GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGY OF CANADA

Reprinted from Canada Year Book 1961,
Information Services Division,
Dominion Bureau of Statistics.

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PART I.—GEOLOGY OF CANADA*

North America comprises six main natural regions, which are both physiographic and geological because the ages, kinds and structures of the underlying rocks determine the natures of the land surfaces. Knowledge of these regions is important because their geological characteristics have much influence on the suitability of different areas for such activities as agriculture, mining, petroleum production and sports, as well as on the varied scenery of the country. The six regions are: the Canadian Shield, a vast area of ancient rocks that is mainly in Canada; the Interior Plains and Lowlands, the largest area of which extends throughout the mid-Continent from the Gulf of Mexico to the Arctic Ocean; the Appalachian Region, mainly in the United States but also forming an important part of Eastern Canada; the Cordilleran Region, extending along the entire west coast of the Continent; the Atlantic Coastal Plain along the eastern seaboard of the United States; and the Innuitian Region, a mountainous belt in the Arctic Archipelago. Canada includes parts of four of these regions, all of the Innuitian Region, but none of the Atlantic Coastal Plain.

The Canadian Shield, embracing about one-half of the total area of Canada, is a roughly horseshoe or shield shaped terrain of some 1,850,000 sq. miles, having Hudson Bay at its approximate centre. The Shield continues into the United States west and south of Lake Superior, and east of Kingston where a belt of resistant rocks called the Frontenac Axis forms the Thousand Islands and, to the south, broadens to form the Adirondack area.

* Prepared by Dr. A. H. Lang and published by permission of the Director, Geological Survey of Canada, Ottawa.

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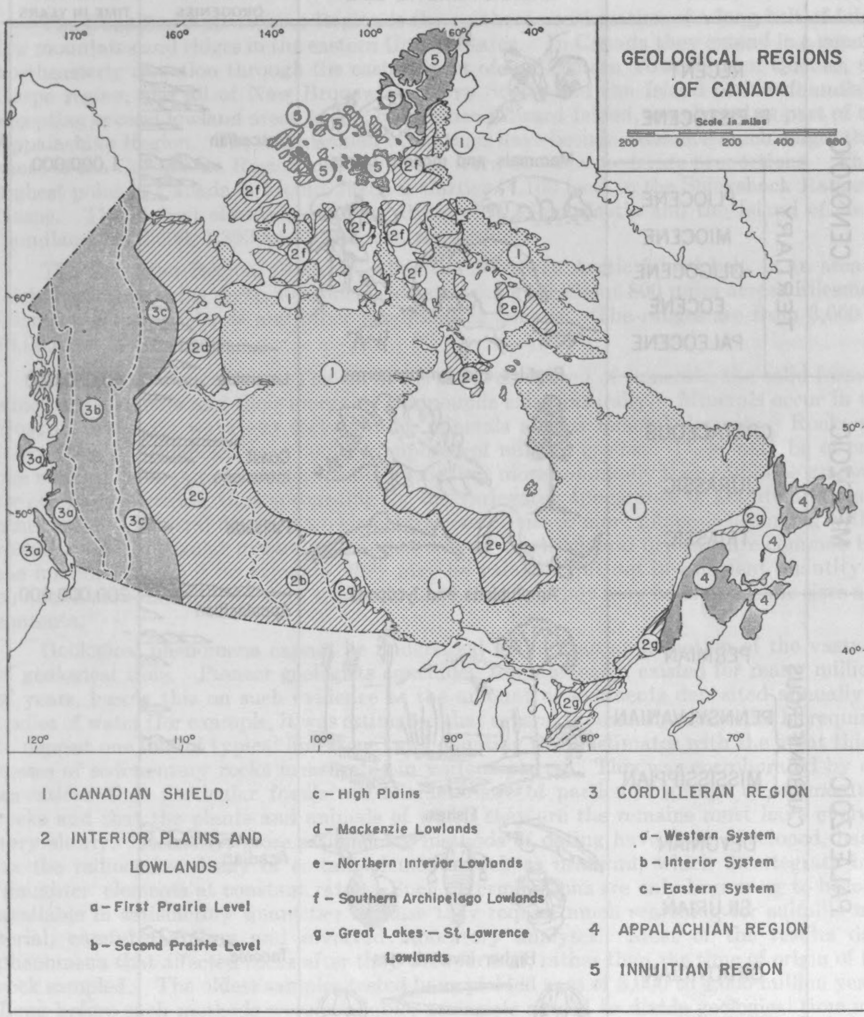
Far back in geological time the Shield contained many ranges of high mountains but these have mainly been worn down to a surface of moderate relief consisting of hills, ridges and valleys containing innumerable lakes and streams. Most of the surface is from 600 to 1,200 feet above sea-level, but higher uplands form such well-known features as the Laurentian Mountains north of Montreal where Mount Tremblant rises to an elevation of 3,150 feet, and the Haliburton Highlands in southeastern Ontario which are up to about 1,800 feet. Along the coast of Labrador and in Baffin Island are mountains rising 5,500 and 8,500 feet, respectively, above the sea.

Flanking the Shield are large expanses of plains and lowlands underlain by relatively young and soft rocks overlain in many places by good agricultural soils. A notable characteristic of the boundary between the Shield and the lowlands is the presence of large lakes that lie partly in rock basins in the Shield and partly in depressions in the younger strata. The most prominent are Great Bear Lake, Great Slave Lake, Lake Athabasca, Lake Winnipeg and Lake Huron. The largest lowland area is that of the Interior Plains, sometimes called the Great Plains or Western Interior Lowlands. These constitute the prairies of Western Canada and their wooded continuation to the north. They are divided into the first prairie level, also called the Central Lowlands or Manitoba Plain, from 600 to 900 feet in elevation; the second prairie level, in western Manitoba and eastern Saskatchewan, averaging 2,000 feet in elevation; the High Plains of Alberta and western Saskatchewan, up to 4,300 feet; and, to the north, the Mackenzie Lowlands, from 500 to 4,000 feet. The Northern Interior Lowlands include the Hudson Bay Lowlands south of Hudson Bay, the Foxe Basin Lowlands in and near western Baffin Island, and the Southern Archipelago Lowlands which occupy large parts of the more southerly Arctic islands. The Arctic Coastal Plain farther to the north is sometimes classed as a separate physiographic region comparable to the Atlantic Coastal Plain but is here grouped with the other plains and lowlands for simplicity. The Great Lakes–St. Lawrence Lowlands form two important agricultural and industrial areas in southern Ontario, separated by the Frontenac Axis; the more easterly continues in Quebec, on both sides of the St. Lawrence River, and an isolated continuation forms Anticosti Island.

