

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The Geology of Canada

La Géologie du Canada

J. M. HARRISON, *Assistant Deputy Minister (Research), Department of Mines and Technical Surveys, Ottawa, Canada*



SUMMARY

Canada has a land surface of about 10 million square kilometers. It extends from about latitude 42° North to approximately 83° 10' North, and west from longitude 52° 30' approximately to longitude 141°. As might be expected, this vast area encompasses a great variety of geological and geographical environments.

The nucleus of the North American continent is the ancient Canadian Shield, now exposed over 4.5 million square kilometers as an immense northwest-trending rectangle. These rocks range in age from about 1000 million to more than 4000 million years. Extensions of this stable foundation of the continent are hidden beneath a relatively thin veneer of younger sedimentary rocks that were deposited in shallow seas, in the present Hudson Bay region, some Arctic Islands, the St. Lawrence Lowlands, and the Interior Plains. West of the Interior Plains and on the northern and southeastern flanks of the Canadian Shield, deep elongate troughs developed, accompanied by volcanism and rapid sedimentation. The accumulated materials were subsequently uplifted to form the Cordillera on the west, and the older and more extensively eroded Innuitian mountain belt on the north and the Appalachian on the southeast. Erosional products from the then-young mountains accumulated in basins and formed softer rocks such as the coal measures of the Maritimes and Tertiary beds of the Cordillera. Finally, about 10,000 years ago, continental glaciers covered much of Canada, scoured and removed residual soils and some surface bedrock, and left in their stead polished bedrock of many varieties, and glacial tills or fluvioglacial deposits, mainly derived from unweathered bedrock of the region. On this bedrock and its derived glacial *débris*, the present soils of Canada were developed under various climatic and topographic controls.

The bedrock and glacial geology of Canada dictates to a very considerable degree the kind of community that will be built upon it. For much of the great unforested area of the Canadian Shield, the only real hope for stable communities depends on mineral production. Apart from major iron deposits in New Quebec-Labrador, however, most of the mineral deposits exploited to date lie near the southern and southwestern fringe of the exposed Shield. The Great Plains, Canada's breadbasket, is now known to contain great quantities of petroleum resources and potash deposits of major world rank, both potential and actual.

Similarly, the potentialities of the Arctic islands for petroleum are considered good and they are currently being actively prospected for oil and gas, as well as for metallic minerals in the eastern area. In the western mountains many types of mineral deposits are known between the 49th parallel and the northern Yukon. The Appalachian region in the southeast contains both metallic and non-metallic deposits, and parts of the region are

SOMMAIRE

La superficie du Canada est d'environ 10 millions de kilomètres carrés. Le pays s'étend approximativement du 42° de latitude nord jusqu'à 83° 10' de latitude nord, et de 52° 30' de longitude ouest jusqu'à 141° de longitude ouest. Comme on peut s'y attendre, cette vaste étendue offre une grande variété de milieux géologiques et géographiques.

Le noyau du continent nord-américain est constitué par le Bouclier canadien qui affleure maintenant sur une superficie de plus de 4 500 000 kilomètres carrés, sous forme d'un immense rectangle à direction nord-ouest. L'âge des roches qui le composent s'échelonne sur 4 milliards d'années. Les prolongements de cette fondation stable du continent sont masqués par une couverture relativement mince de roches sédimentaires plus jeunes qui se sont déposées en mers peu profondes dans la région actuelle de la baie d'Hudson, dans quelques îles de l'Arctique, dans les basses terres du Saint-Laurent, et dans les plaines intérieures. À l'ouest des plaines intérieures et sur les flancs nord et sud-est du Bouclier canadien, des géosynclinaux profonds et allongés se sont formés et ce phénomène a coïncidé avec le volcanisme et la sédimentation rapide. Les matériaux accumulés ont ensuite été soulevés pour donner naissance à la Cordillère à l'ouest, à la région montagneuse plus vieille et plus érodée des Innuitiennes au nord et aux Appalaches au sud-est. Les produits d'érosion de ces montagnes se sont accumulés dans des bassins et ont donné des roches plus tendres comme celles où se trouvent les gisements houillers des Maritimes et les couches tertiaires de la Cordillère. Enfin, il y a environ 10 000 ans, les glaciers continentaux ont recouvert la majeure partie du Canada. Ils ont abrasé et enlevé les sols résiduels et parfois la roche en place affleurante, laissant à découvert la roche de fond polie de tout genre, et des moraines glaciaires ou dépôts fluvioglaciaires provenant surtout de la roche en place non altérée de la région. Sur cette roche en place et sur les débris abandonnés par les glaciers, les sols actuels du Canada se sont formés sous les conditions climatiques et topographiques les plus diverses.

