RESEARCH IN GEOLOGY AND GEOMORPHOLOGY IN THE NORTH AMERICAN ARCTIC AND SUBARCTIC

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THIS paper defines, in general terms, the status of research in the north in geology and geomorphology, and reveals some of the limitations to present knowledge in these fields.

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Geological mapping

Of first importance in the understanding of the geology of any region is the availability of adequate geological maps. Ideally such an understanding develops from the exploratory, through the reconnaissance, to the detailed stage. In the North American Arctic and Subarctic this pattern broadly applies, but the six great regions, Alaska, Yukon, Mackenzie, Keewatin, Ungava and Franklin each present special problems owing to their diversity in character. Because of this it is not feasible to adhere everywhere to the ideal pattern, and individual variations are necessary to facilitate more rapid coverage with maps of practical scales and standards for the different terrains.

In Alaska, the Yukon, and the Cordilleran parts of Mackenzie, the system is fairly standard. Exploratory, reconnaissance, and detailed mapping are in progress, though at different stages of completion. The exploratory geological mapping, usually published on a scale of about 1:500,000 or smaller, is perhaps 60 per cent complete in Alaska and in the Yukon. It is followed by reconnaissance mapping using scales of about 1:250,000, and for this some 38 per cent of Alaska and 15 per cent of the Yukon have been covered. More detailed maps on scales from 1:63,360 to 1:12,000, and occasionally on even larger scales, are made of selected areas.

In the unforested parts of the Precambrian areas of Mackenzie and Keewatin geological mapping is following a somewhat different course. In 1952 "Operation Keewatin", undertaken by C. S. Lord and others of the Geological

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Survey of Canada, introduced a new method of Canadian reconnaissance mapping. By use of helicopters and supply aircraft 57,000 square miles were methodically traversed for geological maps on a scale of 1:500,000 and, where it seemed desirable, interesting localities were examined in greater detail. This method of mapping is being applied to all suitable terrain where it is filling the role of both exploratory and reconnaissance mapping of bedrock and Pleistocene features. From its results areas for more detailed mapping will be selected. In the forested areas of these districts, largely in Mackenzie where the aerial technique is less suitable or impracticable, the system of mapping is similar to that used in Alaska and the Yukon; and some 16 per cent of these areas have been completed on a reconnaissance scale of 1:250,000.

In Ungava, which is largely forested, the exploratory mapping has been taken over by companies holding great concessions, and the government work has concentrated on reconnaissance mapping. The Labrador Trough region is being covered first, and about 10 per cent of Ungava has been mapped on a scale of 1:250,000 and more detailed mapping of selected districts is also in progress.

For Franklin, the plan is similar to that for the open areas of Mackenzie and Keewatin and coverage with maps on a scale of 1:500,000 is the first objective. The work was first begun with boats for transport in the field, but in 1955 "Operation Franklin" was carried out almost entirely with helicopters and supply aircraft over a huge area in the Queen Elizabeth Islands. No mapping on the reconnaissance scales is planned, but detailed maps of selected areas are contemplated.

Most of the geological mapping in the north has been of bedrock. In the past few years, however, some minor attention has been paid to the mapping of surface deposits, and the need for such mapping must be emphasized in view of the development that is underway or planned in the north.

In the last ten or twelve years, mapping programs have been accelerated by the development of modern methods, instruments, equipment, and transportation, and by the increase of general interest in the north. Among the new "tools", the use of air photographs is of paramount importance, and has done more than any other development to enhance the speed, accuracy, and completeness of mapping on all scales.

In general, while geological mapping in the Arctic and Subarctic, and the compilation and release of information have been and will probably continue to be the responsibility of government surveys, certain work is nevertheless suitable for other groups. In particular, the fields of local studies and mapping, and of research on topical problem studies, which always includes some mapping, may be mentioned. Some notable contributions to geological mapping have already been made by companies, and various agencies in papers, periodicals, books, and maps. But as a rule, companies have no desire to make their work public, although a few in Canada have turned over their general results to the government for publication. A notable instance is the 'Canol geological investigations', largely the work of the Imperial Oil Company Limited, compiled by G. S. Hume and T. A. Link, and published in Paper

45-16 of the Geological Survey of Canada. The recent condition for grants of large prospecting concessions in Canada, that copies of the geological maps and reports of the companies be given to the government within a specified period is expediting mapping by non-governmental groups.

