine origin, and with an aggregate thickness of about 4,500 feet. The marine lower Cretaceous extends down Mackenzie River Valley to the Arctic, and in those regions is at present included in the Sans Sault group composed largely of shales, some 3,800 feet thick, that rest on an eroded surface of Devonian rocks.

Upper Cretaceous

The Blairmore group and Crowsnest volcanic rocks are overlain by the marine Alberta shales of Upper Cretaceous (Colorado and early Montana) age. In the Foothills belt they have been divided into three formations, and have an aggregate thickness of 2,200 feet in the south, 3,000 feet in the central area, and 3,800 feet in the vicinity of Athabaska River. At the base is the Blackstone formation, varying from 400 to 1,000 feet in thickness, and composed of dark grey shale with sandy beds at the base. In places the basal bed is a conglomerate. The succeeding Bighorn formation is composed of sandy shale, sandstone, and pebble-conglomerate. It attains a thickness of about 450 feet in the western Sheep River region, but thins rapidly eastward, and to the south is the equivalent of what has been called the Cardium sandstone or formation. It is overlain by the Wapiabi formation, composed chiefly of dark grey shales and 1,500 to 1,900 feet thick.

The Wapiabi is succeeded by freshwater sandstones and shales of the Belly River formation. These sediments become coarser from east to west. In southern Alberta their thickness increases from 2,000 feet in the eastern Foothills to more than 4,000 feet in the Rocky Mountains. South of Bow River the Belly River is overlain by dark marine shales of the Bearpaw formation, and these extend far eastward beneath the Plains (*See* Figure 51). The Bearpaw varies greatly in thickness, but rarely exceeds 800 feet in the Foothills. The succeeding Upper Cretaceous strata (Edmonton or St. Mary River formations) are composed of 2,500 to 3,000 feet of sandstones and shales of freshwater origin, with coal seams in the basal part. North of Bow River the marine Bearpaw beds are absent, and it becomes increasingly difficult to separate the later thick assemblage of Upper Cretaceous strata into formations and to draw the boundary between Cretaceous and Paleocene beds. In the Foothills between North Saskatchewan and Athabaska Rivers these strata have an average thickness of 11,000 feet. They have been divided into a lower assemblage of Upper Cretaceous beds, those of the Brazeau formation, which probably includes both Belly River and Edmonton equivalents, and an upper assemblage of Paleocene beds carrying Paskapoo flora, and, towards the base, some important coal measures.

In the Peace River region of northeastern British Columbia (*See* Figure 54) a threefold division of the Upper Cretaceous has been made. At the base the Dunvegan formation, consisting of interbedded sandstones and shales of brackish and freshwater origin, attains a thickness of 1,100 feet. The Dunvegan is overlain by the Smoky group, which is thought to be roughly equivalent to the Alberta shales of the south. At its base is the Kaskapau formation, composed chiefly of dark fissile shales of marine origin. These are overlain by marine sandstone, shale, and conglomerate. The Smoky group is succeeded by the Wapiti group of sandstones and shales of non-marine origin.

Farther north, near the junction of Fort Nelson and Liard Rivers, the Upper Cretaceous is represented by the Fort Nelson formation, composed largely of conglomerate and coarse sandstone of non-marine origin, and which attains a thickness of at least 560 feet. The Fort Nelson formation is overlain by an unnamed series of shales and sandstones that contain marine fossils of Upper Cretaceous age. Still farther north, in the Carcajou River basin of lower Mackenzie River Valley, the Upper Cretaceous has been divided into three formations, which, in ascending order, are the Slater River, Little Bear, and East Fork. The Slater River formation rests on the Lower Cretaceous Sans Sault group and is composed of about 1,000 feet of black, fissile shale with ironstone concretions and a few thin bands of bentonite. The Little Bear formation consists of sandstone, shale, and lignite. The beds include both brackish and freshwater sediments, and have an estimated aggregate thickness of 700 feet. The East Fork formation consists essentially of grey marine shale, with a little sandstone, and has an aggregate thickness of 850 feet, with the top eroded.

In the Far North, strata of Cretaceous age are known to occur on Arctic Red and Peel Rivers, in Richardson Mountains, and on Porcupine River to the west, but have not been studied in any detail.

Cenozoic

At about the beginning of the Cenozoic era and continuing to the close of the Paleocene epoch, the thick succession of Proterozoic, Palæozoic, and Mesozoic sediments deposited in the Rocky Mountain geosyncline was subjected to deep-seated orogenic movements that together with subsequent erosion produced the Rocky Mountains. The rocks were folded and faulted, and large blocks were thrust eastward. The Mackenzie and Franklin Mountain areas were subjected to similar compressive forces at about the same time, or earlier, producing a wide belt of mountain ranges. This northern area had been a land mass during late Palæozoic and early Mesozoic time, as evidenced by lack of sediments of post-Devonian and pre-Cretaceous age.

Evidence of igneous activity in the Rocky Mountains at the time of the folding is very meagre. Beds of bentonite occur in various Upper Cretaceous formations of the Foothills and Mackenzie River Valley. These suggest volcanic activity, but the vents that supplied the material are not known. An intrusive body of nepheline syenite and associated alkaline rock types occupies an area about 12 miles square on Ice River near Field, British Columbia. A small body of the same rocks is exposed at the head of Moose Creek Valley. This intrusive complex may represent the upper part of a much larger mass that lies buried in the western Rockies, and may be the source of the mineralization at Field. The age of the intrusion is thought to be late Cretaceous, but proof is not conclusive.

Early Tertiary sediments are known from widely scattered areas within the Eastern Cordillera. Paleocene freshwater sandstones and shales of the Porcupine Hills and Paskapoo formations extend eastward along the outer edge of the Foothills belt of Alberta (*See* Figures 51 and 54). In the south the Willow Creek formation underlies the Porcupine Hills formation, in places disconformably, and may be of late Upper Cretaceous age. It consists of sandstone and shale, and is about 2,760 feet thick. The formation as a whole is characteristically reddish, but this colour fades to the north, and beyond Porcupine Hills the Willow Creek has not been recognized. No definitely diagnostic fossils have been found in the Willow Creek beds, but they overlie the late Upper Cretaceous St. Mary River formation with apparent conformity.

The Porcupine Hills formation occurs on the eastern edge of the Cordilleran belt and extends eastward into the adjoining Plains. It is composed of sandstone and shale of freshwater origin, and has a maximum thickness of 3,500 feet. The beds overlie the Willow Creek formation, and their fossils indicate a Paleocene age. The Paskapoo formation occupies the centre of a broad syncline in west-central Alberta, and its outcrop is continuous northward from Porcupine Hills to Athabaska River. Only the lower part of the formation is exposed in the Eastern Cordillera. The beds consist of grey, lenticular sandstone and sandy shale that have an estimated maximum thickness of 4,000 feet. The Paskapoo is thought to be the approximate equivalent of the Porcupine Hills formation. Recent investigations in the Foothills north of Bow River have indicated that important coal-bearing beds formerly thought to be of late Upper Cretaceous age carry a Paleocene flora. Early Tertiary deposits, all of freshwater origin, and containing coal seams, occur in various intermontane areas. In the south, along Flathead River Valley, some 1,500 feet of light-coloured, soft sands and shales (Kishinena formation) have been tilted during the later stages of mountain building. A small basin of Tertiary strata in the northern Rocky Mountains along Coal River, a tributary of the Liard, contains a coal seam 15 feet thick. In the Rocky Mountain Trench along Finlay River and through Sifton Pass are Tertiary deposits consisting predominantly of coarse conglomerate, sandstone, and shale. In places these beds are tilted 10 to 40 degrees, showing that they have been affected by the later mountain building movements. In the vicinity of Fort Norman on Mackenzie River, strata of Paleocene age consist of shale, soft sandstone, and conglomerate. On Little Bear River, due west, these beds attain a thickness of 1,600 feet, and contain coal seams 8 to 10 feet thick. These beds lie unconformably on Upper Cretaceous strata.

On Wind and Bonnet Plume Rivers, headwaters of the Peel, Tertiary strata are 1,000 feet thick, and consist of gravels, sands, and shales with lignite beds. These strata have a thick basal conglomerate. They lie unconformably on steeply folded formations and are themselves gently folded. To the west of Richardson Mountains, along Porcupine River, light-coloured beds of clay, sand, and conglomerate rest unconformably on Cretaceous and older strata, and are thought to be of Tertiary age. Although early Tertiary time was characterized chiefly by mountain building, there were stages of erosion that reduced large areas to low relief. Remnants of these peneplains are evident in the Mackenzie and Rocky Mountain areas.

Pleistocene

In Pleistocene time much of the Eastern Cordillera region was subject to glacial action. Some areas, however, apparently remained free of ice, and in a large part of Yukon west of Richardson Mountains there is no evidence of glaciation. The Foothills of the Rocky Mountains and the eastern edge of Mackenzie Mountains were reached by the Keewatin ice-sheet, which came from the east. On reaching the foot of Mackenzie Mountains this ice-sheet spread both north and south along Mackenzie River Valley. The effects of glacial action are to be seen in the various types of deposits left by the ice mass, and in the deepening and broadening of the mountain valleys.

STRUCTURE

The Eastern Cordillera system was produced by compressive forces believed to have operated from west of the Rocky Mountain Trench. These stresses acted on the thick succession of strata, producing folds and large, west-dipping thrust faults (Figure 55).

The Rocky Mountain structures are usually parallel folds and thrust-fault blocks that give rise to long, northwest-trending ridges and ranges. Many of these thrust faults are moderately steep, with displacements not usually more than a few hundred feet. There are, however, several low-angle faults of large displacement, a notable example being the Lewis overthrust, which extends some distance into southwestern Alberta and southeastern British Columbia from Montana, and along which the displacement is measured in miles. The thrust faults generally dip west, but immediately east of the Rocky Mountain Trench some dip east. The Foothills belt along the eastern edge of the Rocky Mountains has structures similar to those found in the mountains, except that subsidiary thrust faults are more numerous in the Mesozoic sediments common to this belt. In the northern part of the Foothills belt faulting is less evident, and the folds are more symmetrical than farther south. The Rocky Mountains are bounded on the west by the Rocky Mountain Trench, a complex structural feature about which very little is known as the trench floor is for the most part widely covered with glacial and river deposits.

Mackenzie Mountains are characterized by broad folds with a subordinate amount of thrust faulting. These folds commonly show arcuate outlines and

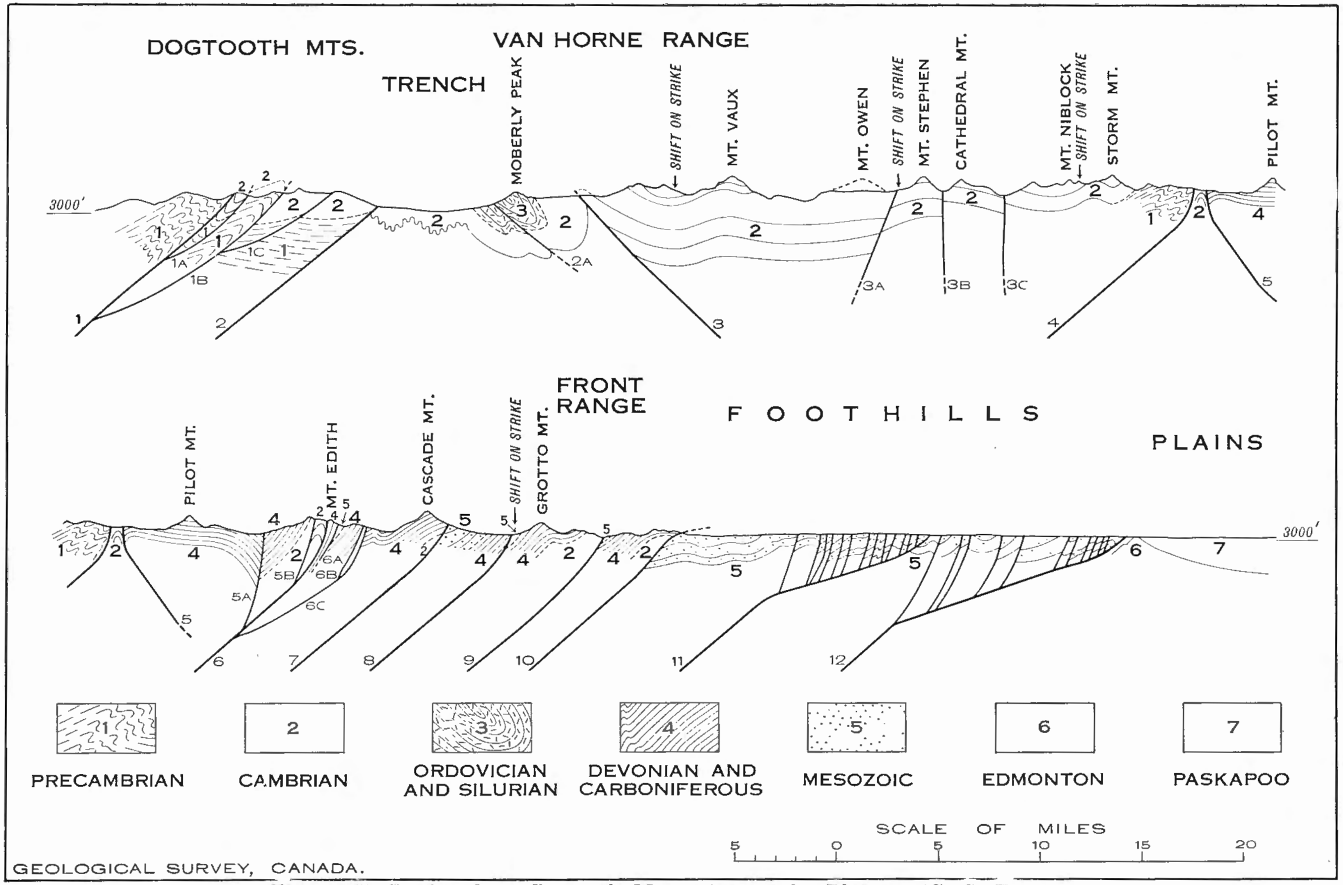


Figure 55. Section from Dogtooth Mountains to the Plains. (C. S. Evans.)

are arranged *en échelon.* The Franklin Mountains exhibit this arcuate form to a marked degree. The southern ends of some of the mountain ranges swing to the west, and trend towards the northern extremity of the Rocky Mountains.

The structures of Richardson Mountains are not well known, but broad, north-trending folds have been reported as characteristic of the region.

ECONOMIC GEOLOGY

Mineral Production

The Cordilleran region contributed about one-quarter of all mineral wealth produced in Canada up to the end of 1945. In that year production from this region was valued at about $96,500,000 or about one-fifth of the 1945 mineral production for Canada. Of this amount metals valued at about $51,700,000 (Figure 56), and comprising mainly copper, gold, lead, silver, and zinc, came from the Western Cordilleran region (Yukon and British Columbia). Non-metallic products, with an aggregate value of about $44,800,000, comprised mainly coal, natural gas, and petroleum, and these fuels, except for part of the coal, were derived from the Eastern Cordilleran region (Alberta).

Metalliferous Deposits

(*See* Figure 57)

GENERAL STATEMENT

With the exception of a small area near Field, British Columbia, essentially all known metalliferous occurrences, both lode and placer, are in the Western Cordilleran region. Most of the lode deposits are genetically related to the widespread, late Mesozoic and early Tertiary granitoid intrusions, such as the Coast and Nelson batholiths, and formed by solutions that accompanied or closely followed their emplacement. In many instances it is clear that the rising mineralizing solutions were guided by structural features. 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 yet known. With minor 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.

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, and the other includes the major intrusions that extend from lower Fraser River, through Nelson, nearly to the Rocky Mountains. The apparent concentration of metalliferous deposits in these regions may be due, in part at least, to their greater accessibility. Scattered prospects and a few productive mines have been found throughout much of the remainder of the Western Cordilleran region in both British Columbia and Yukon. Much of this country remains, even today, difficult of access, tedious to explore, and essentially unprospected, and, with the possible exception of the wide areas of Tertiary rocks stretching northwesterly from Kamloops, undoubtedly contains many undiscovered concentrations of metals.

The known deposits are mainly in Proterozoic, Palæozoic, or Mesozoic rocks. Most of them lie near the borders of intrusions. Some, however, as at Field and in the Barkerville Gold Belt, occur in strata many miles from the nearest exposed intrusive bodies to which they could be related. The greater number are veins or tabular bodies resulting from the replacement of country rock along faults or sheared or brecciated zones. The mineral deposits range

	YUKON				BRITISH COLUMBIA				ALBERTA				YUKON, BRITISH COLUMBIA AND ALBERTA			
	1945		TOTAL TO END OF 1945		1945		TOTAL TO END OF 1945		1945		TOTAL TO END OF 1945		1945		TOTAL TO END OF 1945	
METALS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS	QUANTITY	DOLLARS
GOLD (*fine ounces*)	31,721	1,221,258	9.718.686	212,148,844	186,854	7,193,879	16,191,763	420,749,056	7	269	17,731	399,001	218.582	8,415,406	25,928,180	633,296,901
SILVER (*fine ounces*)	25,158	11,824	45,113,284	20,994,934	5,620,323	2,641,552	311,096,950	166.088,816	1		249	106	5,645,482	2,653,376	356,210,483	187,083,856
LEAD (*pounds*)	119,516	5.976	95,073.097	4.386,084	336,976.468	16,848,823	8.677.256.013	372,813,931					337,095,984	16,854,799	8.772,329,110	377.200,015
ZINC (*pounds*)					294,791,635	18,984,581		234,640,085					294,791.635	18,984,581		234,640,085
COPPER (*pounds*)			13.062,512	2.711,695	25,751.252	3,231,782	2,382,356,552	335,367,342					25,751,252	3,231,782	2,395,419,064	338,079,037
OTHER METALS				13.902		1,549,253		27,864,247						1,549,253		27,878,149
TOTAL METALS		1,239,058		240,255,459		50,449,870		1,557,523,477		269		399,107		51,689,197		1,798,178,043
NON-METALLICS																
COAL (*tons*)			145,184	803,192	1,699,768	7,137,859	118,278,848	424,967,763	7,800,151	27,751,377	211,676,919	658,178,244	9,499,919	34,889,236	330,100,951	1,083,949,199
NATURAL GAS (*M. cu ft.*)									40,393,061	7,095,910		114,127,191	40,393,061	7,095,910		114,127,191
PETROLEUM (*barrels*)									7,979,786	13,169,692	82,583,031	138,844,620	7,979,786	13,169,692	82,583,031	138,844,620
OTHER NON-METALLIC PRODUCTS						6,476,113		117,292,879		1,470,630		40,639,615		7,946,743		157,932,494
TOTAL NON-METALLICS				803,192		13,613,972		542,260,642		49,487,609		951,789,670		63,101,581		1,494,853,504
TOTAL METALS AND NON-METALLICS		1,239,058		241,058,651		64,063,842		2,099,784,119		49,487,878		952,188,777		114,790,778		3,293,031,547

G.S.C.

Figure 56. Chart showing mineral production of the Cordilleran region.

from very high temperature assemblages found at the borders of granitic intrusions, such as the contact metamorphic magnetite deposits of the Pacific coast, to those formed at quite low temperatures and pressures and at a great distance from their source, such as the Pinchi Lake mercury ores. In some camps, such as the Slocan, the ores do not extend to very great depths; there they lie within an undulating zone 1,000 to 2,000 feet thick wherein the silver-lead orebodies of its upper part grade downward into pyritic zinc bodies near its base. Exceptionally, as in the gold-bearing quartz veins of the Bridge River camp, orebodies occur at intervals through a vertical range of several thousand feet without significant changes in mineralogy or precious metal content.

Placers contain gold, platinum, scheelite, and cassiterite. Gold is by far the most important metal, but platinum and scheelite have also been recovered. The gold placers are primarily the result of long-continued weathering and erosion, in Tertiary time, of great volumes of rock containing a very small proportion of gold. Concentration of the gold by streams resulted in pay-streaks in pre-Pleistocene gravels. These have since been variously disturbed and reworked by ice and streams, and placer gold is now found in Tertiary, Pleistocene, and Recent gravels. The most productive placer field, that of the Klondike in Yukon, is in an unglaciated area, but all placer areas of British Columbia and some of Yukon were buried and partly or completely eroded by Pleistocene ice.

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 the Manson Creek area began to open up 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 $4,000,000 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 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, 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 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 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

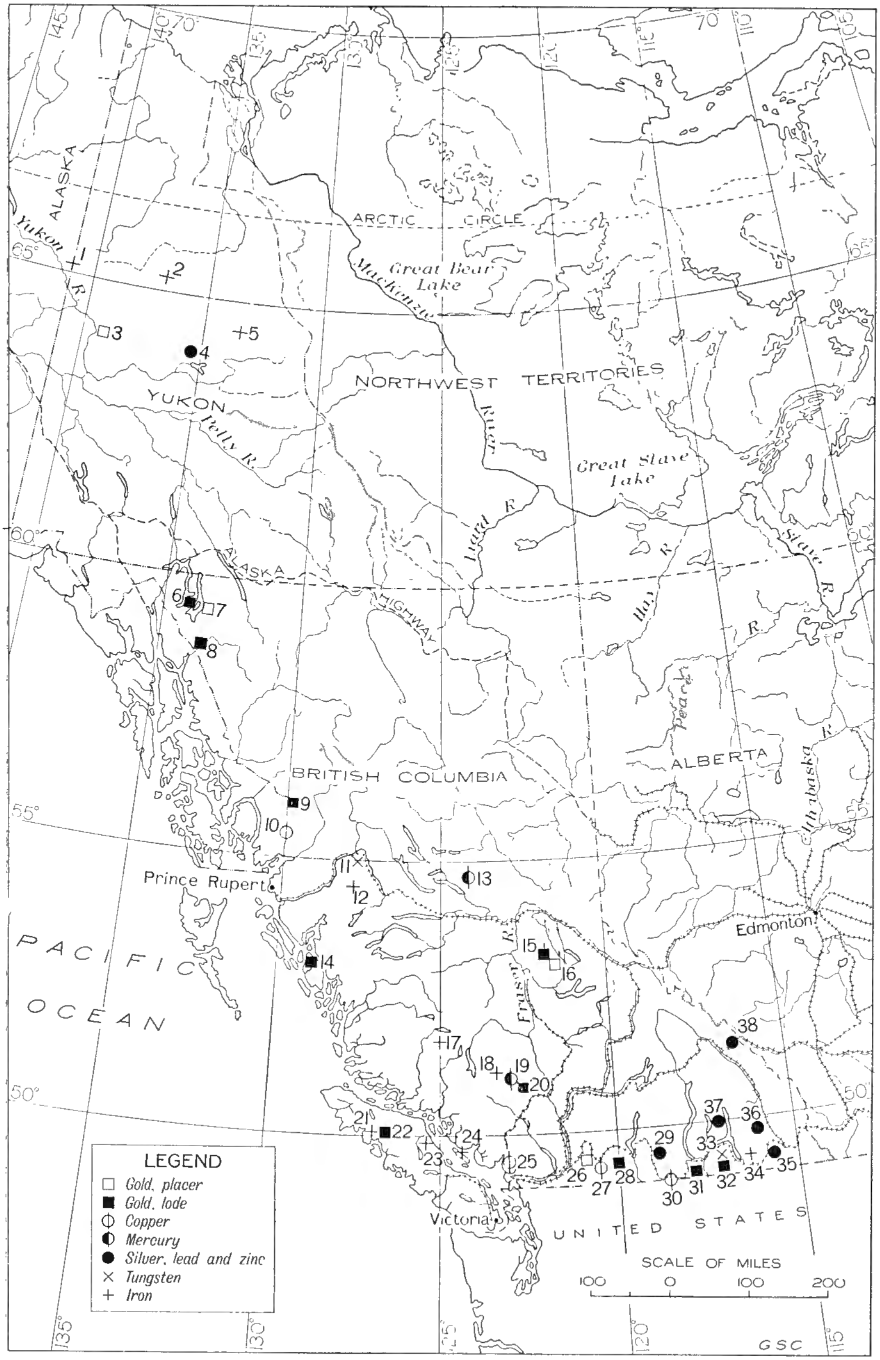


Figure 57. Some metalliferous mines and mining camps of the Cordilleran region. Reference to numbers given in text of report.

smelters had been built to treat various ores. All have since been abandoned. The Rossland gold-copper camp attained maximum production 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 Britannia and Sullivan mines entered continuous large-scale production in 1923 and intermittent but important production at Copper Mountain commenced in 1926.

Although lode mining was well established in southern British Columbia by 1900 it was not until 10 years later that the northern part of the province received much attention. 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 Granby 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 and were 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 these ores. The mill was closed in 1932, moved to nearby Galena Hill in 1935, and abandoned in 1941.

The rise in 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. In 1939 gold produced in British Columbia was valued at $22,659,323 and far exceeded, both in quantity and value, that produced in any year prior to 1933. It also far exceeded the value of any other metal produced in 1939. 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, none milling more than a few hundred tons a day, were revived or brought into initial production between 1933 and 1939 in the Cariboo, Hedley, Nelson, and other areas. The most outstanding gold discovery in recent years is the Zeballos camp on the west coast of Vancouver Island, which 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.

Gold

Gold produced in the Cordilleran region up to the end of 1945 was valued at about $633,300,000, and far exceeded the value of any other metal recovered. This production, in point of view of value, was about equally divided between placer and lode operations. Essentially all gold derived from Yukon, valued at about $212,100,000, came from placer mines. In British Columbia placer mines contributed about $92,000,000 and lode mines a little more than $300,000,000.

Placer Gold

Placer gold mining, in spite of its long history, is still an important industry. In 1945 gold from this source was valued at about $1,620,000, of which $1,221,258 came from Yukon, mainly from dredging operations in the Klondike district (Plate XLIV).

Since its discovery in 1896 the *Klondike* district (3)[1], embracing about 800 square miles in the vicinity of Klondike River and Dawson, has yielded gold valued at probably more than $200,000,000, and thus ranks as Canada's foremost placer field. Much smaller quantities of gold have come from Fortymile, Sixtymile, Mayo, Big Salmon, and Kluane areas of Yukon. Klondike district is a plateau thoroughly dissected by stream valleys. The oldest and most important formations consist of schists, partly of clastic and partly of igneous origin, and the principal producing creeks of the district flow over them. These formations are of Precambrian or later age, or both, and have been penetrated by bodies of granite. Short quartz veins presumably related to the granite bodies are abundant in some of the schists, and contain pyrite and other sulphides and a little visible gold, though their average gold content is perhaps only a few cents a ton. The gravels are composed mainly of vein quartz. The area was not glaciated, and the ground is permanently frozen to depths ranging from a few feet to more than 200 feet.

PLATE XLIV

Modern cold-water thawing plant and dredging operations below Granville on Dominion Creek, Klondike placer mining district, Yukon. Photo by H. S. Bostock, Geological Survey (79314).

A cross-section of any of the gold-bearing stream valleys in the Klondike usually shows a comparatively narrow inner valley, bordered by wide benches beyond which the surface rises gradually to the crests of the inter-valley ridges. The benches are remnants of old valley bottoms partly destroyed by the excava-

[1] This number appears on Figure 57 and indicates approximate location.

tion of the present valleys. Narrow terraces occur in places between the level of these old channels and the level of the present stream. Auriferous gravels thus occur on the present valley bottoms, on the rock benches cut into the valley sides, and on the preserved parts of the old, high-level benches or channels. These deposits may be classified as: (*a*) low-level gravels, comprising creek, gulch, and river gravels; (*b*) gravels at intermediate levels, or terrace gravels; and (*c*) high-level gravels, including river gravels and the White Channel gravels.

The creek gravels are the most important, and floor the bottoms of the valleys to depths of 4 to 10 feet. They rest on bedrock and the gold is commonly found in cracks and joints to depths of 2 or 3 feet or more. On Eldorado Creek, for example, creek gravels yielded more than $25,000,000 in gold from a pay-streak 300 feet or less wide and 3½ miles long. Gulch gravels occupy smaller tributary valleys and the upper parts of main creek valleys. River gravels containing gold in paying quantities occur on the wide flats bordering the lower part of Klondike River. The creek and gulch gravels are of Quaternary age.

Terrace gravels, of irregular distribution, occur on rock benches cut into the steep slopes of the present valleys at various levels.

High-level river gravels, commonly 200 to 300 feet above the river flats, occur at various points along Klondike River, but as a rule contain only a little gold. These, and the intermediate terrace gravels are probably of Quaternary age.

The White Channel gravels are the oldest in the district, and probably date back to the Pliocene at least. They occur on benches and in old channels bordering the present valleys at elevations of 150 to 300 feet. The deposits range up to nearly 400 feet thick, but large parts were destroyed during the deepening of the present valleys. They are the result of a long period of erosion during which perhaps several thousand feet of schists and associated mineralized quartz veins were worn down and the derived gold concentrated into definite pay-streaks. Practically all the gold in the present low-level valley flats was derived by reconcentration from these high-level gravels.

Placer gold produced in British Columbia in 1945 had a value of about $399,000, and came mainly from Cariboo and Atlin districts. Placer fields are scattered throughout the length of the province, mainly within that part of the Western Cordilleran region lying east of the Coast Mountains. The Cariboo field has been by far the most productive of these, and the Atlin district ranks second. Other notable districts are those of the Omineca, centring on Germansen Creek; the Cassiar, chiefly in the vicinity of Dease Lake; Tulameen and Similkameen Rivers; and various sections of southeastern British Columbia and lower Fraser and Thompson Rivers.

Placer gold recovered from the *Atlin* district (7), in the northwest part of British Columbia, amounted to nearly $15,000,000 by the end of 1945. In 1899, the year after its discovery, production was valued at $800,000, and did not again approach that value until recent years. The 1945 production was valued at $317,062.

The area is a deeply eroded and glaciated plateau region bordered on the west by the rugged Coast Mountains, and with a relief of from 2,800 to 3,800 feet.

The underlying formations present great variety in structure and composition, and range in age from Palæozoic to Pleistocene. The principal gold-bearing streams traverse an area on the east side of Atlin Lake that was not so heavily glaciated as other parts of the region. This area is underlain by greenstone, biotite and actinolite schists, peridotite, and serpentine. These rocks contain gold-bearing quartz veins and mineralized zones. The placer gold was derived from the destruction of great quantities of similar country rock that included auriferous quartz veins and zones.

The gold-bearing gravels are: (*a*) yellow, much decomposed gravels, commonly buried beneath glacial drift; and (*b*) gravels formed by stream erosion of the glacial drift and included masses of ancient auriferous gravels. The gravels formed by stream erosion commonly rest on boulder clay, no gold being found in the boulder clay or on the bedrock beneath it. Profitable placer mining is rendered uncertain by the occurrence in places of an overburden of barren glacial drift, and by the presence of boulder clay and numerous boulders.

PLATE XLV

Hydraulic placer mining on Keithley Creek in the Cariboo district of British Columbia. Photo by A. H. Lang, Geological Survey (79974).

Total placer gold production of the *Cariboo* district (16) probably exceeds $45,000,000, of which more than $35,000,000 came from the Barkerville area and the balance from the Quesnel River area, including Cedar Creek, Keithley Creek (Plate XLV), the Bullion mine, and Horsefly River. In its peak year of 1863 the Cariboo produced most of the provincial total of $3,913,563. In 1945 production from the Cariboo aggregated $42,554.

The Barkerville area is a deeply dissected plateau with a general upland elevation of about 6,000 feet. Bedrock consists mainly of folded, metamorphosed Precambrian sediments, traversed by a zone $\frac{1}{4}$ to 1 mile or more wide within which are quartz veins carrying galena, pyrite, arsenopyrite, scheelite, and gold. Fine and coarse gold has been recovered from the upper oxidized parts of such veins where it has been concentrated from eroded parts of the veins. The gold of the placer deposits presumably owes its origin to the long-continued action of such processes during late Tertiary time.

The entire Cariboo district, unlike the Klondike, was occupied by an ice-sheet in Pleistocene time. In many places the Tertiary placer deposits were destroyed by glacial action, but in a few places they were preserved and buried beneath glacial drift. In the process, some gold was incorporated in the glacial deposits. The preservation of the auriferous Tertiary gravels seems to have been due, in part, to the ice-sheet having been stagnant. Other placer deposits are of post-glacial and interglacial age, and owe their gold content to the erosion and re-sorting of the glacial drift and Tertiary gravels. They lie on the valley floors and on benches bordering the valleys. Pay gravels ordinarily are only a few feet thick, but gold in places extends for several feet downwards into the fissured bedrock. Exploitation of the field has been retarded by the thick cover of glacial drift. Williams Creek, in Barkerville area, was the most productive, and it and its tributaries, to the end of 1896, were reported to have yielded gold valued at $19,320,000. This production amounts to about $1,000 to the running foot of valley, a figure greatly exceeded by that for either Eldorado or Bonanza Creeks in the Klondike district.