La géologie glaciaire et de la roche en place au Canada influe considérablement sur le genre de communauté qui s'y établira éventuellement. Pour la plus grande partie du Bouclier canadien qui est dénudée, le seul véritable espoir de colonies stables repose sur les richesses minérales. Exception faite des grands gisements de fer du Nouveau-Québec-Labrador, cependant, la majorité des gisements minéraux exploités jusqu'à ce jour se trouvent près de la limite sud et sud-ouest du Bouclier affleurant. On sait maintenant que les grandes plaines qui sont le grenier du Canada renferment d'énormes quantités de pétrole et de potasse d'une grande importance à l'échelle mondiale, qui sont à la fois exploitées et en réserve.

De même, il est de notoriété publique que les îles de l'Arctique

excellent farming land. Vast tracts of the continental shelf off Nova Scotia and Newfoundland have been leased for oil exploration, and recently acquired geological evidence suggests petroleum possibilities beneath the waters of Hudson Bay.

renferment des gisements pétrolifères prometteurs et l'on poursuit activement des travaux de prospection. On cherche du pétrole, du gaz et aussi des minéraux métalliques dans la partie orientale de l'archipel. Dans les montagnes de l'Ouest on connaît l'existence de plusieurs gisements de minéraux entre le 49^{ième} parallèle et le nord du Yukon. La région des Appalaches au sud-est renferme des gisements métalliques et non métalliques et certaines parties de la région offrent de bonnes terres arables. De vastes étendues du plateau continental au large de la Nouvelle-Écosse et de Terre-Neuve ont été concédées à des sociétés qui y cherchent du pétrole et, dernièrement, on a acquis la preuve géologique qu'il pourrait y avoir du pétrole sous les eaux de la baie d'Hudson.

WHEN YOUR CONVENOR, DR. LEGGET, was kind enough to ask me to give an outline of the geology of Canada to the Sixth International Conference on Soil Mechanics and Foundation Engineering, I was naturally pleased to accept the honour. In the first place, knowledge of the geological environment is the base on which your own work must be built. At that time also, I still had the great honour of being the Director of the Geological Survey of Canada, which is one of the oldest scientific agencies in the world and is the oldest scientific organization in the government service of Canada, twenty-five years older than the country itself. Naturally I think it is one of the finest scientific organizations in the country as well. My present duties are considerably different from those of a year and a half ago but I still find the geology of Canada a most interesting problem.

In Canada, there are a great number of geological environments, simply because the country is very large. Because Canada is a country in the same sense that, say, Switzerland is a country, people are inclined to forget how large it is. It has a land area of about ten million square kilometers and it includes parts of all but one of the geological zones of the North American continent. These geological zones are, of course, the reason for our physiographic regions because the rocks and surficial deposits determine the characteristics of the land surface. This fact alone explains the wide varieties of natural resources, the problems of land utilization and suitability for settlement, and the scenery. You can, of course, add to this the serious problems due to the wide variations of climate.

About half of Canada is underlain by the ancient, generally hard rocks that form the nucleus of the continent, the great Canadian Shield (Fig. 1). These rocks slope gradually beneath much younger, relatively unaltered sedimentary strata that form the Interior Plains, and the St. Lawrence, Hudson Bay, and Arctic Lowlands. West of these Interior Plains and on the northern and southeastern flanks of the Shield, deep elongate troughs or geosynclines were developed. The strata deposited in them were eventually compressed, elevated, and subsequently eroded to form the Appalachian system on the east, the Inuitian system in part of the Arctic Archipelago, and the great Cordilleran mountain belt on the west. The continent is not bounded by the coastlines, however, but by the limits of the Continental Shelf, as was agreed at the Geneva convention a few years ago. This shelf extends considerably beneath the Pacific, entirely through Hudson Bay and between the Arctic Islands, and, for great distances, beneath the Atlantic. This factor naturally extends greatly the chance of finding petroleum, natural gas, and other minerals within the continental limits of Canada.