Geological processes

Like geological mapping, the study and interpretation of geological processes peculiar to, or of special importance, in the north offers a most fruitful and much neglected opportunity. It should, of course, be kept in mind that processes such as ore deposition and vulcanism can be studied more effectively in temperate and accessible regions, although there will always be special instances when research on these two processes will have to be carried on in the north.

Under the rigorous climate of the Arctic and Subarctic, both chemical deterioration and mechanical disintegration differ from these processes in more temperate areas. This difference is due in part to frequent temperature changes, which cause materials near the surface to move back and forth from below to above the freezing point of water. The transportation of released material has not yet been investigated in the systematic fashion it deserves. More thorough studies should be made, for example, of the effects of rapid fluctuation and frequent overloading of glacial streams, the sediment contributed by the abrasive action of glaciers, and the transportation of material by floating ice on rivers as well as on the sea, the drying of surface materials in relatively arid areas as a result of the lowering of the permafrost level, the rapid growth of plants that form the mat-like tundra vegetation in the long, warm, summer days, severe and repeated frost action, low evaporation, and many other factors. Frost action is one of the most important geological processes in cold areas; some work has been done in the laboratory, but quantitative study in the field is needed.

Of special importance in the north is the mass wasting of material through such means as solifluction and rock glaciers. Some qualitative investigations have been made in these fields but there is specific need now for quantitative data, for example on rate of movement and angle of slope. The rate and type of soil formation would also be significant. Data could be gathered from carefully selected, easily accessible localities without great cost. As might be expected, the deposition of material is also widely different from the better known pattern in lower latitudes. This difference obtains on land and in streams, lakes, and the Arctic Ocean.

Large annual icefields are developed along many of the major rivers of the Arctic. The ice of such fields is sometimes referred to as "aufeis", and the process as "glacial icing". The literature is not clear as to just how such icefields form, how they grow, or the nature of their annual cycle. Some of these fields are large, 50 square miles or more, and their study would combine the application of geomorphology, hydrology, and related subjects.

Permafrost

A better understanding of the various phenomena of permafrost would be immediately useful in construction and development projects in the north. The English-speaking countries have made a late start in systematic investigations of permafrost, although considerable opportunity is available in North America to study geological processes controlled or modified by permafrost. Some work has been done in the investigation of such processes. For instance, R. E. Wallace and R. F. Black in Alaska have studied lake modification. Physiographic phases of the floodplain have been studied in permafrost areas, and the processes controlling them have been worked out by T. L. Péwé on the lower Yukon River, and the results applied to other large rivers in interior Alaska such as the Kuskokwim, Koyukuk, and Tanana. Processes important in the development of thermokarst topography have also been partially studied, and ice wedges have been examined in some detail. Accurate temperature measurements of frozen ground, including long- and short-term fluctuations, are now being made, and have been discussed by G. R. MacCarthy and M. C. Brewer. The origin of permafrost, however, has scarcely been touched upon.

Glaciology

In general, glaciation and glaciology in North America can be studied most effectively in the Subarctic ranging into the temperate zone but some work in the Arctic is essential. Substantial progress and much interest in these large fields have recently been shown by a number of groups, especially in Alaska and the Yukon, but much more remains to be done. In particular, research is needed on the glaciers and icefields of the north and on all the circumstances of their existence throughout postglacial time, before a proper grasp can be obtained of the many variable factors which lead to the presence of glaciers and to the phenomena associated with Pleistocene glaciation. In conjunction with these studies, work on glacial processes, including the physics of ice, is needed. A complete plot of all the northern glaciers, including the present boundaries and past stages, and extending back as far as possible in geological time, would also be valuable.