The placers of *Tulameen* district (26) are unusual in that both gold and platinum are important constituents. Coarse gold was discovered there in 1885, and by 1910 this field had produced gold valued at $724,860, and more than 10,000 ounces of platinum valued in excess of $46,000. Only small amounts of these metals have been recovered since that time. Bedrock includes sedimentary and volcanic strata of Triassic age and intrusive Jurassic peridotite and pyroxenite. Much of the placer gold and platinum is coarse and rough: the gold nuggets commonly contain vein quartz whereas the platinum is often associated with pyroxene, olivine, or chromite. Auriferous quartz veins and other gold-bearing deposits in the Triassic rocks furnished most of the gold, and the basic rocks provided the platinum.

Lode Gold

Practically all gold derived from lode mines of the Cordilleran region of Canada comes from British Columbia. The production from this province exceeded $1,000,000 in 1896. For the next 35 years the value of the annual production fluctuated between $2,000,000 and $5,500,000 and then rose rapidly to its peak of about $22,462,000 in 1940. The 1945 production was valued at about $6,752,000. Most of the early production came from complex gold-copper and gold-silver ores from the southern interior and along the Pacific coast, but in recent years much of the gold has come from deposits consisting essentially of gold ores.

The *Engineer* mine (6), in the Atlin district, is on the east side of the Coast Mountains near the northwest corner of British Columbia. It operated intermittently between 1910 and 1934, and, though well known for its spectacular gold showings, was never an important producer, because of the pockety nature of the deposits. The country rocks are Mesozoic argillites and greywackes cut by a granodiorite stock and its satellitic dykes. The dykes are cut and offset by the auriferous veins. Two quartz-vein stockworks, locally known as "hubs", have been tested extensively but are not known to carry commercial amounts of gold. The principal gold-bearing veins lie on either side of a shear zone and trend towards it at various angles: none has been traced into the shear or across it. The shear has an indicated length of about 4,000 feet, and is as much as 65 feet wide. It is well mineralized with quartz, is heavily impregnated with pyrite, and contains encouraging amounts of gold. The veins range from mere stringers to 2 feet or more in thickness, and several are more than 1,000 feet long. The better mineralized parts are in many cases only 6 to 8 inches thick. Most of them are filled with quartz, but one has a calcite-mariposite filling. Native gold, gold tellurides, and mariposite occurred in very rich pockets.

In 1937 the *Polaris-Taku* mine (8) near Taku River became British Columbia's most northerly producing gold mine. It closed in 1942 due to war conditions, and up to that time yielded 89,330 ounces of gold and 4,990 ounces of silver. The host rocks, hard, massive andesite and silicified tuffs interlayered with soft phyllite and schist, strike about west and dip 60 degrees south to vertical. They are of Mesozoic age and are cut by the Coast batholith, the east flank of which lies a few miles west of the mine. The productive veins occur: (*a*) along contacts between schist and massive andesite; and (*b*) within massive andesite. The largest and most persistent vein is of the first type; it averages about 8 feet wide and is more than 1,000 feet long. Veins of the second type average about 4 feet in width and one has been followed for about 450 feet; they end where they enter schist. Reverse faults, of pre- and post-mineral age, strike about north, and offset the veins from 10 to 40 feet. The vein matter is quartz and carbonate with about 5 per cent sulphides, mainly arsenopyrite, pyrite, and stibnite. Most of the gold is intimately associated with the arsenopyrite and no free gold can be seen even in rich specimens. The wall-rocks, for as much as 30 feet from the veins, have been replaced by carbonate, pyrite, arsenopyrite, and a chromium-bearing mica. Ore shoots range from 50 to 800 feet in length and up to 35 feet in width. Their average gold content varies between 0·25 and 0·60 ounce a ton.

About 220 miles to the south, near the head of Portland Canal, is the *Silbak Premier* mine (9), which since 1935 has included the Premier and adjoining B.C. Silver and Sebakwe properties. This mine is notable in that it produces an ore in which the silver amounts to a fifth of the gold value, a much higher ratio than in any of the other larger gold mines. Production began in 1918 and by the end of 1945 had amounted to 1,711,294 ounces of gold, 38,338,818 ounces of silver, and 28,294,238 pounds of lead.

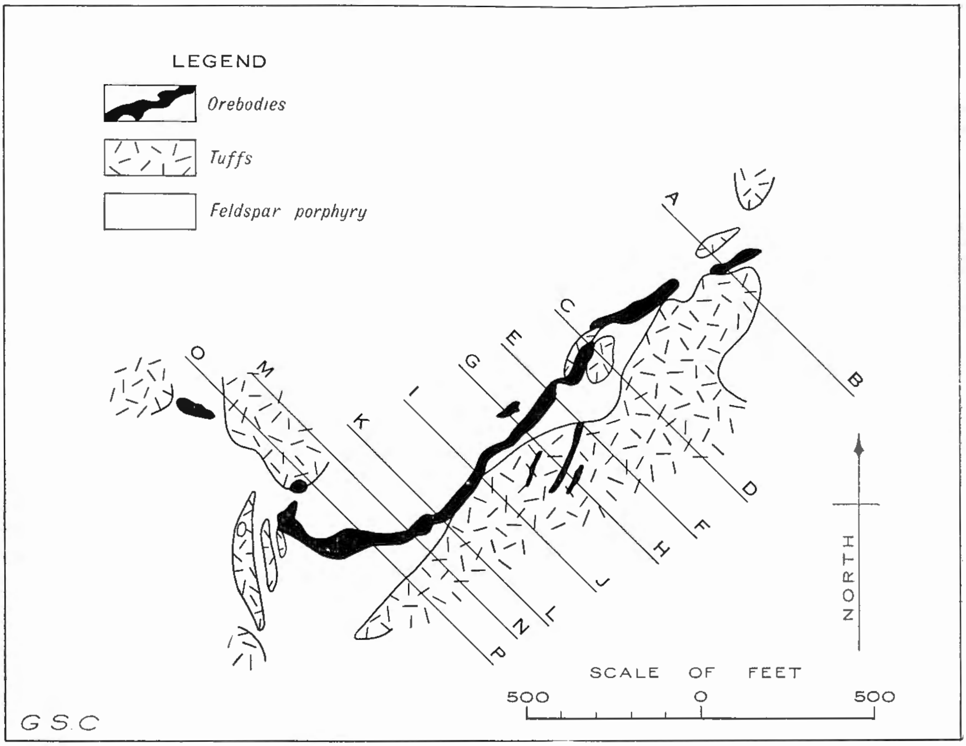


Figure 58. Plan of No. 3 level (elevation 1,550 feet), Premier mine, Portland Canal, British Columbia. (For sections A-B, C-D, etc., *See* Figure 59.) (After G. Hanson, 1935.)

The property (Figures 58 and 59) lies close to the eastern edge of the Coast batholith. The country rock at Premier mine is feldspar porphyry holding many large inclusions of sheared volcanic rocks altered to greenstones or chloritic schists. The porphyry forms a stock about 3 miles long. The ore-bodies occupied fracture or shear zones, and most of the ore occurred where these

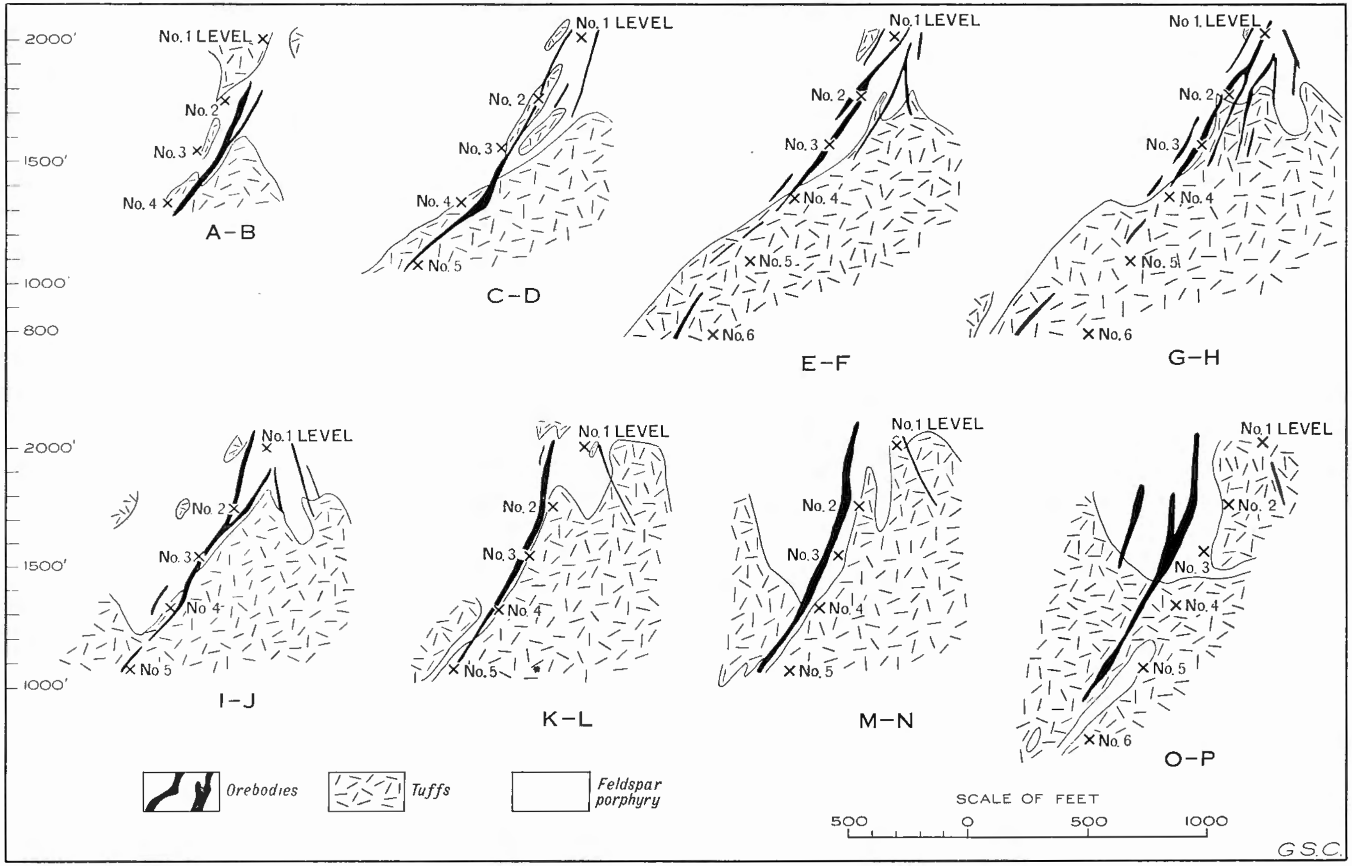


Figure 59. Vertical sections, Premier mine. Width of orebodies approximate only. (*See* Figure 58.) (After G. Hanson, 1935.)

zones cut brittle porphyry rather than where they crossed the more easily sheared volcanic rocks. The main fracture system strikes north 50 degrees east, dips 50 to 75 degrees northwest, and is 1,500 to 2,000 feet long. At its southwest end it swings to a course nearly due northwest for about 3,000 feet. A large part of the northeasterly striking zone was a wide body of solid ore, but only a few ore shoots were found in the northwesterly striking zone. The orebodies were in general 30 feet or less in width, except at the bend where a width of more than 50 feet was mined. The ore was, for the most part, fairly solid sulphide consisting at depth of pyrite, galena, sphalerite, and a little chalcopyrite. Nearer the surface it contained important amounts of polybasite, ruby silver, argentite, native silver, electrum, native gold, and argentiferous tetrahedrite. The walls of the ore zone are silicified, sericitized, and impregnated with pyrite to distances of 10 feet or more from the orebodies. Early shipments of ore from near the surface contained as much as 7 ounces of gold and 220 ounces of silver a ton, but the quantity of these metals in the ore decreased rapidly with depth. Their relative abundance nearer the surface was presumably due to the secondary enrichment of a primary ore through the agency of downward-percolating waters.

The *Surf* and *Pugsley* mines (14) on Princess Royal Island were operated successfully from 1916 to 1926 and again from 1936 to 1942. Overall production amounted to 385,200 ounces of gold, 6,294,750 pounds of copper, and 199,950 ounces of silver. At the surface the Surf deposit consisted of two veins of pyritized quartz 100 to 160 feet apart, one on each side of a large northerly trending shear zone. The veins joined at depth to form a single vein 40 feet wide in places. Other quartz veins have been found. Individual veins have lengths as great as 1,000 feet. The country rock is mainly quartz diorite of the Coast batholith, but the sheared zone cut through a large mass of chlorite schist included in the batholith. The veins are somewhat richer in the schist than elsewhere. Quartz and ankerite are the principal gangue minerals. Auriferous pyrite composed up to 25 per cent of the vein material, and native silver, chalcopyrite, hematite, molybdenite, and other minerals were also present.

Zeballos. This camp (22), on the west coast of Vancouver Island, includes the valley of Zeballos River and its watersheds. Important gold discoveries were made here in 1934. Normal production commenced at the Privateer and Spud Valley mines in 1938, and soon after at several other mines, but by late 1943 all properties had been forced to close because of the wartime shortage of men and supplies. During this short period of activity the four principal mines produced 335,000 tons of ore and recovered about $\frac{3}{4}$ ounce of gold from each ton, in addition to some silver.

A quartz diorite intrusion 1 to 2 miles wide, trends northwesterly through the camp, and is flanked by older, Mesozoic volcanic rocks and limestone. Most of the known properties lie within the quartz diorite, or in the volcanic and sedimentary rocks near its southwestern border. The main productive veins strike about east or northeast, and most of them occupy fault fissures. They are rarely more than a foot wide and normally maintain a fairly uniform strike and dip. The walls are marked by a film of gouge, and the vein matter is quartz, carbonate, and sulphides. The latter make up about one-quarter of the vein filling and include pyrite, sphalerite, arsenopyrite, chalcopyrite, galena, and pyrrhotite. Gold is commonly visible, and in general occurs wherever galena and spalerite are found.

Bridge River. The Bridge River area (20), near the east flank of the Coast Mountains, about 100 miles north of Vancouver, contributes annually about one-quarter of all gold produced in British Columbia. The operating mines are the Pioneer and Bralorne, and the latter, with a normal capacity of about

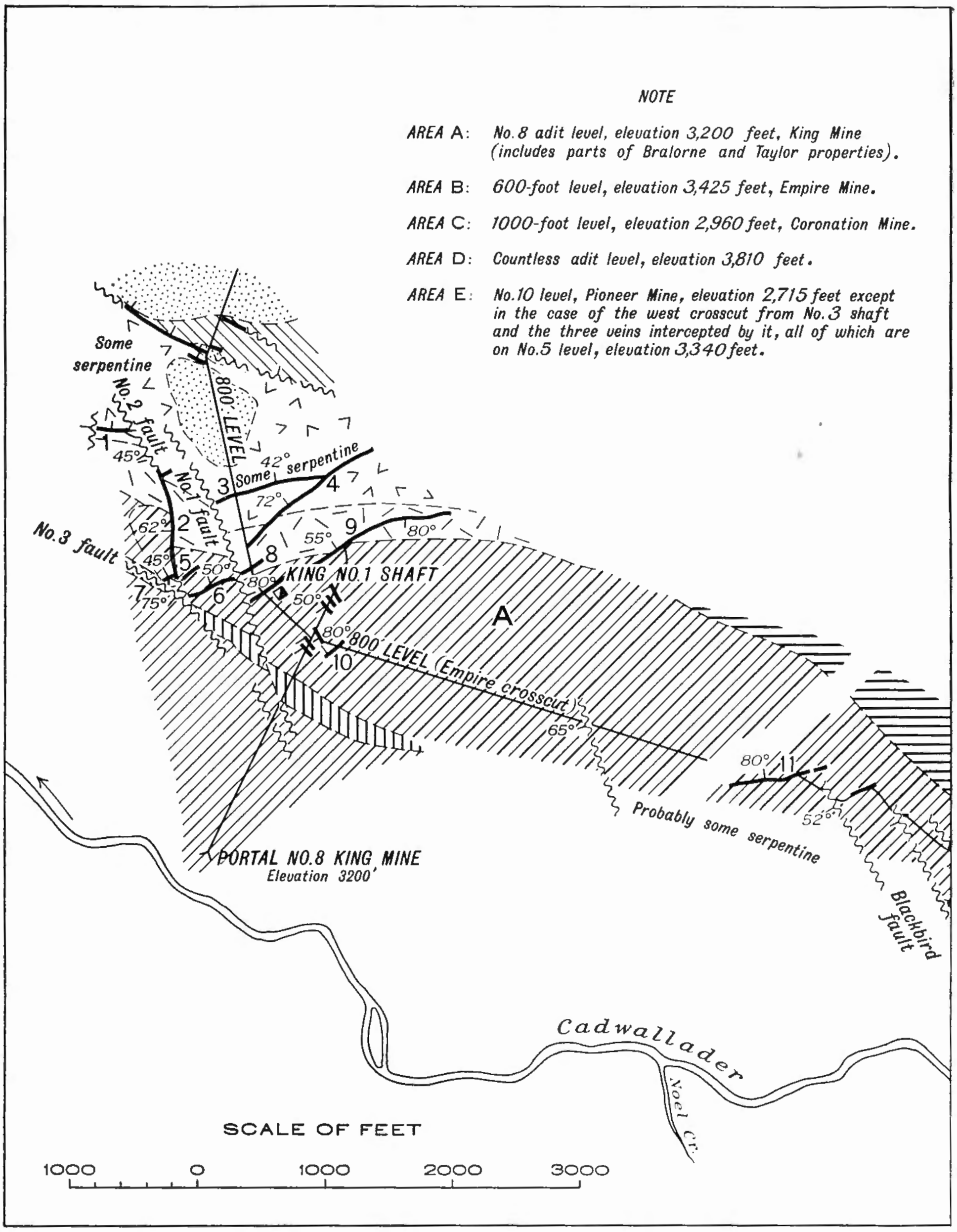
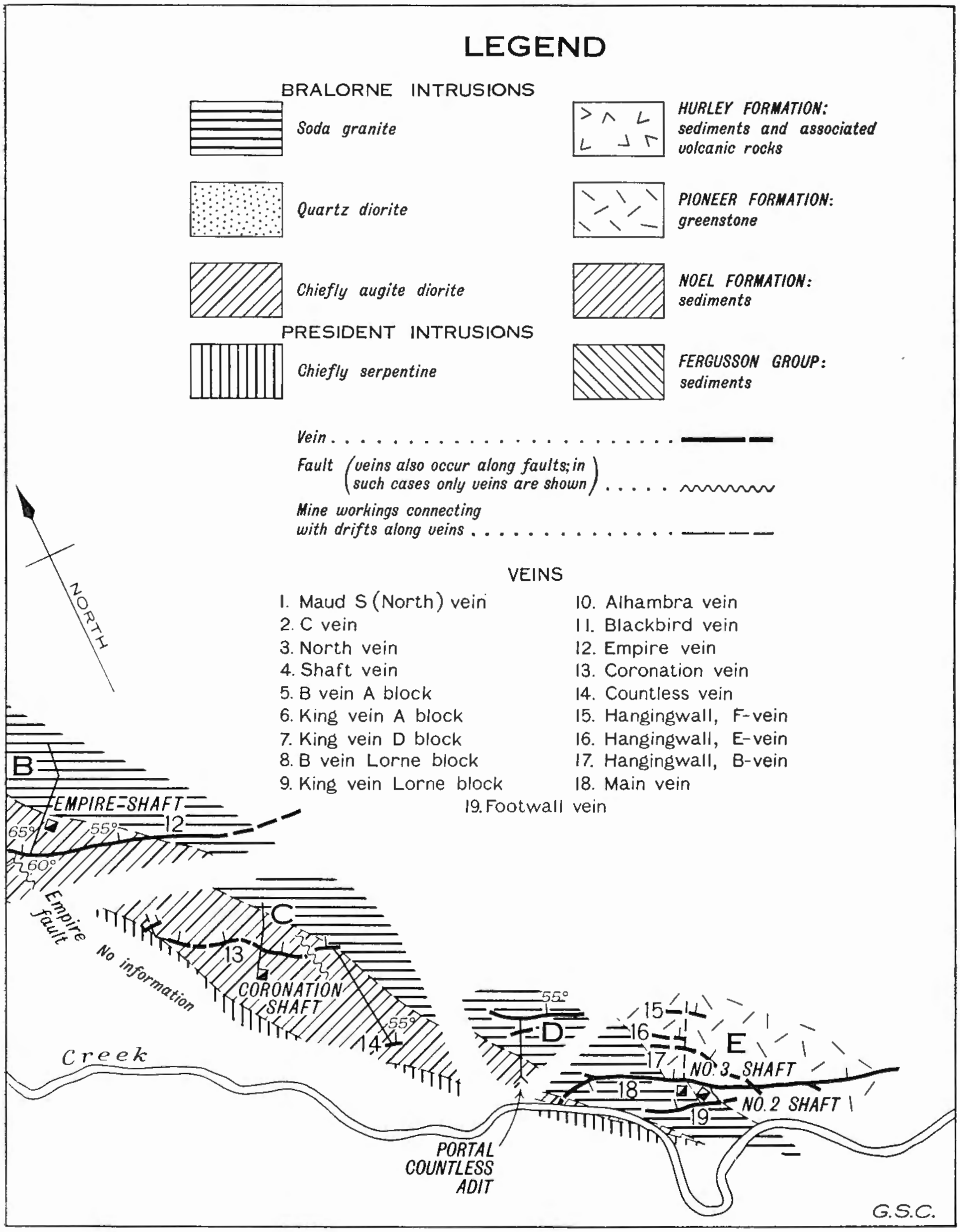


Figure 60. Vein and fault systems at Bralorne and



Pioneer mines, British Columbia. (After C. E. Cairnes.)

500 tons of ore a day, is the largest gold mine in the province. Important production commenced at Pioneer mine in 1929, and at Bralorne mine in 1932, and to the end of 1945 these mines had supplied 1,707,569 ounces of gold and about 432,000 ounces of silver from 3,237,424 tons of ore. Tungsten concentrates and arsenic have also been recovered.

The Pioneer and Bralorne properties (Figure 60) adjoin one another and occupy a belt approximately parallel to, and on the northeast side of, Cadwallader Creek, a tributary of Bridge River. Most of the gold-bearing quartz veins are related to, and occur in, a long, relatively narrow, steep-sided, stock-like body of Mesozoic augite diorite, quartz diorite, and related highly siliceous soda granite. This mass trends about northwest and is about 3 miles long and less than a mile wide. The variation in composition is attributed to differentiation prior to intrusion, and the mineral deposits are regarded as a late, probably the last, phase of this differentiation.

Although the principal vein-bearing fissures occur mainly within the intrusive mass, they also extend for some distance into the adjoining Mesozoic greenstone. They have a general west to northwest strike with steep dips, and, consequently, angle obliquely across the stock-like intrusion. The gold-quartz vein deposits occur in fissures along which there has been more or less faulting and shearing. Some of them are remarkably persistent, and in March 1937 the main Pioneer vein fissure was known to be 2,700 feet long and at least 3,200 feet deep. Gangue minerals of the vein filling are mainly quartz and calcite, but also include other carbonates, sericite, chlorite, mariposite, and scheelite. Metallic minerals make up only a small part of the vein filling, and are chiefly pyrite and arsenopyrite. Others include native gold, gold telluride, sphalerite, galena, pyrrhotite, chalcopyrite, tetrahedrite, stibnite, and marcasite. Native gold occurs with the sulphides, principally arsenopyrite, and disseminated through massive vein quartz.

A pronounced ribbon structure is a common feature of the veins, which range in width from a few inches to about 20 feet. Neither vein widths, type of mineralization, nor gold content has changed materially over a vertical range of more than 2,800 feet (1936). Altered wall-rock, which extends outwards from the veins for distances of a few inches to many feet, contains abundant ankerite and other carbonates and smaller amounts of pyrite, mariposite, quartz, and albite. Ore shoots may be 350 feet or more in length with maximum widths of as much as 20 feet of mineralized quartz. Ores, as mined, carry gold values ranging from a fraction of an ounce to the ton to bonanza shoots carrying as much as 50 per cent gold by weight. Average values of the principal orebodies have varied from less than $\frac{1}{2}$ ounce to 3 ounces or more a ton, with richer parts affording much higher values.

Barkerville Gold Belt. Although the Barkerville Gold Belt (15) in the Cariboo district lies in the heart of a highly productive placer field discovered about 1860, important lode-gold mining did not get under way there until the Cariboo Gold Quartz mine started milling in 1933. Production commenced at the neighbouring Island Mountain mine in 1934, and by the end of 1945 these properties had treated 1,285,532 tons of ore and recovered 531,397 ounces of gold and 56,625 ounces of silver.

The upper part of the Precambrian Richfield formation in the vicinity of Barkerville, and particularly the Rainbow member (Figure 61), is cut by a multitude of quartz veins, many of which are gold bearing. The part of the formation characterized by these veins is called the Barkerville Gold Belt. It trends northwesterly, and in general underlies an area less than a mile wide and at least 10 miles long. The rocks of the belt are interbedded argillite, quartzite, and limestone, and lie on the northeast flank of a northwesterly trending anticline. Several northerly striking post-mineral faults, with horizontal offsets of 1,200 feet or less, cross the gold belt. Pre-mineral faults also occur.

The mineral deposits are of two types: (*a*) gold-bearing pyritic quartz veins, and (*b*) gold-bearing pyritic replacement deposits. Most of the mineable gold deposits of the belt are of the first type.

The veins of greatest commercial value are of two classes; transverse veins crossing the strata roughly at right angles, and diagonal veins striking north 70 degrees east to east. They dip steeply or are vertical. The transverse veins are in general 150 feet or less in length and 4 feet or less in width. The diagonal veins are a little wider and longer than those of the transverse type, but are less numerous. Fractures occupied by commercial veins are in the main in several groups or zones. Individual veins in a group may not go far along the

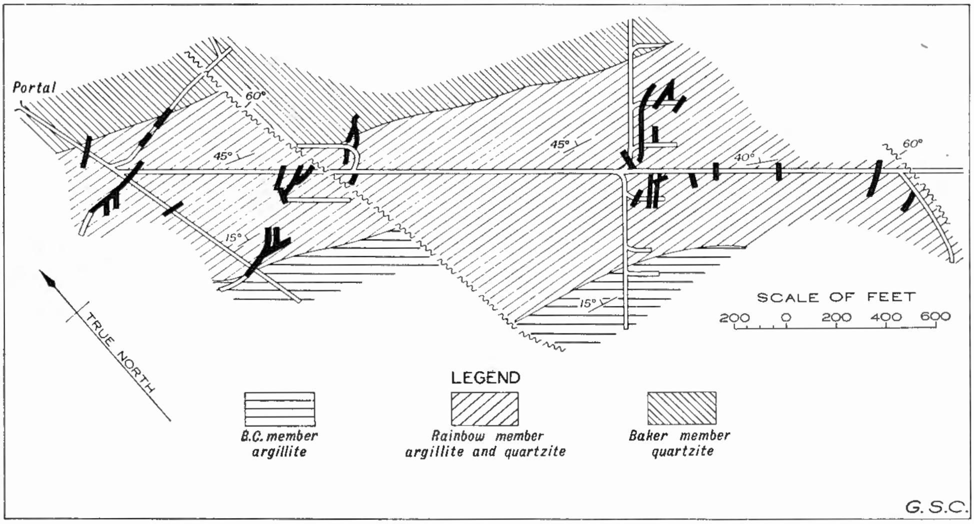


Figure 61. Cariboo Gold Quartz mine, Barkerville Gold Belt, British Columbia. (By G. Hanson.)

strike or dip, but others take their place, and, so far as is known, there is no diminution in the number or size of veins in a zone with depth. An individual vein tends to be confined to a single rock type. The vein-filling is closely fractured. Gangue minerals are mainly quartz and ankerite; other minerals make up 50 per cent or less of the veins, and include pyrite and arsenopyrite, and a little gold, galena, sphalerite, bismuth-lead sulphides, marcasite, gold telluride, and scheelite. Free gold is especially abundant in nests of bismuth-lead sulphides. Ore derived from the veins to date had yielded a little less than half an ounce of gold a ton.

The other main type of deposit was formed by replacement of limestone beds. The best ore consists of massive, fine-grained pyrite with free gold and small amounts of other minerals, and is generally of higher grade than the vein ore. Where replacement is less intense the ore consists of silicified limestone with pyrite and ankerite or dolomite. One replacement orebody was at least 300 feet long and as much as 9 feet or more wide, and contained about an ounce of gold a ton.

Hedley District. The Nickel Plate mine, at one time Canada's largest gold producer, has contributed much of the gold recovered from the Hedley district (28). Mining began in 1903 and ended early in 1931 when the ore-bodies were thought to be essentially worked out. A revival of the camp was brought about by extensive, detailed geological work, and 1935 witnessed the resumption of production at the Nickel Plate-Sunnyside mine. First gold was won from the adjoining Hedley Mascot mine in 1936. These mines, near the summit of Nickel Plate Mountain, are still operating, and the camp is once more a major gold-producing centre of the province with greater ore reserves than ever before. Up to 1918 the mines of the Hedley district produced from $500,000 to $750,000 in gold annually, with a peak production in 1915 of more than $900,000. Figures for production prior to 1907 have not been obtained, but production from that year to the end of 1930 was nearly $11,000,000, almost all of which came from the Nickel Plate system of orebodies. Production from Nickel Plate-Sunnyside and Hedley Mascot mines, 1935 to 1945 inclusive, has amounted to 498,574 ounces of gold, 72,957 ounces of silver, about 2,163,000 pounds of copper, and some arsenic, from 1,474,690 tons of ore.

Rocks of the productive, upper part of Nickel Plate Mountain comprise about two-thirds Triassic limestones, quartzites, and argillites and one-third gabbro and diorite as intrusive sills and other bodies. The strata strike in general about north and dip about 25 degrees west, but are traversed by several minor folds that trend about northwest. The youngest rock is granodiorite, which forms the base of the mountain. Low-angle thrust faults from the west divide the upper part of the mountain into several superimposed slices separated by breccias. Each slice has independent bedding attitudes approximating, but not identical with, the attitude of the bounding thrusts.

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. They lie within an area characterized by intense metamorphism of the sediments and associated sills, by the abundance of these sills, and by the series of northwesterly trending minor folds. The metamorphosed rocks are in the form of a cup or funnel wherein the sediments of the Nickel Plate formation have in the main been thoroughly recrystallized to a skarn of garnet, epidote, diopside, and other minerals, and the sills have been somewhat less altered. Within this highly altered rock mass the location of the ore is controlled by the edges of the cup, by minor folds, by gabbro sheets, such as that locally known as the Midway or Hot sill, and by other structural features.

The Nickel Plate system of orebodies is the most extensive and productive, and is being exploited by the currently operating mines. They occupy a zone at least 3,000 feet long, 500 feet or more wide, and several hundred feet thick. This zone trends northwest along one of the above-mentioned minor folds, and follows gabbro sheets, which dip a little more steeply than the adjacent strata. The orebodies within the zone form a series of sheet-like bodies or "shingles", each of which plunges about 25 degrees northwest along its longest axis and overlaps those below *en échelon*. This arrangement of the orebodies gives the axis of the system a plunge of about 30 degrees to the northwest. The shingle-like orebodies are, in the main, laid along the top and bottom of the Midway gabbro sheet, which then forms the foot-wall or hanging-wall of the individual bodies. In other directions the ore passes gradually into mineralized rock. The ore is slightly younger than both the skarn rocks and the gabbro, and the solutions that brought it in may have come from the same source as the gabbro. Arsenopyrite is the principal sulphide, and contains minute particles of gold. It commonly comprises 10 to 50 per cent of the ore. The solutions that introduced the auriferous arsenopyrite also deposited scapolite, calcite, and clinozoisite. Minor sulphides include chalcopyrite, sphalerite, pyrrhotite, and pyrite.