During the last million years almost all of Canada was covered by the continental glaciers that removed our residual soils, and gouged and polished bedrock leaving most

of it covered by glacial *débris* in the form of till, gravel, sand, and clay, just as they did in northern Europe.

I propose to describe briefly the bedrock geology of the main geological zones, then discuss the surficial deposits, with perhaps a few comments concerning groundwater, in the hope that you will have an idea of the physical complexity of this vast land. Geological phenomena, however, cannot be understood without an appreciation of the immensity of geological time. Early geologists, beginning about 150 years ago with Charles Lyell, made remarkably good estimates of its order of magnitude. Lyell made his guess by comparing the present rate of accumulation of sediments with the thickness of ancient sedimentary rocks. As a matter of fact, it was not until Charles Lyell showed that the earth was a very ancient piece of planetary material that Charles Darwin was able to expound his theory of evolution because, until the immensity of geological time was realized, there was insufficient time for evolution to take place. In more recent years estimates based on the radio-active decay of certain elements appear to have added much precision to these earlier estimates. It should be remembered however that isotopic ages date the time of igneous intrusions; the rocks they intrude may be very much older.

It is probably impossible for most of us to realize the length of geological time, which, by the way, is only a small part of astronomical time. One comparison I find impressive, however, relates geological time to a twenty-four-hour clock. The earth is about 4500 to 5000 million years old, so that each hour is equal to approximately 200 million years. We can then come up with some interesting hours in the geological day. Only at about 3 o'clock in the afternoon were the first primitive forms of life generated on the earth. It took until 9 o'clock in the evening for creatures to evolve that had a usable skeleton, even though they were all sea animals and their skeletons were external. A few primitive animals—such things as scorpions and millipedes—and some rudimentary plants began to live on land at about 9:45 in the evening. By about 11 o'clock vertebrates, mostly reptiles, had begun to replace invertebrates as the dominant form of life and about 11:15, warm-blooded mammals first appeared. Many modern trees, such as oak and maple, came into being in the few minutes remaining, and in the last 30 seconds before midnight *homo sapiens* was added to the list.

The earth is extremely ancient, and so many things have happened to it, that nowhere has a remnant of the original crust of the earth ever been recognized. (Incidentally, this is one of the main reasons why the geologists are so interested in the moon. Because it is small, it lacks an atmosphere that can produce much erosion and it probably does not generate as much heat as the earth, so we may there find some primordial crust, and learn what the earth was like in its earliest days.)

Crustal rocks, commonly formed as sediments or lavas,

are subjected from time to time to great stresses that cause the folding and uplifts that produce our mountain belts. These upheavals are confined mainly to the geosynclines, but the less deeply sedimented regions may be uplifted and gently folded or tilted. Major folding and uplifting is commonly accompanied by igneous intrusion, and deformation of nearly any kind is accompanied by faulting, whereby rocks are displaced from a few feet to many miles along great fractures. These displacements accumulate over many millions of years, and we feel them today through the individual earthquakes that create such havoc.

CANADIAN SHIELD

For a hundred years or more, the great Precambrian Shield was, and as a matter of fact still is, referred to as the basement complex. Because most of the rocks are intensely deformed and metamorphosed, and because there are no fossils to aid in correlation, it was difficult to do anything more than describe their complexity. However, as time went on geologists learned to tackle these problems, and Canadians have become among the world leaders in understanding Precambrian geology. They had to, because so much of their country is underlain by Precambrian rocks (Fig. 1). In recent years the Shield has been divided into geological and structural provinces based on structural trends and isotopic age determinations. These ages are the averages of many and represent the time when the rocks were built into mountains and intruded by igneous rocks.

The Precambrian was first studied in detail in northern parts of Ontario and adjoining Quebec where the oldest and most intensely folded and metamorphosed rocks consist chiefly of altered sedimentary, volcanic, and plutonic rocks. These were classed as Archean, the ancient rocks, and this era accounts for the larger part of Precambrian time—in fact it accounts for the larger part of earth's history. Other rocks, less strongly altered but nevertheless intruded by granites, overlie the Archean and they were classed as Proterozoic, the time of first life. These younger strata form two distinct units, the older of which is folded but more gently than most of the Archean rocks, and in several places it is overlain by later, more gently dipping or even flat, Proterozoic strata. This condition was found in several other parts of the Shield and most geologists tended to extend the use of the terms Archean and Proterozoic to all these areas, even though the strata could obviously represent recurrence of similar conditions at greatly different times.