The Arctic and Subarctic of North America contain excellent fields for glaciological research in the western Cordillera and the eastern and northeastern islands. On the west there are the numerous great valley glaciers of the Alaska Range, the various coastal ranges, and the St. Elias Mountains. The larger glaciers, which have their sources in the icefields of these great ranges, flow outward in nearly all directions to regions of very different climates. Those moving southward are subjected to the relatively even temperatures and nourishing high precipitations of the coast in contrast to those passing northward into the semi-arid interior climate with its extreme temperatures. In these ranges, too, every variety of alpine glacier from the small, isolated individuals in cirques to great branching, many-headed, valley glaciers exist. It seems likely that the study of the distribution of the small glaciers and groups of glaciers in northern Alaska, the Yukon, and western Mackenzie may shed light on the local microclimates, recent climatic changes, and geological history. The recent development of these regions, with the accompanying improvements in transportation, has brought a number of glaciers within the reach of modestly financed expeditions, of which many will be required in the future, since each glacier commonly requires individual study.

Northeast of the Mackenzie Mountains, the nearest glaciers and icefields are those of the eastern and northeastern Arctic Archipelago, where they are scattered over the areas east and north of an arc extending from Meighen Island, through Devon Island, to Cumberland Peninsula on Baffin Island. These glaciers, lying largely in latitudes well north of those on the western mainland of the continent, have environments of their own, and some appear to be thriving in areas which, in the light of present knowledge, receive inadequate precipitation for their existence.

In Alaska, the study of glacial processes has been receiving increasing attention. The early reconnaissance work done by Capps, Moffit, Smith, and others who studied glacial deposits incidentally to bedrock geology, has given way to a new phase in which the glacial deposits of broad areas have been mapped by Detterman, Fernald, Hopkins, Karlstrom, Krinsley, Muller, Péwé, Wahrhaftig, and others, and the information has been brought together by Péwé for publication. A glacial map of Alaska comparable in quality to the 'Glacial map of the United States', is now being compiled, by tying together by means of airphoto interpretation the areas where study has been completed.

In the Canadian north the study of Pleistocene and glaciological phenomena is increasing. This trend is due partly to the growing realization of the economic importance of the region, and also to the fact that the new topographical maps and air photographs are making information expressed by surface features more readily obtainable for large and remote areas. In the Yukon, much attention is being paid to the study and mapping of overburden, glacial phenomena, and general surface features both in the glaciated and unglaciated regions, but this work is still second to the mapping of the bedrock geology. In the other districts to the northeast the same is true. In 1952 the Geological Survey of Canada allotted a specialist to "Operation Keewatin", to devote his entire time to Pleistocene and surface geology, and this practice is expected to be continued for similar operations in the future.

Some problems of soil formation in different parts of the Arctic and Subarctic are closely associated with glaciation. Great differences, for instance, are apparent between the well developed soils of the large Yukon valleys between 60° and 65°N. latitude and the general lack of soil in central Ungava at about 55°N. The study of the factors contributing to this difference may show that the two regions have had different climatic histories since the close of the Pleistocene epoch.

The investigation of the origin and movement of loess provides a great opportunity for studying processes related to glaciation. Alaska, particularly, and the southwestern Yukon, with their active, braided, glacial streams and outwash plains, offer excellent fields for such studies.

Stratigraphy and structure

The geology of an area cannot be fully interpreted or correlated with that of other areas without understanding the geological succession in the stratified rocks, their structure, and their relationships within the area and with other areas. Over much of the North American Arctic, knowledge of the stratigraphy and structure is fragmentary, general, and only broadly useful.

The nature of the major geological structures in Alaska is fairly well known, and many details of the structural geology of a few areas, such as much of the Arctic Slope, have been studied. Over most of Alaska, however, structural detail has not been worked out. Such details are needed both for local application, and for helping to fill the gaps in current knowledge of the major structural patterns. Modern air photographs of Alaska are expected in the near future to lead to major advances in understanding the structural geology of the Territory.

Regional studies by specialized stratigraphers and paleontologists are particularly needed. The value of such work can readily be seen in the recent and very important contribution to knowledge of the Jurassic and Cretaceous systems in Alaska made by Ralph Imlay of the U.S. Geological Survey. One particularly important part of Alaska requiring study is the area along the international boundary between the Yukon River and the arctic coast. This, and studies of some other areas, might well extend across national boundaries, and include reviews of Siberian literature.