Rossland Camp. The Rossland camp (31), centred about the town of Rossland, has afforded far more gold than any other lode mining camp in western Canada. Production began in 1894 and continued on a large scale from 1897 to 1916. In 1902 the camp attained its peak production of 126,000 ounces of gold, 373,000 ounces of silver, and 11,667 pounds of copper, from about 330,000 tons of ore. By 1923 the annual output had fallen to less than 7,000 ounces of gold. Mining at a reduced rate continued until about 1930. The total production of the camp, from 1894 to 1930 inclusive, was 2,868,227 ounces of gold, 3,616,465 ounces of silver, and 118,037,675 pounds of copper. Former operations included the Centre Star-War Eagle, Le Roi, and Le Roi No. 2 groups of mines. In recent years small operators have recovered substantial amounts of gold by mining remnants of ore in the old workings and dumps.

The oldest rocks of the camp are folded, late Palæozoic slates. These have been intruded extensively by sills of augite porphyry, by granodiorite with offshoots of diorite porphyry, and by an irregular mass of monzonite.

The gold ores occur in replacement veins along fissures or shears cutting the brittle, competent intrusive rocks. The veins generally follow the contacts between the augite porphyry and any one of the other intrusive rocks. They commonly strike about east and dip steeply north. Some of the veins extend for as much as 4,000 feet along the strike, and mining has been carried down the dip more than 1,500 feet below the surface. They are offset by faults. The vein-widths range from a few inches to 130 feet. Ore shoots within the veins ranged from 50 to more than 500 feet in drift length, and from a few feet to 130 feet in width. Most of them pitched steeply, either to the east or west, and pitch lengths ranged up to 750 feet. Some wall-rocks, notably the more sodic diorite, were apparently more favourable for replacement than others, and in these the orebodies were wider and richer than elsewhere. The ore consisted mainly of pyrrhotite and chalcopyrite in a gangue of country rock and quartz. Other metallic minerals included pyrite, arsenopyrite, molybdenite, galena, and sphalerite. Some of the ore was almost solid sulphides, but other gold ore was nearly barren of such minerals. The country rock was silicified for many feet on both sides of the ore shoots.

Sheep Creek. An area 10 to 20 miles wide, extending from Kootenay River at Nelson southward for about 40 miles to the International Boundary, contains more than one hundred deposits from which gold has been derived. Nearly all this gold has come from quartz veins. The most productive camp within this area is that of Sheep Creek (32), near Salmo, first active in 1899. To 1945 this camp has produced 693,618 ounces of gold and some silver from a little more than 1,500,000 tons of ore. Recent producers include the mines operated by the Kootenay Belle, Sheep Creek, Gold Belt, and Reno companies.

The productive belt in the Sheep Creek camp trends north-northeast across the upper part of Sheep Creek, and is about 3½ miles long and less than a mile wide. It is underlain, for the most part, by brittle quartzites of Windermere (Late Proterozoic) age that strike about north and dip west. Nearby, these and other strata of Windermere age are cut by granitic stocks of the Nelson batholith. Aplite dykes are numerous, and one follows closely the strike of the quartzites and occupies a medial position in the productive belt. The mineral deposits are believed to be genetically related to the Nelson batholithic rocks, but were formed after these rocks had solidified.

The gold occurs in quartz veins. These occupy fault fissures striking north of east diagonally across the bedded rocks. The fissures are vertical or dip steeply southward. They are tight where they cross softer rocks, such as argillite and limestone, but commonly contain quartz veins and ore shoots where they cut the brittle quartzites. The fissures vary from a tight joint to a width of 20 feet of vein matter and crushed rock. The veins, as mined, rarely exceed 5 feet in width and average slightly less than 2 feet. Ore shoots range up to several hundred feet in length. In addition to quartz the veins contain pyrrhotite, pyrite, sphalerite, galena, chalcopyrite, bornite, and tungsten minerals. Gold accompanies pyrite, sphalerite, and galena. Oxidation of the sulphide minerals extends in one vein to a depth of 1,000 feet or more.

Copper

The Cordilleran region, to the end of 1945, had produced 1,197,710 tons of copper. Most of this, with the exception of that recovered from the cupriferous gold ores of the Rossland camp, came from the relatively few mines and districts described below. All of these are in the Western Cordilleran region of British Columbia. Almost the entire production in 1945, amounting to 12,876 tons, valued at $3,231,782, came from the Britannia and Copper Mountain mines in southwestern British Columbia.

Ore from the *Hidden Creek* mine (10) at Anyox, on Observatory Inlet, was mined and smelted from 1914 to 1935, inclusive. Total production was approximately 320,150 tons of copper, 106,200 ounces of gold, and 6,503,000 ounces of silver, from 23,700,000 tons of ore treated.

The deposits occurred within a remnant of metamorphosed argillites and amphibolite lying within the granitic rocks of the Coast batholith (Figures 62 and 63). This remnant is about 10 miles wide and 20 miles long. It is closely folded, broken by several faults, and cut by numerous basic and acidic post-ore dykes. The contact between the amphibolite and argillites trends about north. The amphibolite, which underlies the western part of the area, is intrusive into the argillites. Seven orebodies were found, six of which have been mined. Some lay at the contact of the amphibolite and argillite, and others within the amphibolite close to the contact. The surrounding rock has been extensively silicified. The orebodies varied considerably in size. The largest extended 1,200 feet down the dip: its greatest strike length on any one level was 1,500 feet and its greatest width 250 feet. It produced about 8,600,520 tons, carrying 1·85 per cent copper. The ore of the Hidden Creek mine consisted of solid sulphide, of amphibolite ribboned with sulphide, of highly silicified rock with sulphides, and of material exhibiting all gradations between these types. The metallic minerals were chalcopyrite, pyrrhotite, pyrite, magnetite, arsenopyrite, sphalerite, and galena. Most of the ore mined contained between 1·2 and 2·3 per cent copper, and about 0·005 ounce of gold and 0·30 ounce of silver a ton.

The principal copper producer of western Canada is the *Britannia* group of mines (25) on Howe Sound, about 20 miles north of Vancouver. First ore was shipped in 1905, and production to the end of 1934, in round figures, amounted to 250,000 tons of copper, 15,650 tons of zinc, 225,000 ounces of gold, and 2,700,000 ounces of silver. Production from 1935 to 1945, inclusive, was 15,454,267 tons of ore, providing 133,362 tons of copper, 154,313 ounces of gold, and 1,291,834 ounces of silver, as well as some zinc and sulphur. About 5,800 tons of ore were milled daily in 1940, and the resulting concentrates for that year contained about 19,750 tons of copper, 22,000 ounces of gold, and 210,000 ounces of silver.

The rocks in the immediate vicinity of the mine are in metamorphosed slaty tuffs overlain by greenstones (Figure 64). They are part of a roof pendant, about 7 miles long and 2 miles wide, that rests in younger granitoid rocks of the Coast batholith. The strata strike about northwest, parallel to the long axis of the pendant, and dip about 70 degrees southwest. They are cut by many sills and dykes of feldspar porphyry. Movements along 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. Adjacent to these folds the greenstones were silicified, repeatedly brecciated and fissured, and partly replaced by pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, barite, and anhydrite. The resultant orebodies, worked at the Bluff, East Bluff, Fairview, Empress, and Victoria mines, occur at intervals along nearly 1½ miles of the greenstone band. The shortest horizontal distance between any known orebody and the batholith is about 5,000 feet. The ore deposits extend to a depth of several thousand feet.

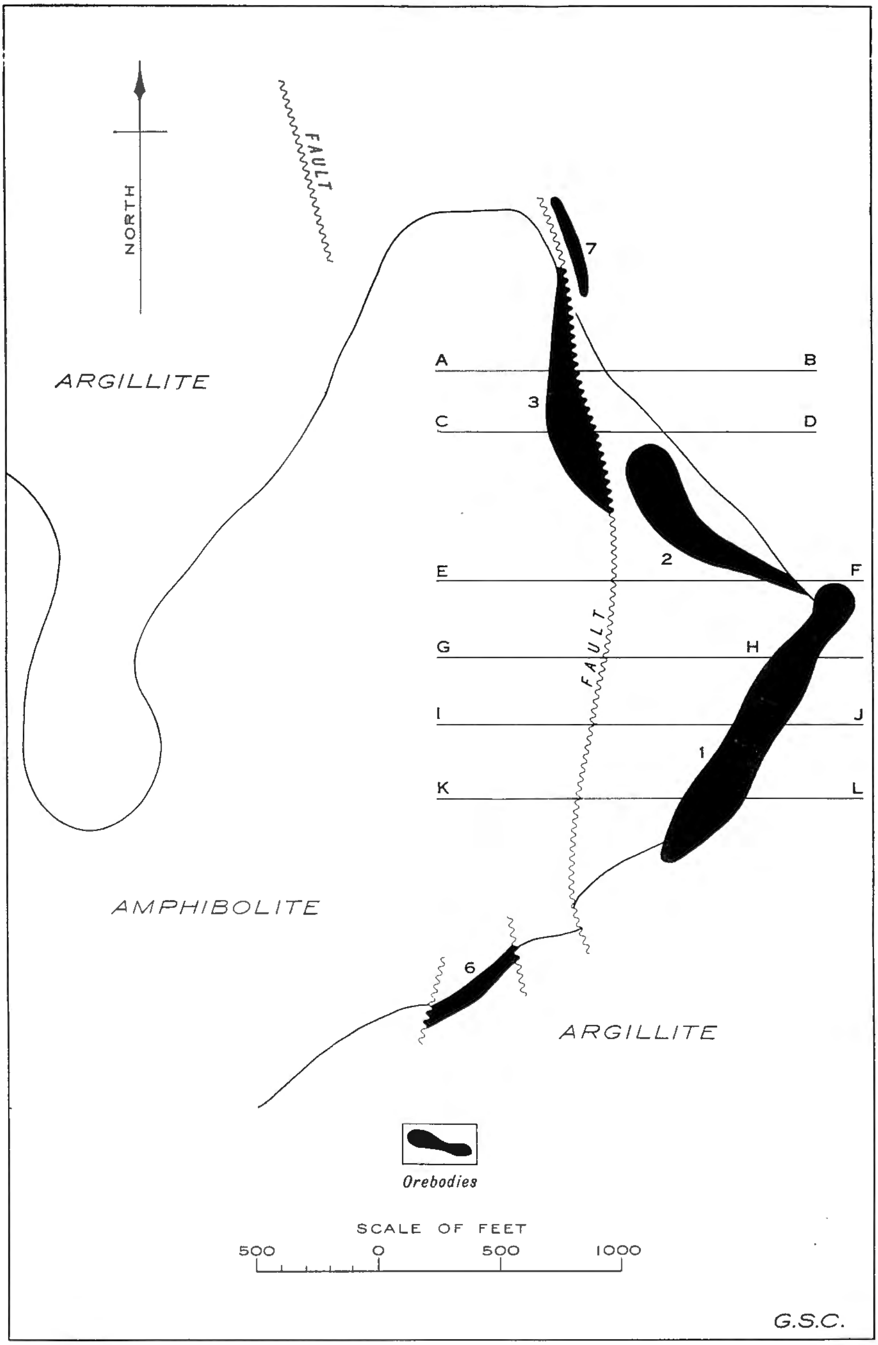


Figure 62. Generalized surface plan of Hidden Creek mine, Anyox, British Columbia. (For sections A-B, C-D, etc., *See* Figure 63.) (After G. Hanson, 1935.)

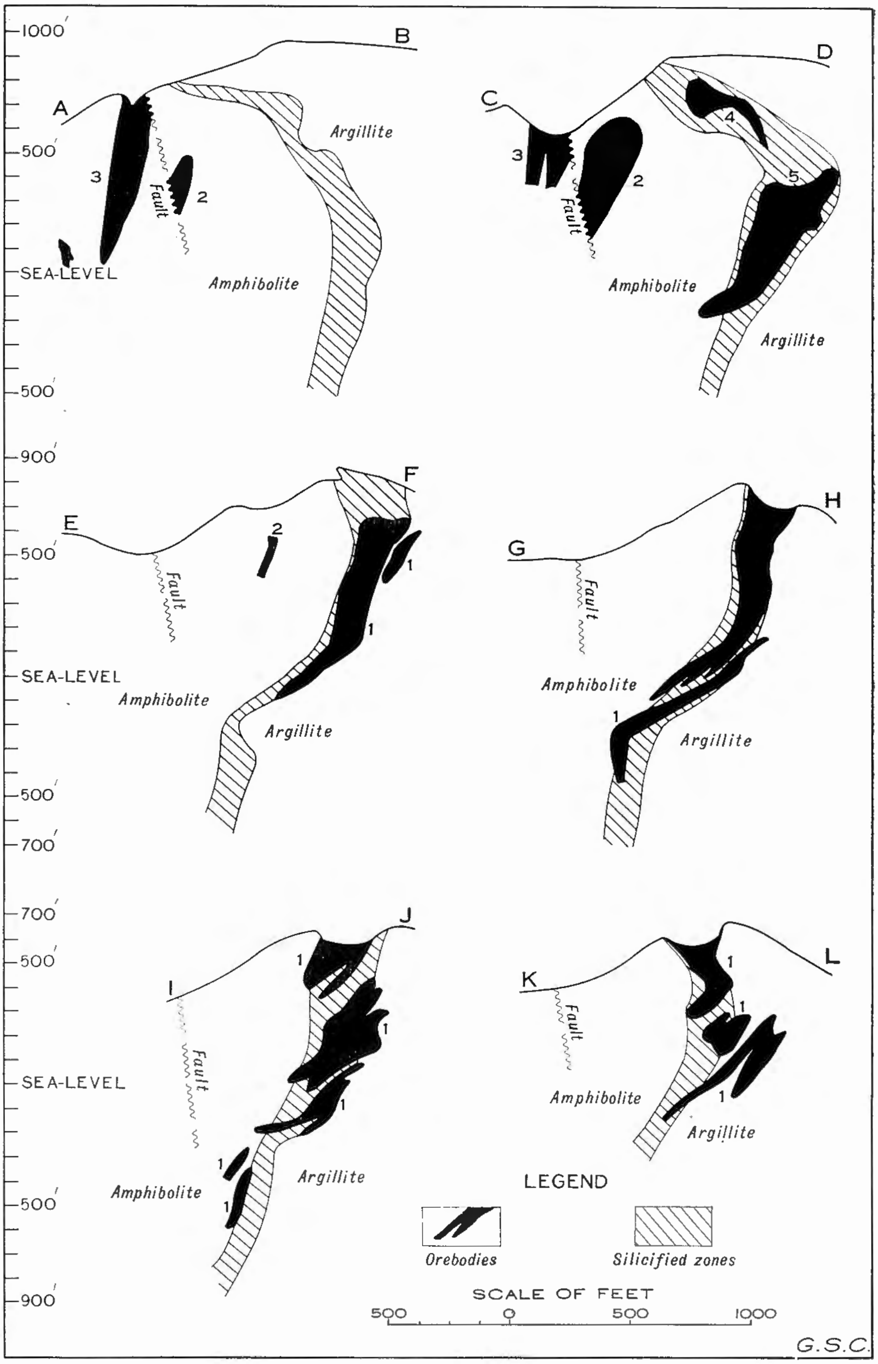


Figure 63. Vertical sections, Hidden Creek mine. (*See* Figure 62.)
(After G. Hanson, 1935.)

Copper Mountain is 12 miles south of Princeton and about 20 miles nor of the International Boundary. One of the large number of copper deposits its sides and summit has been developed into the important producer wide known as the *Copper Mountain* mine (27), the ore from which is concentrate nearby at Allenby. Discovered in 1892, the mine operated from 1926 to la 1930 and again from 1937 to the present. About 11,766,541 tons were mil from 1937 to 1945, inclusive, and the resulting concentrates afforded 76,3 ounces of gold, 1,651,941 ounces of silver, and 118,847 tons of copper. Abou 4,800 tons of ore were treated daily during 1941 and 18,892 tons of coppe recovered. Ore reserves in 1942 amounted to about 17,000,000 tons containing 1·32 per cent copper.

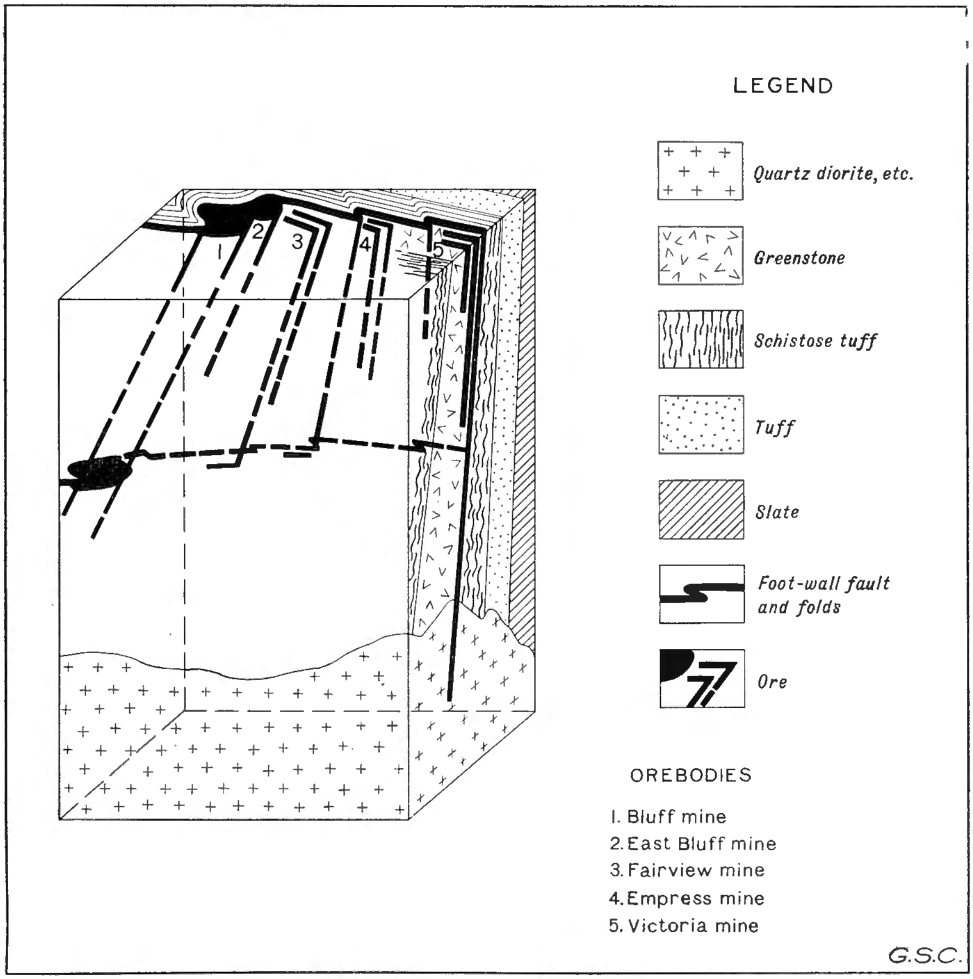


Figure 64. Showing relations of ore deposits to structure at Britannia Mines, Howe Sound, British Columbia. (After F. Ebbutt, 1938.)

The Copper Mountain stock, about 6 miles long and 3 miles wide, ranges in composition from basic gabbro at its outer margin to a copper-bearing pegmatite at its centre (Figure 65): all phases are characterized by the absence of quartz. The components differentiated from a single magma and differentiation took place largely in situ. The stock intruded Triassic tuffs and breccias

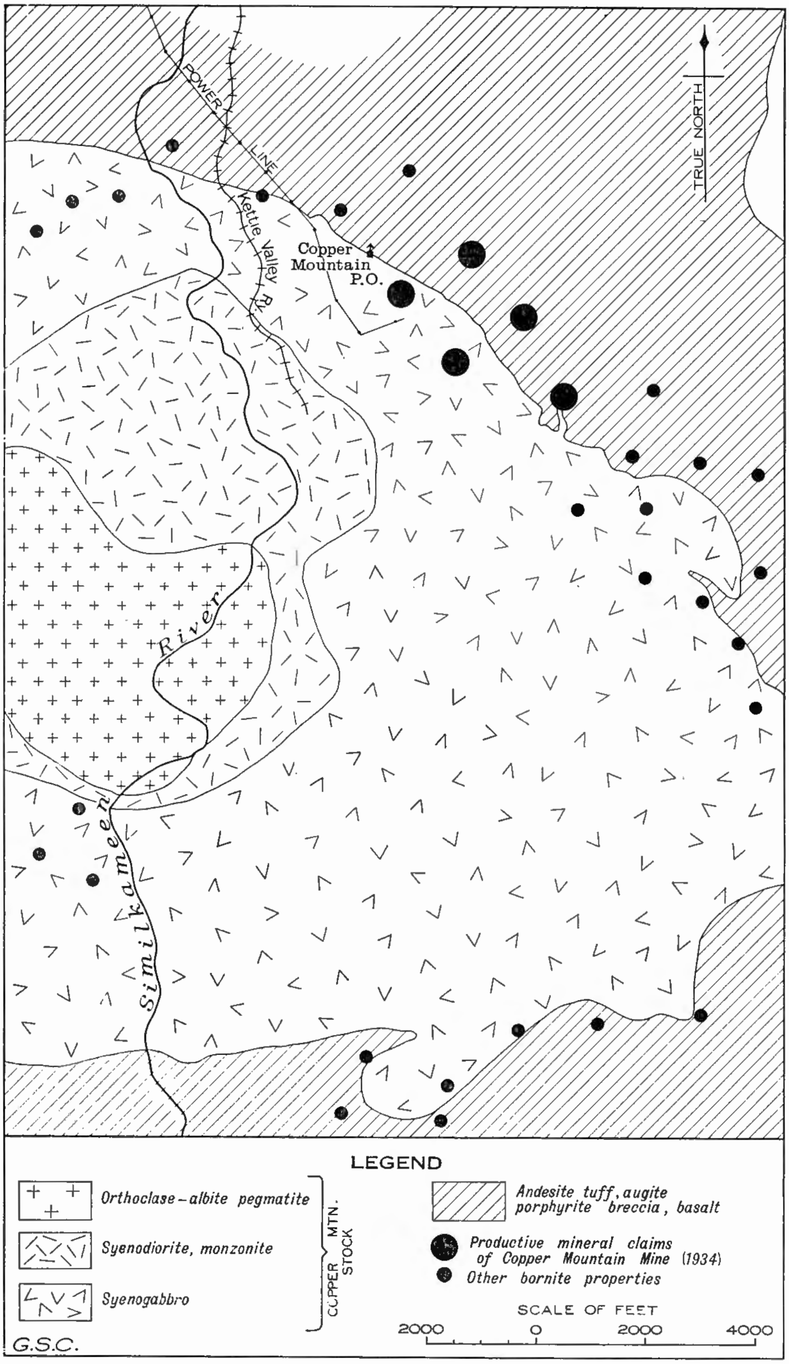


Figure 65. Copper Mountain mining area, Similkameen district, British Columbia.

after they had been steeply folded. Syenitic pegmatite dykes and veins are abundant in and near the intrusion.

The northeast edge of the stock trends about northwest and is nearly vertical. Adjacent to this edge lies a band of the fragmental volcanic rocks. These are interlayered, several hundred feet from the stock, by northwesterly trending flows or sills of massive, non-fragmental rock. The orebodies occur mainly in the fragmental volcanic rocks between the non-fragmental material and the contact of the Copper Mountain stock. The host rocks are foliated parallel to the edge of the intrusion, are broken by numerous, narrow, transverse fractures, and were replaced by much biotite, pyroxene, plagioclase, epidote, and zoisite. Slightly later, the pegmatitic minerals, biotite, orthoclase, and albite, and the metallic minerals, bornite, chalcopyrite, chalcocite, and magnetite were introduced along fractures. The ore is highest in copper where the fractures are most numerous, and grades into lower grade mineralized rock. One body is at least 2,570 feet long on one level. These ores differ from other copper ores of British Columbia in the large proportion of bornite, the near absence of pyrite and pyrrhotite, the large amount of syenitic pegmatite, and the absence of quartz.

The principal mines of the Boundary district in southern British Columbia were at *Phoenix* and *Deadwood* (30) near Greenwood. Great quantities of low-grade copper ore were mined and smelted at these places from 1900 to 1919, and the aggregate production made up nearly all of the 219,285 tons of copper derived from the Boundary district during that period. This copper amounts to nearly one-fifth of all copper recovered from the Cordilleran region in Canada to the end of 1945.

The orebodies of Phoenix and Deadwood lay in areas of highly altered limestone having all the characteristics of zones of contact metamorphism. The limestone is part of a sedimentary series presumably of Palæozoic age. At Deadwood a comparatively small area of these strata is partly surrounded by granodiorite and, presumably, underlain at no great depth by the same intrusive rocks, which also penetrate the sediments as dykes and other small bodies. At Phoenix the granodiorite does not occur in the immediate vicinity, but appears to be represented by a few small intrusions of syenite and syenite porphyry. The plutonic rocks are probably of late Mesozoic age. The orebodies were connected with them in origin and replaced the limestone, commonly at its contact with underlying silicified tuffs or argillaceous sediments. They were irregular, lens-like bodies that lay at all attitudes from vertical to horizontal, and varied from quite small to, in one instance, 2,500 feet long and as much as 125 feet thick. This body outcropped and extended to a depth of about 675 feet, and in general the ore deposits of these camps did not extend to much greater depths. At Deadwood the ore consisted of chalcopyrite, pyrite, and magnetite finely and uniformly disseminated through a gangue made up largely of actinolite, garnet, epidote, calcite, and quartz. At Phoenix, hematite (specularite) predominated over magnetite, but the ore was otherwise similar. In general the iron oxides and various silicates formed at about the same time and in places partly replaced the granitic rocks to which they were genetically related. The chalcopyrite and pyrite were somewhat later than the other ore constituents. The ores of Phoenix and Deadwood were self-fluxing. The average ore mined during the first 10 years contained between 1 and 1½ per cent copper and about $1 in gold and silver a ton.

In addition to the camps and mines mentioned, a host of smaller ones are known, some of which have produced important amounts of copper. Many of these are found along the coast and islands of British Columbia on the west side of the Coast batholith or in the southern interior of the province eastward from lower Fraser River to beyond Kootenay Lake. In most cases they lie at or close on the border of the Coast batholith or other intrusions. Perhaps the most common type is in veins, or replaces country rock along fissures or shear zones in Mesozoic sedimentary and volcanic strata or in plutonic bodies. They contain chalcopyrite, pyrite, pyrrhotite, magnetite, sphalerite, bornite, quartz, and calcite, and, commonly, small amounts of gold and silver. Another type on the islands and mainland of the Pacific coast has been formed in highly altered limestone at or near the contacts with the Coast batholith and bordering intrusions. Characteristically, such deposits consist of irregular or lenticular bodies of magnetite, hematite, silicate minerals, and remnants of country rock, and carry chalcopyrite, pyrite, bornite, and other sulphides. Some of these contain only small amounts of sulphides and might be classed as iron-ore deposits.

Silver, Lead, and Zinc

In 1945 the Cordilleran region produced: silver, 5,645,482 ounces; lead, 168,548 tons; and zinc, 147,396 tons. Essentially all of this came from British Columbia, and it amounted to most of the lead, more than half of the zinc, and nearly half of the silver recovered in Canada in that year. The Sullivan mine, at Kimberley, is by far the outstanding current contributor. Silver is mainly a by-product of lead-zinc, copper, and gold mines. Silver-lead-zinc deposits are particularly numerous in southeastern British Columbia in an area reaching from Arrow Lakes on the west to the Rocky Mountains on the east and extending northwestward from the International Boundary past the "Big Bend" of Columbia River. This area includes hundreds of deposits, dominantly silver-lead, with silver forming the more valuable part. Other important deposits occur at intervals to the northwest, east of the Coast batholith, as far as the Mayo district of Yukon. Important quantities of lead are recovered from the gold-silver ores of the Silbak Premier mine in the Portland Canal district.

Keno and Galena Hills. The rich silver-lead deposits of Keno and Galena Hills (4), about 40 miles northeast of Mayo, comprise Yukon's most productive lode camp. Mining started there in 1913, and shipments have been made nearly every year, though on a drastically reduced scale since 1941 when the lone concentrator was closed. Products included hand-sorted crude ore and concentrates, and these were shipped mainly to Bradley, Idaho, for smelting. The main producers from 1920 to 1932 were Keno Hill, Limited, and Treadwell Yukon Company, operating on Keno Hill. Principal production from 1934 to 1941 came from the Calumet, Elsa, and Silver King mines on Galena Hill. From 1913 to 1945, inclusive, Yukon yielded 43,344,737 ounces of silver and 47,537 tons of lead, most of which came from Keno and Galena Hills. In the peak year of 1937, Yukon production, largely credited to Galena Hill, amounted to 3,956,504 ounces of silver and 3,220 tons of lead with an aggregate value of $2,104,826.

The hills are underlain by ancient schists and quartzites, intruded by dykes, sills, and other bodies of greenstone. The resulting complex is cut by acid sills and dykes some of which contain particles of pyrite, galena, and tetrahedrite or freibergite. About 8 miles north of Galena Hill is a granite stock believed to be a cupola of a batholith extending under much of the district. The dykes, sills, and stock are thought to be Mesozoic or possibly in part of Tertiary age.

The deposits at Keno Hill are veins deposited in fault fissures. The faults were of the normal type and of small displacement. The veins have been called longitudinal and transverse, depending on whether they follow the trend of the strata or cut across them. During the first stage of mineralization quartz, arsenopyrite, and pyrite were deposited in the longitudinal fissures. During a second stage of mineralization siderite, freibergite, galena, sphalerite, and other minerals were deposited in the re-opened longitudinal veins and in the transverse fissures. Secondary enrichment has not been important. In large shipments of ore the silver has proved to be remarkably uniformly distribute: through galena when free of gangue. Shipments made up to 1923 averaged close to 200 ounces of silver to a ton, and this may approximate the average of clean galena on the hill. Where much freibergite is present, this content is greatly increased. The deposits are younger than the greenstone. It is thought that the veins and the acid dykes and sills had their origin in the granite mass that is believed to underlie much of the district.

The veins on Galena Hill follow faults, which generally strike about northeast and dip steeply southeast. One group of veins is characterized by a high silver content and a filling of manganiferous siderite, galena, and freibergite. In another group the vein matter is either quartz or ankerite, and galena, sphalerite and pyrite. The silver content is important in some cases. The Silver King deposit, mined in the earlier years of the camp, was of a distinctive type. It was a rich silver-lead deposit with a quartz gangue, and contained in addition to other minerals much ruby silver and minor amounts of marcasite and chert. These deposits have the same origin as those of Keno Hill, 4 miles to the east.

Beaverdell Camp. This camp (29) on Westkettle River is notable for the high-grade silver deposits found on a number of properties lying within an area less than a mile long. The principal producers have been the Bell and Highland Lass properties, operated as the Highland Bell mine since 1936. It is now the only mine in British Columbia that relies almost entirely upon the silver content of its ore and, with the Silbak-Premier mine of the Portland Canal district, vies for second place among the current silver producers. The ore is hand sorted and shipped to Trail for smelting. From 1936 to 1945, inclusive, the mine afforded 1,583 ounces of gold, 6,024,732 ounces of silver, and some lead and zinc from the 41,447 tons of ore shipped.

The oldest rocks of the camp are much altered sedimentary and volcanic strata of Palæozoic age. These have been intruded by Mesozoic quartz diorite of the Westkettle batholith. A stock of granitic rock, about 1½ miles in diameter, outcrops within the batholith at the town of Beaverdell and is believed to be of early Tertiary age.

The deposits are mineralized shear zones in the quartz diorite. These zones strike east to northeast, dip south, and vary from about 1 foot to 10 feet in width. They are composed of sheared and brecciated rock and vein matter. The latter includes quartz, calcite, fluorite, galena, sphalerite, pyrite, grey copper, ruby silver, polybasite, argentite, and native silver. Lead and zinc may each comprise as much as 10 per cent of the ore shipped. Values have been principally in silver, and for the deposits as a whole have averaged 150 to 200 ounces a ton. The shear zones and orebodies are intersected by numerous post-mineral, normal faults of small displacement, and these, together with the irregular disposition of the ore shoots, have resulted in high mining costs. Although the deposits have only been mined to a depth of a few hundred feet it has been suggested that at greater depths they may change in type to quartz-pyrite-chalcopyrite ores with values principally in gold, such as are found at Carmi, a few miles to the north. Latest studies suggest, but do not prove, that the Westkettle batholith was the source of the mineral deposits.

