# PERMAFROST IN CANADA*

## Origin and distribution of permanently frozen ground, with special reference to Canada

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In Canada comparatively little study has been devoted to the subject of permanently frozen ground (permafrost); yet an understanding of it, through an investigation of its origin, its extent in lateral distances and vertical depths, and its actions, may ultimately open up vast new tracts of land within the largest undeveloped areas of the world. Soviet Russia recognizes this possibility, and has long shown a strong interest in promoting scientific research within the arctic and subarctic regions of the U.S.S.R.; and it is to Soviet scientists that we owe much of our present knowledge of permanently frozen ground. The writer of this article has a three-fold objective: first, to re-emphasize some already known facts which are particularly pertinent to the study of permafrost; second, to make a few deductions concerning its origin and its present distribution in Canada, by correlating some facts that have already been published with evidence gained from more recent fieldwork; and lastly, to indicate certain regions from which there is great need for information and to suggest the type of investigation likely to yield the most results.

Although authorities differ in the meaning they give to the word permafrost—some apply it only to soils that are at a permanently sub-freezing temperature and contain ice-crystals—a wider interpretation will be used in this paper. Any soil, or even bedrock, irrespective of its texture, degree of induration, water content, or geological character, in which the temperature has been continuously below freezing over a period of years (varying from several to perhaps tens of thousands) will be considered as permanently frozen ground.

Permanently frozen ground appears to be confined to areas in which the mean annual temperature of the atmosphere near the surface of the ground is below 0° C. These areas lie mainly in northern Asia and northern North America. Permafrost thus underlies about one-fifth of the land surface of the world; it affects half the territory of the U.S.S.R., is widespread in Greenland, Alaska and northern Canada, and undoubtedly exists in the Antarctic. Fringing these permanently frozen areas are islands of permafrost that become less and less numerous with distance; and beyond (i.e. south of) them may be isolated patches, "relics" of some earlier period of colder climate, which because they have been insulated against

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exposure, persist in localities where the mean annual temperature is today not low enough for the ground to remain frozen from one year to another. Even in tropical climates permafrost may appear at high altitudes, but this phase of its occurrence has received very little attention.

The depth below ground surface at which permafrost is encountered differs from one locality to another; it may appear within a few inches of the surface, or not within several feet. Always there is an "active layer" above it, a layer subject to annual freezing and thawing; sometimes, too, a permanently unfrozen layer, what the Russians call *talik*. The thickness of the active layer depends, in the main, on two factors: (1) latitude, or, more accurately perhaps, the mean annual temperature; and (2) the heat conductivity of the soil. Thus the active layer at any spot along the Arctic coast may be 2″ or 18″ thick according to whether the soil is clay or gravel.

The thickness of the permafrost, too, varies from locality to locality. The highest figure was recorded at Anderma on the Arctic coast of Siberia; here the permafrost was penetrated to a depth of 230 metres, and its thermal gradient indicated that it probably extended downward 120 metres farther. The record for North America comes from Umiat in Alaska, where American Seabees testing for oil in 1946 found the ground frozen to a depth of more than 500 feet (152.4 metres). Broadly speaking, the thickness of permafrost diminishes from north to south, and is apparently greatest where an extremely cold climate with very short summers is accompanied by either a light snowfall, or a snowfall that does not begin until late in the season.

### *Formation and Growth of Permafrost*

It seems most reasonable to suppose that this permanent frost in the soil is an outgrowth of the normal process of gelation, that it has resulted from seasonal ground-frosts becoming more deeply embedded than subsequent summer thaws were able to penetrate. Theoretically, therefore, its areal extent may be fluctuating; it may be increasing or diminishing at the present time.

Several factors determine whether a soil will freeze permanently. Temperature of the air, precipitation, cloudiness, and direction of prevailing winds obviously affect its surface layers, but its vegetative covering, its texture, water content, and degree and direction of exposure also play a part. Vegetable fibre is an insulator of heat, most efficient when it is dry. Just as in temperate climates a foot of sawdust will preserve a mass of ice throughout the summer, so will muskeg moss and certain other types of vegetation which are widely distributed throughout the permafrost belt. Superimposed upon unfrozen ground, they delay frost penetration and may entirely protect the underlying ground from freezing; superimposed upon already existing frozen soil they reduce or eliminate the seasonal thaw. Since they likewise delay the upward transfer of heat during the winter months when the air is much colder than the ground, they tend to check the downward extension of the frost.