Detailed paleobotanical collecting and research, including spore studies, are needed to solve some Cretaceous and Tertiary problems in Alaska. For example, gently deformed Tertiary sections containing coals of low rank, as in the Kenai and Little Susitna districts, have in the past been assumed to be equivalent to more strongly deformed Tertiary sections containing high-rank coal beds, as in the Matanuska Valley area. It is now believed that the latter rocks, which are approximately conformable with Cretaceous strata, are older, possibly Paleocene, and may unconformably underlie the large areas of the less deformed beds, which in turn may be Eocene. The solution of this problem by paleobotanical studies, supplemented by test drilling, is important because of the shortage of bituminous coal in Alaska.

Detailed micropaleontological studies of Mesozoic formations in Alaska are also needed. Mesozoic rocks generally contain few megafossils, but recent age determinations by micropaleontological methods of Mesozoic rocks in northern Alaska have shown what could be done if such work were extended throughout the Territory.

In the Yukon and the Cordilleran part of Mackenzie, many aspects of stratigraphy and structure await further study. For example, much of the Yukon Plateau consists of metamorphosed, stratified rocks, referred to as the "Yukon group", of which the age, succession, and structure present a multitude of problems. Not only does the altered condition of the rocks make the solution difficult, but their concealment by overburden and by younger rocks, and their interruption by many intrusions frequently prevent the tracing of marked horizons. The main problems are establishing the succession and correlation within the group, and determining the age. These problems are followed by those of correlating the structure of infolded or downfaulted areas of somewhat similar rocks, which by slight differences of composition and metamorphism and, in some instances, the presence of organic remains, suggest a younger age. Recent work by H. Gabrielse of the Geological Survey of Canada, in northern British Columbia, close to the Yukon, has revealed excellently preserved Lower Cambrian fossils in strata apparently overlying a great thickness of metamorphosed sedimentary rocks. Farther north, similar strata occur in the Yukon group. Thus, while most of the Yukon group is generally believed to be Precambrian, some rocks included in it may be Paleozoic, while others may be divisible from the main part as late Precambrian.

In the mountains around the Yukon Plateau the Paleozoic is present nearly everywhere. To the northeast in the Mackenzie Mountains a relatively complete section seems to await study: the Paleozoic appears in considerable thicknesses and, though large gaps occur in the succession, all the major periods are represented somewhere.

The relationships of the Upper Paleozoic and the Mesozoic in the Yukon Plateau present a variety of problems. Determinable faunas of Carboniferous, Permian, Triassic, and Jurassic ages have all been found, but persistent fossil horizons are usually rare. Moreover the general lithological similarities, and the intermingled masses of volcanic materials, make the understanding of their stratigraphy and structure extremely difficult. The early Mesozoic, however, is relatively well represented with several fossil horizons, and is now being studied by E. T. Tozer of the Geological Survey of Canada.

The Upper Mesozoic marine strata are unconformably overlain by a great assemblage of coarse, continental, clastic, sedimentary rocks with small amounts of volcanic material interbedded. The upper part of this assemblage, the Tantalus coal measures, is dated by its early Lower Cretaceous flora, but the age of the lower part, generally considered to be Jurassic, is uncertain. The Tantalus measures are overlain by a huge mass of volcanic rocks very similar to those mixed with the earlier Mesozoic and late Paleozoic. An analysis of the stratigraphy and structure of this mass of strata presents many intricate and difficult problems particularly in view of the general lack of fossils in the Upper Mesozoic.

The late Mesozoic volcanic rocks and the Tantalus measures are invaded by granitic intrusions, and are truncated by the erosion surface on which the Tertiary rocks rest. The whole interval at the close of the Mesozoic in the Yukon is poorly understood. The volcanic rocks are grouped together on such uncertain bases as lithology and distribution, and show obscure or varied relationships with the different intrusions and older strata. Determination of the succession, structure, and history of these rocks and their correlation with events at the close of the Mesozoic and opening of the Tertiary are major problems.