The Canadian Shield with its abundance of intrusive rocks, complex structures, and ancient geosynclines is a veritable storehouse of minerals and about half of Canada's mineral wealth comes from this vast Canadian Shield. It is receiving a great deal of attention from geologists now, and it will in the future, because of an understanding of this vast terrain will depend our future discoveries of the minerals and metals that help so much to make our country prosperous.

PLAINS AND LOWLANDS

Sedimentary strata of Paleozoic and later ages overlie the Shield to form large flat Interior Plains, the St. Lawrence, Hudson Bay and Arctic Lowlands (Fig. 1). The southern parts of the Interior Plains are Canada's principal agricultural areas and producers of petroleum and gas. In drilling for petroleum and gas, we have found that the Shield dips very gently underneath this cover of younger rocks, so that the extent of typical Shield rocks is really much greater than

the area exposed. The younger rocks outcrop for hundreds of miles from the Shield to the Cordillera, and north down the Mackenzie Valley and across more southerly parts of the Arctic Archipelago. This great area is underlain by Paleozoic strata of various ages, largely dolomites and limestones, and these in turn are overlain by much more extensive beds of Mesozoic and early Tertiary ages, which are largely sandstone and shale. I am sure there is no one here who has not heard of the Bearpaw shale which was deposited during this time. Because the Shield has been stable since the beginning of Precambrian times, and the cover rocks are generally rather thin, somewhere in the order of 3,000 meters, these cover rocks have been subjected only to gentle tiltings and warpings.

The Hudson Bay Lowland is underlain by poorly exposed, almost flat-lying Paleozoic strata, mainly limestone and dolomite, and, in the southeastern part, by Mesozoic strata including large deposits of lignite. Studies undertaken in 1965, however, indicate the possibility of 2000 meters of sedimentary rocks under the waters of Hudson Bay.

The Great Lakes–St. Lawrence Lowlands extend along the southern margin of the Shield and are separated by a narrow strip of exposed Precambrian rocks called the Frontenac Axis, which forms the Thousand Islands in the St. Lawrence River and widens to the south to join the Adirondack area of the United States. These Lowlands are underlain by gently warped Paleozoic limestone, dolomite, sandstone, and shale and it is the differential erosion of these beds that has produced Niagara Falls. The first petroleum and gas produced in Canada were derived from some of these strata north of Lake Erie, but although still productive, the area is now greatly outranked by the Interior Plains.

The generally flat character of the St. Lawrence Lowland is broken by a chain of hills called the Monteregian Hills, of which Mount Royal is one. They are remnants of small pods of alkaline rocks, more resistant than the surrounding strata, which were intruded during Mesozoic time and are the potential source of several of the rarer elements, such as columbium.

THE APPALACHIAN REGION

The Appalachian region of Canada is the northern terminus of an ancient mountain system that occupies much of the eastern part of the United States (Fig. 1). These mountains were formed from the great thicknesses of sedimentary and volcanic rocks deposited in a large geosyncline in Paleozoic time. The island of Newfoundland is a part of the sequence and several geologists have speculated on the possibility that Newfoundland may be the actual link between the Appalachians of North America and the Highlands of Scotland. This region is characterized by a long curving fault that probably extends far to the east beneath the Gulf of St. Lawrence and the Cabot Strait. It is called Logan's line after its discoverer, Sir William Logan, the first director of the Geological Survey of Canada, and it marks a zone of modern earthquakes.

The rocks in the Appalachians are principally Paleozoic, many of which appear to have been deposited in local basins in an area that was sinking over a fairly broad belt, but at different rates at different times and different places. This belt was deformed by three main orogenies, one in fairly early Paleozoic time, another about the middle of the Paleozoic, and finally the formation of the main Appalachian mountains. In Canada, however, this last activity was not as pronounced as it was farther to the south in the United States. The Canadian Appalachian is a source of coal and

mineral deposits, and has potential for oil and gas, especially in the continental shelves.