Slocan District. This district (37) lies between Kootenay and Lower Arrow Lakes, the larger part of the silver, lead, and zinc production coming from an area within a radius of 3 or 4 miles from the town of Sandon. Altogether more than two hundred properties have at one time or another made ore shipments, and many others have been extensively prospected. The year 1891 marked the start of the great mining boom in Slocan. Peak production, not since approached, was reached in 1918 when forty-four properties made shipments, having an aggregate value of about $3,500,000. Production from the Slocan, Slocan City, and Ainsworth mining divisions from 1895 to 1945, inclusive, as given in Annual Reports of the Minister of Mines for British Columbia, amounted to 4,089,234 tons of ore containing 60,338,798 ounces of silver, 221,751 tons of lead, and 147,901 tons of zinc, as well as a very little gold and copper. Most of this came from the restricted area near Sandon. In 1945, 191,181 ounces of silver, 925 tons of lead, and 7,915 tons of zinc were won from 120,287 tons of ore, mainly at the Whitewater, Lucky Jim, Noble Five, Standard, and Mammoth mines. Outstanding past producers include, in addition to these, the Galena Farm, Hewitt, Payne, Rambler Cariboo, Ruth-Hope, Silversmith-Slocan Star, and Van Roi.

The following data apply mainly to the highly productive area about Sandon: the deposits occur mainly in the Slocan series, but a few of importance have been found in the Nelson granite. The deposits in the intrusive rocks are on the whole smaller than those in the Slocan series, but are richer, carrying high silver and sometimes gold values, but relatively small percentages of lead and zinc.

The Slocan series, of probable Triassic age, comprises slates, argillites, limestones, quartzites, conglomerates, and tuffaceous beds. Some beds are massive and others are fissile and slaty. The strata are highly deformed and the structure is complicated by numerous faults, shear zones, overturned folds, and, locally, intense contortion.

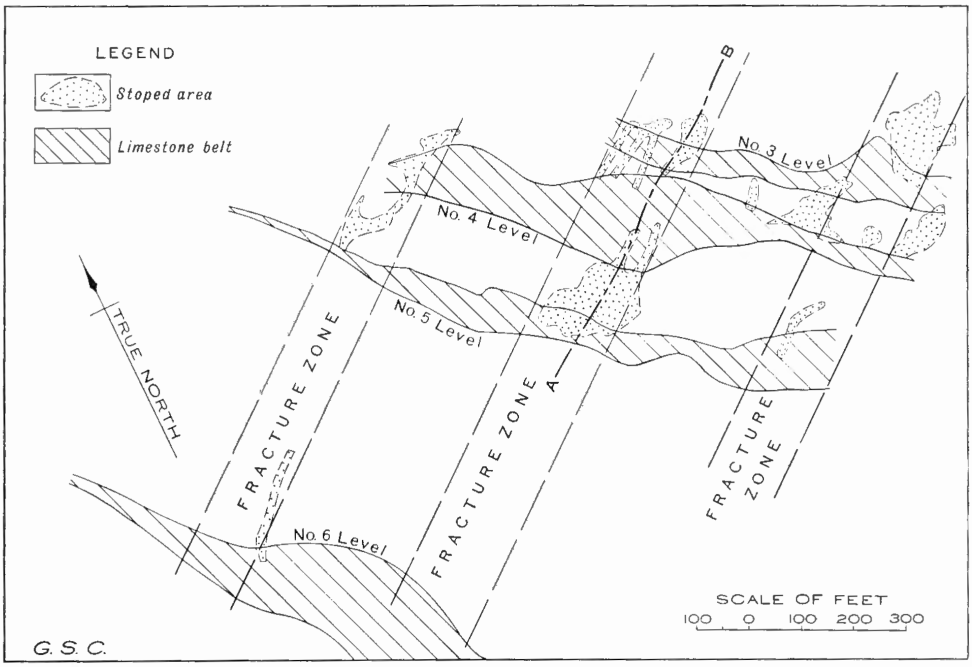


Figure 66. Plan of part of Lucky Jim mine, Slocan district, British Columbia. (After C. E. Cairnes, 1935.) (For vertical section along line A-B, *See* Figure 67.)

The great majority of the mineral deposits are either single or composite veins. The single veins follow fault fissures. One vein of this type, the "Reco-Goodenough", was traced for more than 1,000 feet and over a vertical range of more than 500 feet. It averaged 7 inches in width, and contributed nearly 4,000 tons of ore averaging 226 ounces of silver a ton and 43 per cent lead. Composite veins occur in zones of fractured ground, known as composite-vein lodes, and have been formed by repeated deposition of vein minerals. These lodes are a foot to 150 feet or more wide: they may be miles long and, in some instances at least, 4,000 feet deep. The vein matter occupies only part or parts of the length and width of a lode. In a number of composite-vein lodes, explored for lengths of from 1,700 to 6,000 feet, the main veins in each lode were between 500 and 1,000 feet long. Several such veins have observed depths of 500 to 1,300 feet. The most productive lodes strike between north and east and dip southeasterly.

A few replacement deposits occur in limestone or notably limy strata. At the Lucky Jim mine a limestone belt from a few feet to more than 100 feet thick is intersected, nearly at right angles, by fractures striking about northeast and dipping steeply southeast. Replacement from groups of these fractures formed a succession of chimney-shaped orebodies varying from about 10 to 50 feet in diameter and extending vertically 150 to 200 feet. Some of the shoots were nearly solid sphalerite: others contained, in addition, a little galena, pyrite, calcite, quartz, and unreplaced limestone (Figures 66 and 67).

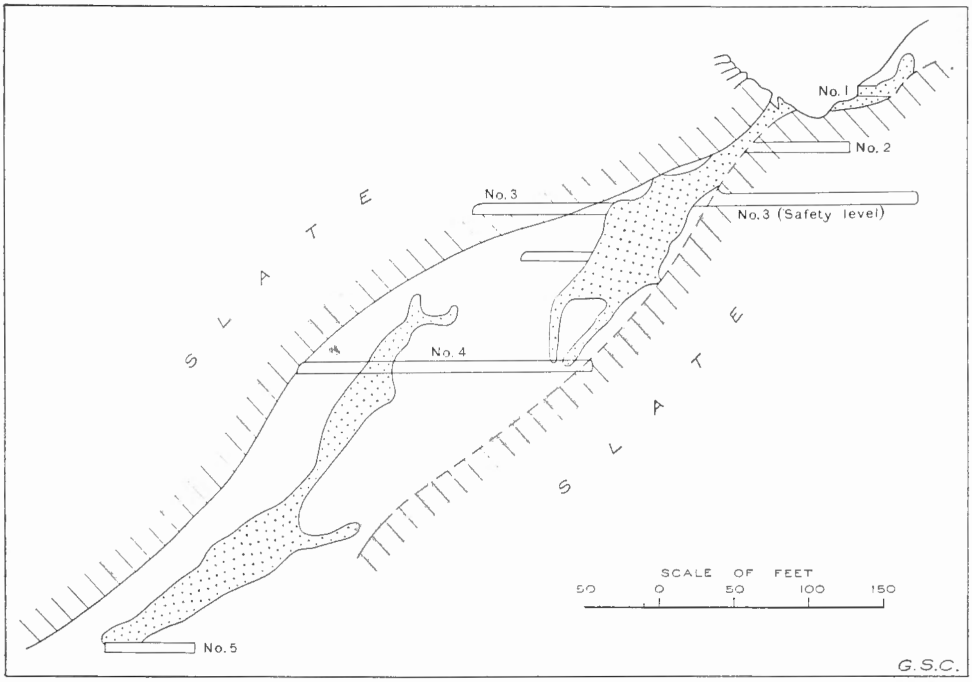


Figure 67. Vertical section, Lucky Jim mine (*See* Figure 66), showing two of the principal ore shoots (pattern of dots) and boundaries of the limestone belt (pattern of sloped ruling). (After C. E. Cairnes, 1935.)

Ore shoots range in length from less than 100 feet to several hundred feet; in thickness from a few inches to 50 feet; and in depth from less than 50 feet to several hundred feet. The largest and most valuable shoot was in the Standard mine, with a maximum length and depth of about 400 feet, and a maximum thickness of about 50 feet, including as much as 20 feet of clean galena ore. This ore had a gross value of between $6,000,000 and $7,000,000. An ore shoot at the Silversmith mine yielded ore having a gross value of nearly $4,000,000.

The most important minerals are argentite, galena, grey copper, pyrargyrite, silver, and sphalerite, and are commonly accompanied by pyrite. Silver-lead-zinc deposits are most important, and occur characteristically in the Slocan series. Galena and sphalerite are there abundant and the proportion of ore minerals may equal or exceed that of the gangue minerals, quartz, calcite, and siderite.

In deposits of another type, mostly confined to the Nelson granite, silver is the metal of chief importance. Quartz is then the abundant gangue mineral, and is greatly in excess of the metallic minerals.

The silver-lead-zinc deposits appear to have formed in an undulating zone 1,000 to 2,000 feet thick, which, over considerable areas, accidentally parallels the present surface. The upper part of this zone is characterized by silver-lead orebodies, some of which grade downwards into pyritic zinc bodies.

The *St. Eugene* mine (35) at Moyie, now abandoned, was at one time the largest producer of lead in Canada. Production started about 1899, declined in 1910, and continued with interruptions until 1923. Production to September 30, 1913, was 1,017,106 tons of ore containing 5,365,232 ounces of silver and 114,653 tons of lead. Zinc was not recovered. In 1925 a 600-ton concentrator was built to recover this zinc from the tailings and the plant operated until late in 1929.

The surrounding rocks are thin-bedded, argillaceous quartzites and siliceous argillites of Proterozoic (Purcell) age.

The deposit formed by replacement along a zone of fissuring in the quartzites. This zone strikes about east and in it are two important fissures, both of which strike east and dip 70 degrees south. On the 1,000-foot level the two fissures are 600 feet apart and converge downward and to the west. Joining these two main fissures is a system of connecting fissures that usually meet the main fissures at a small angle. Most of the important orebodies occurred at or near such junctions.

The ore consisted of galena with minor amounts of sphalerite, pyrite, pyrrhotite, magnetite, and chalcopyrite. The gangue material was small in amount, and included garnet, actinolite, and quartz. These minerals were more abundant in the transition zone between the ore and country rock. Magnetite was formed first, then the gangue minerals, and the sulphides last.

The *Sullivan* mine (36), near Kimberley, is the largest silver-lead-zinc mine in the British Empire. The ores are concentrated at Kimberley and smelted at Trail. Products recovered include silver, lead, zinc, tin, cadmium, and sulphur. Early development was delayed by metallurgical difficulties, and the first unit of the present concentrator was not in operation until 1923. Peak production was attained in 1942 when 2,697,434 tons of ore were treated and 717,646 tons of concentrates shipped: the latter contained 8,693,041 ounces of silver, 254,434 tons of lead, and 199,236 tons of zinc. In 1945, 2,435,877 tons of ore were treated, affording concentrates containing 5,103,027 ounces of silver, 172,473 tons of lead, and 146,389 tons of zinc.

Sedimentary rocks at the mine are mainly early Proterozoic argillite, silty argillite, and quartzite. These are cut by sills and other bodies of gabbroic Purcell intrusions of probable Precambrian age. One of these is 700 feet thick. The tops of some of the sills grade into more acid material, but the granophyric rocks found at or near the tops of some of the sills are believed to have resulted, at least in part, from the granitization of adjacent sedimentary strata. Granitic rocks, presumably of Cretaceous or early Tertiary age, outcrop within 10 or 12 miles of the mine.

The mine lies on the eastern limb of an open anticline, the axis of which strikes about north. The regional trend is interrupted at the mine by a gentle fold that plunges about northeast. The curvature of this structure decreases at depth in the mine, and there the beds have a fairly uniform northwest strike. The strata are broken by major faults.

The deposit is a sulphide replacement of argillite and silty argillite beds that form a stratigraphic zone 200 to 300 feet thick. The zone has an average dip of about 30 degrees northeast. Only parts of it have been replaced by sulphides. The hanging-wall of the zone is quartzite, and the foot-wall, in m[illegible] places, an argillite-pebble conglomerate. The ore is well banded, and [illegible] principal metallic minerals are galena, sphalerite, pyrrhotite, and pyrite: oth[illegible] include chalcopyrite and arsenopyrite, magnetite, and cassiterite. Non-metal[illegible] minerals, which commonly make up only a small part of the ore, include qua[illegible] sericite, chlorite, muscovite, tremolite, clinozoisite, titanite, tourmaline, garn[illegible] biotite, albite, and calcite. Individual orebodies have drift lengths of upwa[illegible] of 1,000 feet, with a maximum thickness, at right angles to the walls, well [illegible] excess of 200 feet. Ore occurs over a vertical range of at least 1,300 feet. The contacts between the ore and wall-rock are commonly remarkably sharp. Much tourmaline has been introduced into the foot-wall rocks and albite and chlori[illegible] into the hanging-wall strata. Purcell dykes, where they cross the ore zone, a[illegible] usually well mineralized. Large faults near the deposits are believed to be pre-mineral features, although movements along them have extended into the post-mineral period.

Some difference of opinion exists as to whether the ore is related to the Purcell intrusions or to the younger granite: probably most investigators believe that the ore-bearing solutions came from the magma from which the granitic rocks were derived, and that the ore deposits formed in Cretaceous or, possibly, earliest Tertiary time.

The *Monarch* and *Kicking Horse* mines (38) at Field are the only productive metalliferous properties in the eastern Canadian Rockies. The Monarch deposits outcrop on the precipitous north slope of Mount Stephen, on the south side of Kicking Horse River, and the Kicking Horse deposits outcrop on the south side of Mount Field, on the north side of the river. The deposits were probably connected at one time and later separated by the valley-cutting of Kicking Horse River. The Monarch deposit was staked in 1884. A little ore was mined and milled prior to 1929. A 300-ton concentrator commenced operations late in that year and continued intermittently until late in 1935. It was re-opened early in 1940 and treated ore from the Monarch and Kicking Horse deposits until operations were suspended in 1946. Production from 1910 to 1945, inclusive, amounted to about 599,000 ounces of silver, 42,000 tons of lead, and 61,000 tons of zinc from 702,000 tons of ore milled.

The mines lie on the east flank of a northerly trending anticline, where the beds have an average dip of about 20 degrees east. Minor folds trend parallel to the major structure. The rocks are Middle Cambrian dolomites and dolomitic limestones, and overlie Lower Cambrian quartzites. Major, steep, normal faults strike about north. A gently dipping alteration zone, with a maximum thickness of 400 feet, cuts across the bedding of the Middle Cambrian rocks at a small angle. At its base is a breccia. The breccia is most pronounced above minor synclines developed in an underlying, thinly bedded, dolomitic limestone, and in such places is 15 to 80 feet thick. It is made up of grey dolomite fragments in a white dolomite matrix. The breccia grades, on top, into structureless dolomite of the upper part of the alteration zone. The whole zone is traversed by vertical pre-ore cracks.

All known ore lies within the altered zone close to its lower edge. The two principal orebodies at the Monarch mine occur in minor synclines and are long, narrow, flat bodies striking about north and lying about 660 feet apart (Figure 68). The ore occurs mainly within the brecciated rock and its edges are commonly in sharp contact with the country rock. The most common minerals are sphalerite, galena, pyrite, and dolomite: minor constituents include chalcopyrite, quartz, barite, and silver. The sulphides have replaced the breccia fragments and the white dolomite matrix. The rock adjacent to the ore shows little change other than the general dolomitization. One orebody was 1,400 feet long, averaged 19 feet thick, and had a maximum width of 158 feet. Most of the ore from this body averaged 1·7 ounces silver a ton, 10·5 per cent lead, and 12·5 per cent zinc.

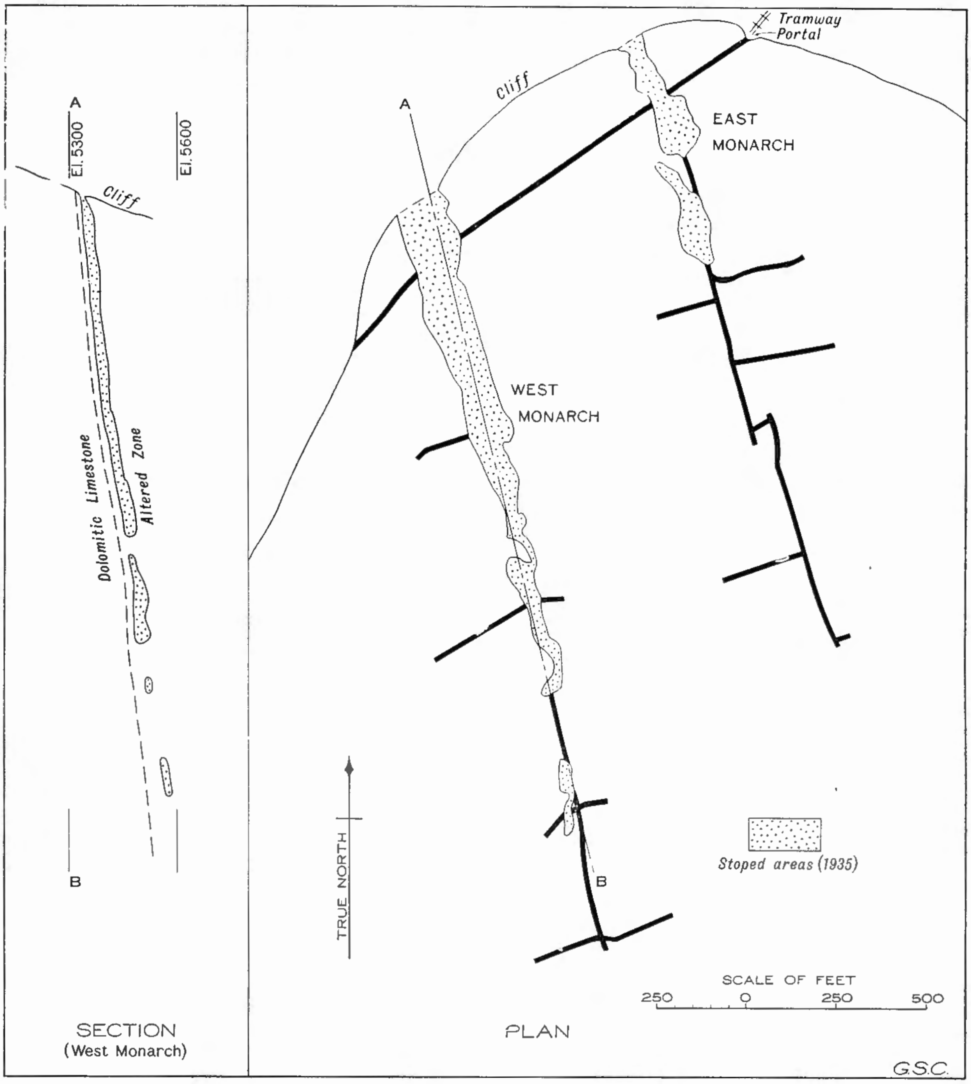


Figure 68. Monarch mine, Field, British Columbia. (After E. A. Goranson, 1937.)

The source of the mineralizing solutions may have been an underlying igneous body of which a complex alkaline intrusion, 15 miles to the south, is the only visible part. This intrusion is of post-Lower Ordovician age.

Mercury

Pinchi Lake Mercury Belt. Although mercury deposits have been found in the Kamloops and Bridge River areas and at Sechart on Vancouver Island, the Cordilleran region did not become a significant source of mercury until the Pinchi Lake mercury mine entered production in 1940. This was found to be only one of a number of deposits in what became known as the Pinchi Lake mercury belt. In 1943 the Bralorne Takla mercury mine, lying in the same belt but 90 miles to the north, commenced production. Due to special wartime conditions rather than to depletion of orebodies, both mines were closed during 1944. From 1940 to 1944, inclusive, the above mines afforded 4,150,892 pounds of mercury from 702,874 tons of ore, nearly all of which came from the Pinchi Lake mine.

The mercury belt (Figure 69) lies along a major fault zone extending from southeast of Fort St. James, 150 miles northwest to Omineca River and beyond. This is the largest fault known in the Western Cordilleran region. In most places the width of the fault zone does not exceed 1,000 feet. In its southeastern part, where it has been examined in greatest detail, it marks the site of major thrust faulting from the west, and has involved late Palæozoic and Mesozoic volcanic and sedimentary strata, later Mesozoic pyroxenite intrusions, and still later Mesozoic granodiorite of the Cassiar-Omineca batholith. The amount of displacement is not known. Intense faulting occurs in the Permian rocks within the zone. There the more important faults trend northwesterly, dip steeply southwest, and may join a major low-angle thrust fault at depth. In and near the fault zone limestones have been partly to completely changed to dolomites, ribbon cherts and quartzites to quartz-carbonate rocks, greenstones to chlorite-carbonate rocks, and serpentines to mixtures of carbonate, quartz, and mariposite.

At the Pinchi Lake mercury mine (13) the faults cut Permian sedimentary rocks that strike northwest and dip northeast. Cinnabar is the principal ore mineral, and is concentrated in brecciated zones along the faults as well as in dolomitized limestone and in carbonatized quartzite, ribbon chert, and schist cut by the faults. Most of the cinnabar fills pre-existing openings in the host rocks, such as solution cavities, fissures, and spaces between breccia fragments. Associated minerals include stibnite, pyrite, quartz, calcite, dolomite, and alunite. The fault zone provided the channelways for the mineralizing solutions, and in many places relatively impervious rock layers and fault gouge have trapped rising solutions and resulted in local concentrations of cinnabar. Orebodies, except where they abut against faults, grade into country rock, the largest being in limestone overlain by schist. The deposits were formed at low temperature and under low pressure, and are of post-Upper Cretaceous age.

The widespread cinnabar deposits of *Tyaughton Creek* (19) and vicinity, in Bridge River area, have received some attention from time to time during the past 15 years, and have contributed a few flasks of mercury. Most of the cinnabar has been found in sheared, fractured, and partly dolomitized greenstones of probable Permian age. These rocks are interlayered with cherty sedimentary members, and many of the more promising deposits lie in shear zones in the greenstones along contacts with the cherty strata. In many deposits cinnabar is the abundant and, in some cases, the only sulphide mineral. In others stibnite is common and may be in excess of the cinnabar. Globules of mercury may be seen in some of the richer parts of the deposits. Calcite, and, less commonly quartz, are associated gangue minerals, but much of the cinnabar occurs without either. The origin of the cinnabar is uncertain, but the coincidence of the deposits with an area riddled with porphyry dykes of probable Tertiary age suggests that these are in some way related to the source of the mercury.

Tungsten

Scheelite occurs in placer deposits in the Mayo district in Yukon, and has been found in many lode deposits in British Columbia. In general the proportion of scheelite in the latter is too low or the occurrences are too small to permit profitable mining, although a number of scheelite-bearing veins, as in the Bridge River and Cariboo districts, are mined for their gold content. As a

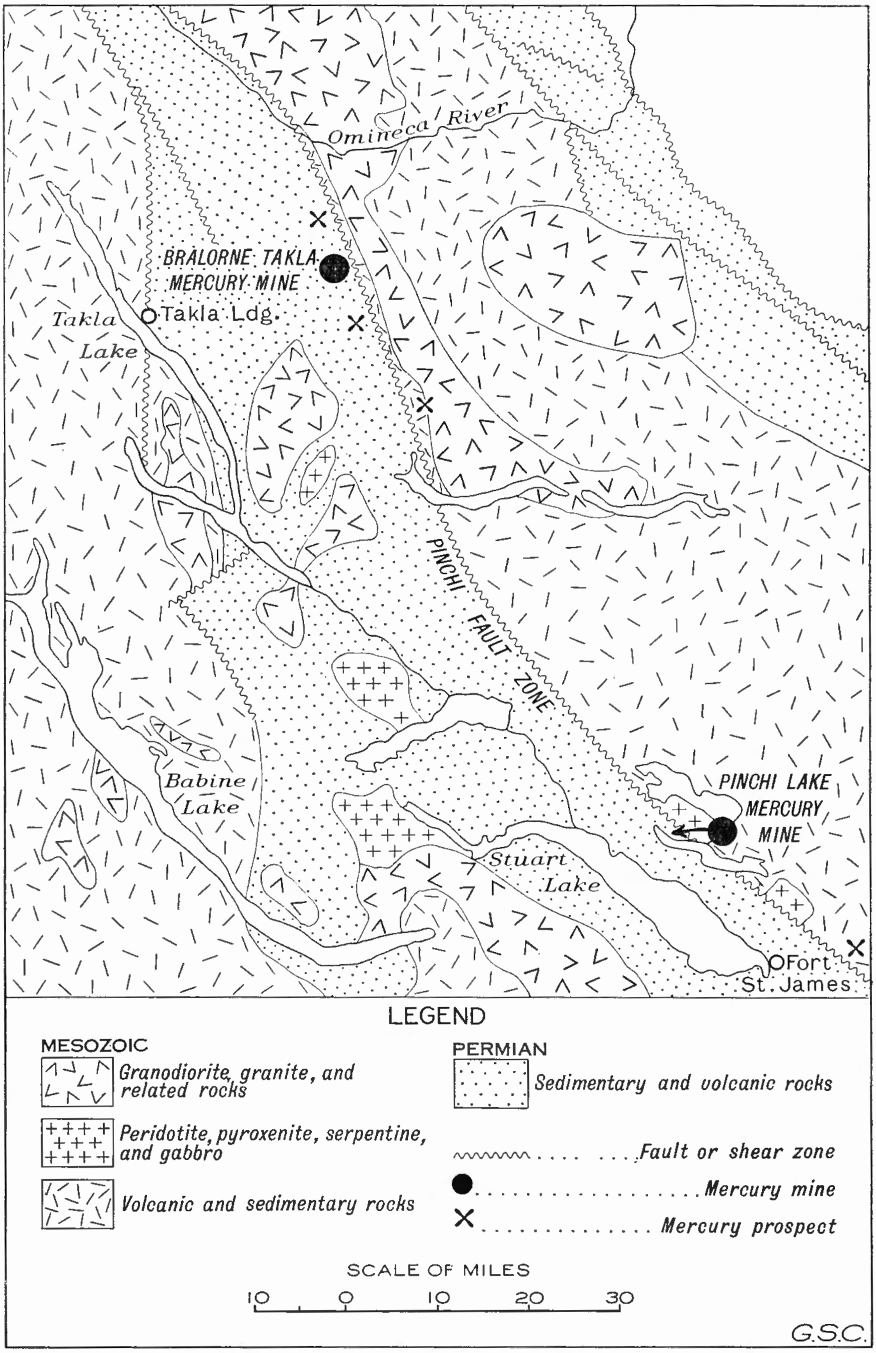


Figure 69. Pinchi Lake mercury belt, Omineca mining division, British Columbia. (After J. E. Armstrong, 1945.)

wartime measure the *Red Rose* mine (11), near Hazelton, was operated as a tungsten property during 1942 and 1943, and milled 25,896 tons of ore to recover 597 tons of tungsten concentrates. Scheelite occurs there in a silicified shear zone in a diorite sill about 750 feet from a large mass of granodiorite. Adjacent sedimentary rocks have been altered by the granodiorite and contain much biotite. The zone ranges in width from 18 inches to 8 feet, and contains veinlets and lenses of milky white quartz with chalcopyrite, molybdenite, orthoclase, apatite, scheelite, ferberite, biotite, and tourmaline.

Scheelite orebodies of another type were found at the *Emerald* property (33), about 25 miles south of Nelson, in 1942. After a period of intensive development, during which a 300-ton mill was erected and put into operation, the property was closed late in 1943, on instructions from Wartime Metals Corporation.

Three stocks of Nelson granite intrude argillites with thin interbeds of limestone. Some of the limestone bands are completely altered to a skarn of garnet, diopside, a little scheelite, and other minerals.

The Emerald ore zone is the most important of the several scheelite occurrences found on the property. It trends south along the west edge of one of the stocks. The northern section has a surface area of about 9,000 square feet and, according to preliminary exploration, a depth of about 15 feet. The ore is fine-grained, disseminated scheelite and various sulphides in silicified granite at its contact with argillite. A transverse fault separates the north section from the south section. The latter is a southerly trending band of easterly dipping limestone more than 1,700 feet long with a maximum width of about 140 feet at the surface. It is wedge-shaped in cross-section, lies between the granite on the east and argillite on the west, and ends at a depth of 75 to 200 feet where the easterly dipping argillite meets the granite. Much of the ore occurs as tabular bodies of pyrrhotite, pyrite, augite, and scheelite, with minor amounts of actinolite, epidote, biotite, chalcopyrite, molybdenite, wolframite, and other minerals. Such bodies represent preferentially replaced limestone beds or groups of beds of limestone, dip towards the granite, and vary in width from a few inches to 12 feet or more.

Iron

There has been no significant production of iron ore from the Cordilleran region. Nevertheless, many deposits of magnetite and a few of hematite and limonite are known, and in recent years serious consideration has been given to the development of an iron and steel industry on the coast using the magnetite ores. Inasmuch as there is as yet no important market for iron ores in western Canada, prospecting for such deposits has not been as active as it might otherwise have been, and the known deposits, for the most part, have received only casual development.

Sedimentary iron deposits occur in Yukon in strata of probable Precambrian age, but only meagre information is available as to their grade, size, and distribution. Hematite and magnetite, and their weathered products, comprise a considerable percentage of some beds of the Tindir group south of *Cathedral Creek* (1) on the Yukon-Alaska boundary. In places, limited parts of these deposits, occurring in beds ranging from 2 to 10 feet thick, contain up to 40 per cent metallic iron. In the same region, on a tributary of Tatonduk River, limited parts of a hematite-bearing conglomerate contain 5 to 25 per cent metallic iron. Somewhat similar occurrences have been reported 120 miles to the east on *Hart River* (2), and as much as 140 miles southeasterly from Hart River near the headwaters of *Wind, Bonnet Plume,* and *Stewart Rivers* (5). Abundant float from the latter region, seen on early exploratory traverses by the Geological Survey, is fine-grained, compact hematite, or hematite and magnetite, interlayered with red jaspilite.

Limonite or bog iron deposits have been found at a number of localities in British Columbia, and some are known to be of large size. They are of Recent age, and have been produced by springs that derived their iron content from pyritiferous rocks. Some are of considerable areal extent, but none is known or expected to extend to any great depth.

On *Zymoetz River* (12), 40 miles from Telkwa, a sheet of bog iron ore of unknown thickness lies at the surface on the steep side of Limonite Creek Valley. Available data indicate that this deposit contains at least 500,000 tons of easily mined, nearly pure limonite, and that it may contain more than 1,000,000 tons. The ore is soft, earthy limonite in layers 1 to 3 inches thick lying parallel with the hillside. 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* (18), 65 miles west-northwest of Lillooet, contain an aggregate of 670,000 tons of limonitic material with a probable iron content of nearly 50 per cent. They consist of sheets of brown limonite of varying shape, size, and thickness, built up of thin layers of brown, cellular, and generally loose-textured limonite, lying parallel with the surface of the ground on which they rest. Iron sulphate solutions, derived from the oxidation and leaching of pyritic tuffs, trickled down the mountain slopes and deposited the limonite on the more gently inclined valley bottoms. The thickness of the limonite sheets ranges from a few inches to a probable maximum of 15 feet.

Iron deposits of igneous origin are abundant in western British Columbia and southern Yukon in the vicinity of the Coast batholith and its satellitic bodies. They are also quite numerous in southern British Columbia near the various granitic intrusions that extend easterly from the Coast batholith to about Kootenay Lake. In most of the occurrences the principal ore mineral is magnetite, but in a very few it is hematite.

On *Chromium Creek* (17), the main source of Klinaklini River, is a deposit of more than 100,000 tons of exceptionally pure hematite. The hematite is in a bed of tuff 10 to 30 feet thick and, locally, has completely replaced the bed. The sedimentary and volcanic beds between the deposit and the east edge of the Coast batholith, about a mile to the south, are thoroughly impregnated with pyrite.

Other hematite deposits of igneous origin lie on *Iron Range Mountain* (34) near Kitchener, in southeastern British Columbia. A fault many miles long has resulted in a broad zone of fracturing involving Lower Purcell (Proterozoic) argillaceous quartzite and argillite and diorite sills. Hematite-quartz lenses from 2 to 20 feet wide and of unknown length occur along this zone. The mineralized material varies from nearly solid hematite to brecciated quartzite healed with quartz and hematite. The quartz and hematite were deposited by hydrothermal solutions passing along the zone of fracturing. These solutions probably originated from the same granitic magma as the Nelson batholith, the nearest exposures of which lie about 8 miles west of Iron Range Mountain.