The Canadian Cordilleran Region is a northwesterly-trending belt about 500 miles wide composed of high mountains and lower plateaux and valleys. It comprises southwestern Alberta, all of British Columbia except its northeastern corner, almost all of Yukon Territory, and the southwestern part of the Northwest Territories. The individual mountain groups and plateaux are arranged in a complex pattern divisible into three parallel northeasterly-trending zones; in most places these zones are quite distinct and are called the Western, Interior and Eastern Systems. Because the Western and Interior Systems are distinct geologically from the Eastern System they are grouped as the Western Cordillera in some geological literature, and in that case the Eastern System is called the Eastern Cordillera. The greater part of the Western System is composed of the high, rugged Coast Mountains along the mainland coast of British Columbia, which are up to 13,260 feet in elevation. Along part of the Yukon–Alaska boundary they are flanked to the southwest by the still higher St. Elias Mountains, up to 19,850 feet above the sea. In southern British Columbia a fairly small area is formed by the Cascade Mountains. Separated from the mainland by the Insular Passage are ranges forming Vancouver and Queen Charlotte Islands, with peaks up to 6,968 feet in elevation. The Interior System is a complex group of plateaux and mountains, respectively up to 6,000 and 11,000 feet above sea-level. Its principal plateaux are the Yukon in central Yukon Territory, the Nechako in central British Columbia, and the Fraser farther south. Some authorities separate the southern part of Fraser Plateau as the Kamloops Plateau, which extends to the 49th Parallel near the Okanagan River. The principal mountain divisions of the Interior System are the Ogilvie and Selwyn Mountains in the Yukon, the Cassiar, Omineca, Skeena, and Hazelton Mountains in northern British Columbia, and the Cariboo, Monashee, Selkirk, and Purcell Mountains in the south-central part of the province, east of Fraser and Kamloops Plateaux.

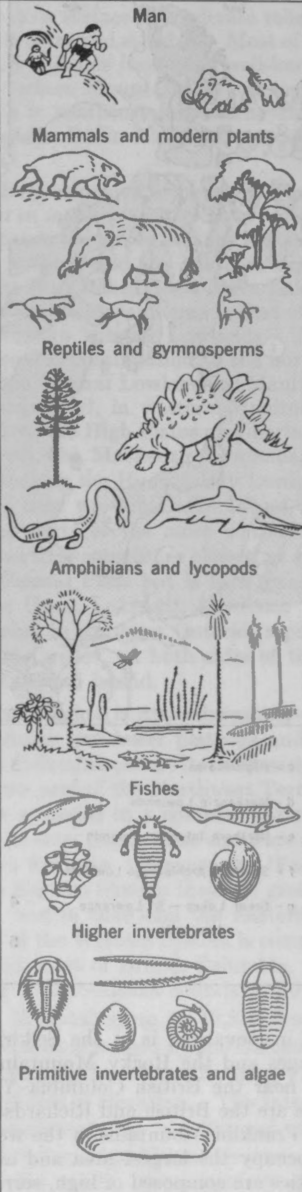


Geographical Branch, Department of Mines and Technical Surveys, 1960

The highest peak, 11,590 feet in elevation, is in the Selkirks. The Eastern System is divided into the Northern Ranges and the Rocky Mountains, separated by a plain and plateau along the Liard River near the British Columbia–Yukon boundary. The main features of the Northern Ranges are the British and Richardson Mountains near the Arctic Coast, and the Mackenzie and Franklin Mountains in the western part of the Northwest Territories. The Mackenzies occupy the largest area and are up to about 9,000 feet in elevation. The Canadian Rockies are composed of high, serrated ranges extending northward from the 49th Parallel; the elevation of the highest peak, Mount Robson, is 12,972 feet. Flanking them on the east are the Rocky Mountain Foothills which form a transition with the Plains. The Rocky Mountains, although extensive, are but a relatively small part of the mountains of Western Canada; therefore the popular tendency to apply the name to the entire Canadian Cordillera is inadmissible.

GEOLOGICAL TIME CHART

ERA	PERIOD	CHARACTERISTIC LIFE	NORTH AMERICAN OROGENIES	TOTAL ESTIMATED TIME IN YEARS
CENOZOIC	RECENT	Man		
	PLEISTOCENE	Mammals and modern plants	Cascadian	1,000,000
	TERTIARY: PLIOCENE			
	TERTIARY: MIOCENE			
	TERTIARY: OLIGOCENE			
	TERTIARY: EOCENE			
	TERTIARY: PALEOCENE	Reptiles and gymnosperms	Laramide	60,000,000
MESOZOIC	CRETACEOUS		Coast intrusions	
	JURASSIC		Palisade	
	TRIASSIC	Amphibians and lycopods	Appalachian	200,000,000
PALÆOZOIC	PERMIAN			
	CARBONIFEROUS: PENNSYLVANIAN			
	CARBONIFEROUS: MISSISSIPPIAN	Fishes		
	DEVONIAN		Acadian	
	SILURIAN	Higher invertebrates	Taconic	
	ORDOVICIAN			
	CAMBRIAN	Primitive invertebrates and algae	Killarnean*	500,000,000
PRECAMBRIAN: PROTEROZOIC	KEWEENAWAN*			
	HURONIAN*	Nil	Algoman*	1,000,000,000 or more
PRECAMBRIAN: ARCHÆAN	TIMISKAMING*		Laurentian*	
	KEEWATIN*			3,000,000,000 or more



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*Classical region only

The Canadian Appalachian Region is the northern continuation of a long belt of fairly low mountains and ridges in the eastern United States. In Canada they extend in a general northeasterly direction through the eastern part of the Eastern Townships of Quebec, the Gaspe region, and all of New Brunswick, Nova Scotia and the Island of Newfoundland excepting several lowland areas which, like Prince Edward Island, are classed as part of the Appalachian Region. The Appalachian Mountains have been in existence much longer than those of the Cordilleran Region and have been worn down to moderate proportions. Their highest point in Canada is Mount Jacques Cartier (4,160 feet) in the Shickshock Range of Gaspe. The highest elevations in New Brunswick, Nova Scotia and the Island of Newfoundland are 2,690, 1,392 and 3,500 feet, respectively.