THE CORDILLERAN REGION

In spite of its great extent in Canada, the Canadian Cordilleran is but a small segment of a huge system of mountains extending from Alaska to the southern tip of South America (Fig. 1). The Canadian part is divided geologically, and physiographically, into two northerly-trending zones by an extraordinarily deep and persistent valley called the Rocky Mountain Trench. It extends virtually the entire length of British Columbia and is related, at least partly, to erosion along zones of faults. The Cordilleran contains great thicknesses of sedimentary strata that are undoubtedly of late Precambrian age, but most of the rocks are Paleozoic and Mesozoic.

The western region of the Cordilleran, that west of the Rocky Mountain Trench, contains a great variety of rocks all subjected to, or a result of, various orogenies that culminated in the Nevadan orogeny late in Mesozoic time. This was accompanied by very large, complex intrusive bodies, generally known as the Coast Range intrusions. After erosion had worn down the mountains, freshwater sediments that later became sandstone and shale were deposited in local basins, and basaltic lava was spread over wide plateau areas. Some volcanic activity has continued almost to the present day.

In the eastern region sedimentation continued until late Mesozoic or early Tertiary times. These great accumulations were folded and faulted by the Laramide orogeny which concluded early in the Tertiary—that is, somewhat later than in the western region. There are relatively few indications of volcanic or intrusive activity associated with this western orogeny. Some regard the Cordilleran as a classic example of parallel geosynclines of different kinds, one being deformed earlier accompanied by much igneous activity, the other being mainly a site of sedimentation and deformed later. Other geologists, however, think that there may be igneous rocks beneath the presently exposed strata of the eastern region. However that may be, the western block with its igneous intrusions is a source of great mineral wealth, whereas the eastern block contains few such deposits, though rich in coal and with possibilities for petroleum.

INNUITIAN REGION

This mountainous belt, which extends across the Canadian Arctic (Fig. 1), is known mainly from reconnaissance surveys, although much activity is now in progress, not only by the Geological Survey of Canada and other agencies of government but by petroleum and mineral exploration companies. The mountainous belt is composed of moderately to intensely folded sedimentary volcanic and metamorphic strata of several ages. So far, five separate belts of intense folding have been recognized, belts in which deformation occurred in different directions and different times ranging from fairly early Paleozoic to Tertiary. Undoubtedly Precambrian strata are involved in this folding. Because there is so little vegetation in the Arctic some of the most spectacular exposures of geological structures are displayed in this region—reefs, piercement domes, folds, and so on. No deposits of economic value have so far been discovered but the region does contain occurrences of metallic and non-metallic minerals and of coal. In the less deformed parts there are excellent possibilities for petroleum and natural gas, which are now being investigated.

PLEISTOCENE GEOLOGY

The mantle of gravelly, sandy, and clayey materials that forms the ground upon which most of us work and live is the product of the latest events in the long geological history of the earth (Fig. 2). In Canada, most of these unconsolidated, or surficial, deposits owe their existence to the latest of the glacial ice sheets that were the manifestation of the great continental glaciation of the last million years. Unconsolidated deposits form the surface ground in more than 90 per cent of the area of Canada, covering the solid bedrock to depths ranging from a few inches to many hundreds of feet and in a complex arrangement. Such deposits are the parent materials of the soils that grow our crops and forests. They serve—well or poorly—as foundations for most buildings, roads, and other structures, and supply some of the materials from which they are built. Some of these deposits constitute underground reservoirs that supply water to wells or rivers, whereas others conveniently absorb sewage or industrial waste. Moreover, the varied forms of the surface of these deposits make up part of the landscape of the earth and are responsible for hills, valleys, and plains; lakes and rivers; sandy beaches; and so on.

During the last glaciation, almost all of Canada was covered with ice. As a matter of fact, Canada includes a much larger area of glaciated terrain than any other country, including the U.S.S.R. From its maximum some 15,000 to 13,000 years ago the main continental ice sheet withdrew on all sides in a general way into the Hudson Bay region and then broke up into remnants. The last ice disappeared from the continental mainland some 6500 or 7000 years ago. Thus most of our soil and foundation problems originated in a fraction of a second on our geological clock.