The magnetite bodies are contact metamorphic replacement deposits. They are most numerous along the mainland Pacific coast and on the bordering islands, that is, along the west side of the Coast batholith; others lie near the east edge of the batholith in southern Yukon and in southern British Columbia. In general the phosphorus content is low, so that the deposits are of Bessemer quality, and none contains appreciable quantities of titanium. All contain pyrite, but in some the sulphur content is quite low. In certain occurrences the copper content is appreciable, and in extreme cases such deposits may even contain low-grade copper ore. Silicates like garnet, epidote, pyroxene, and hornblende normally accompany the magnetite, but the proportion of these to magnetite varies widely from deposit to deposit and within individual deposits. The magnetite occurs within Mesozoic volcanic and sedimentary strata near or at their contact with the granitic rocks of the Coast batholith and its related intrusions. Limestone is by far the most common host rock. The orebodies vary widely in size, shape, and attitude and, although their bodies are generally sharp, close exploration is required to determine their contained tonnage. Among the larger known occurrences are those of *Zeballos River* (21), *Iron Hill* and *Iron River* (23), and *Texada Island* (24). All these are well situated with respect to transportation, coal deposits, and important industrial centres, and the possible ore available at the latter two localities has been estimated to exceed 3,600,000 tons.

Non-metallic Deposits

Non-metallic deposits, including the fuels—coal, oil, and gas—are the principal mineral products of the Eastern Cordilleran region, and are also of considerable importance in the western region. Coal is present in large amounts along the eastern margin of the Rocky Mountains. Canada's largest oil and gas field is located in the Foothills of Alberta, and the second largest field is along Mackenzie River in the eastern part of the Mackenzie Mountain area.

Coal

Coal deposits are widely distributed in the Cordilleran region (Figure 70), but the largest occurrences are along the western and eastern borders. On the west the principal deposits are on Vancouver and Queen Charlotte Islands, whereas on the east the eastern Rocky Mountain ranges and adjacent Foothills hold the largest reserves. Most of the coal mined comes from beds of Lower Cretaceous or Upper Cretaceous ages; the remainder is obtained from Tertiary deposits. Production during 1945 amounted to 5,848,203 tons, of which 5,122,440 tons came from the Rocky Mountains and Foothills belt, and mostly from Alberta. Coal production reached a high of 6,644,626 tons in 1920, after which it declined to a low of 3,662,909 tons in 1933. In 1942 production reached an all time high of 6,709,707 tons.

In the southern Rocky Mountains the coal measures are of Lower Cretaceous (Kootenay) age and occur in basins among the folded and faulted Palæozoic and Mesozoic strata. These basin areas extend from the International Boundary north to about midway between Bow and North Saskatchewan Rivers. Kootenay coal measures are present along the western side of the Foothills area for the same distance. Farther north, both in the mountains and in the foothills, the commercial coal seams are in higher beds stratigraphically, namely the lower part of the Blairmore group (Luscar formation) (Plates XLVI and XLVII). Coal in Peace River Valley is believed to be of the same age. The coals of Lower Cretaceous age are of bituminous rank or, as at one locality, semi-anthracite. Along the eastern foothills coal of Upper Cretaceous age occurs in the Belly River and Edmonton formations. These coals are of semi-bituminous rank. Coals of the same age may vary in rank, as a result of differences in intensities of metamorphism brought about by mountain building stresses. Recent studies have indicated that some of the coal thought to be Upper Cretaceous is probably Paleocene in age.

The major coal deposits from the International Boundary north are as follows. In Flathead Valley the Kootenay formation, more than 1,100 feet thick, contains five seams in the lower 500 feet of strata. All of them exceed

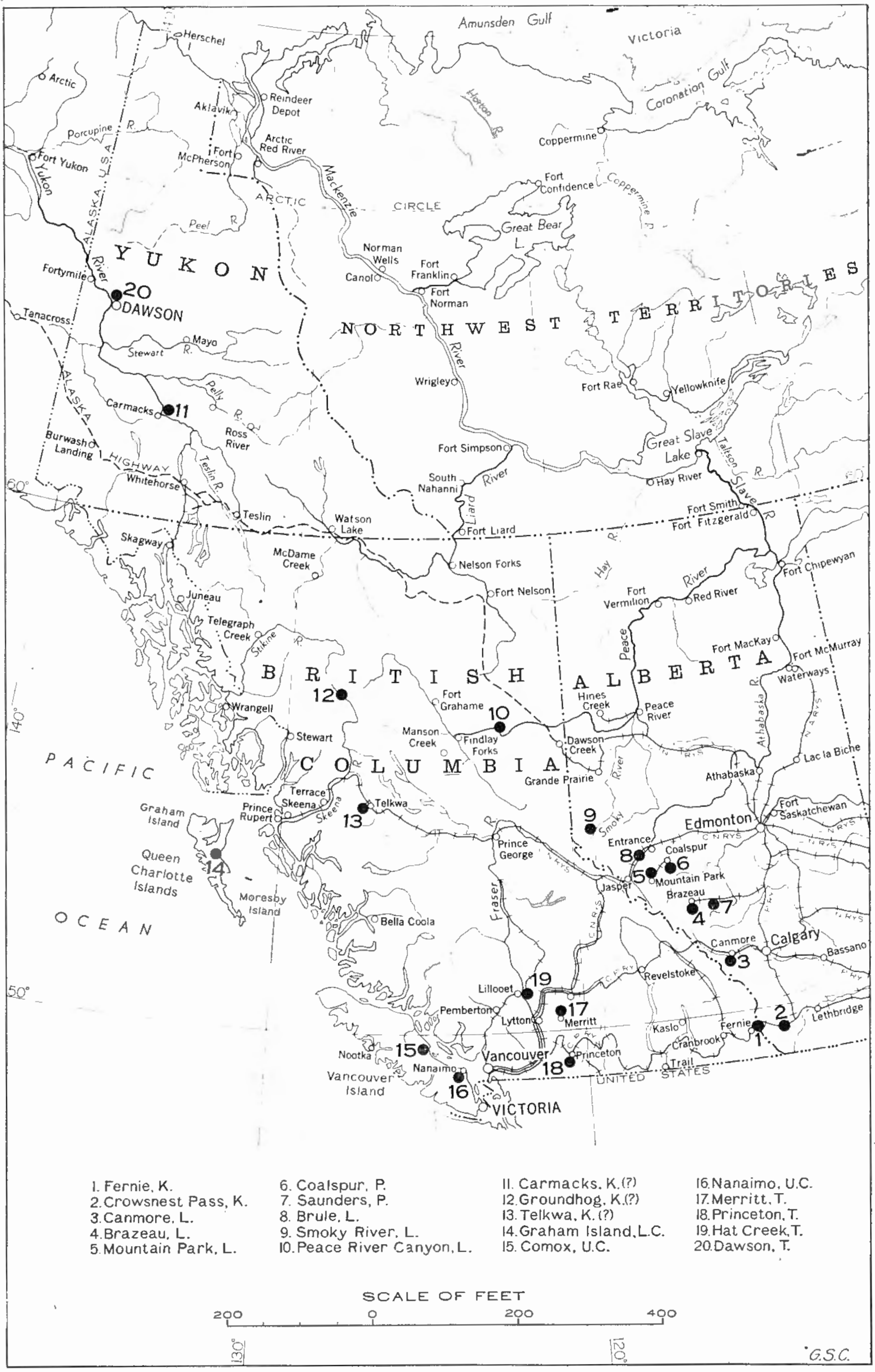
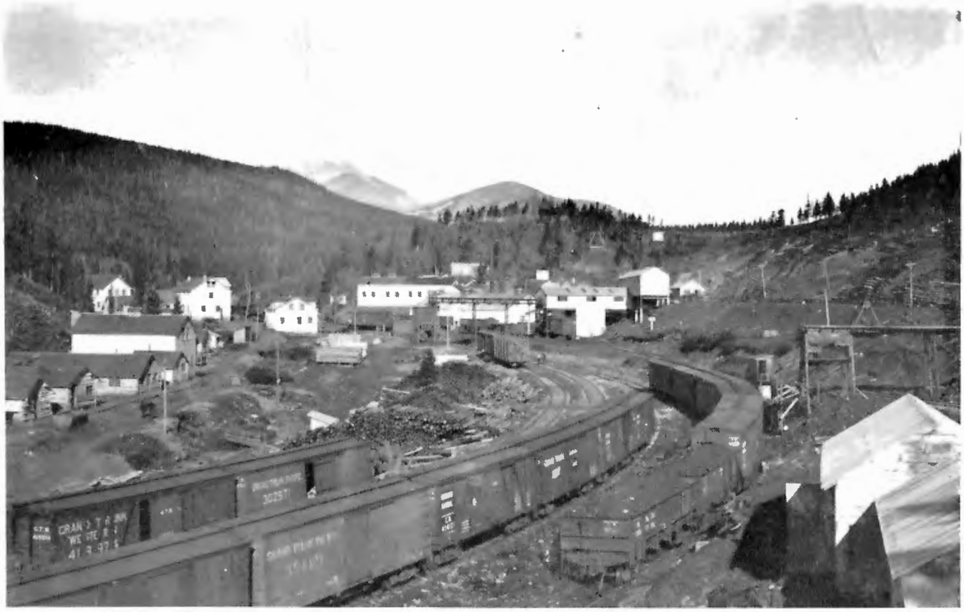


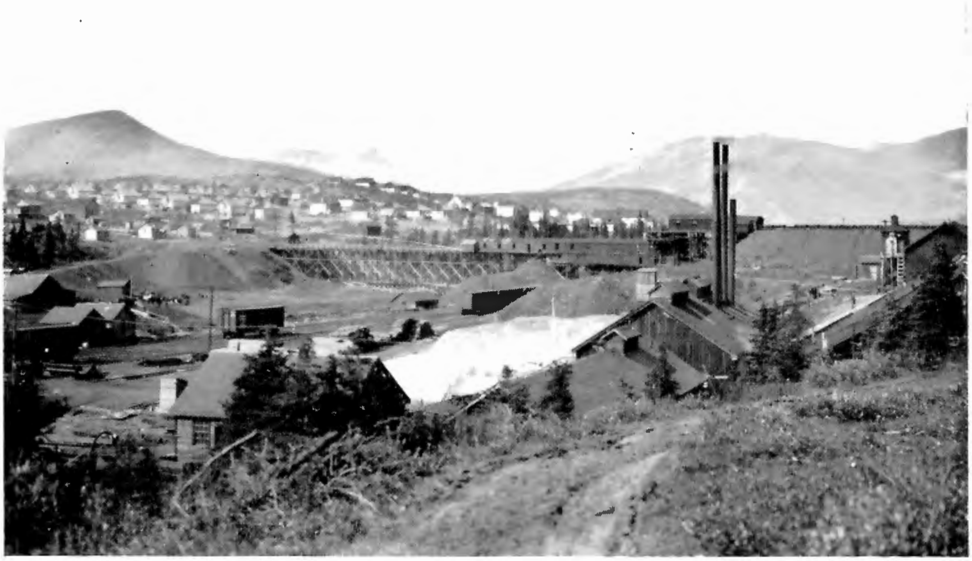
Figure 70. Coalfields of the Cordilleran region. K-Kootenay; L-Luscar; P-Paleocene; L.C.—Lower Cretaceous; U.C.—Upper Cretaceous; T-Tertiary.

PLATE XLVI



Luscar Collieries, Alberta. Photo by B. R. MacKay, Geological Survey (64925).

PLATE XLVII



Mountain Park Collieries, Alberta. Photo by B. R. MacKay, Geological Survey (66891).

3 feet in thickness, and one measures about 25 feet. This area has not been developed beyond the prospecting stage. The Crowsnest basin lies immediately to the north, and as it is traversed by the Canadian Pacific Railway coal mining has been continuous there since about 1899. Production from this basin in 1945 was 2,830,547 tons. The Kootenay formation is more than 4,000 feet thick in this area. It contains more than twenty seams in the lower part, with an aggregate thickness of 170 to 216 feet of coal, of which 100 feet is mineable. At Corbin the strata have been folded and faulted, and a 60-foot seam has been squeezed to form pockets more than 100 feet thick. Open-pit mining has been in operation on this property intermittently since 1911. The coal is badly crushed and requires cleaning. Coal deposits of comparable importance are present along the upper part of Elk River. In the Alberta section of the Crowsnest Pass coal is being mined from the Kootenay formation at Coleman, McGillivray Creek, Blairmore, and Bellevue. Mines have also operated at Hillcrest, Frank, and Burmis. The Kootenay formation decreases in thickness from 800 to 360 feet from west to east in this area. Of the three seams of importance, only two are mined at any one place. The main seam has an average thickness of about 12 feet. On upper Highwood River, on the west side of Highwood Range, the Kootenay formation contains several coal seams more than 10 feet thick. These continue northward to Sheep River where one seam is 38 feet thick. Development work has not been carried past the prospecting stage in this area.

Along Bow River, Kootenay coal has been mined continuously since 1888 in the vicinity of Canmore. The coal measures are about 1,100 feet thick and contain twelve seams, some of which are too small to mine. Small deposits of semi-anthracite occur where the coal has been more intensely metamorphosed, but the bulk of the coal is of bituminous rank. Production from this area for 1945 was 318,036 tons.

The commercial coal deposits on and north of North Saskatchewan River are of Lower Cretaceous age, but occupy a higher stratigraphical position than the southern deposits, as substantiated by the fossil plants. These higher coal measures occur in the Luscar formation, near the base of the Blairmore group. Several coal seams are present, but usually only two are workable. These range in thickness from 6 to 40 feet. The principal coal deposits in the Luscar formation adjacent to the front range of the Rocky Mountains include the Bighorn, Mountain Park, Cadomin, and Luscar basins, deposits at Brûlé on Athabaska River, and others northwest to and beyond Smoky River. In the Peace River area the coal deposits are in the Gething formation of the Bullhead group. Seams vary from a few inches to 8 feet thick, and the coal is of good bituminous grade.

Coal seams of Upper Cretaceous and Paleocene age are present along the outer Foothills belt from the International Boundary north to and beyond Athabaska River. The seams are usually thin, but some attain a thickness of 9 feet. The coal varies in rank from bituminous to sub-bituminous.

Along Liard River at the south end of Mackenzie Mountains are seams of Upper Cretaceous coal several feet thick and of bituminous grade. Coal of Cretaceous or Tertiary age occurs on Moose River north of Aklavik, adjacent to Richardson Mountains.

On Vancouver Island the coal-bearing strata belong to the Nanaimo group of Upper Cretaceous age, and occupy a narrow lowland along the southeastern coast and adjoining islands. The Nanaimo strata consist of conglomerate, shale, and sandstone, and have a total thickness of about 7,000 feet in the Nanaimo area. The different kinds of sediments alternate with one another and single beds seldom have any lateral extent, but the group is divisible into a number of lithological units, each maintaining its general character. The upper part of the succession is mainly non-marine, but several lower horizons carry marine fossils. The strata were deposited in a downwarped area on a deeply eroded, uneven surface of Mesozoic sedimentary, volcanic, and plutonic rocks. The floors of the coal seams are frequently of sandstone rather than shale, and seldom or never contain remains of roots of the vegetation from which the coal originated. It has been suggested that the coal has resulted from deposits analogous to peat bogs. Individual coal seams are absent locally, partly as a result of erosion, which took place as they accumulated, and partly because of the presence of projections of the uneven surface on which the strata rest. The whole series has a comparatively low dip, but has suffered minor folding and considerable faulting. The productive fields are in the vicinity of Nanaimo and Comox. In the Nanaimo field there are three persistent seams, one about 700 feet above the base of the series, a second 800 to 1,000 feet above the first, and a third 25 to 100 feet above the second. In the Comox field to the northwest, the coal seams are also confined to the lower part of the Nanaimo group. The coal is of high volatile bituminous rank. Production for Vancouver Island for 1945 was 623,960 tons.

Coal deposits of the same age as those at Nanaimo occur farther north on Vancouver Island, at Suquash, and also on Graham Island, the most northerly of the Queen Charlotte Islands.

Coal seams of Upper Jurassic or Lower Cretaceous age occur in the sedimentary division of the Hazelton group at a number of localities in Bulkley River Valley, and in the Kispiox area on Skeena River north of Hazelton. The strata in which the coal occurs are cut by minor 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 of the igneous rocks. Seams range up to 14 feet in thickness, but have been folded and crushed. The only recorded production comes from Lake Kathlyn basin near Smithers, and from Goat Creek and Telkwa River Valleys close to Telkwa. Current production, amounting to 25,492 tons in 1945, comes from Goat Creek and Telkwa River. The strata of the remotely located Groundhog coal field at the headwaters of Skeena River belong presumably to the same division of the Hazelton group.

The principal coal mining area in Yukon was at Carmacks, where coal was mined until 1938. During the peak year of 1913, 19,722 tons were mined in Yukon, mainly at Carmacks. The coal-bearing rocks, extending for many miles to the southeast, are of early Lower Cretaceous age and belong to the Tantalus formation of conglomerate, sandstone, and shale. The coal ranges from bituminous to anthracite.

Coals of Tertiary age are widely distributed over the interior Cordillera, northern Rocky Mountains, and Mackenzie River Valley. The principal producing areas are near Princeton and Nicola in southern British Columbia, where the production of coal of lignitic, sub-bituminous, and high volatile bituminous rank amounted to 59,362 tons in 1945. The coal measures are sandstone, conglomerate, and shale, and in places are tightly folded. In the Princeton area, where they accumulated in local basins, plant and insect remains indicate a lower Tertiary age. Production from Hat Creek, 30 miles northwest from Ashcroft, amounted to 1,978 tons in 1942. In the Chu Chua area in North Thompson Valley the coal occurs in three seams and is of bituminous rank. Lignitic coal of Tertiary age is also found on Graham Island. The coal in Tertiary beds on Coal River and Mackenzie River Valleys is of lignitic rank. A little lignite has been mined from time to time in Yukon about 40 miles north of Dawson.

Petroleum and Natural Gas

The greatest part of Canada's oil production comes from two fields in the eastern Cordilleran region, Turner Valley in the south, and Norman Wells in the north close to the Arctic Circle.

Turner Valley, Canada's largest oil field, lies close to the outer edge of the Foothills in southern Alberta (Figure 71). It is also Canada's largest producing gas field. In 1942, the peak year, it produced 10,136,296 barrels of oil and 47,260,390 M cubic feet of gas. The field was first discovered in 1914, when production of naphtha was obtained from sands in the Lower Cretaceous Blairmore group. Production continued from these sands until 1924. At that time the first well tapped the underlying limestone reservoir of the Rundle formation of Mississippian age on the gas cap, resulting in larger wells of naphtha and gas. In 1936 the first well reached the crude oil zone in the limestone reservoir below the gas cap. The oil is high gravity, ranging from crude at 38 to 42 degrees A.P.I. Production since 1936 has been mostly from the lower crude oil zone, conserving the gas as much as possible for more efficient recovery of the oil. Total production to the end of 1945 was 81,130,000 barrels. Turner Valley has a length of 21 miles and a width of as much as 2½ miles in its central part. The extent of the field has been fairly well outlined, though the northern limit has not been determined to date (Plate XLVIII). Production is obtained from two porous horizons in the upper 350 feet of the Rundle formation. The wells range in depth from about 4,000 feet on the top of the structure or gas cap to more than 9,000 feet to the lower part of the crude oil zone. Structurally, Turner Valley is a west dipping fault block with an anticline on its east edge, but in which the east limb of the fold is largely replaced by the major thrust fault that underlies it (Figure 72). On the west flank the closure within the producing zones is in the neighbourhood of 5,000 feet. Deep drilling on the west flank encountered the major thrust fault beneath the structure in Mississippian strata above the Devonian.

Moose Mountain, a Palæozoic outlier, is a dome-like structure lying in the inner Foothills west of Calgary, and has produced a small amount of oil from a well in Devonian limestone. For a period of 4 years, from 1937 to 1940, the production amounted to 6,144 barrels. The oil has a gravity of 47·7 degrees A.P.I., and enters the well through fractures in the limestone about 1,300 feet below the top of the Devonian, which is about 200 feet below the surface at this locality.

The Foothills belt from the International Boundary to Liard River forms the western part of the large petroleum province of western Canada. In this belt there are numerous folds, but faulting is general and structures are complicated. Exploratory drilling outside of Turner Valley discovered a large gas and naphtha well at Jumpingpound, 21 miles west of Calgary, in 1944. The top of the Rundle limestone was encountered at a depth of 9,618 feet, and oil and gas were found in the upper 200 feet. The size and importance of this field will be determined by further drilling.

Canada's second largest oil field is at Norman Wells on Mackenzie River, 90 miles south of the Arctic Circle (Plates XLIX and L). This field was discovered in 1920, and for many years supplied oil to a local refinery for the requirements of the district. In 1942 development of this field was accelerated by the Canol Project. This was an enterprise undertaken by the military authorities of the United States. It resulted from an agreement between the Governments of the United States and Canada, and was designed to supply motor fuel to the military forces defending the North Pacific region during the war with Japan. The Canol Project had three main objects: (1) to develop the Norman Wells oil field and drill sufficient wells to maintain a supply of 3,000 barrels of crude oil per day, over and above that required for local use; (2) to build a 4-inch pipe-line from Norman Wells to Whitehorse, Yukon, about 600 miles, with booster pumps capable of delivering at least 3,000 barrels a day to Whitehorse (Plates LI and LII); and (3) to build a refinery at Whitehorse to process the crude oil. All these objectives were accomplished. Drilling commenced in 1942, and in 1945, when the project was terminated, sixty productive wells had been drilled.

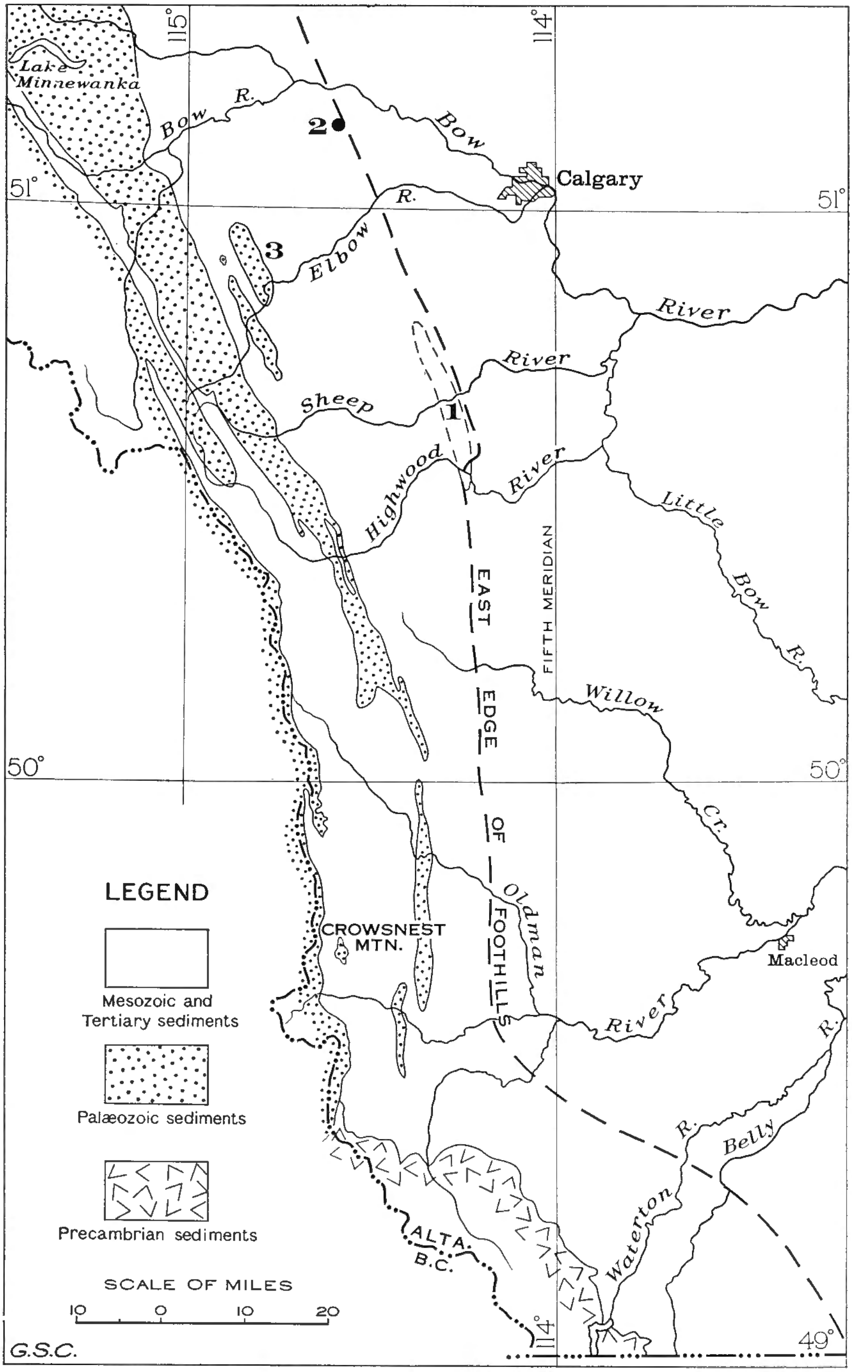


Figure 71. Foothills area in southwestern Alberta. 1, Turner Valley oil and gas field; 2, Jumpingpound oil and gas well; 3, Moose Mountain Palæozoic outlier.

Panoramic view of Turner Valley oilfield at the town of Royalties, Alberta; western range of the Rocky Mountains in the distance.
Photos by G. S. Hume, Geological Survey (82506, 82507).

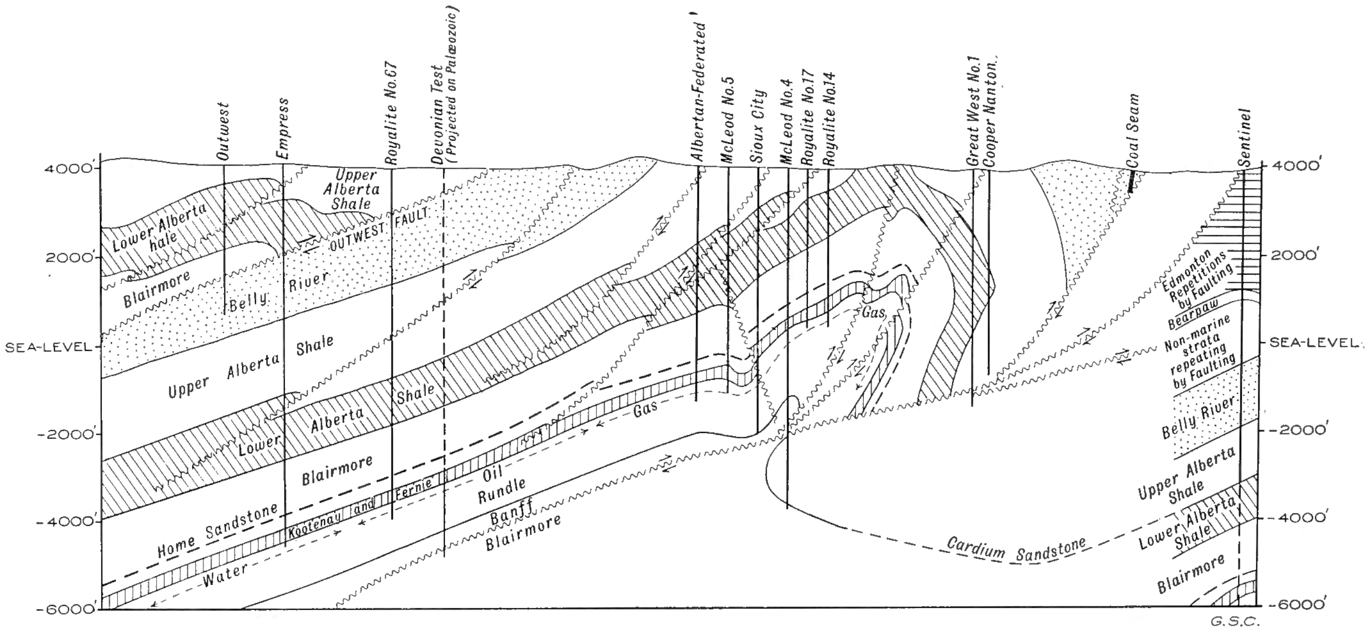


Figure 72. Structure section of central Turner Valley, Alberta. (After G S Hume.)

PLATE XLIX

Norman Wells townsite at Norman Wells, Northwest Territories. Photo by J. S. Stewart, Geological Survey, 1943 (94961).

PLATE L

Dock at Norman Wells on Mackenzie River, Northwest Territories. Photo by J. S. Stewart, Geological Survey, 1943 (93612).

PLATE LI

Canol pipe-line road at Pump station No. 10, 78 miles east of Johnsons Crossing, Yukon. Photo by J. S. Stewart, Geological Survey, 1944 (94989).

PLATE LII

Alaska Highway at Johnsons Crossing, Teslin River, Yukon. Photo by United States Army.

The strata in the Norman Wells oil field (Figures 73 and 74) have a monoclinal dip of about 5 degrees toward the southwest. The oil occurs in a reef limestone of Upper Devonian age that reaches a maximum thickness of 400 feet. This true reef has 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 a pinching out of the reef up-dip. Oil saturation of the reef is irregular both horizontally and vertically. The depth of 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 4,010 acres, of which 1,870 acres underlie Mackenzie River. During the last 6 months of the life of the Canol Project, the field produced at the rate of more than 4,000 barrels a day, and on July 1, 1945, the field had produced a grand total of 2,007,210 barrels of crude petroleum.

The possibilities of finding other oil fields in the region appear to be promising owing to the widespread distribution of petroliferous shales and oil seepages.

Fluorite

The *Rock Candy* deposit, the most extensive occurrence of fluorspar known in Canada, lies about 15 miles north of Grand Forks, British Columbia. It consists of one large ore shoot made up of a stockwork of closely spaced replacement veins in syenite. The veins range from a few inches to 30 feet in width and make up much the greater proportion of the ore shoot. The outcrop of the mineralized zone is about 500 feet in length and has a maximum width of 45 feet. It has been explored over a vertical distance in excess of 450 feet. The veins are characterized by numerous large open cavities, and contain fluorspar, barite, chert, quartz, calcite, pyrite, and kaolin. They were deposited from solutions that originated in the syenite as a result of differentiation processes that accompanied the cooling and consolidation of the magma.

Gypsum

Massive white to translucent gypsum has been quarried, since 1926, at *Falkland,* about 45 miles southeast of Kamloops. The material is shipped to a calcining and board mill near New Westminster on Fraser River. The deposits occur in lens-shaped masses in a major northwesterly trending fault zone in greenish and greenish grey Carboniferous rocks of, chiefly, volcanic origin. Shipments from the quarries during 1941 amounted to about 2,200 tons a month.

Deposits of gypsum occur in the upper Triassic beds north of Jasper, Alberta, and in beds of Silurian age in Franklin Mountains east of Mackenzie River.

Magnesite

Large unexploited deposits of magnesite are known in the Cranbrook area in southeastern British Columbia. The most promising of these was found near *Marysville* by the Geological Survey in 1932. Here, a thin member of the Cambrian Cranbrook formation is made up of magnesite-bearing sediments. This member has been traced for a distance of $4\frac{1}{2}$ miles between terminating faults. It averages about 150 feet thick, of which 30 to 50 feet is remarkably pure magnesite.