The Innuitian Region, formerly called the Northern Arctic folded belt, is an area of fairly high mountains up to 300 miles wide stretching for about 800 miles across Ellesmere Island, the Parry Islands and other neighbouring islands. The ranges are from 3,000 to 10,000 feet in elevation.

Geological Processes.—The earth's crust is composed of minerals, the solid form in which the elements and their inorganic compounds exist naturally. Minerals occur in the crust in two main ways—as rock-forming minerals and as mineral deposits. Rocks are fairly large and homogeneous bodies composed of mineral grains. These may be of only one mineral, as in pure sandstone or limestone, but more commonly they comprise grains of two or more minerals, thus accounting for the variegated appearance of granite and many other rocks. Mineral deposits are concentrations of one or more minerals occurring within rocks as veins, irregular masses, or in other ways. Such mineral deposits are common but the minerals may not be valuable; they may be valuable but not in sufficient quantity to be mined economically; or, as in relatively few instances, they may be of economic sizes and contents.

Geological phenomena cannot be understood without an appreciation of the vastness of geological time. Pioneer geologists concluded that the earth existed for many millions of years, basing this on such evidence as the amount of sediments deposited annually in bodies of water (for example, it was estimated that several thousand years would be required to deposit one foot of typical limestone) and equating these estimates with the great thicknesses of sedimentary rocks measurable in various places. This was corroborated by observations that particular fossils are characteristic of particular groups of sedimentary rocks and that the plants and animals of which they are the remains must have evolved very slowly. Recently, more satisfactory methods of dating have been developed, based on the radioactive decay of certain elements such as uranium, which disintegrate into 'daughter' elements at constant rates. Such determinations are only beginning to become available in satisfactory quantities because they require much searching for suitable material, careful sampling and involved laboratory analyses. Most of the results date phenomena that affected rocks after they were formed, rather than the time of origin of the rock sampled. The oldest samples tested have yielded ages of 3,000 to 4,000 million years. Long before such methods were available, geologists agreed to divide geological time into eras and periods, most of which were terminated by unusually strong disturbances in the earth's crust. The eras and periods are listed on the accompanying chart, together with the most recent estimates of the dates of termination of the eras. The 'Precambrian' lasted more than five-sixths of entire geological time, but because of virtual absence of fossils in Precambrian rocks it was not possible to divide Precambrian time with the same assurance as later time, although, as explained above, progress is now being made. Therefore only two Precambrian eras, called the Early Precambrian or Archæan and the Late Precambrian or Proterozoic, are usually recognized; these have not been divided into periods that can be applied from one large area to another, whereas the younger eras and periods have world-wide recognition.

Because of atmospheric conditions the rocks at the earth's surface have from early time been subjected to weathering and erosion of the same kinds as can be seen at work today in the disintegration of rock surfaces, in the cutting action of streams, waves and winds carrying sand particles, in the spalling of rocks by frost action, in the gouging action of glaciers, in the levelling effects of landslides, and in the slow solution of soluble rocks like limestone. Continued over millions of years, these agencies reduced even great mountain chains to flat or rolling surfaces. The debris was carried away and deposited in basins by streams, waves and winds as mud, silt, sand or gravel. In some places, such as a continental shelf, the thickness of sediments was relatively small, and in others huge thicknesses accumulated in large trough-like depressions called geosynclines (part of the Caribbean Sea near the Lesser Antilles is a modern example). Also, compounds dissolved in water were deposited chemically in the bottoms of seas and lakes. In time, sediments become solid sedimentary rocks by the compaction caused by overlying sediments and by the cementing of grains by material deposited from solutions. Thus mud, sand and gravel, respectively, become shale, sandstone and conglomerate; and chemical precipitates become limestone, dolomite or beds like salt or gypsum.

In addition to sedimentary varieties there are two other fundamental classes of rocks—igneous and metamorphic. Igneous rocks are commonly formed by the crystallization of molten material, of which lava is a surface manifestation. If crystallization takes place beneath the surface it is slow, resulting in coarsely crystalline rocks such as granite, which may be exposed at the surface long afterwards as a result of erosion. If, on the other hand, the molten material reaches the surface from a volcano it crystallizes quickly to form fine-grained stratified volcanic rocks such as rhyolite and basalt; often associated with lavas are clouds of volcanic ash which settle to form sedimentary rocks called tuffs. Metamorphic rocks are formed from sedimentary or igneous rocks by the action of heat or pressure, or both, which in some cases merely causes a different crystallization of the pre-existing minerals and in others produces new minerals by re-arrangement of the elements already present to form new minerals that are more stable under the changed conditions; the latter are commonly platy minerals like mica. Thus shale may become slate, sandstone may become quartzite, and limestone may become marble. Also common results of metamorphism are foliated or banded rocks like schist and gneiss, which may be formed from various rocks and in which the foliation is commonly caused by the parallel orientation of platy minerals; in some gneisses banding is caused partly by thin parallel injections of granitic material. Metamorphic rocks are commonly formed in the 'core' of a mountainous belt, where heat and pressures are increased. Granites and other coarse-grained igneous rocks are also commonly formed there. Some granites and related rocks appear to have been formed as a final stage of metamorphism and recrystallization, without having been melted.