Retreat of the ice left widespread deposits of till and displayed striking topographic forms and patterns, especially in the northern barren lands of Canada. Marine and freshwater clay accumulated in many parts of the country during and shortly after wastage of the ice sheet. These marine clays are the source of a multitude of foundation problems in various coastal regions and in some lowland areas that were flooded by the sea immediately following glacial retreat when the earth's crust was still depressed from the weight of the ice. Particularly noteworthy is the highly sensitive Leda clay of the St. Lawrence and Ottawa valleys which accumulated on the bed of the Champlain Sea between 10,000 and 12,000 years ago. This material has given rise to innumerable land slides, chiefly of the earth-flow or flow-slide type, as well as causing major foundation problems resulting from its high degree of consolidation under load and from shrinking and swelling through changes of its water content. You will hear more about this in the days to come, of that I am sure. Incidentally, if this lecture were being given during the time of the Champlain Sea, we would be about 175 meters below its surface.

Like the marine clays, the glacial freshwater clays and silts have limited load-bearing capacity and will liquefy and flow when disturbed. These materials accumulated in numerous glacial lakes in depressions dammed by the retreating ice or by tilting of the land that accompanied deglaciation. The lakes changed progressively in size and shape as the ice retreated and the land rose. Probably the largest of these was glacial Lake Agassiz, more than 200 miles wide and 500 miles long, that lay along the western edge of the Canadian Shield northwest of the Great Lakes. The city of Winnipeg is built on clays that formed on the bed of this lake.

Glacial erosion and deposition have produced many aspects of the topography of Canada, of course. Thus the