The earliest Tertiary rocks in the Yukon are continental, clastic, sedimentary strata showing extreme variations in consolidation, and usually some warping and faulting. They commonly lie in depressions or valleys of steep relief in the dissected surface of the older rocks. In earlier explorations their floras were dated as Eocene, but those found in recent years are placed in the Paleocene. As in Alaska, the correct dating and sorting out of the many basins of these rocks requires broad study.

The Tertiary sedimentary beds are overlain by volcanic rocks, scattered in large and small patches over the Yukon Plateau and parts of the encircling ranges. These rocks exhibit different relationships from place to place. In some localities they are tilted and truncated by the mid-Tertiary or later erosion surfaces. In others they are spread upon it, and elsewhere they lie at various levels of dissection in its valleys. The record of the Tertiary history of the Yukon contained in them awaits assembling from a regional study.

Much of the western Yukon escaped Pleistocene glaciation. Mapping has now traced the general outline of the irregular front of the ice during its last major advance. More than one advance is recorded in several widely separated localities, and the earlier movements in most cases are the more extensive. These advances have left a sequence of deposits that overlap the gravels and other deposits of the unglaciated region. Together, these phenomena contain an intriguing record of the geological events of the region from the present back into the Pleistocene, and perhaps to the late Tertiary.

In the northern Yukon there has been little exploration on the ground, but air photography has been particularly valuable in delineating the broad geological features. The Porcupine Plain is revealed as an area of relatively flat-lying rocks and few outcrops, while in the surrounding mountains thick sections are exposed where the upturned strata and remarkable open structures of the ridges around the borders resemble those of the Appalachians, and also of the Parry Islands in the Arctic Archipelago. Sections of Tertiary, Mesozoic, Paleozoic, and even Precambrian sedimentary rocks are known in the ranges of the northern Yukon. During 1953 much of this region was explored in a search for oil and metals, and new information on it is expected to be available shortly. But geological exploration is still in too early a stage to pick out problems.

East of the Cordillera in Mackenzie and Keewatin, exploration is still in a preliminary stage, but "Operation Keewatin" extended the knowledge of the Precambrian section, revealing that the areas of Precambrian sedimentary and volcanic rocks are larger than previously supposed, and that many members, previously regarded as Archean, are of Proterozoic age. The sequence of the Precambrian strata in this region presents many interesting problems.

In recent years the discoveries of large deposits of iron ore in Ungava have led to the detailed study of the stratigraphy and structure of the Labrador Trough and the search for areas of similar rocks in the surrounding region. In the northern or subarctic parts of Ungava such rocks have been discovered only in the northern extension of the trough to the west of Ungava Bay and in a belt extending from Wakeham Bay to Cape Smith. The correlation of the rocks of the trough with those of the belt, and again with those of the Belcher Island and Nastapoka Bay group are the main problems.

Franklin is less known than the other districts but the widespread pattern of the explorations dating back to the early nineteenth century forms the skeleton of a remarkably complete general picture of the region. Many of its chief geological features and problems are set out by Y. O. Fortier and R. Thorsteinsson in their important paper on the Parry Islands folded belt.[1] The platform of the Precambrian Shield, composed of old crystalline rocks mantled in part by Proterozoic strata, slopes generally west from the highlands of Baffin, Devon, and southeastern Ellesmere islands, and very gently north from the mainland. In the southern part its surface is characterized by broad undulations whose hollows contain wide basins of both Proterozoic and Paleozoic strata. As a whole the rocks become progressively younger northwestward passing from Proterozoic through Paleozoic to Mesozoic and Tertiary.

In the south, between the waters of M'Clure Strait and Viscount Melville and Lancaster sounds and the mainland, broad ridges of the Precambrian rocks separated by basins of Paleozoic strata present many interesting subjects for study in Precambrian succession and Precambrian–Paleozoic relationships. The Paleozoic sections of the basins also contain many problems. Northward, in a broad arc from Melville Island to the northeast coast of Ellesmere Island and northern Greenland, belts of folded Paleozoic and Mesozoic strata form the Innuitian Region, which presents numerous problems of stratigraphy and structure. Northwest of this region the geology is even less known, though Mesozoic and Tertiary rocks, including some of both extrusive and intrusive origins have been found.