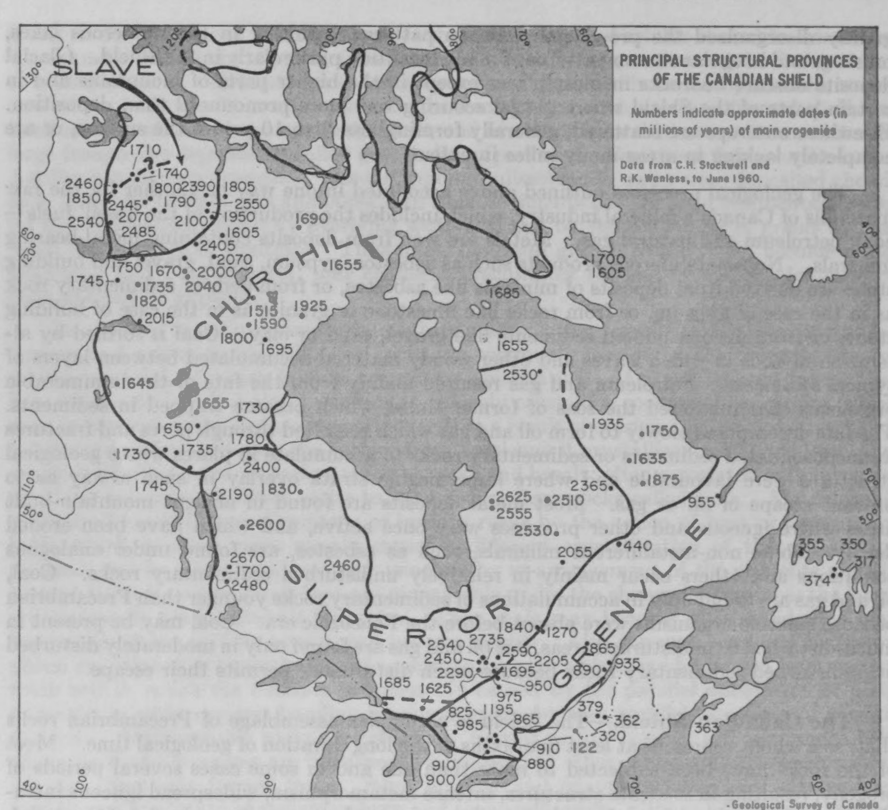
Segments of the crust were elevated from time to time by forces connected with mountain building, earthquakes and volcanic activity. Sometimes segments were uplifted in flat or tilted manner, or in broad, gentle flexures, so that streams and other erosive agencies could again begin their work of degradation, transportation and deposition. Or, particularly where great accumulations of sediments took place in geosynclines, the rocks were cast into arched or crumpled 'folds' such as may be seen on the sides of mountains carved out of sedimentary or volcanic strata. Commonly accompanying such processes were dislocations along fractures, the strata at one side of a fracture no longer matching those at the other; these are called faults, and the vibrations caused by movement along a fault produce earthquakes. Thus the earth's crust is not static, but subject to slow cyclical changes that are continuing at various places today and that culminate from time to time in pronounced disturbances called orogenies. When the highlands formed by an orogeny have been worn down and covered by later rocks a pronounced change in the kinds or structural conditions of the rocks, called an unconformity, is marked by the ancient erosional surface.

Glaciation during the Pleistocene period brought Canadian landscapes virtually to their present forms. In many mountainous regions it has continued since then. Because of fluctuations in the climate, great ice-sheets pushed slowly across almost all Canada, from centres in the Cordillera, Keewatin and Ungava. Rocks frozen in the bases of the ice-sheets and glaciers gouged and smoothed rock surfaces, and vast loads of rocks and rock particles carried by the ice were dumped as gravel or sand, or deposited as silt or clay in large temporary lakes formed by the melted ice. Both the erosive and the depositional actions greatly disorganized the pre-glacial drainage patterns, resulting in the numerous lakes, muskegs and irregular stream patterns of many localities, particularly in the Shield. Glacial deposits obscure bedrocks in most places except in the higher parts of mountains and in certain parts of the Shield where glacial scouring was more pronounced than deposition. Elsewhere outcrops are scattered, generally forming less than 10 p.c. of the surface, or are completely lacking in areas many miles in extent.

The geological processes outlined above accounted in one way or another for the raw materials of Canada's mineral industry, which includes the production of the 'fossil' fuels—coal, petroleum and natural gas. Metals are won from deposits containing metal-bearing minerals. Non-metalliferous products such as asbestos, gypsum, sand, gravel and building stone are derived from deposits of minerals like asbestos, or from beds of sedimentary rock as in the case of gypsum, or from rocks like limestone or granite as in the case of building stone, or from unconsolidated sediments like gravel, sand or clay. Coal is formed by alteration of beds in which leaves and other woody material accumulated between layers of typical sediments. Petroleum and gas resulted mainly from the fats of the innumerable organisms that inhabited the seas of former times, which became trapped in sediments. The fats decomposed slowly to form oil and gas which migrated through pores and fractures in unconsolidated sediments or sedimentary rocks to accumulate in places where geological structures were favourable and where impermeable strata overlay in such a way as to prevent escape of oil or gas. Most metal deposits are found in ancient mountain-built areas where igneous and other processes were once active, and which have been eroded deeply. Some non-metalliferous minerals, such as asbestos, are found under analogous conditions and others occur mainly in relatively undisturbed sedimentary rocks. Coal, oil and gas are found only in accumulations of sedimentary rocks younger than Precambrian because suitable organisms were absent before the Palæozoic era. Coal may be present in much-disturbed or undisturbed areas, but oil and gas are found only in moderately disturbed or undisturbed sedimentary rocks because much disturbance permits their escape.

The Canadian Shield.—The Shield is a complex assemblage of Precambrian rocks that, as a whole, represent at least five-sixths of the long duration of geological time. Most of the rocks have been subjected to more than one and in some cases several periods of orogeny, resulting in intricate structures, intense metamorphism, widespread igneous intrusions, and alteration of much ancient sedimentary rock to granite and related material. Orogenies probably occurred at many more times than suggested by the chart on p. 4, but the records of such early events are fragmentary. These complexities, combined with the absence of fossils, which facilitate the correlation of strata younger than Precambrian, hamper interpretation of the geology of the Shield. Nevertheless, progress has been accomplished and methods developed in Canada have been applied to Precambrian shields of other continents.