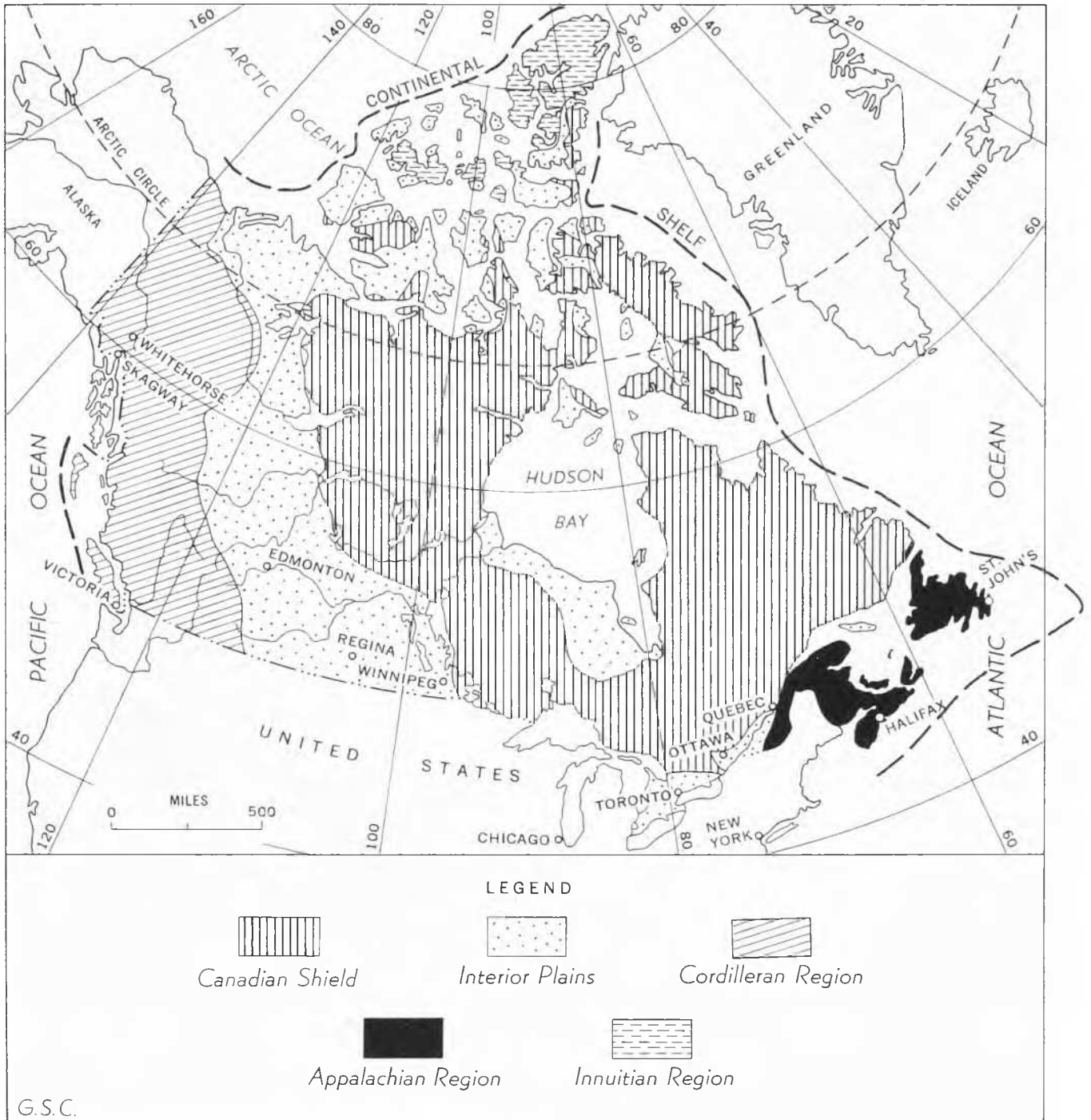


FIG 1. Main geological regions and approximate limits of continental shelves.

present forms of mountains, hills, valleys, and plains have been modified by glaciation; most lakes occupy basins sculptured by glacial action, and the courses of many rivers are controlled by glacial features and glacial history. In the mountainous parts of Canada the steep-walled deep glacial valleys, prone to landslides and other earth movements, create special engineering problems. The deep erosion of valleys by glaciers and by glacial meltwater streams has also produced unbalanced rebound stresses in the underlying rocks. Landslide and foundation problems in the Cretaceous

shales of Alberta and Saskatchewan are a direct result of this effect.

The glacier deposits covered previous unconsolidated materials as well as bedrock, a fortunate phenomenon in some localities. For example, the semi-arid plains of western Canada conceal the buried water courses of preglacial rivers. The gravels of these old rivers store vast quantities of potable water and the development of these sources, now just nicely under way, is of great economic significance to the "bread-basket" of Canada.