The government surveys have expended much of their effort on stratigraphy and structure, and notable advances are anticipated in the next few years. Nevertheless, these are large and important fields, and ample room remains in them for appropriate attack by other research scientists. Many of the fields will involve work in areas which are relatively inaccessible and isolated by long distances, and are therefore expensive to operate in. Economy of cost and efficiency of effort can be greatly enhanced by close cooperation among workers interested in different branches of science and by the joint use of existing facilities.

Geomorphology

The geomorphology of arctic and subarctic areas has been attracting substantial attention over the last few years. Much of this work has been a by-product of other investigations, but some has been done for its own merit. At present the greatest need is for a better grasp of such processes as rock disintegration, transportation, and sedimentation. While geomorphology in the north has probably been receiving about as much attention as other aspects of geological research, it is unlikely that the field will be fully occupied either by the government agencies or by mining companies, although some work has been done by both.

[1]Fortier, Y. O. and R. Thorsteinsson. 1953. "The Parry Islands folded belt in the Canadian Arctic Archipelago". *Amer. J. Sci.* Vol. 251, pp. 259–67.

In appraising the need for additional geomorphological research in the Arctic it should be remembered that the validity of conclusions in this type of research frequently depends on adequate bedrock maps and adequate knowledge of pre-Quaternary stratigraphy. In Alaska, substantial advances in geomorphology have recently been made, especially through projects of the Alaska Terrain and Permafrost Unit of the Military Geology Branch of the U.S. Geological Survey. Areas in Alaska where geomorphological information is lacking or scanty, and in which little or no research to our knowledge is now being done include:

(1) The southern front of the Brooks Range. Investigations should be undertaken preferably in conjunction with geological mapping on the same scale as, and after the completion of, adequate base maps.

(2) The Ray Mountains and the Koyukuk River basin.

(3) The lower Yukon River area.

(4) The Alaska Range between the head of the Nushagak River and the upper Kuskokwim River area, and between the upper Kuskokwim and the McKinley tributary of the Kantishna River.

(5) The Wrangell Mountains and the basin of the White River. Much important information regarding the geomorphological history of Alaska could be obtained in this area, where early Tertiary tills and an almost complete Tertiary volcanic sequence are reported. Good base maps presumably will be available in a few years. The work should be done in conjunction with remapping of the bedrock on an adequate scale.

(6) The basin of the Fortymile River and other parts of the Yukon–Tanana plateau.

(7) The western part of the Susitna River basin. Geomorphological studies could well be made in conjunction with the mapping of the coal resources of the Tyonek area and the gold placers of the Peters Hills.

The following studies should throw more light on geomorphological history:

(1) A study of the Yukon–Tanana plateau with special reference to origin and date of deposition of gold placers. In the Fairbanks district work should concentrate on pre-Wisconsin history.

(2) Geomorphological reconnaissance of Alaska, primarily to work out the preglacial geomorphological development of the Territory. This would consist of (a) intensive review of the literature and reading of old field notes, followed by (b) discussions with field geologists of geomorphological problems and evidence in their areas, followed by (c) study of air photographs, testing and developing hypotheses gained in parts (a) and (b), followed by (d) one or two seasons of intensive reconnaissance along existing routes of travel, to check and develop hypotheses, followed by (e) one or two seasons of intensive helicopter-borne reconnaissance. This would be at least a 6-year project. Its immediate economic value is in connection with gold placers.