Hydromagnesite

Deposits of hydrated magnesium carbonate, in places approximating hydromagnesite in composition, occur in the Cariboo, Atlin, and Kamloops districts of British Columbia. They form horizontal deposits in valley bottoms or on flats near the base of adjacent slopes. The surface of the purer deposits is

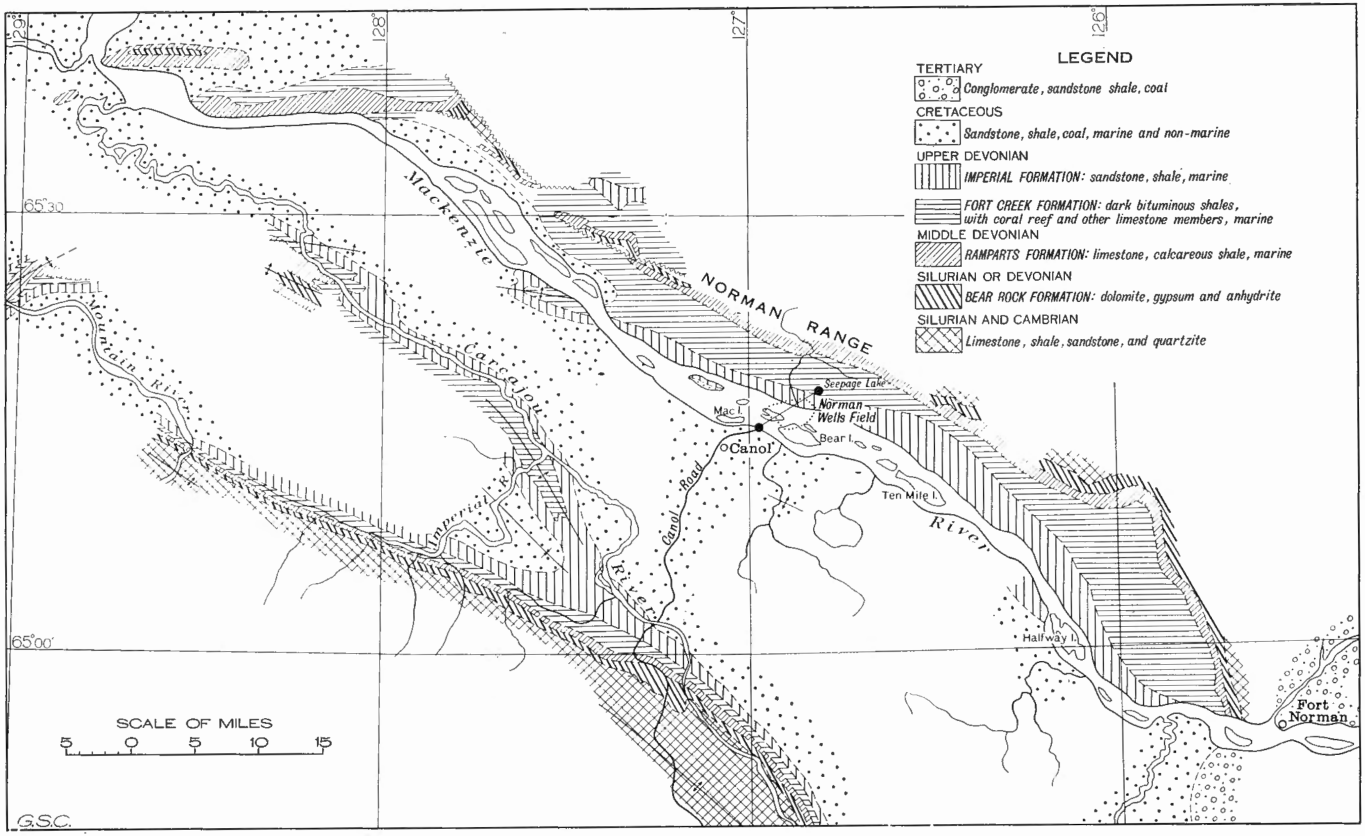


Figure 73. Geology of Fort Norman area, Northwest Territories.

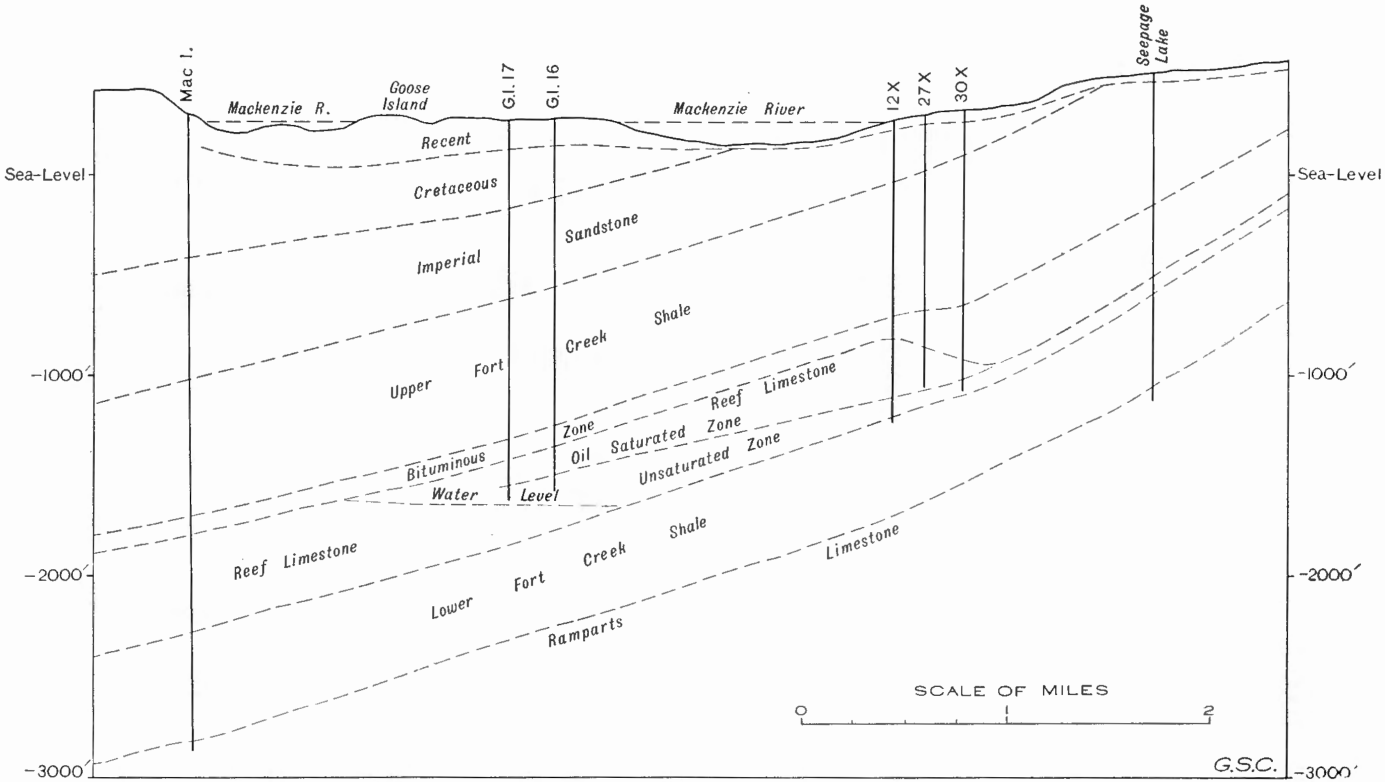


Figure 74. Vertical section northwest across Norman Wells field, Northwest Territories.

hummocky and cracked, and is commonly raised slightly above the surrounding ground level. In general a layer of white, massive hydromagnesite overlies loose, granular, creamy material that in turn grades downward into soil. The calcium content increases progressively towards the base. They are thought to have been deposited from rising underground waters.

The most important deposits are at *Meadow Lake,* near Chasm, on the Pacific Great Eastern Railway. They occupy parts of a shallow depression, some 15 miles in length, which is dotted by small lakes without apparent outlets. The purer deposits are flat sheets up to about 2,000 feet long, raised a few inches to 2 feet above the surrounding swampy ground. Within these, the upper, purer, white layers are a little more than a foot thick, although the calcium content is fairly low to a depth of at least 3 feet. Available material here has been estimated at 220,000 tons, with a lime content not exceeding 3 per cent.

Phosphate

Deposits of phosphate are widespread in the Rocky Mountains, occurring in formations of different geological ages. Beds several feet thick have been found near the base of the Banff formation of Mississippian age, near the top of the Rocky Mountain formation of Pennsylvanian age, and at the base and in the Fernie formation of Jurassic age. The phosphate beds usually occur close to a contact or an erosional surface. The deposits are low grade, and their commercial value is uncertain.

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 range from 4 to 70 feet in diameter and from 1 to 10 feet deep. They aggregate some 70,000 tons containing about 17,500 tons of sodium carbonate.

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 range up to 60 feet in diameter and some exceed 10 feet in depth. The minimum content of crude salts is 75,500 tons, containing about 35,000 tons of magnesium sulphate.

Lime and Cement

Limestone suitable for the production of high-calcium lime is abundant. Lime of a high degree of purity is calcined from 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 argillites. Another cement plant at *Exshaw,* Alberta, uses limestone mixed with shales from the Wapiabi formation.

Building Stone

The most important building and monumental stone is the granodiorite and related rock of the Coast batholith, as quarried at *Jervis Inlet* about 55 miles northwest of Vancouver. The somewhat similar stone of the Nelson batholith has also been used, and other intrusive bodies have found local use in building and monumental work. The only sandstones of commercial importance are those of the Upper Cretaceous, Nanaimo series quarried on southeastern *Vancouver Island* and on various smaller islands between Victoria and Vancouver city. Marble has been quarried at *Marblehead,* north of Kootenay Lake, and on *Texada Island.*

CHAPTER VIII

THE ARCTIC ARCHIPELAGO

(J. E. Armstrong)

INTRODUCTION

The Arctic Islands of Canada, together with Boothia and Melville Peninsulas, form a separate geographic unit extending from Hudson Bay, at 62 degrees north latitude, to the northern tip of Ellesmere Island, at 83 degrees north latitude, or about 1,500 miles. Their greatest extent from east to west is about 1,000 miles. The land area in this vast region exceeds 525,000 square miles (See Figure 75).

Little is known of the hinterlands of the Arctic Islands, exploration having been confined mainly to their coasts, with a few inland trips. However, sufficient information has been gathered to provide a general picture of the geography and geology, though this no doubt will be greatly modified by subsequent more detailed explorations.

The exposed formations of the Arctic Archipelago are successively younger from southeast to northwest. In the southeast rocks of Precambrian age rise, on Baffin Island, to a reported height of 10,000 feet above sea-level. Attempts have been made to classify these rocks as either Archæozoic or Proterozoic, but have been only partly successful. No further division is at present possible, although the various Precambrian formations identified on the mainland are undoubtedly to be found.

Along the northwest border of the main Precambrian area the older rocks are overlain, first by isolated remnants of early Palæozoic strata, and, farther north, by an almost continuous succession ranging in age from Cambrian to Triassic and possibly Jurassic. In places Cambrian, elsewhere Ordovician and Silurian beds, directly overlie Precambrian rocks. The Palæozoic section on Ellesmere Island is at least 10,000 feet thick. These Cambrian and younger strata are everywhere flat-lying or only slightly disturbed, except in part of Ellesmere Island where they are folded. This folded area is mountainous, with peaks as much as 10,000 feet high.

Small basins of Tertiary sedimentary rocks with coal occur at numerous localities throughout the Archipelago.

Various mineral occurrences have been observed in that part of the Archipelago underlain by Precambrian rocks, but are mostly of minor importance, and none has yet been developed.

Coal of late Palæozoic and of Tertiary age is known at many places in the Arctic.

EXPLORATION

The Arctic Archipelago is one of the most inaccessible and least known regions of the world, and the history of its discovery, especially in the earlier stages, is one of incredible hardships and remarkable courage.

Norsemen had settled in Iceland at the end of the ninth century and soon afterwards discovered Greenland, and some migrated there. From these settlements they are believed to have explored Davis Strait and part of Baffin

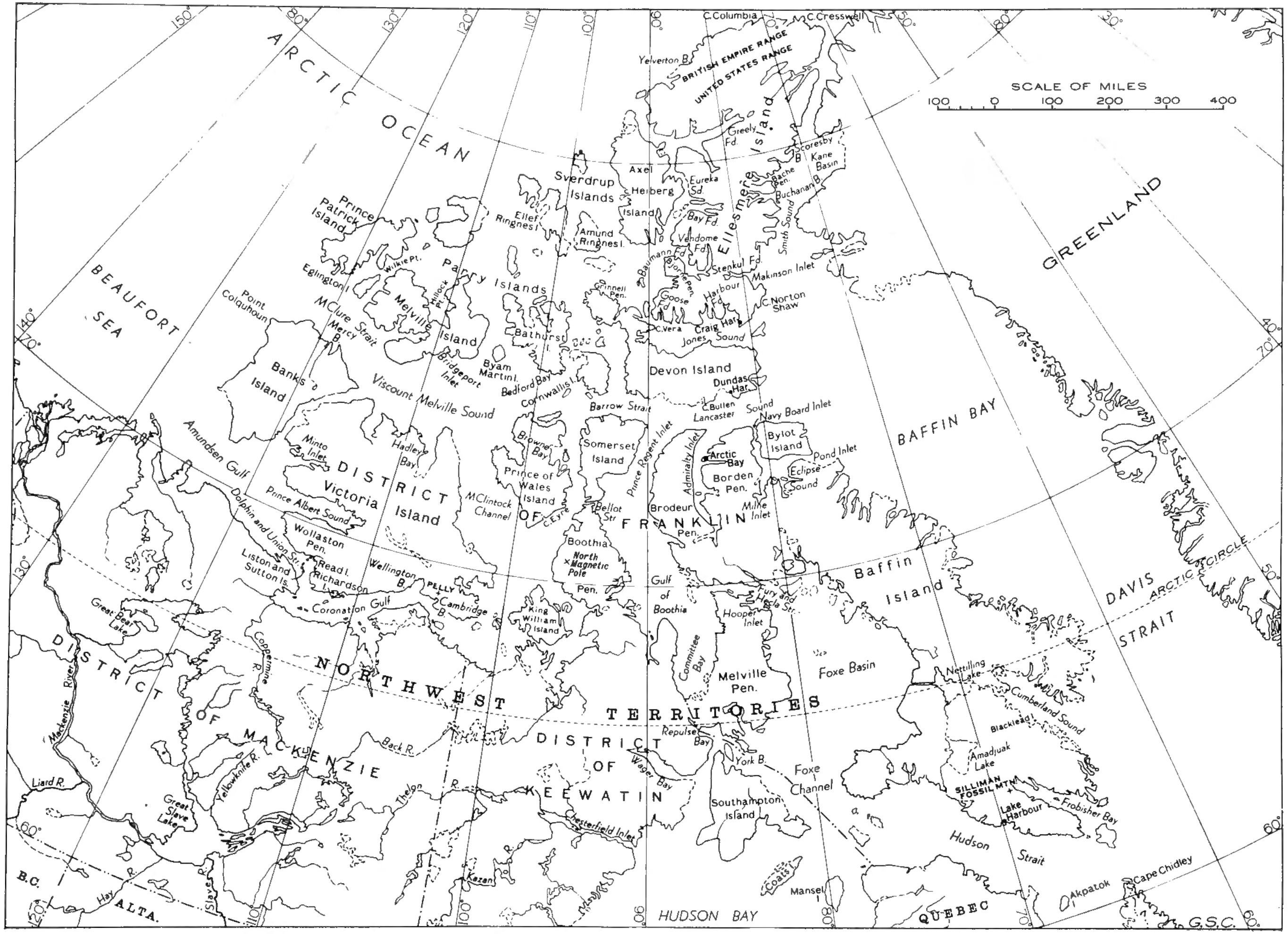


Figure 75. Arctic Islands region.

Bay. The greatest of the Norse adventurers was Leif Erikson, who, on his way from Norway to Greenland in 1000 A.D., is believed to have touched the coast of Labrador and the southeast shores of Baffin Island.

There is no further record of exploration in the Canadian Arctic until 1576, when Martin Frobisher set out from England to find a northwest passage to India, thereby initiating a series of expeditions that in the next 300 years were outfitted in England for this purpose. On his first journey Frobisher discovered the bay in southern Baffin Island that now bears his name. Unfortunately, a false rumour of gold arose on his return, and trips in the succeeding 2 years in search of wealth succeeded neither in finding gold nor in making new discoveries.

The next attempts to discover the northwest passage were by John Davis, who made three voyages to Davis Strait between 1585 and 1587. In 1610 Henry Hudson entered Hudson Strait and discovered the great bay that bears his name. He was obliged to winter there, and on his way home the following year his crew mutinied setting him adrift in a boat to perish in the waters of the strait. In 1612 Thomas Button sailed to Hudson Bay and wintered at the mouth of Nelson River, and the next year he explored the coast of Southampton Island, Robert Bylot and William Baffin sailed to Hudson Bay in 1615, travelling along the Foxe Channel coast to Southampton Island. In 1616 they sailed up Davis Strait and around Baffin Bay, taking note of Smith, Jones, and Lancaster Sounds. These discoveries were doubted by map makers, and it was not until 200 years later that another expedition entered these waters to prove the earlier observations substantially correct.

In 1631 Luke Foxe and Thomas James commanded ships sailing to Hudson Bay in search of a route to the Indies through this bay. Their failure retarded the search for a northwest passage until 1742 when Middleton sailed north from Churchill up the west coast of Hudson Bay to Repulse Bay.

It was not until 1818 that further attempts were made to discover a northwest passage, and in that year four ships sailed from England on which were serving John Ross, Edward Parry, F. W. Beechey, George Back, and John Franklin. John Ross and Edward Parry went to Baffin Bay, but did not attempt to proceed farther west. Parry made voyages to the Arctic in 1819, 1821, and 1824. On the first he entered Lancaster Sound and proceeded west to Melville Island; on the second he sailed through Hudson Strait and Foxe Basin to Fury and Hecla Strait; and on the third he passed through Lancaster Sound and south into Prince Regent Inlet. In 1829 John Ross entered Prince Regent Inlet and continued south to Boothia Peninsula where he wintered. James Ross, the commander's nephew, made winter sledge journeys to the northerly point of King William Island and to the site of the North Magnetic Pole. George Back made an attempt in 1836 to continue the work of Parry and Ross, but his ship was caught in the ice in Foxe Channel.

The British Admiralty made no further attempts at Arctic exploration until 1845, when Sir John Franklin's ill-fated expedition disappeared south of Barrow Strait. During the succeeding 12 years thirty-five ships and five overland expeditions carried a host of explorers to the Canadian Arctic in search of Franklin. It is estimated that 6,000 miles of new coastline were discovered, and when the search was completed only the most northern islands remained to be explored. Of the many famous explorers engaged in this search Leopold McClintock was one of the most versatile and widely travelled, and it was he who solved the technique of Arctic sledging and who in 1859 discovered proof of the loss of Franklin's party. McClintock crossed Melville Island and discovered Prince Patrick Island. A northwest passage was completed in 1854 for the first time when Robert McClure, a member of Richard Collinson's expedition, succeeded in travelling partly by ship and partly on foot from Bering Sea to the Atlantic Ocean.

In these and succeeding years much of our knowledge of the geology of the Arctic Archipelago is based on observations made by naturalists, in many instances medical doctors attached to various search parties. In 1853, Dr. Elisha Kane sailed from New York northward to Kane Basin in search of Franklin. Kane confined his explorations to the Greenland side of the sound, whereas Dr. Hayes, surgeon attached to Kane's ship, crossed Kane Basin to Ellesmere Island. Hayes returned to the Arctic in 1860 and continued his exploration of the eastern coast of Ellesmere Island.

The next big impetus in Arctic exploration resulted from competition to reach the North Pole. In 1871, C. F. Hall, who had previous Arctic experience in the Frobisher Bay and Repulse Bay areas, was encouraged by the United States Government to reach the Pole by sailing north between Ellesmere Island and Greenland. He reached latitude 82° 11′. The British Government fitted out a Polar expedition in 1875 with George Nares in command and instructed him to proceed up Smith Sound with the North Pole as his objective. His sledge parties reached latitude 83° 20′ in the direction of the Pole, and explored the entire northern coast of Ellesmere Island. H. W. Feilden was attached to the Nares expedition as naturalist, and we must credit him for much of our knowledge of the geology of northeastern Ellesmere Island. In 1881 the United States, represented by A. W. Greely, established a base at Fort Conger on the eastern coast of Ellesmere Island at about latitude 81° 40′; sledge journeys from Fort Conger included a trip to the north of Greenland and a crossing of Ellesmere Island to Greely Fiord. One of the greatest of Arctic explorers was Robert Peary, who commenced his investigations in 1886 and who, after 23 years of continuous Arctic experience and after several unsuccessful attempts, is credited with having reached the North Pole in 1909. Frederick A. Cook spent 2 years in the Arctic, 1907 to 1909, and claimed to have reached the North Pole in 1908, but his claims have never been substantiated.

In 1899 Otto Sverdrup from Norway planned an Arctic voyage for the circumnavigation of Greenland, but was obliged to abandon his attempt to traverse Smith Sound, and instead proceeded westward into Jones Sound, spending the next four winters in different harbours in Ellesmere Island. Axel Heiberg and other islands of the Sverdrup group, which lies west of Ellesmere Island, were discovered and mapped. The Norwegian flag was raised in this area, and it was not until 1930 that Norway acknowledged Canadian sovereignty. P. Schei, a geologist, was attached to this expedition, and gained much valuable information.

The first member of the Canadian Geological Survey to investigate the Arctic Archipelago was Robert Bell, who examined the southern coast of Baffin Island in 1884 and 1885. In 1903 A. P. Low commanded a wintering expedition to the Arctic, and from 1906 to 1912 three similar voyages under the command of Captian J. E. Bernier were sponsored by the Canadian Government. J. G. MacMillan, attached to the second expedition as geologist, studied the geology of Melville Island, and on the third voyage J. T. E. Lavoie investigated the geology of Brodeur Peninsula, Baffin Island.

Roald Amundsen was the first to complete the Northwest Passage from east to west in one ship, having sailed from Christiania, Norway, in 1903 and reached Bering Strait in 1906. During the years 1913 to 1917 Donald MacMillan explored the area to the north and west of Jones Sound, and confirmed Sverdrup's discoveries. During the same period Vilhjalmur Stefansson investigated the great bight north of Canada and west of the Parry Islands. He was the commander of the Canadian Arctic Expedition of 1913 to 1918, the main objective of which was the exploration of Beaufort Sea, the last great unknown area in the Canadian Arctic. The expedition was split into a southern party in charge of R. M.

Anderson and a northern party under Stefansson. J. J. O'Neill of the Geological Survey was attached to the southern party as geologist, and as part of his work studied the formations of the southern coast of Victoria Island. G. S. Malloch of the Geological Survey, who was geologist for the northern party, died in the Arctic when the expedition's ship sank and he was obliged to travel with the party to Wrangell Island in the depth of winter over incredibly rough ice.

Within the last 30 years expeditions to the Arctic Archipelago have been interested more in scientific information than in pure exploration. Geological investigations during this period were undertaken at various areas in the Arctic, and prominent workers in recent years have been T. Mathiassen (Southampton Island, Melville Peninsula, and Northwest Baffin Island, 1921-1924), L. J. Weeks (Cumberland Sound, 1926), I. H. Cox (Akpatok Island, 1931), R. Bentham (Bache Peninsula, 1934, and southern Ellesmere Island, 1936-1939), and A. L. Washburn (Victoria Island and adjacent regions, 1938-1941).

PLATE LIII

Hudson's Bay Company's ship *Nascopie* at anchor in Lake Harbour, Baffin Island. Photo by D. A. Nichols, Geological Survey (82081).

In 1912, the Hudson's Bay Company icebreaker *Nascopie* first entered the eastern Arctic, and since then has been used in yearly trips to various Arctic settlements (Plate LIII). In 1937 the trading post of Fort Ross, at the eastern end of Bellot Strait, was opened, and here the *Nascopie* met, and exchanged freight with, the small Hudson's Bay Company schooner *Aklavik* from King William Island, thus making Bellot Strait a meeting place between Eastern and Western Arctic on the Northwest Passage. The boat that has made recent history in the Arctic is the R.C.M.P. schooner *St. Roch* (Plate LIV) under the command of H. A. Larsen. From 1940 to 1942 she completed the Northwest Passage from west to east, the first ship to do so, but was forced to spend two winters frozen in the ice. Again in 1944 the *St. Roch* made the Northwest Passage from east to west in a single season, thereby creating a new record in arctic navigation.

PLATE LIV

Royal Canadian Mounted Police schooner *St. Roch* being driven by ice into Pasley Bay, Boothia Peninsula. Photo by courtesy Royal Canadian Mounted Police.

SOUTHAMPTON ISLAND, MELVILLE PENINSULA, AND ADJACENT ISLANDS

Southampton Island, about 20,000 square miles in area, may be divided roughly by a line running southeast from Duke of York Bay. A Precambrian plateau lies northeast of this line and a Palæozoic limestone lowland to the southwest. The plateau is an area of gently undulating hills rising gradually from the sea and the limestone lowland to an average height of 1,000 feet, an occasional rounded hill reaching 1,500 feet above sea-level. It is underlain mainly by granite and gneiss. The limestone lowland is formed of irregular ridges of limestone debris or of flat-lying limestone outcrops separated by low, swampy, or lake-covered areas. It rises from the sea in a series of raised beaches to a maximum elevation of about 200 feet. Middle Silurian (Niagaran) fossils have been collected from limestone at the most northern tip of Southampton Island; other fossils, from the southwestern part of the island, indicate strata of both Upper Ordovician (Richmond) and Niagaran ages.

Coats Island, about 2,000 square miles in area, lies directly south of Southampton Island. With the exception of a moderately high ridge of Precambrian rocks, which crosses the island diagonally at its eastern end, it is low and flat, with no elevation more than 100 feet, and consists of horizontally bedded Palæozoic limestone, probably of Ordovician or Silurian age.

Mansel Island, to the southeast of Coats Island, is everywhere low and flat, with no elevations exceeding 100 feet. It is underlain wholly by Palæozoic limestone.

Akpatok Island is included in this division although it lies in the mouth of Ungava Bay. It is 550 square miles in area, and is strongly cliffed for the whole of its perimeter. Inland from the coast is a plateau varying in height from 600 to 850 feet. The island is underlain by at least 850 feet of almost horizontally bedded Ordovician limestones containing Richmond (Upper Ordovician) fossils.

Melville Peninsula consists of rounded hills, up to 1,000 feet high, of Precambrian granite, gneiss, and schist, except for a low-lying, limestone plain in its northeast part. Fossils of probable Richmond age occur in the limestone. Richmond fossils have been collected as well from the limestone of Iglulik Island in Hooper Inlet.

PLATE LV

View of Pangnirtung Fiord, Cumberland Sound, and mountains of Baffin Island. Photo by D. A. Nichols, Geological Survey (82086).

BAFFIN AND BYLOT ISLANDS

Baffin Island, the largest in the Arctic Archipelago, has an area of slightly more than 200,000 square miles. A high mountain range extends along the northeast coast from Cumberland Sound to Pond Inlet (Plate LV). On this coast the land rises rapidly to elevations of 1,000 feet or more and then more gently to the axis of the range, which has a general elevation of at least 5,000 feet with occasional peaks possibly as high as 10,000 feet. The area southwest of Cumberland Sound is a rolling plateau, about 2,000 feet above sea-level, and a broad lowland area lies west of Amadjuak and Nettilling Lakes. Borden Peninsula is a plateau rising precipitously from the sea to perhaps a general elevation of 2,000 feet, and Brodeur Peninsula is a tableland about 1,000 feet above sea-level. South of these peninsulas the land becomes gradually lower, and in the vicinity of Fury and Hecla Strait consists of a monotonous, low terrain of rounded hills. South of Eclipse Sound is an area of low, flat country or rolling hills a few hundreds of feet high separated abruptly from the mountains to the southeast. Similar, flat, rolling country forms a narrow border to the west coast of Bylot Island, the greater part of which is mountainous.

The east and south coasts, the lowland area north of Fury and Hecla Strait, and probably much of the interior of Baffin Island are underlain by crystalline rocks of Precambrian age. Granitic intrusions, gneiss, and schist comprise the greater part of the assemblage on the east coast. The rocks of the south coast of Baffin Island include an abundance of crystalline limestone, the general assemblage resembling that of the Grenville sub-province of the Canadian Shield.

Teichert has suggested that some of the rocks outcropping along the coast of Fury and Hecla Strait, on both sides of Admiralty Inlet, and in the vicinity of Milne Inlet are of Late Precambrian age, and he has compared them with the Thule formation of northwest Greenland. They consist mainly of sandstone and quartzite. It is quite possible that some of these rocks are of Late Precambrian age, but it is more probable, especially along Admiralty Inlet, that they are unfossiliferous, early Palæozoic strata.

Brodeur and Borden Peninsulas and the lowland area west of Nettilling and Amadjuak Lakes are underlain in large part by flat-lying Palæozoic sedimentary beds. In addition, a small exposure of Richmond limestone known as "Silliman Fossil Mountain" occurs near the head of Frobisher Bay. The Palæozoic strata of Brodeur and Borden Peninsulas rest on Precambrian rocks. They consist mainly of limestone, with some shale and sandstone. Wherever good sections are exposed the sandstone appears to be basal. The Palæozoic beds on the northwest coast of Borden Peninsula, in the vicinity of Nautilus Mountain, attain a thickness of at least 2,000 feet. In places the limestones are fossiliferous. Most of the Palæozoic rocks appear to be of Ordovician and Silurian age, although some of the basal sandstones are possibly older. Only in a few localities can the Ordovician and Silurian strata be separated. Fossils of Upper Ordovician (Richmond) age occur at several horizons in the Nautilus Mountain section, whereas those obtained from the limestone on the northwest coast of Brodeur Peninsula are of Middle Silurian (Niagaran) age.

The area of Palæozoic rocks west of Nettilling and Amadjuak Lakes is underlain by horizontal beds of Ordovician shale and limestone resting on Precambrian rocks. They have a maximum thickness of 700 feet, of which about 600 feet is shale. In most places the limestone occurs above the shale, forming a cap rock 50 feet thick, but in some localties limestone is interbedded with the shale. Fossils of Richmond age have been collected from the limestone cap rock, and others of Middle Ordovician (Utica) age from the shale. Various fossils collected in drift from the Nettilling Lake region indicate the presence of a Silurian terrain either near this lake or north of it.

At Arctic Bay, on Adams Sound, an arm of Admiralty Inlet, shales are overlain by sandstones and limestones, and the whole is cut by basic dykes. Although these strata are unfossiliferous they are lithologically similar to the Palæozoic beds of Borden Peninsula. Assays yielding values in gold, silver, platinum, copper, nickel, and antimony were obtained from specimens collected in the vicinity of Arctic Bay, and almost all reports of mineral discoveries in the eastern Arctic come from the Admiralty Inlet region.

Interbedded sandstone, shale, and lignite of probable Tertiary age occur on the south side of Eclipse Sound west of Pond Inlet, on both sides of Navy Board Inlet, and at the head of Isabella Bay. Coal has been mined for local use from these rocks on Salmon River about 3 miles south of its mouth on Eclipse Sound. Two main seams, each 3½ feet thick, are exposed.

Occurrences of mica, graphite, and garnet, of possible economic importance, have been found in the Grenville type Precambrian rocks of southern Baffin

Island. In 1876 an American company made a shipment of mica from Cumberland Sound, and in the early part of this century the Hudson's Bay Company mined graphite on Blacklead Island. During and immediately following the first world war this company shipped a small tonnage of mica and garnet from Lake Harbour (See Plate LIII) to England.

DEVON ISLAND AND PARRY ISLANDS

Devon Island has an area of approximately 21,900 square miles. The eastern part is an ice-capped tableland rising abruptly from the sea to an average elevation of about 3,000 feet. This tableland gradually loses height to the west, and the western part of the island does not exceed 1,000 feet in elevation. Low coastal plains mark the southwestern end of the island.

The eastern half of Devon Island is underlain by Precambrian granite and gneiss. Near Dundas Harbour unfossiliferous limestone is found at elevations of about 1,000 feet capping cliffs of grey gneiss. In the bay west of Cape Bullen, Precambrian gneisses are overlain by 50 to 100 feet of flat-lying shale and sandstone succeeded by about 1,000 feet of limestone. Middle Silurian (Niagaran) fossils have been found near the base of the limestone beds. The western half of the island south of Cape Vera, and most of Cornwallis Island, are fringed by cliffs of similar Silurian limestone. Fossils collected from talus in several localities suggest that the top of the section is of very late Silurian or early Devonian age. Devonian limestone outcrops along the north coast of Devon Island between Cape Vera and Grinnell Peninsula.

The Parry Islands comprise Cornwallis, 2,700 square miles; Bathurst, 7,000 square miles; Melville, 16,200 square miles; Prince Patrick, 7,100 square miles; and many smaller islands, including Byam Martin and Eglington. They possess the same physical characteristics, and a general description answers for all. Their shorelines are much broken, the land rising in cliffs 400 to 700 feet high. General elevations inland are less than 1,000 feet.