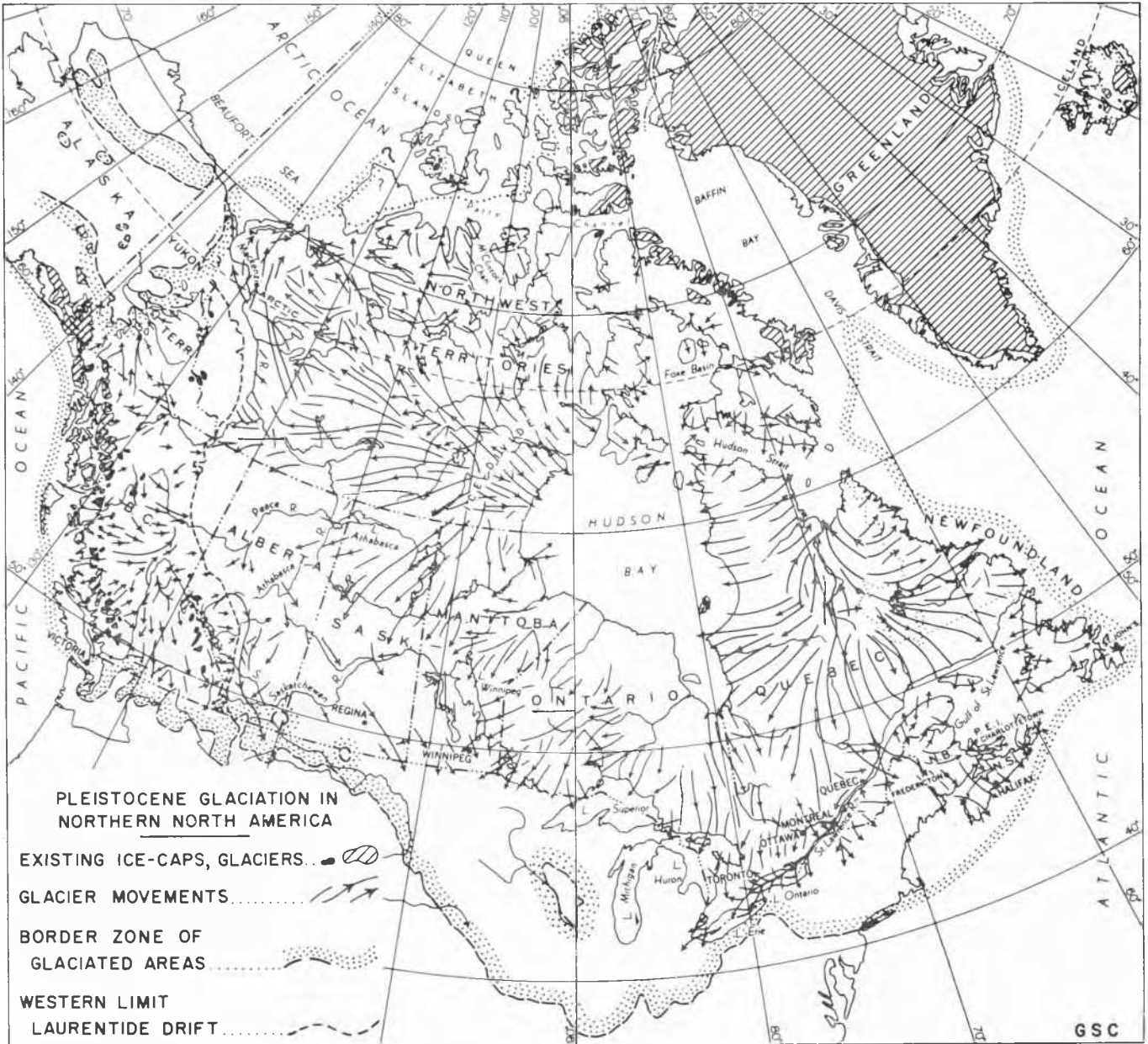


FIG. 2. Pleistocene glaciation in northern North America.

During glaciation the crust of the earth throughout most of Canada was depressed by the weight of the ice. It then rose again when the ice retreated, the rebound in some places totalling more than 1000 feet. The rebound was rapid at first, immediately following ice retreat, and then became progressively slower. Fortunately, the rapid initial uplift, which produced relative movement of local sea level of 20 to 30 feet per century and comparable tilting of lake shores, has now given way to movements of a foot per century or less. Present changes of water level, of course, are the result of various factors. Thus, in addition to residual glacial rebound, other factors include local sea level changes that reflect world-wide changes of sea level (slight rise), tectonic oscillations of the land itself (a "drowning" along the shores of the Maritime Provinces during the past 4,000 years may be attributable to this cause), and sinking caused by accumu-

lation of thick sediments such as at the mouth of the Fraser River.

POST-GLACIAL DEPOSITS AND EVENTS

Recent geological changes in Canada generally are less striking than those related to glaciation. In most situations, the story is one of progressive modification of the landscape by agents that are still operative, such as erosion and aggradation of rivers, degradation and construction of shoreline features, accumulation of offshore sediments, migration of dunes, downslope movements of surface materials, and so on. The pace of these changes has varied as a result of local factors such as lake and sea level adjustments, and long-term climatic trends. The climates, determined from stratigraphic palynology, involved increasing warmth and dryness following deglaciation culminating in a "climatic optimum"

(warmer than present) about 6000 to 5000 years ago, then increasing moisture and dropping temperature until about 2000 years ago, and finally a slight warming to the present.

In the colder parts of Canada, climate since glaciation has been responsible for the establishment of widespread muskeg and bog, the development of permafrost, and the persistence and/or expansion of glaciers. The bog and muskeg deposits, which locally exceed 10 or even 20 feet in thickness, consist of organic material mixed in some places with inorganic sediment that has accumulated during periods of as much as 12,000 years. Throughout much of northern Canada the near surface rocks and soils are in a perennially frozen or permafrost condition. Near the southern limit of its range, permafrost is discontinuous and only a few feet to a few tens of feet in thickness, but farther north it becomes pro-

gressively more continuous and attains thicknesses of hundreds of feet. Much of the permafrost in Canada is believed to have formed since the land emerged from beneath the glaciers, glacial lakes, and the sea and, thus, to be a consequence of post-glacial climate. Variations in post-glacial climate hundreds or thousands of years ago probably are responsible for some of the complexities of permafrost distribution in the discontinuous zone. Much older permafrost probably exists in parts of the Yukon and in other northern areas that were not ice-covered during the last glaciation. The effect of permafrost on the properties of rock and soil materials in northern Canada has been the subject of special studies by the Division of Building Research under the able and imaginative direction of Dr. Legget, to whose care I take much pleasure in returning the meeting.