PERMAFROST RESEARCH

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"PERMAFROST" is a term now widely used to describe perennially frozen ground, a phenomenon which is peculiar to cold regions and at once of unusual scientific interest and of great practical significance. "Pergelisol" has been suggested (Bryan, 1946) as a more accurate name for this ground condition and "cryology" for its study, but the problems introduced into the development of arctic and subarctic areas by perennially frozen ground are becoming well known, and popular usage already appears to have eliminated the possibility of these desirable semantic clarifications. Some of the specialized problems concerned with permafrost are discussed in the papers on geophysical exploration, geology, agriculture, and meteorology in this volume; here the subject will be considered as a whole and the research which has been started and the challenging problems which face those engaged in this branch of scientific enquiry will be outlined.

It is not surprising to find that a large proportion of the surface layers of the northern land mass of the world is always at a temperature below freezing point. It is not generally appreciated, however, that about one-half of the area of Canada (Jenness, 1949) and as much as one-fifth of the land area of the world is perennially frozen near its surface (Muller, 1945). Some of this vast area consists of exposures of solid rock, the properties of which are not significantly changed by freezing or thawing. But when soils or coarsely crystalline rocks form the surface of the ground, especially if water is present in them, their character may be markedly affected by changes of temperature above or below freezing point. The term "permafrost" should correctly be used to describe all parts of the earth's surface which are consistently below a temperature of 0°C, and not merely perennially frozen soil.

Permafrost is no new phenomenon. It is at least contemporaneous with the present cycle of climatic conditions in the Arctic. It was recognized by Alexander Mackenzie and by other early travellers in the north but it is only in comparatively recent years that it has become a problem. As long as water in the summer and snow in the winter provided necessary transportation routes, and with buildings of simple design, the summer thawing out of permafrost was unimportant. When, however, frozen ground had to be cleared, first for road construction and then for the building of airfields, and with the advent of heated basements for buildings, the peculiar properties of permafrost made themselves very evident, especially to engineers. At the same time, the

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rapid extension of scientific work in the north has also automatically directed the attention of geologists in particular to a ground phenomenon which had for long been neglected.

Within the last decade, therefore, active programs of permafrost research have been started by United States authorities in Alaska, and even more recently similar work has been commenced in Canada. Individual studies had naturally been carried out previously, but an integrated approach to this problem is yet another development that resulted from the Second World War, for it was the building of the Alaska Highway and the construction of northern airfields which showed vividly how little was known about this peculiar feature of northern regions.

Detailed investigations were made along the Alaska Highway by United States authorities (Eager and Pryor, 1945). The U.S. Army Corps of Engineers subsequently established (under their St. Paul District Office) a field research station near Fairbanks (*Civil Engineering*, 1947), which is now under the direction of the Arctic Construction and Frost Effects Laboratory of the U.S. Army Corps of Engineers at Boston. This station has already carried out notable experimental work. It has since been joined in its efforts by the Snow, Ice and Permafrost Research Establishment of the U.S. Army Corps of Engineers, located at Wilmette, Illinois, whose mission is to perform research for and to coordinate the research program of the U.S. Department of Defense. The U.S. Geological Survey has had members of its staff engaged upon detailed field studies of permafrost, some of this work being linked with that of the U.S. Naval Petroleum Reserve at Point Barrow (Black, 1951). The programs of these several organizations in Alaska constitute the outstanding contribution to permafrost research in North America; although much of the work has been classified in character, enough records have been published to indicate the great value of the results obtained.

Development along the Mackenzie River Valley, the building of the Hudson Bay Railway, and the steady northern expansion of mining activity in the Dominion have combined to demonstrate to Canadians some of the problems associated with permafrost, but the knowledge and experience thus gained have not been widely circulated. The development of the small oil refinery at Norman Wells by Imperial Oil Limited, and the associated wartime Canol project, resulted in rather more detailed investigations (Hemstock, 1952) of this interesting area.