Because of the size of the Canadian Shield, attempts have been made to divide it into geological or structural 'provinces'. The latter are based on the general directions of structural trends and on age determinations that supply estimates of the dates of orogenies, metamorphism, or igneous intrusions. Several schemes of this kind have been suggested but final agreement on names and boundaries must await further field studies and additional age determinations. A simplified and tentative classification is illustrated by the map on the following page, which also summarizes age determinations by the Geological Survey of Canada to June 1959. According to this plan the Shield is divided into five provinces which, from northwest to northeast, are called Slave, Churchill, Superior, Grenville, and an unnamed one which in other schemes is called Labrador. Some geologists consider that a separate division called Ungava may lie north of the Superior and east of Hudson Bay, and some add another province called 'Arctic Islands' to include the part of the Shield found at and near Baffin Island. More complicated schemes subdivide the provinces into sub-provinces. The Superior and Grenville provinces contain the classical areas where the first geological investigations in the Shield were undertaken. They are, therefore, described in slightly greater detail than space permits for the other provinces.



The Superior province is underlain mainly by Archæan rocks. These are chiefly belts of metamorphosed sedimentary rocks and lavas, and intervening areas of granite and gneiss. Most of the belts trend east and west and are the remnants of strata that were intensely folded and faulted. The sedimentary phases consist largely of altered greywacke, an impure sandy rock commonly containing volcanic ash. Most of the lava contains rounded masses called 'pillows', which are characteristic of lavas that flowed under water. Most of the lava has been metamorphosed to greenish rocks to which the name 'greenstone' is often applied. In much of the province a succession of greenstones and some altered sediments, estimated to be up to 25,000 feet thick, appears to be the oldest assemblage exposed and was named the 'Keewatin' group or series by early geologists. In places it is overlain unconformably by a thick succession of sedimentary strata, mainly greywacke and slate, with conglomerate at the base; this was called the 'Timiskaming' group. Granite pebbles in the conglomerate led to the conclusion that a period of orogeny, called the Laurentian, took place at the end of Keewatin time. The Archæan era was ended by pronounced orogeny and granitic intrusion, called the Algoman. Upon the ancient land surface resulting from erosion at the end of the Archæan are found, in places, bodies of moderately folded conglomerate, arkose, quartzite, limestone, lavas and other rocks. In general these are less metamorphosed than Archæan rocks or, in some cases, unmetamorphosed. The largest assemblages of these rocks, extending fairly uninterruptedly from near Sault Ste. Marie to the northern part of Lake Timiskaming, was named the 'Huronian' by pioneer geologists in 1863. Huronian strata are intruded in places by the Killarney granite, believed to have been formed during the orogeny that marked the end of Proterozoic time. In the Port Arthur area a succession of sedimentary rocks with some volcanic flows, called the Animikie, is regarded as having been deposited in the earlier part of late Proterozoic time, and to represent the 'Upper Huronian'. Overlying the Animikie strata at some localities and directly on Archæan rocks at others is a thick succession of shale, sandstone, lava and other rocks called the 'Keweenawan' and regarded as late Proterozoic in age. These are intruded by diabase and other igneous rocks. Thus the classical subdivisions of the Precambrian rocks in the part of the Shield north of the Great Lakes are two Archæan assemblages called Keewatin and Timiskaming, probably disturbed by at least one early orogeny; a pronounced orogeny and erosional interval at the end of Archæan time; an early and disturbed Proterozoic assemblage called the Huronian; and a late Proterozoic one called the Keweenawan. Although these are the names of groups of rocks, they are sometimes also applied as the names of periods. Such periods are much longer than the periods of the Palæozoic and later eras and they cannot be applied with certainty even in all parts of the Superior province, to say nothing of the remainder of the Shield.

Processes associated in various ways with orogenies formed numerous mineral deposits far below the surface then existing. Many of these have since been exposed by the long erosion to which the Shield has been subjected. The Superior province is Canada's leading producer of metals, but it is impossible to be certain whether this is mainly because more metals were actually deposited there or because the region was more accessible for geological studies, prospecting and mining. It includes orebodies of iron at Steep Rock and Michipicoten, uranium at the base of the Huronian succession near Blind River, nickel-copper-gold ores at Sudbury, the now largely exhausted silver veins at Cobalt, the great gold deposits at Timmins, Kirkland Lake and Larder Lake, and the gold, copper and zinc deposits of the Noranda and Chibougamau areas. It also includes Canada's main lithium and molybdenum mines and the only asbestos mine in the Shield. Many of the orebodies are in or close to belts of Keewatin or Timiskaming strata, and several of the largest, as at Sudbury, Cobalt, Noranda and Chibougamau, occur relatively close to the junction of such belts with the boundary between the Superior and Grenville provinces, which is marked in places by a zone of prominent faults. In the northern part of what is classed tentatively as the Superior province on the map, gently folded strata of Proterozoic type underlying the Belcher Islands contain iron deposits that have received considerable attention. A belt of somewhat similar type crossing Ungava Peninsula from Cape Smith to Wakeham Bay contains occurrences of iron, copper, nickel, gold, zinc and lead.

The western part of the 'Labrador' area contains strata of early Proterozoic type in a belt called the Labrador Trough; the name implies that the belt was a basin of sedimentation in Precambrian time, not that it is now trough-like. It is about 600 miles long and up to 60 miles wide, extending southeasterly from Ungava Bay. Its south end is transitional into the Grenville province where more metamorphosed equivalents of the strata in the Trough, including important iron deposits, have been found. The Trough contains abundant 'iron formation' resembling that of the iron ranges in the Lake Superior region of the United States; the iron formation has been enriched in places to form the large iron deposits now being mined. East of the Trough are more intensely metamorphosed equivalents of strata in the Trough, and other rocks. North of Goose Bay, strata of early Proterozoic type form the Seal Lake belt in which numerous occurrences of copper and uranium have been found.