Much of Bathurst, Melville, and Prince Patrick Islands, Grinnell Peninsula on Devon Island, and Royle Point on Cornwallis Island are underlain by sedimentary rocks of probable Carboniferous and Permian age. These consist mainly of a series of white sandstones containing coal seams overlain by a series of limestones. The "sandstone series" outcrops on the south coast of Melville Island, on Byam Martin Island, and on all the coasts of Bathurst Island except the north. Its maximum observed thickness, on the south side of Melville Island near Bridgeport Inlet, is at least 3,850 feet, consisting of 1,225 feet of shale with minor sandstone overlain by 2,625 feet of white sandstone. The beds have an average dip of 65 degrees south. Fossil plants suggestive of either Pennsylvanian or Permian age have been collected from these rocks at several points on the south coast of Melville Island. Fossil shells collected from coal-bearing beds on Byam Martin Island were identified originally as Carboniferous, but a Permian age now seems more probable. The "limestone series" outcrops on Grinnell Peninsula, the north coast of Bathurst Island, and at Hillock Point, on the north coast of Melville Island, where Permian fossils, probably loose, have been collected. The occurrence of fossils of Carboniferous rather than of Permian age does not appear to have been demonstrated in the Canadian Arctic. Volcanic rocks of probable Permian age occur at Bedford Bay on the southeastern tip of Bathurst Island.

The northwest tip of Bathurst Island, and Wilkie Point on the southeast side of Prince Patrick Island, are underlain by Mesozoic sandstone and shale containing marine fossils of Triassic or Jurassic age, and deposits containing fossil wood of probably Miocene age outcrop in the southwestern part of Prince Patrick Island.

Although the available literature records many reports of coal in the Parry Islands, especially Melville, no reference is made to other than pieces of coal, and no seams are described. This coal was probably derived from seams in the Carboniferous or Permian sandstone series.

Seepages of petroleum or bitumen have been reported on northern Melville Island.

ELLESMERE ISLAND AND THE SVERDRUP ISLANDS

Ellesmere Island, with an area of about 75,000 square miles, extends to within 500 miles of the North Pole. Its general elevation probably exceeds 2,500 feet. North of Bache Peninsula the island is mountainous, with peaks in the United States and British Empire Ranges reaching elevations of 9,000 feet or more. Bache Peninsula is an almost undissected plateau rising 1,200 to 1,500 feet above the sea. From Craig Harbour to Bache Peninsula the east coast of Ellesmere Island is quite mountainous, cliffs rising steeply from the sea to heights of about 1,000 feet, above which the surface continues to rise inland to elevations of 2,500 to 3,000 feet. The southwestern part of the island is a rolling tableland, with an elevation of about 3,000 feet, and is bordered by high cliffs along the coast. The western side of the island, from Bjorne Peninsula to north of Bay Fiord, is a low rolling plain.

The Sverdrup Islands lie west of Ellesmere Island and include Axel Heiberg, with an area of about 13,200 square miles; Ellef Ringnes Island, about 3,200 square miles; and Amund Ringnes Island, about 1,750 square miles. Axel Heiberg Island is probably several thousand feet high in the interior, with a low, wide foreshore. The other islands are lower in general elevation, and are characterized by wide stretches of lowland between sea and crumbling cliffs. The latter rise to an uneven interior plateau that rarely exceeds 700 feet in elevation.

Precambrian granite, gneiss, and schist outcrop along the east coast of Ellesmere Island south of Buchanan Bay and along the south coast east of Harbour Fiord. On the west coast of the island Precambrian rocks have been observed only on Bay Fiord. Granitic rocks are reported to occur on the north coast between Cape Columbia and Yelverton Bay.

Along the southeast coast of Ellesmere Island unfossiliferous beds of dolomite and sandstone overlie the Precambrian rocks at varying elevations. At Craig Harbour (Plate LVI) they are 1,000 feet above sea-level, but westward they occur at lower elevations. Bentham believes they are of Cambrian age.

The best known and probably the best developed Palæozoic section in the Arctic Archipelago occurs on Ellesmere Island. It comprises at least 10,000 feet of flat-lying sedimentary rocks ranging in age from Lower Cambrian to Permian. On Bache Peninsula (Plate LVII) Precambrian rocks are overlain by a sandstone series about 500 feet thick, succeeded by at least 2,000 feet of limestone, limestone conglomerate, shale, and sandstone from which fossils of Lower and Middle Cambrian and basal Ordovician ages have been collected. North along the east coast from Bache Peninsula successively younger beds of Palæozoic limestone with minor shale and sandstone are exposed. Fossils of Lower Ordovician, Middle and Upper Ordovician, Lower Silurian, and late Silurian or early Devonian ages have been found in them. This belt of rocks apparently extends southwesterly, and beds of a similar character outcrop at the head of Bay Fiord on the west coast of the island.

Another excellent Palæozoic section is exposed in the southwest part of Ellesmere Island. In the vicinity of Harbour Fiord, Precambrian rocks are overlain by a basal sandstone above which is about 1,500 feet of limestone conglomerate, limestone, and shale followed by about 2,000 feet of brownish limestone. Richmond fossils occur in the lower part of the brownish limestone series and probable Niagaran fossils in the upper part. As no fossils were obtained

Plate LVI

Entrance to Craig Harbour, Ellesmere Island, Arctic Ocean. Photo by D. A. Nichols, Geological Survey (79098).

Plate LVII

Flat-lying Palæozoic sedimentary rocks at Bache Peninsula, Ellesmere Island, Arctic Ocean. Photo by L. J. Weeks, Geological Survey (69767).

from the strata below the brownish limestone, there is no direct proof as to the age of the basal beds, although, as previously noted, they are possibly Cambrian. In Goose Fiord about 1,000 feet of dark shales and limestone lie conformably above the brown limestone. The fauna from these beds is abundant, but contains few diagnostic fossils and has more of a Silurian than a Devonian aspect. About 1,000 feet of unfossiliferous marly shales and arenaceous deposits overlie the dark shale and limestone series. Still higher in the section is 1,600 feet of shales and limestone, with sandstone at the top. This series contains Lower, Middle, and Upper Devonian fauna, and passes transitionally into a series of at least 2,000 feet of sandstone whose essential fossils are scanty fish and plant remains of Upper Devonian age. Succeeding beds outcrop in Goose Fiord, but have not been studied; they are shales and sandstones of possible Lower Carboniferous age.

Carboniferous or Permian strata outcrop on Bjorne Peninsula on the southwest coast of Ellesmere Island. The lower beds are unfossiliferous, brownish grey limestone, and the upper beds fossiliferous, white, cherty limestone. The fossils indicate a late Upper Carboniferous age, according to the Russian stratigraphic system, or a Permian age according to the American system. Similar limestone has also been found on the northeastern tip of Ellesmere Island and on the north end of Axel Heiberg Island, the latter interbedded with lavas and tuffs.

As previously stated, most of the rocks of known Palæozoic age are flat-lying, but in the vicinity of Vendome Fiord, on the west coast of Ellesmere Island, folded strata of Silurian and Ordovician age have been observed. A series of northeast-trending, sharp anticlines occurs in this region. Towards the south the flexures become less acute, although in many places, as along the north coast of Baumann Fiord, the strata have a very steep dip. Folding also becomes less severe towards the east and is barely recognizable 11 miles from the head of Makinson Inlet. Little is known of the extent of the folding in other directions. No folds can be seen on the south side of Baumann Fiord where the folded Silurian and Ordovician strata are either buried beneath flat-lying, younger Devonian and Carboniferous strata or swing to the west beneath the sea. If the former is the case the folding is pre-Devonian and probably of late Silurian (Caledonian) age.

Another belt of folded rocks is exposed along the northeast coast of Ellesmere Island north from Scoresby Bay to Cape Cresswell. These folded rocks, called Cape Rawson beds, consist of unfossiliferous slates, quartzites, schists, grits, and limestones. The beds are commonly vertical and have a general southwest trend. Their age is not known. Bentham suggests they are possibly the northeast continuation of the folded Silurian strata on Vendome Fiord, and that the folding at both places is of Caledonian age. Koch, who has studied the Cape Rawson beds in northwest Greenland, also believes the folding is of Caledonian age, though his reasons are not conclusive. Schei suggests that the folding is of post-Triassic and pre-Miocene age, and that some of the Cape Rawson beds are Triassic. He bases this conclusion on the fact that he found lithologically similar folded Triassic rocks on the west side of Ellesmere Island.

Triassic sandstones with subordinate schists and limestone underlie most of the east coast of Axel Heiberg Island and the opposite coast of Ellesmere Island. These rocks have provided diagnostic fossils. Schei states that the dip of the Triassic strata is in many places 50 to 60 degrees, and that folds occur north of Greely Fiord.

Tertiary deposits occur at several places along the northeast and west coasts of Ellesmere Island. They consist of sandstone, shale, and lignite, and contain fossil plants. One seam, on Stenkuls Fiord, is 5 feet thick.

The Triassic strata bordering Eureka Sound are intersected by pre-Tertiary diabase dykes. Coarsely crystalline diabases, probably of the same age, are found in the basal part of the Palæozic section on Bache Peninsula and along the south coast of Ellesmere Island.

VICTORIA AND BANKS ISLANDS

Victoria Island has an area of about 79,250 square miles, making it the second largest in the Canadian Arctic Archipelago. Banks Island is about 26,000 square miles in area. The southern part of Victoria Island is low lying, except for a few isolated hills, such as Mount Pelly (675 feet) near Cambridge Bay, and Colville Hills on Wollaston Peninsula, which reach a maximum altitude of about 1,700 feet. North of the height of land between the southerly and northwesterly drainage the country is more rugged and the hills higher, rising to a general elevation of about 2,000 feet east of Minto Island. Banks Island is considerably higher than Victoria, the greater part of the interior being above 1,000 feet, and in the southern part elevations reach 3,000 feet.

PLATE LVIII

Trap rock of Coppermine River series outcropping at group of three small islands about halfway across the mouth of Prince Albert Sound, Victoria Island, Arctic Ocean. Photo by A. L. Washburn (96932).

Sedimentary and trap rocks, similar to those of the Coppermine River series of late Proterozoic age, outcrop along the south coast of Victoria Island in the vicinities of Wellington Bay and Richardson Island. At the former locality they consist of quartzite and quartzite conglomerate intruded by trap, and, at the latter locality, of dolomite, quartzite, sandstone, and trap. Most of the rocks referred to as trap are diabase; some, however, are ophitic gabbro, and others basalt. Another belt of similar sedimentary and igneous rocks outcrops around Minto Inlet and south to Prince Albert Sound on the west coast of Victoria Island (Plate LVIII). This belt is 90 miles wide and is believed to extend easterly to Hadley Bay on the north coast of Victoria Island. Limestone, dolomite, trap, and minor shale comprise the rocks in this northern belt. Flat-lying limestone and dolomite beds containing fossils of Ordovician or Silurian age outcrop along the southwest coast of Wollaston Peninsula, Victoria Island, and on Read Island. Fossils collected from dolomite on Liston and Sutton Islands, which lie in Dolphin and Union Strait, have been identified as Silurian.

Limestone is reported from a large area around Prince Albert Sound, probably a northward extension of the Ordovician or Silurian limestone on the south coast of Wollaston Peninsula.

Horizontally bedded limestone and dolomite, and to a lesser extent shale, sandstone, siltstone, and conglomerate, are exposed along the southeastern coast of Victoria Island. Some of these rocks contain fossils of Palæozoic age, quite possibly Ordovician or Silurian.

Sedimentary rocks containing coal have been reported from the northwest coast of Victoria Island. The presence of coal indicates a post-Silurian age, probably Carboniferous or Permian, as strata of this age containing coal are known to occur on nearby Banks and Melville Islands. The strata may, however, be in part of Tertiary age.

The stratigraphy of Banks Island is very little known, and most of the significant geological data recorded deal with the north coast. Limestone has been noted at Point Colquhoun and eastward to the south end of Mercy Bay. East of this bay the coast is underlain by sandstone containing coal. Fossils from several localities suggest a Permian age for both the limestone and sandstone. Limestone has been recorded at the southern tip of Banks Island, where it is reported to be overlain by a dark brown, columnar formation. The latter, if correctly identified, suggests Coppermine River series of Late Precambrian age.

Tertiary deposits of probable Miocene age occur on the northwest coast of Banks Island. Carbonized fossil tree trunks have been found in them.

PRINCE OF WALES, SOMERSET, AND KING WILLIAM ISLANDS AND BOOTHIA PENINSULA

Prince of Wales Island has an area of 14,000 square miles, and nowhere exceeds 500 feet in elevation. Precambrian granite and gneiss outcrop on the east side of the island in the vicinity of Browne Bay and Cape Eyre, and the remainder of the island is underlain by flat-lying limestone. Silurian fossils have been collected from limestone on the east coast.

Somerset Island, with an area of about 9,500 square miles, is separated from Boothia Peninsula, 13,000 square miles, by Bellot Strait, which is only a mile wide in places. Little information is available on the topography of Somerset Island and Boothia Peninsula except such as has reference to the shorelines. Limestone cliffs rise to 1,000 feet on the east side of Somerset Island, and granite hills reach altitudes of 1,500 feet along the shores of Boothia Peninsula. A belt of Precambrian granite and gneiss extends northerly from the southeast part of Boothia Peninsula to the northwest coast and crosses Bellot Strait to the western shore of Somerset Island. A flat-lying series of limestones, at least 1,000 feet thick, occupies the remainder of Boothia Peninsula and Somerset Island. Fossils of Upper Ordovician (Richmond) age have been collected from several points along the east coasts, and of Silurian age from the north coast of Somerset Island and the northeast coast of Boothia Peninsula.

King William Island has an area of about 5,000 square miles. It is generally low lying and is characterized by an abundance of lakes. Flat-lying limestone and dolomite outcrop along all the coasts, and fossils of Richmond and Niagaran ages have been collected from them.

CHAPTER IX

PLEISTOCENE GLACIAL DEPOSITS

(R. T. D. Wickenden)

INTRODUCTION

This chapter is concerned mainly with the distribution and description of deposits associated with Pleistocene glaciation in Canada. These are found in nearly all parts of the Dominion (Figure 76), and are related to many phases of economic and cultural development of the country.

Many sources of information have been made use of in preparing this account, and to a few of the more important of these the reader is referred for more exhaustive treatment of the subject. Among those who have contributed extensively to our knowledge of glaciation in Canada are the late Professor A. P. Coleman of the University of Toronto; Dr. Ernst Antevs, and Messrs. W. A. Johnston and J. B. Tyrrell, formerly of the Canadian Geological Survey; and the late F. B. Taylor. Publications by these authors not only provide more detailed information, but will be found in some instances to express opinions at variance with those offered here. Geological reports of the British Columbia Department of Mines, the Research Council of Alberta, the Ontario and Quebec Departments of Mines, and the Geological Survey generally contain some information about glaciation and the glacial deposits of the particular area or region under discussion, and together constitute a wealth of information of which free use has been made in this report. In addition, the writer wishes to acknowledge assistance freely provided by his colleagues on the staff of the Geological Survey.

Accounts of the history of the Pleistocene epoch and of general features of glaciation appear in all standard textbooks on geology, and hence only a very brief summary need be given here.

Fossil remains of plants and animals found in pre-Glacial, Tertiary formations indicate that the climate in Canada, as indeed in other parts of the world, was becoming colder towards the end of Tertiary time. By the close of the Pliocene or latest Tertiary epoch, or soon afterwards, cold, moist conditions had developed that favoured the accumulation of snow and ice in the north, with a maximum amount around Hudson Bay. These deposits eventually consolidated into great glaciers or ice-sheets that commenced to spread out in all directions under their own weight, thereby initiating the great Glacial age on this continent. It is generally agreed the process commenced about a million years ago, and that it concluded with the last retreat of the ice about 10,000 to 25,000 years since, depending on the latitude.

During the Pleistocene or Glacial age there were intervals when the climate grew warmer and the ice disappeared, as well as times when the glaciers readvanced to cover the land. Altogether four such advances of the ice interrupted by three interglacial periods have been recognized. The successive stages of glaciation are known as Nebraskan, Kansan, Illinoian, and Wisconsin, the last including a time when the ice retreated part way only to advance again. At least two of the interglacial periods lasted a long time, as indicated by the great thickness of weathered rock and soil that formed during these intervals and was protected from later weathering by younger glacial deposits.

Interglacial deposits are scarce in Canada, as the accumulated deposits from earlier glaciations and those formed during interglacial periods were mostly removed during the advance of the last or Wisconsin ice-sheet, or buried beneath glacial debris of that stage. Relationships of glacial and interglacial periods have, consequently, been determined mostly from studies in the region near the southern limits of glaciation in the United States (*See* Figure **76**).

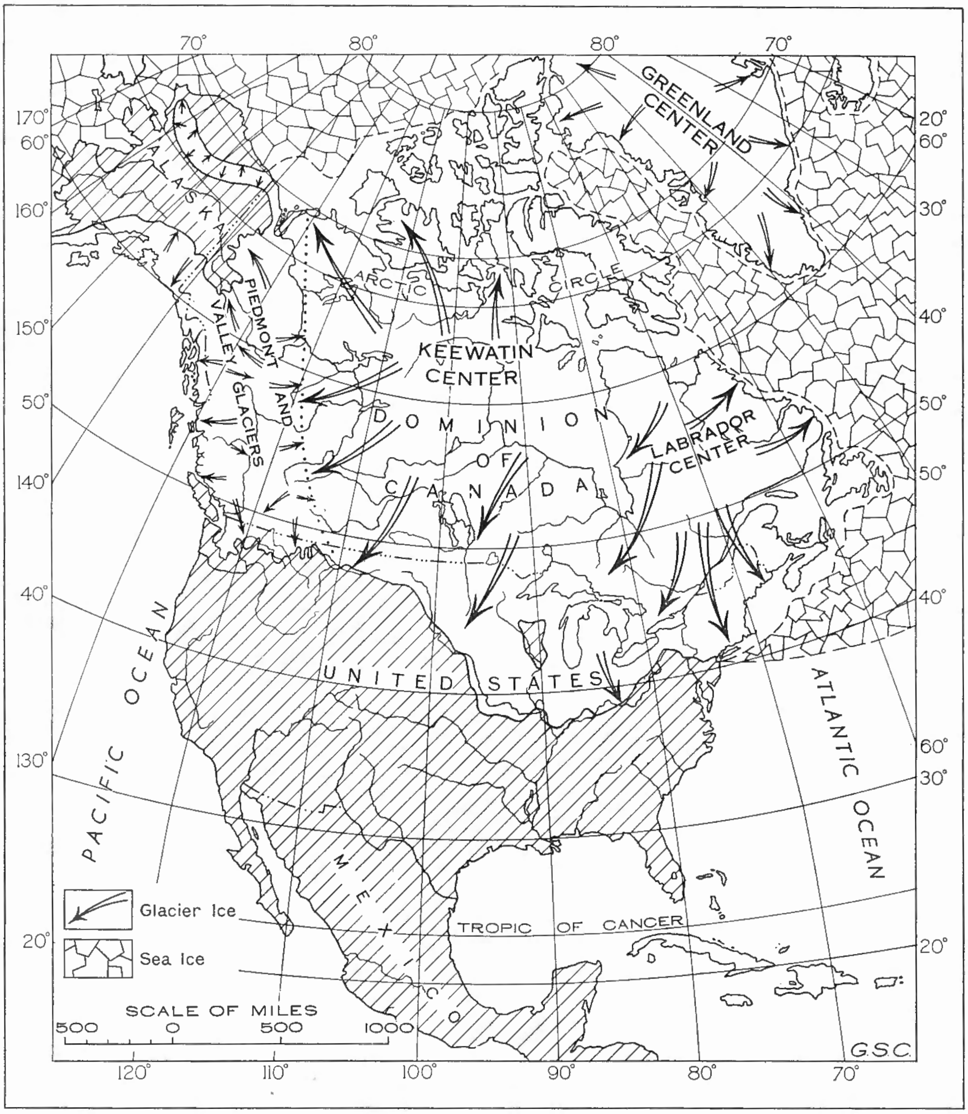


Figure 76. Pleistocene glaciation in North America

The front of each successive ice-sheet was irregular, exposing broad lobes of ice and uncovered re-entrants. Thus, while some districts were under active glaciation others were free of ice. This has resulted in a discontinuity of deposits, and, together with the fact that equivalent phases in different parts of Canada are not always recognizable, has added to the difficulties encountered in the interpretation of glacial history.

During Pleistocene time animals existed in Canada that have since become extinct, as the hairy mammoth, the mastodon, a species of bison with a very large horn spread, and a native species of horse. On the other hand, man is known to have inhabited Europe throughout the glacial period, though some doubt exists as to whether he had reached the Americas before the close of Pleistocene time. It has proved difficult to establish the relationship between deposits containing artifacts and glacial deposits, and the only extinct animals associated with the traces of early man in this continent belong to species that survived into late Wisconsin time at least.

The changes in the landscape as a result of glaciation were many and varied. Weathered rock, soil, and some of the underlying fresh rock were removed, mixed together, transported by the ice for variable distances, and redeposited. Over wide areas, particularly in the northern regions, the rock was left bare, and in other districts, wherever the ice-front remained relatively stationary for any length of time, great heaps of till, the heterogeneous mixture of materials carried by the glacier, accumulated as moraines. Valleys became blocked with debris or their streams diverted, leaving lakes or new stream courses. Lakes formed in front of the ice received deposits of silt and clay in alternating light and dark bands, known as varved clays, the fine darker material settling during the winter seasons of meagre precipitation, and the coarser, lighter coloured, thicker bands during each summer season. Streams flowing in tunnels in the ice formed long, serpentine shaped deposits of gravel called eskers. Elsewhere these streams built deltas into the glacial lakes, and in some places left broad areas covered with sand and gravel termed outwash plains. Where some of these deposits were ploughed up or partly destroyed by readvance of the ice, mounds or knolls of gravel were left that are called kames.

The weight of the vast sheets of ice apparently depressed the earth's surface as much as 1,000 feet or more where the load was heaviest, as in the central or Hudson Bay region. Subsequently, when the ice melted, the surface rose slowly and irregularly, and may have only partly regained the elevation it lost. This lag permitted the sea to encroach for a time over some previous lowland areas, and elsewhere the irregular rise of the land surface caused tilting that, in some localities, prevented normal drainage so that great lakes were formed, much larger than any now present (Figure 77). These remained until further adjustment of the surface renewed the older drainage and permitted a near restoration of more normal conditions. The tilt of the beaches, as observed along sites of the former shores of these lakes, was in part accomplished while the glaciers were retreating.

The shapes and extent of the present Great Lakes may be the result, in part, of glacial action and post-Glacial uplift and tilting. Not only were these lakes the sites of much more extensive bodies of water during late Glacial times, but the damming of some of the former outlets may have resulted in the present lakes covering a greater area than any body of water that existed there in pre-Glacial times. It is, in fact, believed the area now occupied by the Great Lakes was formerly a large, broad valley occupied by important streams but, perhaps, by no very considerable lakes. The glaciers may also have deepened the lake basins by scouring, as the bottoms of some of the Great Lakes are now well below sea-level. On the other hand, there is no assurance that the present great depths of these lakes may not have been due to tectonic disturbances in pre-Glacial time.

While great continental ice-sheets swept southerly over the now populated areas of central and eastern Canada, and in part northward into Hudson Bay and the Arctic Ocean, the Cordilleran area of Western Canada was also being extensively glaciated. In the mountain regions of British Columbia, Alberta, and parts of Yukon, valley glaciers formed and grew until they coalesced across intervening ridges and formed thick ice-caps over much of the mountain area. The present shapes of the valleys and peaks in much of the Cordillera are the result of both severe valley glaciation and regional movements of the capping ice-sheets. In the western coastal area valleys debouching into the sea were gouged by the ice for as much as hundreds of feet below present sea-level, forming the long narrow fiords so characteristic of the Pacific coast. It is probable, however, that the formation of these fiords was facilitated by the lowering of sea-level, due to the removal of water to form the great ice-sheets. It has been estimated that the amount of water withdrawn from circulation would have lowered the sea to 250 feet below its present level. Under these conditions mountain glaciers could have eroded valleys far below the level of those occupied by present day glaciers.

In the discussion of glacial deposits that follows general regions are reviewed separately, partly to facilitate correlation of the deposits with the bedrock formations of the various regions, and partly to emphasize the variations of the effects of glaciation in different parts of the Dominion.

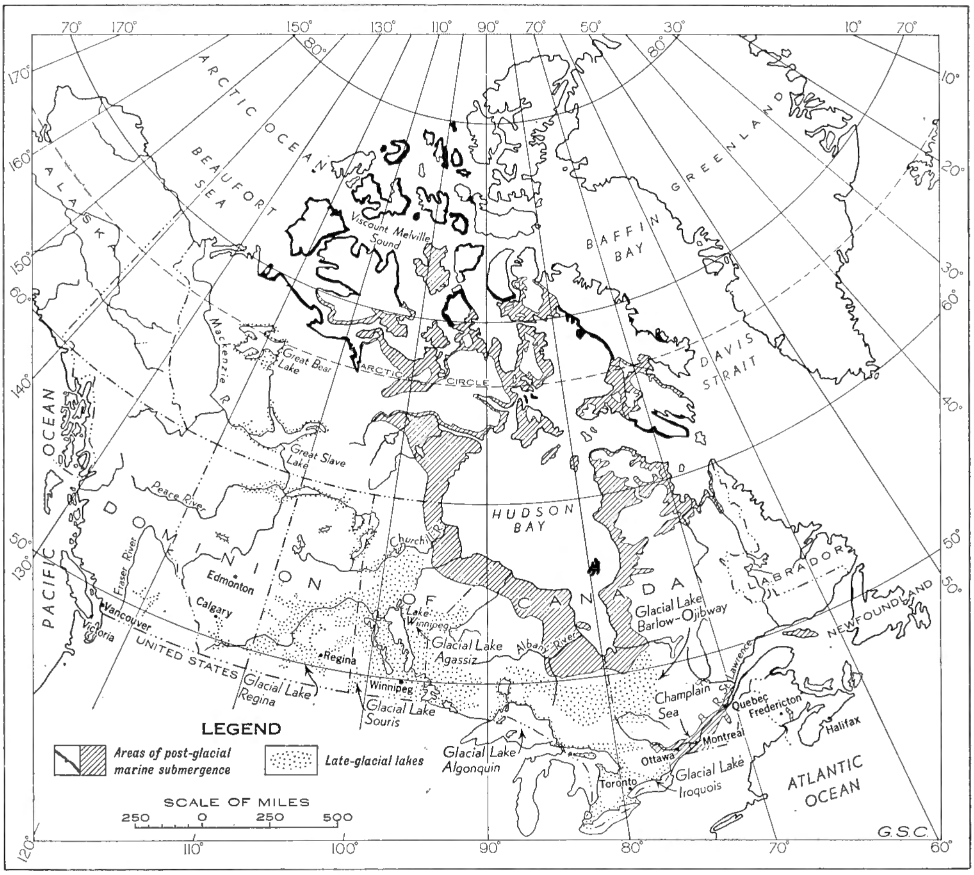


Figure 77. Glacial lakes and marine submergence.

CONTINENTAL GLACIATION

Continental glaciation was chiefly effective in the large area east of the Rocky Mountains and on all sides of Hudson Bay. Great accumulations of ice formed in these northern parts of the continent spread out in all directions, carrying material caught up in it for hundreds of miles. It has been usual to consider that the ice accumulated at three rather definite centres: the Keewatin centre west of Hudson Bay; a Patrician centre south of Hudson Bay; and the Labrador centre east of Hudson Bay (*See* Figure 76). More recent studies, however, indicate that the centres may have changed from time to time and have occupied various parts of the Hudson Bay region. For example, the moraines of Manitoba and Saskatchewan have a trend that indicates movement from the northeast, whereas in part of western Saskatchewan and southeastern Alberta a northern source is indicated, and farther north in these same provinces the trend of moraines points to movement from the east. At some stages, too, the entire Hudson Bay region, from the mountains of Labrador to the western part of the Northwest Territories, was covered by a continuous ice-sheet.

REGIONS OF THE CANADIAN SHIELD

The principal effect of glaciation in the Canadian Shield was to sweep the bedrock clear of soil and weathered products, but it is doubtful if the erosion produced great changes in the topography, and in a few protected valleys pre-glacial soils and weathered rock were left relatively undisturbed. In other places valleys were filled with glacial debris, streams were diverted, and even some watersheds were changed. The effect varied with the type of rock. Where soft formations or deeply weathered rocks occurred much more material was removed than where the formations were hard.

The deposits over most of the Shield consist of recessional moraines, eskers, outwash plains, and varved clays. Ground moraine, deposited by the retreating ice, is not very noticeable in most places, except that some of the valley fill may have originated in this manner. Probably the ground moraine over much of the area was thin, and post-glacial stream erosion has carried away all but a few scattered boulders and other coarse deposits.

The till or boulder clay found in the Precambrian area is usually very stony. The eskers, too, contain a high percentage of coarse material such as angular boulders. Glacial lake deposits are scattered over many parts of the Shield, many of the lakes being small, and it is supposed that many of the muskeg areas are underlain by clays that were deposited in glacial lakes.

Information on the distribution of the deposits is scattered; much of the area is unexplored; and in many parts that have been examined by the geologist no record was made of the glacial deposits.

In the northwestern part of the Canadian Shield the glaciers moved material from the east and possibly also in part from the southeast. Striæ, and material in the drift in the vicinity of Great Bear Lake show that the ice moved in from the east. Bare rock is exposed on nearly all the high ground in that district, the valleys and lowland being covered with till, or in some parts with lake deposits. Boulder-strewn terraces in many parts of the area are the remnants of beaches of a large body of water that covered much of the area near the close of the Glacial period (Plate LIX). No evidence indicating marine origin for these beaches has been found, and it seems probable that they mark the shores of a very large lake. High beaches show that the lake also included the area occupied by Great Slave Lake and much of the adjoining lowland, and it is probable that ice dammed the outlets to the northwest. No evidence has been found to indicate that the land level has changed since the existence of this late-Glacial lake, although more detailed studies may provide such evidence.

In the vicinity of Great Slave Lake extensive sand and gravel deposits are known and are considered to be part of a glacial outwash plain. Associated with them are eskers that extend to the northeast for several miles. Some eskers in the northern part of this area also run northwest, one of them having been traced on the ground and by means of air photographs for more than 200 miles.

Some moraines have also been observed in the Great Slave Lake region. The material in these is made up of many boulders and coarse rock fragments with

Raised beaches at east end of Great Bear Lake, Northwest Territories. Photo by permission of Royal Canadian Air Force (A4116.37).

comparatively little sand, silt, or clay. The long axis of these moraines trends northwesterly, indicating ice movement from the northeast, a direction in agreement with that of most of the glacial striæ and the trend of the eskers.

About 40 miles north of Great Slave Lake, however, the eskers and striæ indicate ice movement from east to west or even a little north of west, and farther northeast, near Thelon River, the direction of movement, according to the eskers, seems to have been toward the southwest. It is probable that the latter part of the region was depressed during Glacial times, and that the sea flooded much of the area and modified the glacial deposits to a height of what is now 500 feet above sea-level.

Farther east, in the Cree Lake district of northern Saskatchewan, an area underlain by soft rocks probably of Late Precambrian age, as well as by hard, older Precambrian formations, the glacial deposits differ somewhat from those already described. The principal distinction is in the occurrence of numerous drumlins. These are confined to that part of the area underlain by Athabaska sandstone. Sand and sandstone make up most of the material in the drumlins, with early Precambrian detritus uncommon and clay very scarce.

In the Cree Lake district there are also some recessional moraines that trend northwest, indicating that the ice moved from the northeast. A peculiar type of moraine called "ice-crack" moraines (Plate LX) has also been described from this district. These are straight ridges 35 feet or less high, usually not more than 100 yards wide, and as much as 3 miles long. They lie mostly at right angles to the movement of the ice, but a few occur at acute angles to the others.

Most of the deposits so far described were made by ice whose region of accumulation was west of Hudson Bay, and the indicated variable directions of movement suggest that the ice did not radiate out from a single centre, but came from different centres at different times.

No observations indicate the presence of interglacial material in this region, though lack of evidence may be in part due to insufficient study of the area. It is also probable that the succeeding advances of the ice would have been sufficiently strong to remove almost all such material. The hard formations of the Shield did not supply enough debris to overload the carrying capacity of the ice, as is evidenced from the fact that boulders of rock originating in this region were transported at least 500 miles southwest across the prairies.

In eastern Manitoba and western Ontario there is further evidence of the advance of glaciers from different directions at different times. Older striæ in many places show movement from the northwest and are crossed by later striæ indicating movement from the north or northeast. This condition is pronounced in the more easterly and northern parts of this district, but has also been observed as far south and east as Port Arthur, and may exist still farther east.

In the Rainy River district three tills have been recognized. The oldest is a calcareous till containing boulders from the Palæozoic limestone formations to the northwest. The middle till is reddish, and contains only Precambrian boulders. The uppermost or youngest till is again a calcareous till similar to the oldest and occurs as far east as Fort Frances.