It was therefore not surprising when, after a survey of permafrost conditions in northern Canada, the Division of Building Research of the National Research Council of Canada selected Norman Wells as the site of its Northern Research Station. This was established in 1952 in cooperation with Imperial Oil Limited. It is intended that this station will be both a base for field and laboratory studies of permafrost, and a centre of information in connection with the special problems of building in the north of Canada. Work at Norman Wells is being started in close association with the United States organizations already noted so that duplication of effort will be obviated and integration of work ensured (Pihlainen, 1951).

All the problems connected with permafrost are determined by the local pattern of ground temperature. Temperatures in the ground are determined by the transfer of heat to the surface from the centre of the earth, representing a heat gain to the covering layer, and by the heat losses and heat gains at the surface, which are determined by the thermal environment above ground. Two distinct parts can be recognized in the heat exchange between surface and atmosphere, the conduction–convection heat exchange with the air and a radiant heat exchange with the sky. The former may at any given time represent a heat gain or a heat loss; the latter involves a large heat gain to the earth when the sun is shining, and a much smaller radiation exchange when the sun is not shining, which may be either a gain or a loss. Day-to-night variations in both air temperature and solar radiation may therefore cause a daily fluctuation in ground temperature, marked at the surface but extending only a few inches in depth because of the heat storage capacity of the earth. The yearly cycle is similar, but with the longer period the depth of influence may extend as much as 20 feet below the surface. There is also the possibility that a still longer cycle, involving geologic time intervals and therefore effective over a much greater depth, may also be involved. Other factors such as wind, snow cover, rainfall, evaporation, and vegetation cover may introduce variations in the thermal pattern, in addition to those inherent in air temperature and sunshine and in the physical properties of the ground (Legget and Peckover, 1949).

In southern Canada, it is usual for the ground to freeze in mid-winter although only to a relatively shallow depth. Because of the time-lag in temperature changes beneath the surface, the frost layer may be correspondingly lowered as the year advances, but, even in extreme cases, it will have disappeared by mid-summer. The annual mean temperature in this upper crust, about which the annual variations take place, appears usually to be very close to the mean annual local air temperature. The mean annual temperature of local ground water will be similar.

In areas where permafrost is encountered the local annual mean soil temperature is below freezing, but with the coming of summer the temperature of the upper crust will be raised above freezing point. This thawing will be evident only in those soils which contain water (clays and silts and some soil mixtures, sands, and gravels), and their consistency may change from being solid and rock-like to being wet and sloppy. This part of the soil which thaws out is called the "active layer". Its depth may vary locally from year to year but, under natural conditions, the variation will be small. The muskeg which is so prevalent over permafrost acts as an excellent insulating medium and tends to keep the active layer shallow.

When the muskeg, or any other natural cover, is removed, as in the clearing operations for road building, then the normal thermal pattern is lowered, frozen soil which has not previously been thawed will be so affected, and the problems of the engineer begin especially if, as is so frequently the case, the newly thawed-out soil has a high moisture content. If artificial heat, for instance from a heated basement, is applied to such frozen ground, then

Fig. 1. Thawing of frozen soil following clearing for road construction; the soil was a fine silt with such a high moisture content that it slumped and flowed as it thawed, once the vegetation cover was removed.

the problems created may extend throughout the year instead of being confined to the warm months of summer.

The problems demanding research in connection with permafrost almost suggest themselves from this brief outline. First, and perhaps most obvious, is the need for accurate knowledge of the distribution of permafrost so that those who have to plan operations in the north may know with certainty if they are going to work in a permafrost area, irrespective of the time of year when they have to make their site studies. This knowledge is essential for engineering operations, but it is also of importance for agriculture. Such regional survey research work is well advanced in Alaska, and investigation of the southern limit of permafrost has now been started on a detailed scale in Canada by the Division of Building Research of the National Research Council. The correlation of meteorological statistical studies with permafrost distribution is another major research task in which only a start has been made, and which could be attempted despite the scarcity of long-term climatic data for the north.