The Churchill province contains many northeasterly-trending belts of strata of Archæan and early Proterozoic types, with large intervening areas of granites and gneisses and large patches of strata of late Proterozoic type. Prominent among the northeasterly-trending belts is one north of Lake Athabasca which contains both strata of Archæan type called the Tazin group and of Proterozoic type called the Athabasca series; both types contain many uranium occurrences, some of which provide the ores for the important mines of the Beaverlodge area. This belt continues in a general way to Rankin Inlet on Hudson Bay; the eastern part is not known to contain many uranium occurrences but several deposits of gold and a few of copper, nickel and platinum have been found, including the deposit mined for those metals at Rankin Inlet. Belts of strata of Archæan type contain important copper-zinc deposits near Flin Flon, copper-nickel and nickel deposits near Lynn Lake and Thompson, and gold deposits at several locations.

In the northern part of the Slave province a series of altered sedimentary and volcanic strata of late Proterozoic type contains copper deposits which have attracted attention but which have not been developed. More deformed and altered rocks of early Proterozoic type east of Great Bear Lake contained the Eldorado uranium-radium orebodies that have been recently exhausted. North of Great Slave Lake northeasterly-trending bodies of greywacke, slate, and volcanic rocks called the Yellowknife group contain important gold ores. North and south of the East Arm of Great Slave Lake and in its islands, occurrences of various metals have been found and a few of gold and tungsten have been mined.

A large part of the Shield, extending from Georgian Bay to the Strait of Belle Isle, has long been recognized as forming a distinct segment called the 'Grenville'. It was named after the Grenville series, characterized by crystalline limestone, impure limy strata, and large areas of sedimentary gneisses in various stages of alteration to granite. The eastern part of the province contains large igneous intrusions of anorthosite. The age relations between Grenville strata and those of the neighbouring Superior province are puzzling. Recent work has indicated that near Sudbury, as well as at the south end of the Labrador Trough, beds can be traced across the boundary into more metamorphosed rocks of Grenville type. It is believed, therefore, that the distinctive features of the Grenville may be related more to the time and degree of metamorphism than to distinctions in the original age of deposition of strata. The Grenville province contains an unusually large variety of mineral occurrences but has not been as important a producer as the Superior. Several fairly large deposits are mined, including those of nepheline syenite near Peterborough, uranium near Bancroft, iron of the magnetite variety at Bristol and Marmora, zinc and lead in the Ottawa valley and at Tetreault west of Quebec City, and iron and titanium near Havre St. Pierre. Large iron deposits are being prepared for production at the south end of the Labrador Trough.

The Plains and Lowlands.—Sedimentary strata of Palæozoic and younger ages overlap the Shield to form the principal Plains and Lowlands. These strata once covered much more of the Shield before being removed by erosion. The Shield continues under the Plains, as is proved by numerous wells drilled for oil or gas in the Great Plains and in southern Ontario having been bottomed in typical Shield rocks, but it is customary to regard the Canadian Shield Region as the part that is exposed or covered by glacial deposits. The overlying strata are undisturbed or gently tilted or flexed, the Shield and the Plains and Lowlands together forming a central continental region that has been relatively stable since Precambrian time, while orogenies were active in the flanking geosynclinal belts now indicated by the Appalachian, Cordilleran and Innuitian mountains.

The Shield slopes at a rate of 15 feet per mile under the Great Plains, in the western part of which the overlying strata reach a thickness of 10,000 feet. The older overlying beds have been bevelled by erosion along the border of the Shield, exposing in central Manitoba sea-deposited beds of limestone, sandstone and shale of Ordovician, Silurian and Devonian ages. Farther north the exposed Palæozoic strata are mainly Devònian. The Palæozoic formations are overlain by early Mesozoic strata of marine origin and these by both marine and freshwater Cretaceous formations which are the uppermost strata in much of Saskatchewan and Alberta. In places, however, as at Turtle Mountain in Manitoba and the Cypress Hills in Saskatchewan, these are overlain by remnants of early Tertiary formations.

The rich soils of the Great Plains, particularly in the Manitoba Plain, were derived from the weathering of the underlying strata and the unconsolidated deposits resulting from glaciation. Most of Canada's oil and gas is produced from Palæozoic and Mesozoic strata underlying the Great Plains, mainly in Alberta but also in Saskatchewan, Manitoba, northeastern British Columbia and at Norman Wells in the Northwest Territories. The productive beds range from Devonian to Cretaceous in age, the reservoir rocks being largely reefs containing many openings, although 'stratigraphic' traps such as lenses of porous sediments in non-porous ones are also important. Exploration for oil and gas has recently been extended through most of the plains including those in the Arctic Archipelago. The Athabasca oil sands, extending for more than 100 miles along the Athabasca River in northern Alberta, are accumulations of heavy oil and sand of Lower Cretaceous age; the total amount of oil is estimated at 100,000 to 300,000 million barrels, more than all other known reserves of the world. Coal is being or has been produced from many places in the Great Plains. They also yield potash, salt, gypsum, limestone and other non-metalliferous products. The only important known metalliferous deposits are of zinc and lead, in Devonian limestone at Great Slave Lake.

The Arctic Lowlands and Plateaux form most of the southern part of the Arctic Archipelago, lying between the Innuitian Region and the exposed part of the Shield. They are underlain mainly by Ordovician and Silurian limestone, dolomite and shaly dolomite, but strata of Cambrian, Devonian and Tertiary ages are also present. Some of the beds contain coal. Active interest is now being shown in the oil and gas possibilities of the strata.

West and east of the Frontenac Axis, the Great Lakes and St. Lawrence Lowlands are underlain by gently dipping beds of limestone, dolomite, sandstone, and shale of Cambrian, Ordovician, Silurian, Devonian and Mississippian ages. West of the Axis they have a total thickness of 5,877 feet but few places are underlain by all formations; the greatest thickness penetrated by drilling is 4,727 feet. East of the Axis, formations in Quebec have a total thickness of at least 10,000 feet. Ordovician and Silurian strata are exposed on Anticosti Island. The first petroleum field in Canada was in the area north of Lake Erie, which is still producing natural gas and some oil. Most oil was derived from Devonian strata and most gas from Silurian. Important amounts of salt and building materials are produced from the St. Lawrence Lowlands but only a few metalliferous occurrences have been found other than the Marmora iron deposit which is in Precambrian rocks that were overlapped by a thin covering of Palæozoic strata and so are technically within the Lowlands.