Near the Manitoba-Ontario boundary, in the vicinity of Stull and Sachigo Lakes, a long ridge, considered to be a moraine, extends a little south of west for 30 to 40 miles. Striæ on the east side of the ridge show an average direction of movement of south 65 degrees west, whereas those on the west side indicate a general direction of south 25 degrees east. It is possible that this ridge is a moraine formed between two lobes of glaciers advancing from different centres.

The Patrician area of ice accumulation was south of Hudson Bay. Although a mass of ice may have formed there, large enough to spread out into some parts of this district, the major features already mentioned indicate no single, definite point of origin, but suggest rather a belt of accumulation with some different parts more active than others at different times.

"Ice-crack moraines" near Cree Lake, northern Saskatchewan. Photo by permission Royal Canadian Air Force (A5202-8.L).

The results of glaciation where the formations are soft, as compared with the predominantly hard rocks of most of the Shield, are illustrated in glacial deposits found in the area underlain by rocks of Palæozoic and later age on the southwest side of Hudson and James Bays. The covering of glacial drift in this area is much more general and thicker than in most parts of the Shield. Towards the south, post-glacial marine sediments cover the glacial deposits, and at many localities two layers of till separated by interglacial beds containing peat and other indications of plant life have been observed.

Sediments of glacial lakes have covered much of the ground moraine and other deposits in the southeastern part of Manitoba and in southwestern Ontario. The lake deposits are fine-grained silts and clay, and many of the muskegs of the area are underlain by these sediments. Lake Agassiz, one of the very large lakes that existed at the close of the glacial period, covered part of the Canadian Shield near the Manitoba-Ontario boundary (*See* Figure 77).

Farther east, in the southern part of the Shield, other large lakes formed in front of the continental glaciers. Probably the first was Lake Algonquin, which occupied the basins that at present hold Lakes Superior, Michigan, and Huron. Gravel and sand beaches of Lake Algonquin now stand several hundred feet above the Great Lakes. At some places outwash sand and gravel were deposited as deltas where streams flowed from the glaciers into the lake. The line of the Canadian Pacific Railway is near the northern limits of Lake Algonquin and follows the terraces developed by the lake.

Probably the most extensive lake deposits associated with the continental glaciers on the Canadian Shield in eastern Ontario are those of pro-glacial Lake Barlow-Ojibway. This lake occupied a large area extending northeast from Cochrane in Ontario probably as far as Lake Mistassini, Quebec. Its northern limits have not been determined, but it is probable that the entire area was not occupied by the lake at one time, because the lake was related to the retreating glacier and the rising land surface. This lake appears to have been formed by the damming by the glacier of the drainage into Hudson and James Bays. The ice retreated to the northeast, and various sediments were laid down in the lake although over most of the area clay and silts are the most common. This region is now known as the "clay belt" of northeastern Ontario and western Quebec.

Much of the northeastern part of the area covered by the sediments of Lake Barlow-Ojibway contains numerous, fairly narrow, parallel ridges of unsorted sand and boulders. These ridges are considered to be annular moraines, deposited when the ice front was stationary during the winter seasons. Associated with the moraines, but trending at right angles to them, are very large esker-like ridges of sand and gravel, the size of which suggests that they were formed as deltas that migrated northward with the retreating ice front.

Although the deposits of Lake Barlow-Ojibway show that the ice retreated to the northeast towards the mountains of Labrador, this does not necessarily imply that the ice advanced from that direction. Actually, the last advance in this part of the Shield evidently took place from the northwest, and a moraine that marks the limit of that advance, and may partly cover the lake deposits, extends northeast from Cochrane.

The deposits in the eastern and northern parts of Quebec have not been studied in detail. Apparently some areas contain eskers and other outwash deposits as well as moraines and other deposits of till. The striæ radiate more or less from a centre in Labrador. In parts of the north shore of the Gulf of St. Lawrence U-shaped valleys are reported, and it is possible that valley glaciers existed there.

ARCTIC ISLANDS

The glacial deposits of the Arctic Islands are known in detail only in a few places. Apparently the ice from the centres in the Shield spread out at times over many of the islands, but there were also centres of glaciation on the islands themselves. At present a few small glaciers exist on some of the eastern islands, and evidence has been found to indicate that mountain glaciers existed in some of the other islands in post-Pleistocene time. Thus the islands exhibit a combination of both continental and mountain glaciation.

The original deposits are difficult to identify in places, for seasonal freezing and thawing have led to flowage in the solid state, known as solifluction, making even water-lain deposits resemble till; thus mud flows have masked the origin of the deposits over extensive areas. Doubt has been expressed that all the eastern islands were covered by glaciers. Most of them, however, show emerged beaches (Plate LXI) and marine sediments similar to those of areas of the mainland, in other parts of Canada, where these features are supposedly due to uplift following the melting of the load of ice that had depressed the land. As, however, the islands all show signs of emergence from the sea in much the same proportions, it seems probable that they were all subjected to the same conditions. In the more southern regions it is obvious that this emergence took place as the ice front retreated, and that the areas with the greatest load were depressed the most. It seems probable, therefore, that the islands that show raised beaches may have been depressed by a load of ice in the same way as the mainland to the south.

GLACIAL DEPOSITS OF THE ST. LAWRENCE LOWLANDS AND APPALACHIAN REGIONS

The lowland areas of these regions are occupied mostly by sedimentary rocks, and the glacial deposits vary in character with the underlying formations. An area in Nova Scotia northwest and west of Lunenburg, is, for example, underlain by hard quartzite and granites and softer slates. In that part occupied by the hard rocks the glacial drift is thin, whereas the part underlain by slates has numerous drumlins (Plate LXII), and these constitute almost the only good soil in the region. A few drumlins extend for short distances into the area of harder rocks, where the glacier moved the material from the softer slates.

In much of Nova Scotia and New Brunswick the glacial deposits are not thick, and the make-up of the drift is closely related to the underlying bedrock. It is probable that the high mountains of Gaspe and the deep valley of the St. Lawrence obstructed the advance of the glaciers and protected much of the maritime area, so that the amount of foreign material carried in by the ice was greatly reduced.

Moraines are uncommon in the Maritimes, and do not form extensive deposits. Till constitutes most of the glacial material, and occurs mostly as ground moraine. Outwash plains and eskers occur in many places, but glacial-lake deposits are few and not large. Fairly thick deposits of sand and gravel occur along the shores of some of the bays, such as the north shore of Cobequid Bay in Nova Scotia, and are probably part of the outwash from glaciers. Marine, deltaic deposits may have formed on this shore when the sea-level was higher, but the absence of marine faunas and the complete lack of any evidence of such deposits on the other side of Cobequid Bay render this suggestion of doubtful value.

No evidence of interglacial deposits has been found in the Maritimes. At several places where thick deposits of till are found, in valleys or where the material was otherwise protected, there are colour changes that may indicate more than one period of deposition. Such occurrences can be seen in the vicinity of Joggins and along Shubenacadie River north of the crossing of the Dominion and Atlantic Railway. The latter section shows more than 80 feet of till down to high tide-level, and it is probable that the glacial drift is more than 100 feet thick, which is very unusual in this part of the country.

PLATE LXI

Emerged strand lines on southwest side of northwest nose of Mount Pelly, Victoria Island, Arctic Ocean. Photo by A. L. Washburn (96933).

PLATE LXII

Drumlin in bay, Chester Harbour, Nova Scotia. Photo by J. W. Goldthwait (31177).

In Nova Scotia the glacial striæ indicate that the ice moved from the northeast, north, and northwest. There are also a few striæ that indicate a west-east or east-west movement. The relative age of these various movements is not clear, but the distribution of certain rocks indicates that in western Nova Scotia the principal movement was from the northwest.

Conditions in most of New Brunswick are similar to those in Nova Scotia; glacial deposits, in regions underlain by sandstone or hard rocks, are very thin, and many areas underlain by swampy woodlands have less than 10 feet of glacial till. In areas underlain by soft shale the drift is thicker and includes more clay. Valleys of the principal streams no doubt at one time also contained thick deposits of till and fluvioglacial material, but the streams that occupied these valleys were fed by the melting ice and have succeeded in reworking these deposits into fertile river flats such as are found in the valley of St. John River.

Along the shore at the west end of Chaleur Bay the glacial deposits near sea-level are hidden by marine deposits in many places up to elevations of 150 feet. Beyond the edge of the marine beds the glacial deposits are generally fairly thin, but exhibit some indication of having been deposited from ice moving north from the higher ground to the south. Varved clays in some of the valleys in this part of New Brunswick indicate that their streams were dammed either by older glacial deposits or by lobes of ice before the last movement of the ice from the north.

The glaciation of Gaspe Peninsula has been a controversial subject. For many years it was thought that the mountains in the highest parts of this area had not been covered by the Labrador ice-sheet. More careful investigation in recent years has, however, proved that erratics of Precambrian rocks that must have been brought in by continental ice occur on or near the top of Mount Albert, one of the highest mountains of Gaspe. Although it is probable, therefore, that the ice-sheet did cover the region, the presence of this highland adjacent to the deep depression of St. Lawrence Valley must have seriously obstructed its southern advance, and it may be that some ice first advanced into New Brunswick from lobes in the lower country to the west, or even from across the Gulf of St. Lawrence to the east. It is also probable that local glaciers existed on the highlands of Gaspe before and even after the continental glaciers occupied the country. No moraines or similar deposits from such glaciers have been observed, but land forms identified as cirques occur near the top of Mount Albert.

The glacial deposits in much of southern Quebec west of Gaspe are hidden by the marine deposits of, or were modified by, the Champlain Sea to elevations of 450 to 500 feet above present sea-level. Above 500 feet the lowlands are occupied by a fairly general covering of boulder clay, but on the several mountains in the area glacial deposits are much thinner or absent. As the slope of the country was, as at present, towards the north when the glaciers retreated, the drainage was blocked and glacial lakes formed in the valleys. As a result the larger valleys nearly all carry deposits of sand and clay or, in some places, gravel. Boulder clay spread over most of the higher ground, and in places a few eskers have been observed.

The movement of the ice in this part of Quebec was mainly from one or other of several northerly directions, according to striæ, but in a few places boulders have been found that came from the south, indicating that glaciers had moved to the north from mountains in southern Quebec and the northern New England States.

Two different types of till have been recognized in some parts of the Eastern Townships, but it is uncertain whether an interglacial period intervened or whether they merely indicate a re-advance of the ice front.

Farther up the St. Lawrence and its tributaries marine deposits have hidden the glacial deposits in most of the lowland areas. This condition exists at least as far upstream as Brockville. Above this point it is possible that the sea extended into Lake Ontario, where, however, great quantities of fresh water prevented the existence of marine organisms.

Before the ice had retreated far enough to permit the sea to come into the area, the Great Lakes region was the site of extensive glacial lakes. In the Lake Ontario basin glacial Lake Iroquois was formed, and its beach deposits occur at elevations higher than Lake Ontario and 2 to 10 miles from the present shore. Beaches formed at the eastern end of glacial Lake Iroquois are now as much as 460 feet higher than those at the western end, and some of the beaches at the western end are submerged, because differential uplift occurred when the load of ice melted.

The glacial deposits in that part of Ontario underlain by sedimentary rocks differ somewhat from those formed in the Precambrian regions. The softer formations, such as shale, furnished more and finer material to the glacier, so that the covering of glacial drift is more continuous and the till is more clayey than in the region of harder rocks, and drumlins are more common.

Groups of drumlins occur south of Ottawa and northeast of Smiths Falls and near the St. Lawrence Valley east of Cornwall. Another belt of drumlins 5 to 30 miles wide extends from west of Kingston to south of Lake Simcoe. In southwestern Ontario two more areas of drumlins have been noted, one near Guelph and another a little to the northwest. The direction of ice movement, as indicated by the long axes of the drumlins, is east-northeast in the eastern part to north and even a little northwest in the western areas. The drumlin areas are associated with moraines in the central and western part of southern Ontario, but no well-defined moraines have been noted in the eastern parts. In many places the drumlins occur both in front of and behind the moraines.

No well-defined areas of moraine have been observed in the eastern part of the Ontario lowlands, but several such occur farther west and south. The deposits in these moraines consist in part of clayey till and in part of sandy and gravelly kames. A morainal area associated with a drumlin belt also extends from a little west of Trenton to southwest of Lake Simcoe about 10 miles north of and approximately parallel with the shores of Lake Ontario, and a horseshoe-shaped belt of moraines in the peninsula of southwestern Ontario occupies an area that, apparently, was covered by two lobes of ice with a re-entrant between them. Moraines of boulder clay and the kame type both occur here, and a complex history of changes in the direction of ice movements and the position of the ice front is indicated. Within the district bordered by these moraines are numerous deposits of sand and gravel, probably glacial outwash or deposits from streams that flowed away from the ice front.

A few eskers also occur in southwestern Ontario, but these do not form a prominent part of the glacial deposits.

Although all the surface deposits appear to belong to the Wisconsin or last stage of glaciation, evidence of earlier glacial deposits has been found at several places. Such deposits may be fairly extensive, as 100 to 200 feet of unconsolidated material are common in many places in southwestern Ontario, and one well north of Toronto was drilled through about 600 feet of such deposit before reaching bedrock. In many places streams have not eroded through the glacial deposits or are not on the same site as the pre-glacial or interglacial streams, and many of the pre-glacial valleys are hidden beneath a thick mantle of till. Near Toronto and along the shores of Lake Ontario exposures of the earlier glacial deposits have been studied in detail. The oldest deposits there are a few feet of boulder clay exposed at a few localities only. Above this clay are beds of fossiliferous clay and sand in some localities and in others a younger till sheet. The interglacial beds contain fossils that indicate a warm climate, and were probably deposited during a fairly long interglacial period. Above the stratified, interglacial beds are two other till sheets separated in places by stratified deposits.

It is possible that as many as four advances of the ice front may be represented by these various deposits. Undoubtedly many of the beds are not continuous over wide areas, and correlations are difficult.

THE INTERIOR PLAINS

The Interior Plains area west and southwest of the Canadian Shield is underlain by sedimentary rocks. As in southwestern Ontario it is almost completely covered with glacial drift, and, as many of the underlying formations are soft and easily eroded, the deposits on the whole are thicker than in regions already described. Near Regina and Indian Head, Saskatchewan, for example, some wells have passed through 500 to 700 feet of glacial and interglacial deposits before reaching bedrock. These deposits give a more complete record of the retreat of the last ice-sheet than in any other region of Canada. In places interglacial deposits are fairly thick, and a fair idea of the entire glacial period is, consequently, available. Apparently the several successive ice-sheets all advanced from west and southwest of Hudson Bay across Precambrian, Palæozoic, and Mesozoic formations, and, as a result, the deposits contain a mixture of boulders from all of them. Till or boulder clay, in the form of ground moraine or of terminal or recessional moraines, covers the greater part of the area of the Plains (Plate LXIII). Glacial-lake deposits of clay and sand are of next importance, and glacial outwash is rare.

The terminal and recessional moraines, those formed at the southernmost margins of the ice-sheets or left by the retreating ice, are usually high areas of knob and kettle topography. The moraines form the highland areas commonly because they coincide with the pre-glacial highlands, and partly because of the great amount of material deposited by the glaciers. Most of the morainic material occurs in long, almost continuous belts, varying in width from ½ mile to 50 miles, and broken only where they have been eroded along major valleys or where they are covered by lake or other deposits of more recent origin. About ten such belts of moraine are known on the Great Plains, and all have been assumed to be the results of the latest or Wisconsin glacial stage, although some evidence is available to suggest an earlier stage for the deposits in southern Alberta.

During the retreat of the ice, glacial lakes were formed along the southern edge of the ice front, and the deposits from them covered considerable areas. Lake Agassiz, one of the best known, spread from northern Minnesota far north of Lake Winnipeg (*See* Figure 77 and Plate LXIV). It is probable that this area was not completely occupied at one time, but that the lake migrated northward as the ice retreated and the land rose in the south.

In the central part of the area covered by Lake Agassiz thick clay deposits were formed, most of which show varved beds. In front of the Manitoba escarpment and on the eastern side of the glacial-lake basin, sand and gravel terraces and ridges were formed as beach deposits, some of which are continuous for long distances. When the lake was in existence the drainage of much of the western plains was diverted through Assiniboine Valley where a wide area of deltaic deposits was laid down. These deposits are mostly sands, and have since been blown by the wind into dunes.

Two other glacial-lake areas of fair size are known in Manitoba, one in the south named Lake Souris, and another near the headwaters of the Assiniboine. Lake Souris existed before the glacial-Lake Agassiz, and later part of its basin was flooded by the waters of that lake. The deposits near the surface are mostly of sand.

Succession of ridges near front of Missouri Coteau moraine, southern Saskatchewan. Photo by permission Royal Canadian Air Force (A.5800-69L).

View over part of Glacial Lake Agassiz at Winnipeg, Manitoba. Photo by permission Royal Canadian Air Force (T36-L-20).

Several lakes were formed in Saskatchewan during the retreat of the last ice-sheet. Either these lakes did not persist long enough to develop sand and gravel beaches, or the material along the shores of the lakes was not of a type to supply sand and gravel. At a very few places sand and gravel deposits indicate the positions of what must have been the shores of these lakes.

Lake Regina once occupied the flat area south and southwest of Regina; Rosetown Lake extended from a little west of Rosetown east nearly to South Saskatchewan River; and on both sides of South Saskatchewan River, from Pennant to Leader and from White Bear to Eston, is an irregular area of ancient lake deposits. These three main areas are covered with very heavy clay, varved in places. To the southwest the last mentioned area of lake clays merges into an area of sand and silt also deposited when the drainage to the north was blocked. This area extends north of the Cypress Hills with various irregularities from Medicine Hat to near Swift Current. These lakes apparently formed as the glacier front retreated and while the drainage of South Saskatchewan River and its tributaries was blocked. Farther north and east along the Saskatchewan more lakes or flood-plain deposits occur on both sides of the valley. Undoubtedly some of these extend for many miles, but the area has not been thoroughly mapped. The deposits are more sandy than those of the lakes previously mentioned.

Some of the above lakes extended into Alberta, and similar deposits occur at places along the valleys of South Saskatchewan, Red Deer, and Oldman Rivers. An area of heavy clay that originated in a glacial lake occurs near McGrath in Alberta, and many similar lakes must have existed within the prairie region.

Lake clays, silts, and sands cover many valleys and adjacent areas in front of the Foothills, as south of Calgary and between Calgary and Red Deer, Alberta, and may have been formed between the Foothills and the retreating continental glacier or have occupied valleys dammed by glacial deposits. These deposits have not been mapped in detail, and their origin and extent are uncertain. They do not occur at the same maximum elevation, and it is doubtful if they represent deposits in a lake that occupied the entire region. In many places, too, where the flatness of the terrain suggests a lake bottom origin, examination reveals that the underlying superficial deposits consist entirely of boulder clay.

Very few areas of glacial outwash sand or gravel are known in the southern parts of the prairies, and eskers and kames are even rarer. A few of both types of deposits are, however, found in the more northern parts. Near Lethbridge, Alberta, a yellowish, fine-grained deposit covers some of the hills as well as valleys. It is possible that this is loess, a fine, wind-deposited soil. Other areas of similar deposits may not yet have been recognized.

Most of the exposed glacial deposits in the prairies are supposed to have been laid down in the last glacial advance, the Wisconsin. The land surface in southeastern Alberta, however, is more dissected than in central Saskatchewan or in eastern, northern, and central Alberta, indicating that it was free of ice for a much longer time than the other parts of the prairies, and that either the Wisconsin glaciation did not extend into this area, and the deposits are of an earlier Glacial epoch, or the Wisconsin ice remained there for a short time only.

Interglacial beds separating glacial deposits are known from several places in each of the Prairie Provinces. The greatest number of advances of the ice is indicated by a succession of such deposits exposed on Swift Current Creek in Saskatchewan. There three layers of boulder clay are separated by stratified deposits that contain traces of organic material, and by their weathering indicate considerable interglacial intervals. At several other places along South Saskatchewan River sections show two tills separated by interglacial beds, the youngest of which, in most of these localities, contains thin beds of lignite. In southwestern Saskatchewan lignite seems to have formed in beds that are now exposed, and, together with the fact that only two tills separated by interglacial deposits have been found in sections along Oldman River in Alberta, may indicate that this part of the country was not covered by ice in the last glacial advance.

At several other places beds containing fossils separate two tills, and from their location and limited weathering seem to indicate that the overlying till is younger than any on Swift Current Creek, and that the beds may represent an oscillation of the ice front during Wisconsin time. Among the fossils found in these beds are fragments of white spruce, some of which came from trees more than a foot in diameter. Their discovery, near Lake Johnson, Saskatchewan, where the present climate is much too dry to produce such trees under natural conditions, indicates a former climate more moist but no warmer than now.

Though the preceding information has been based mainly on studies in the southern part of the Prairie Provinces, it is probable that similar conditions exist farther north, although the direction of ice movement has varied. If the long axis of the moraines is assumed to be at right angles to ice movement, the ice in the eastern parts came from the north and northeast. In Alberta the northern direction seems to have been dominant in the eastern part of the provinces, whereas ice moved from the northeast and east in the more northern parts. The continental ice front extended almost to the Foothills in the south, but farther north reached only the west side of Mackenzie River Valley.

Although the ice front seems to have reached all parts of the Plains, at least two areas within them were left driftless. One is a small area south of Wood Mountain in Saskatchewan near the International Boundary; the other farther west, is the top of the Cypress Hills near the Alberta-Saskatchewan boundary. The reason for these driftless areas is unknown; height at least is not the sole cause, as areas farther south and west were covered by glacial deposits to higher elevations.

GLACIAL DEPOSITS OF THE CORDILLERA

The deposits found in the Cordillera are the results of both alpine and, probably, ice-cap or regional glaciation, the latter similar in effect to the continental glaciation already discussed. Evidence indicates that valley glaciers first formed, and that, eventually, the accumulation of ice became great enough to cover most, if not all, of the peaks. When deglaciation set in the valley glaciers became active again, and the results of their erosion obliterated or covered the deposits left by the ice-sheet except in some of the outer low mountains. Remnants of the valley glaciers, such as the Columbia Ice Field, are still in existence in many parts of the Cordilleran region. Evidence of ice-cap glaciation, on the other hand, is mostly found in the occurrence of erratics at very high elevations and in localities where the surface is flat enough to retain them (Plate LXV). Otherwise the till and other deposits from the mountain ice-caps are not very different from those of the preceding and following valley glaciers.

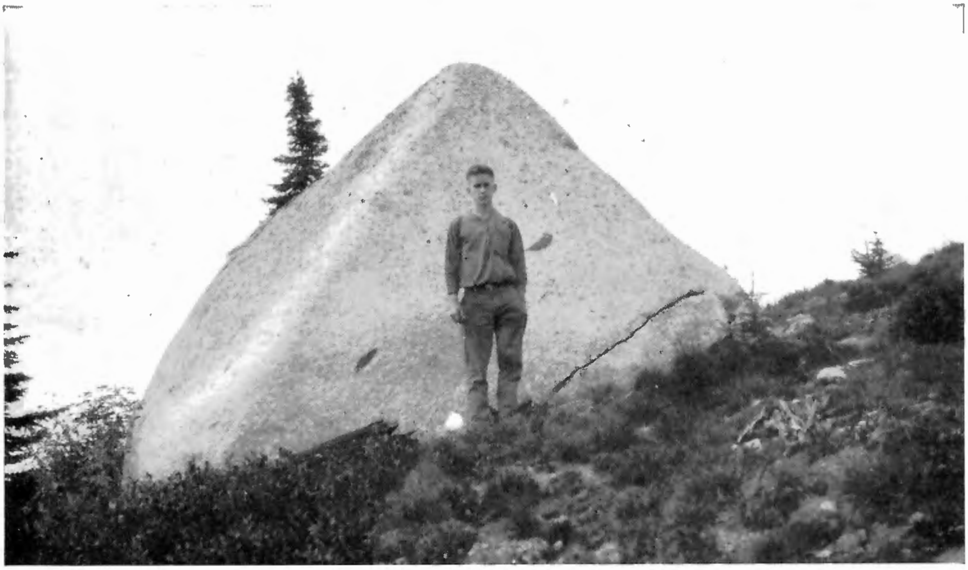
As a result of this combination of types of glaciers a few patches of till are left on the sides of valleys or on isolated hills. Most of the deposits are, however, in valleys, and streams formed by the melting ice have covered most of them with water-lain sediments. In many places where moraines or ice blocked the valleys, lakes were formed and fine silts and sand were deposited in them.

Later when the barriers were removed, either by erosion or by melting of the obstructing ice, streams cut through the lake deposits and left the old lake beds as terraces on the sides of the valleys.

Much of the fine-grained glacial deposits in the valleys is composed of light grey rock flour; very little clay is present.

The thickness of the material left by the glaciers varies. In the higher regions a few erratics occur on the mountains, and sands, gravel, and till are found in the valleys. As sea-level is approached the covering is more general, and some valleys have as much as 1,000 feet of fill. These valleys were over deepened by the valley glaciers and later filled with sediments, chiefly sand and gravel.

PLATE LXV



Glacial erratic on summit Carpenter Mountain ridge, elevation 6,300 feet, Slocan mining district, British Columbia. Photo by C. E. Cairnes, Geological Survey (67565).

The only deposits recognized in most of the Cordillera region belong to the latest glacial stage. In a few places in northern British Columbia and Yukon an older, hard, compacted till has been observed, but no occurrences of definite interglacial beds are known, although in some places this older till appears to have been reworked by streams below the younger till. Interglacial beds separating two tills, or underlying only one till but containing material derived from glacial deposits, have been observed at several places in southwestern British Columbia. On Vancouver Island the interglacial deposits consist of silts and clay overlain by sands and gravels. The clays contain marine shells, but are now 200 feet above sea-level, indicating post-glacial uplift in this region. On the mainland similar beds containing plant fossils occur almost at sea-level. Occurrences at both localities are presumed to be correlative with the interglacial deposits overlain and underlain by till in the Puget Sound region of the state of Washington, but correlation with interglacial deposits in the eastern part of Canada has not been established.

Striæ and other indications of movement found in the mountains are mostly associated with the valley glaciers (Plate LXVI), but in a few places striæ and erratics indicate a more general movement of the ice-cap across the present slope. There is some indication, too, that in south and central British Columbia the ice-cap was first formed in the Coast Mountains, and that this ice moved eastward into the Rocky Mountain Trench. Whether or not an ice-cap formed farther east in the Rocky Mountains or whether the entire Cordilleran region was at one time covered by one ice-cap is unknown.

PLATE LXVI

Typical glaciated valley of Leckie Creek on the eastern margin of the Coast Range, Bridge River district, British Columbia. Photo by C. E. Cairnes, Geological Survey (82964).

It is probable that glaciers also covered Vancouver Island and Queen Charlotte Islands. On the former the occurrence of marine shells in inter-glacial deposits has been reported. If local ice-caps formed on these islands they probably joined with the Cordilleran ice-sheets at the maximum stages of glaciation.

The fact that cold is not the only climatic factor that determines the existence of glaciers is demonstrated by the occurrence of a large, unglaciated area in the Yukon. This area is in western Yukon about 160 miles from the coast, and its boundaries are approximately west and north from Carmacks. The change there from completely glaciated to unglaciated terrain is gradual, the upper limit of glaciation varying, for example, from an elevation of about 6,500 feet, at latitude 61 degrees, to 1,000 feet lower between latitudes 63 and 64 degrees. The limitation of the ice-cap in the Cordillera is also apparent in Mackenzie and Franklin Mountains, where only results of alpine glaciation have been observed. In fact some evidence has been found to indicate that the valleys on the east were filled to some extent with ice from the continental glaciers in the east.

MARINE DEPOSITS

Although the marine deposits that covered the depressed parts of the glaciated areas (Figure 77) can in no way be considered glacial deposits, they are so closely associated with the Glacial period that they require some brief mention here.

At the close of the Glacial period much lowland of eastern Canada was inundated by the sea. Around Hudson Bay some localities at least 900 feet above present sea-level were at that time beneath the sea, as proved by the presence at such elevations of beaches with marine fossils. Most of the deposits, however, occur at much lower elevations. Sand beaches with adjacent areas of clay make up most of the sediment in the mainland and island coasts of the Arctic. These deposits have filled the old river valleys for long distances back from shore.

In southern Canada the sea flooded the St. Lawrence Lowlands, reworking the till and other glacial deposits. The highest extent of this marine invasion is indicated by a trace of a beach at an elevation of about 690 feet in the vicinity of Ottawa. Most of the beaches, however, in the St. Lawrence basin are less than 450 feet above sea-level.

The marine deposits are mostly blue-grey clay or silty clay with minor sand and gravel. The clays and silt extend throughout most of the lowlands, although in some places they are missing, due either to non-deposition or to erosion since the region was uplifted. The thickness of the clay varies. In places it is nearly 200 feet thick, but generally appears to be less than 100 feet. Marine shells are fairly common in these clays and in hard concretions in them, and at some localities bones of fish, whales, and seals have been found. Some of these are thought to belong to extinct species, and because of this, the great thickness of the deposits, and the occurrence of shells in till at Montreal, it has been suggested that the land was depressed more than once, and that part of the marine deposits is of interglacial age. Along the shores of the Gulf of St. Lawrence and the coasts of Nova Scotia and New Brunswick raised marine deposits occur at lower elevations or are missing. This may indicate that the load of ice was not as great in this part of Canada, or possibly, that the cause of the submergence was not everywhere a load of ice.

The maximum elevation of some doubtful beaches on the west end of Prince Edward Island is about 75 feet, and deposits containing shells are only about 25 to 30 feet above sea-level. Along the north shore of Nova Scotia no deposits showing changes in sea-level have been found, but farther south, in the Bay of Fundy region, sand and gravel terraces, 75 to 100 feet above sea-level, suggest that the sea was at a higher level when these were deposited by streams flowing off the Cobequid Mountains during the latest advance of the ice in this region. These terraces may also be accounted for by the surplus of material brought in as glacial outwash. No similar terraces are found on the south shore of Cobequid Bay. Marine shells in clay a few feet above present sea-level have been found in Annapolis Valley on the south shore of Cobequid Bay, and represent the only authentic occurrence of raised marine deposits in Nova Scotia.

Along the Atlantic coast of New Brunswick some interglacial or post-glacial marine deposits occur in the vicinity of Saint John. These consist of gravels, sands, and clays with marine shells. The deposits of proved marine origin are all less than 50 feet above sea-level.

ECONOMIC SIGNIFICANCE OF GLACIAL DEPOSITS

Much of our economic development, as related to agriculture, mining, transportation, and water supply has been affected by glaciation and glacial deposits. Although ice-sheets have removed most of the soil from the Canadian Shield, some of the best soils in Canada are the deposits of the various late-glacial lakes. The clay belts of northern Ontario and Quebec are such deposits, and the former sites of glacial-Lake Agassiz and Lake Regina now provide some of the richest grain growing areas in the southern Interior Plains.

Similarly, in British Columbia, the silts and clay deposits of lakes formed in valleys towards the close of the glacial period form the soils for much good agricultural land.

The effect of glaciation on mineral development in Canada has varied in different districts. In areas where soil and weathered rocks have been removed prospecting has been facilitated, though the result is perhaps not an unmixed blessing as, doubtless, quantities of valuable minerals have been eroded in the process. In many areas, however, the potential mineral belts are covered or partly covered with glacial drift. In such areas 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 of this sort have resulted in tracing material back to the original source, as has been demonstrated in the case of the iron ore deposits at Steeprock Lake, and in many placer deposits of the Cordilleran region. Unglaciated areas in the Cordillera have provided rich placer fields, and it is important to be able to distinguish such pre-glacial deposits from those of surrounding glaciated areas.

Outwash gravel and beach gravels are principal sources of constructional materials and road metal, and occurrences of beach terrace deposits and eskers have in part determined the location of routes of transportation, such as roads and railways. In the north, eskers have enabled man and animals to cross areas of swamp and muskeg, and in this way have determined travel and migration routes. The numerous lakes that occupy depressions gouged by the continental glaciers, or that were formed as the result of the damming of valleys by glacial drift, have also proved very important in meeting transportation problems within the vast area of the Canadian Shield. In the earlier days these lakes afforded innumerable canoe routes, but latterly are increasingly in use as readily available landing fields for aircraft equipped with pontoons or skis, according to the season.

A knowledge of glacial deposits has proved very important in the search for underground water supplies in many parts of Canada. Porous sands and gravels in the glacial drift form reservoirs for the storage of subsurface water, and their occurrence has assisted industrial and agricultural developments.

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