These approaches are regional in character and yet the practical problems which permafrost creates are usually quite local. Further advances must therefore be made in techniques of detecting permafrost with certainty and yet with a minimum expenditure of time and money. Aerial photo interpretation gives promise of aiding this work considerably (Woods *et al.*, 1948), both for detailed site surveys and for regional surveys, but much more work is required in developing such aids as specific interpretation keys. Geophysical exploration methods have been used with considerable success in Alaska,[1] and much research is still being done along these lines.

The need for such detailed local information results from the fact that there is no regularity in the southern limit of permafrost, despite the smooth line which may be indicated on small-scale maps. Moreover, there may often be a conflict of local opinions as to whether permafrost is or is not present at a particular site. This may be due, in cases where the local soil is dry sand and gravel, to the absence of water, the dry material failing to reveal its frozen state through visual inspection alone. Since these soil conditions appear almost ideal for building sites, the possible change in ground conditions when vegetation cover is removed and surface drainage can enter such dry frozen ground may be serious. Little is known of building on this type of site, but much could be learned from a research study.

Similar detailed local studies must be made of the performance of roads, airports, and ordinary buildings which have to be built on permafrost, but this type of investigation is perhaps the most obvious of all desirable permafrost research so that it need be no more than mentioned. What is not so obvious is the research necessary into the effect upon permafrost of unusually large structures, especially those which expose much metal, such as steel towers, and which therefore act as collectors for solar radiation. An interesting theoretical approach to this problem has been made by Nees (1952).

No detailed investigations of engineering problems can proceed very far without the necessity for accurate data (or assumptions, in the absence of data) on the physical and mechanical properties of frozen soils of varied types. Some work has been done, but so far this has only been enough to show the need for extensive laboratory and field research into the many complex aspects of this matter (Hardy and D'Appolonia, 1946). Fortunately, such investigations should serve a dual purpose as much should be learned at the same time about the mineralogy of these soils and so about their geological origin and history. Of even greater interest, however, will be the search for an explanation as to how the soil became frozen. Many samples of soils in permafrost, for example, have a phenomenally high water content and a structure rarely encountered in normal soils today.

This, in turn, leads to the greatest question of all in relation to permafrost. Is it merely the cumulative result of successive winter seasons or is it a relic of the last ice age, or is it partly recent and partly relic? There are some who have already formed their own conclusions on this question. There are others (of whom the writer is one) who still have open minds on the subject and who will, therefore, welcome all research work which may throw some light on this unusually significant matter.

It is probable that all approaches to this question will have to be very long-term in character. Fortunately a start has been made at one approach by the installation of sensitive temperature-measuring devices in at least two very deep holes in the Arctic. One of these is a United States venture at

[1]*See* paper by H. R. Joesting in this volume.

Point Barrow, Alaska (MacCarthy, 1952) and the other Canadian at Resolute Bay, Cornwallis Island (Thomson and Bremner, 1952). Results so far obtained show that the ground is below 0°C at both locations to a depth considerably in excess of 1,000 feet. If arrangements can be assured for the maintenance of accurate temperature records over a long term of years from these and many similar holes which may be instrumented, the puzzle of the character of permafrost may one day be solved.

Finally, reference must be made to Russian work and to the striking similarity that must exist between the permafrost problems of North America and those of the U.S.S.R. Early Russian studies were pioneer steps in this field of applied scientific research, and their publications of the 'thirties show clearly how far advanced permafrost studies in the U.S.S.R. were even at that time. It is known that this early Russian work has been continued and extended and a Permafrost Research Institute established, but few recent Soviet publications on permafrost have become available in North America. It is greatly to be hoped that in the future information on this strictly factual and scientific subject will be freely exchanged between the U.S.S.R. and North America.

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