Exceptions to the flat character of the St. Lawrence Lowlands are the Monteregian Hills at and near Montreal. These are the remnants of small alkaline igneous intrusions of Devonian or younger age, which are more resistant to erosion than the surrounding strata.

An area extending for about 800 miles between Churchill and the south end of James Bay is underlain by Ordovician, Silurian and Devonian strata composed largely of limestone and dolomite and by a smaller amount of Jurassic or Cretaceous strata. The thickness of this assemblage of sedimentary rocks is not well known because outcrops are scarce and little drilling has been done. Large deposits of gypsum have been found in the Devonian succession and substantial lignite deposits occur in Mesozoic beds.

The Cordilleran Region.—The Cordillera are on the site of a great geosyncline where sediments were laid down at least as early as late Precambrian time, where marine sedimentation continued in places as late as the Upper Cretaceous, and where freshwater sediments were deposited locally during the Tertiary.

In parts of the interior of British Columbia and the Yukon are exposed highly metamorphosed rocks bearing some resemblance to the Archæan of the Shield. All available evidence indicates, however, that these are partly late Precambrian and partly younger strata that were metamorphosed in pre-Permian and, probably, partly in Precambrian time.

The oldest strata whose age is clear are beds of quartzite, argillite, dolomite and other sedimentary rocks totalling many thousands of feet, principally in the Cariboo, Purcell, Selkirk and Rocky Mountains. In places, these unfossiliferous beds are overlain by others containing Lower Cambrian fossils. In general, the Cambrian rests unconformably on the rocks beneath but in many places there is no marked unconformity. It is concluded, therefore, that at least some of the Precambrian strata may be younger than any strata classed as Proterozoic in the Shield and may have been deposited during the time when the Shield was being eroded before Palæozoic sediments were deposited on it.

In the western part of the region the principal Palæozoic strata exposed are volcanic and sedimentary strata, largely limestone, of Carboniferous and Permian ages. More extensive are great accumulations of volcanic and sedimentary strata of Triassic, Jurassic and Lower Cretaceous ages. In the Eastern Cordillera the Palæozoic periods are better represented, as limestone, dolomite, quartzite, shale and other rocks of Ordovician, Silurian, Devonian, Carboniferous and Permian ages are present. These are overlain in places by shale, sandstone, limestone and other rocks ranging in age from Triassic to Upper Cretaceous. The combined thickness of strata of different ages exposed in various parts of the Rocky Mountains, including the Precambrian beds mentioned earlier, is estimated at 68,000 feet. In many parts of the Rocky Mountains, particularly along the eastern border, low-angle faults thrust Precambrian and Palæozoic strata above younger beds.

As already indicated, some evidence now largely obliterated by later events points to early orogenic activities. The principal mountain-building and igneous processes of which good evidences remain began locally in early Mesozoic time, culminated in the Western Cordillera in the Nevadan orogeny in late Jurassic and early Cretaceous time, but was not significant in the Eastern Cordillera until the Laramide orogeny early in the Tertiary. Thus the Western Cordillera were formed much earlier than the Eastern, were largely worn down by erosion by the time the Rockies and other eastern mountains were built, and the western part of the region was uplifted at the time of the Laramide orogeny so that renewed erosion could carve the surface into the present mountains and plateaux. Therefore if one stands on a peak in, say, the Coast or the Selkirk Mountains he is impressed by the uniformity of summit levels representing the ancient, uplifted surface.

The strata in the Western Cordillera are intruded by many bodies of igneous rocks, from small to very large in size. Most are granodiorite or diorite, but many others are granite, gabbro, or other related types; still others are ultrabasic, i.e., composed mainly of iron and magnesium minerals. Most are related to the Nevadan orogeny but some must have been intruded in late Cretaceous or early Tertiary time, and there is incomplete evidence that some are of ages from late Precambrian to Triassic. The intrusions are scattered widely, the largest concentration being the Coast Instrusions which form the greater part of the Coast Mountains. In a general way, this belt of intrusion swings easterly in southern British Columbia and is represented by many large and small bodies in the Kamloops Plateau and the Monashee, Selkirk and Purcell Mountains. Intrusive rocks are rarely exposed in the Eastern Cordillera, probably because the mountains there have not been eroded sufficiently to reveal many.

In the Interior belt much lava was deposited on the plateaux at various times during the Tertiary, mainly in or about Miocene time. The lavas are chiefly of the basaltic variety, and apparently issued from long fissures rather than from volcanoes. Sandstone, shale and volcanic ash were deposited in local freshwater basins in the same belt.

Mountain-building in the western part of the United States formed the Cascade and Coast Ranges there during late Tertiary or early Pleistocene times. These movements, which took place over considerable time and were accompanied by much volcanic activity, are sometimes called the Cascadian orogeny. In the Canadian Cordillera this orogeny was mainly limited to uplifts and some volcanic deposition. Some volcanic activity occurred locally as late as the post-Pleistocene, as evidenced by lava and ash resting on glaciated rocks and glacial debris and by a well-preserved cinder cone in northern British Columbia.

Glaciation was widespread in the Cordillera during the Pleistocene and glaciers persist today in many places, chiefly in the St. Elias and Coast Mountains and the Columbia Ice Field in the Rockies. A large area in Yukon Territory, however, escaped glaciation because the high St. Elias Mountains barred the moisture-laden winds from the Pacific to such an extent that ice did not form in much of the interior, despite the increased coldness of the times. This lack of glaciation was largely responsible for the preservation and discovery of the Klondike gold placers and for other characteristics of mineral deposits in the area.

The Cordilleran region was Canada's leading producer of minerals until mining in the Shield took the lead about the turn of the century. Notwithstanding greatly increased production in British Columbia, the Cordilleran region now produces only some 7 p.c. of the Canadian total because of the greatly expanded production of metals from the Shield and the value of oil and gas from the Great Plains. Metal mining in the Cordillera is and has been almost entirely in the Western Cordillera, but important quantities of coal and structural materials are obtained from the Eastern Cordillera, and much oil was produced from the Foothills in Alberta, chiefly at Turner Valley.