In northern Canada the study of geomorphology has received little attention. The essential need is for a better grasp of the working of geomorphological processes characteristic of the north. In the Yukon, on the border of the region where arctic processes are active, the main features appear to owe their character to those processes normal throughout most of Canada, but surface features are, at least, modified by such arctic processes as solifluction. Eastward and northward from the southern Yukon, the processes of the Arctic become more important in their bearing on the development of land forms. In Franklin, particularly, they are at a maximum. Here the problem is first to recognize the relative importance of marine submergence, glaciation, and such distinct arctic processes as solifluction, which now commonly mask features of other origins. The less conspicuous processes too, require study. For instance, the effects of erosion by the hard, sandy snow, driven so continuously by the wind against the outcrops of the arctic deserts through long winters, solution of rock by the cold waters, and chemical decomposition of rock under arctic conditions, all need proper evaluation before arctic geomorphology can be fully interpreted.

Ground water and engineering geology

Up to recent years, the subjects of water supply and sewage disposal have not been considered pressing in the Arctic and Subarctic. Actually, such problems have always existed and have always been closely related to the health situation of both native peoples and white inhabitants. With the coming of larger settlements and military establishments to the north, these problems have become critical. Water-supply and sewage-disposal problems are shared by surface-water and ground-water specialists. Surface water is dealt with in the field of hydrology and hence is not included in the scope of this paper. Ground water lies clearly within the bounds of geology.

It now seems inevitable that ground-water geology must play an important role in northern development. Already some of the larger communities such as Anchorage and Fairbanks are facing serious water problems that may well be solved in large part by the further development of ground-water supplies. Ground-water research appears to be largely a responsibility shared by the government surveys and the communities involved. At least two systematic government studies have been made in this field in Alaska. One of these applies specifically to the Anchorage area, and the other is of more general scope applying to all permafrost areas, and emphasizing ground-water principles rather than ground-water conditions in specific areas. In addition, a preliminary report on permafrost in the Fairbanks area, which briefly considers ground water, has recently been declassified and made available to the public.

While ground-water principles, as generally understood, apply in large parts of the Subarctic, new principles and new factors need to be appraised for permafrost areas. Thus ground-water geology in the north is closely related to both the permafrost and the geomorphological fields.

The application of geology to engineering works of various kinds such as highways, dams, tunnels, and foundations, and to deposits of such construction materials as sand, gravel, and clay, has long been a useful practice. This type of geological work has come to be known as engineering geology. In the past ten years or so the value of engineering geology has become increasingly appreciated until now it has assumed an important place in geological work.

The need for engineering geology is especially great in the Arctic and Subarctic. Here special problems of foundations for large structures and for such works as highways, dams, and airfields, are created by the presence of permafrost, by the thick ice that annually forms on streams and lakes, by severe frost action, by wide stream valleys, by great variation in stream flow, by floating ice, and by many other factors.

In Alaska, the U.S. Geological Survey has carried on a number of engineering geology projects; some of these were projects of the Military Geology Branch. An engineering geology study has been made of the Anchorage area. A study involving engineering geology has been carried on at Fairbanks and in the Dunbar vicinity west of Fairbanks. Similar studies have been made in a few other places and a few special projects have been carried on, such as the study of slide problems along the Nenana River gorge as related to railroad maintenance. A full-time engineering geologist has now been stationed in Alaska by the U.S. Geological Survey to work on principles needed in coping with highway and other pressing problems.

Engineering geology in the north shares with other branches of geology certain limitations imposed by inadequate knowledge of some geological processes. It is, however, a field which can make extraordinary contributions to northern development, and in which the governments must participate to a large extent. At present, the most pressing need is probably for research on the principles, whose application will then be the special responsibility of smaller government units, such as provinces, territories, and municipalities, and of private groups, such as contracting firms and mining companies.

The limits to present knowledge in geology and geomorphology have been emphasized throughout this paper, because an understanding of them is necessary for appraising the relative values of proposed research programs. In addition, the paper has pointed out some opportunities open to geologists in the Arctic and Subarctic; opportunities which are now far greater than the anticipated supply of geologists. The failure of universities to stimulate interest in northern research may be partly responsible for this scarcity of arctic geologists. Another factor may be the difficulties facing scientists in isolated northern regions. But the great demand for results from the north, and the opportunity for working in little-known fields where individual initiative is both required and rewarded should be ample compensation for any difficulties involved. It is hoped that this paper, although incomplete, may serve as a guide and stimulus to future geological and geomorphological research.