Broadly speaking, all parts of the Western Cordillera except those covered by Tertiary lavas or sediments are favourable for the occurrence of metals. Numerous occurrences of many kinds have been found, most having been formed directly or indirectly as a result of the Nevadan orogeny, although some mineralization attended the early Tertiary disturbances and some may have taken place before the Nevadan. British Columbia contains many large and moderate sized mines of lead, copper, zinc, gold, silver and iron, mainly along the flanks of the belt of Coast Intrusions and in the southern part of the province, where the Sullivan mine is the largest lead-zinc-silver operation in Canada and one of the largest in the world. British Columbia also contains rich mercury and tungsten mines that are now inactive because of reduced demands for these metals, and an asbestos deposit of exceptional quality which is now being mined. Barite, gypsum and structural materials are produced and extensive coalfields are available although the production of coal has declined. Yukon Territory also contains diversified mineral deposits, but mining at present is limited to rich silver-lead-zinc veins at Mayo, the waning placers of the Klondike, and coal extracted for local use.

The Appalachian Region.—This region is the northern continuation of a long belt of folded strata extending along the eastern side of the United States. It is on the site of a geosyncline that existed mainly in Palæozoic time in which great thicknesses of sedimentary and volcanic strata were laid down. The northwestern boundary of the region is a long curving fault or zone of faults which extends from Lake Champlain at least as far as the Gulf of St. Lawrence and which causes the curved shape of the northern coast of Gaspe. The strata in the Appalachians have been folded and faulted by successive periods of orogeny along axes that strike northeasterly; thus strata of different kinds and ages and belts of intrusive rocks form northeasterly-trending bands, many of which are responsible for the peninsulas, bays and ridges of the region. Three principal periods of orogeny, called the Taconic, the Acadian and the Appalachian, have been recognized. The Taconic occurred at the close of the Ordovician, the Acadian during the Devonian, and the Appalachian at the close of the Palæozoic. In Canada the Taconic disturbances were fairly widespread, the Acadian were more so, affecting areas that were previously affected by the Taconic and areas that were not, but the Appalachian orogeny, which was a major feature in parts of the United States, was of minor and local importance.

Precambrian rocks of Grenville types exposed in parts of western Newfoundland probably represent an extension of the Shield but are separated from it by younger strata along the Strait of Belle Isle. Less deformed strata, including quartzite, slate and other rocks in eastern Newfoundland and in parts of Nova Scotia and New Brunswick, bear a general resemblance to Proterozoic strata of the Shield. They are overlain unconformably by Palæozoic strata deposited intermittently from Cambrian to Pennsylvanian times. In much of the region, deposition apparently took place in local basins, strata of the same ages varying widely in kind and in their contained fossils. The rocks are largely limestone, shale, sandstone and volcanic rocks, some of the formations being of great thickness. For example, the greatest thickness of Middle Silurian beds in North America—8,427 feet of sedimentary and 4,626 feet of volcanic strata—is exposed near Chaleur Bay. Near the Bay of Fundy, Triassic sandstone with interbedded volcanic strata similar to those of the Hudson River Palisade in New York represent the youngest rocks of the Appalachian Region.

Numerous bodies of granite and related igneous rocks intrude the strata. Most of these were associated with the Acadian orogeny and were intruded in Lower, Middle and Upper Devonian times. Many bodies of ultrabasic rocks occur intermittently in northeasterly-trending belts in the Eastern Townships and in Newfoundland. Most of these intrude Cambrian and Ordovician strata and are probably related to the Taconic orogeny.

The Appalachian Region now produces about 7 p.c. of the Canadian production of minerals, including fuels. This is mainly asbestos associated with basic rocks in the Eastern Townships, iron from Ordovician sedimentary beds at Bell Island, Newfoundland, and coal from Pennsylvanian strata in Nova Scotia. The Eastern Townships contain the world's leading asbestos occurrences. Elsewhere copper, zinc, lead, gold and silver are produced, mainly from central Gaspe and central Newfoundland. Most of the deposits are related to the Acadian orogeny, as were numerous gold-bearing veins formerly mined in Nova Scotia. Gypsum, barite and salt are produced from Mississippian strata in Nova Scotia, and some gypsum is also produced in New Brunswick. From veins in granite and related rock in Newfoundland comes most of Canada's production of fluorite.

The Innuitian Region.—This mountainous belt is known mainly from reconnaissance surveys. It is underlain by moderately-to-intensely folded sedimentary, volcanic and metamorphic rocks of various ages, the oldest being probably Proterozoic and the youngest being Tertiary. Folding occurred at different times and in different directions, some before the Silurian period, some in Silurian or Devonian time, some late in the Palæozoic era, and some in Tertiary time. Five fold-belts have been recognized—Cornwallis, Parry Islands, Central Ellesmere, Northern Ellesmere, and Eureka Sound. Granitic intrusions have been found in the Northern Ellesmere belt. Lead and zinc have been reported from Little Cornwallis Island and magnetite from Axel Heiberg Island. Gypsum occurs in beds of various Palæozoic ages. Coal has been found at several places, in strata of different ages, the thickest known seams being in beds apparently of Tertiary age on Ellesmere and Axel Heiberg Islands. The less deformed parts of the region offer possibilities for oil and gas and are now being investigated by companies.

The foregoing are only brief sketches of the subjects covered. Further information is supplied by *Geology and Economic Minerals of Canada* ($2, including Map 1045A) and *Prospecting in Canada*; the latter also contains chapters on the principles of geology and on minerals and rocks. The *Geological Map of Canada* (1045A, 50 cents) and *Canada, Principal Mining Areas* (900A) are also recommended. Map 900A is revised annually; one copy is sent free to residents of Canada and additional copies are 25 cents each. These publications can be ordered from the Director, Geological Survey of Canada,* together with lists of reports and maps of the Geological Survey of Canada on specific topics and areas, for each province. Other publications are available from provincial mines departments.

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QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1961

Cat. No. CS 11-202/61r2