Another insulating element is water. The bed of the Mackenzie River is unfrozen, judging by some experiments made by the Imperial Oil Company near Norman Wells. Unfrozen also, probably, are the beds of Great Bear, Great Slave, and other lakes. D. W. McLachlan, when Engineer-in-Charge of the Hudson Bay Railway Terminus, found that the beds of some swamps in the vicinity of Port Nelson were unfrozen, although that locality has a mean annual temperature of -6.2° C. Water in the form of snow also has great insulating properties, so great, indeed, that a commercial firm at Ottawa regularly counts on adding 6″ to the thickness of the river ice in winter merely by keeping its surface free from snow. Over the greater part of the Arctic, however, the precipitation is very light, and the wind sweeps into gullies and other depressions much of what little snow does fall, so that large areas carry only a very thin mantle all winter.

Brunt has pointed out that "the wetting of soils has three distinct effects; it increases the absorption of solar radiation; it leads to evaporation from the surface and consequently tends to lower the temperature; and, finally, it increases both heat capacity and conductivity of heat."[2]

All these factors influence the depth to which a wet soil freezes, and the rate. Again, water high in mineral content, or under hydrostatic pressure, will remain unfrozen below the normal freezing point and fail to bind the soil into a solid mass.

One or two other factors deserve brief notice. Exposure to sun and wind permits greater radiation and evaporation than occurs in sheltered localities, as is shown by the delayed melting of the snow-cover in dense forests, and on slopes that face northward. In the Carmacks district of the Yukon permafrost has been found on north-facing slopes when it was absent from south-facing ones. Man himself can slightly modify the thermal regime of the ground by interfering with the surface layer; ploughing, for example, will aerate the soil, thus increasing the thickness of the active layer and the depth to the top surface of any permanently frozen subsoil.

Nevertheless, apart from climate, the most important factor in promoting and preserving permafrost is the conductivity of the soil. Different soils and rocks vary widely in their conductivity; but because ice is a much better conductor than water, the freezing of any kind of soil invariably increases its conductivity. Thus Russian experiments would indicate that the conductivity of sand can be trebled by freezing and that of clay increased 1.5 times. It follows, therefore, that the amount of heat transferred from a frozen soil to the air during a winter day will be greater than the amount transferred from the air through the unfrozen soil during the corresponding day in summer when the temperature ratio between ground and air is exactly reversed (leaving out for the moment any insulating effects caused by snow in winter and vegetation in summer). The conductivity of the ground cannot alter the temperature at which it begins to freeze; but it can greatly affect the rate of freezing, and the depth to which the frost penetrates. It would seem to have been the decisive factor in determining how far down in any place the permafrost could extend before further accumulation became impossible other than by a change of climate.

It is not often that one can follow the actual growth of permafrost, but McLachlan did so at Port Nelson. His workmen drained a swamp whose bed was unfrozen. During the following winter frost penetrated this patch of ground to a depth of 8′, in the second winter it extended downwards to 20′, and in the third to 30′. There, at a level that coincided with the bottom of the permafrost in the surrounding area, it stopped.[2] No record is available of the exact nature of the soil, but its conductivity was so low, apparently, that under the prevailing climatic conditions—a mean annual temperature of -6.2° C.—frost could not penetrate it at a faster rate, on the average, than some 10′ per year.[3]

The workmen at Port Nelson did not observe the exact times during the second and third winters when the frost began to creep downwards, but clearly this process could not begin until the active layer that had thawed out during the summer had frozen solid again. Russian investigations have shown that not only the active layer, but also the upper levels of the permafrost may be affected by seasonal conditions, although in the latter the temperature never rises high enough to produce a thaw. These seasonal changes in temperature diminish with depth, and finally cease to occur at what has been named the "level of zero annual amplitude," a level that varies with soil and climate. In the swamps at Port Nelson it evidently lies more than 30′ below the surface.

It is difficult to understand how permafrost can grow downwards unless its upper surface is in contact with the active layer, and experiences the low winter temperatures that freeze that layer. It is equally difficult to conceive of any conditions that would cause it to grow below the level of zero annual amplitude. How then are we to explain why permafrost does exist in many cases out of contact with the active layer, and often for hundreds of feet below the level of zero annual amplitude?

Let us consider first those cases in which a permanently unfrozen layer keeps the permafrost out of contact with the active layer. There may be three causes for this:

1. The permafrost may date from an earlier and harsher climatic period and have become buried below the depth of seasonal freeze and thaw. In this case the present climate is not cold enough to create a permanently frozen layer, and the seasonal ground-frost does not extend deep enough to contact the buried permafrost table. The permafrost obviously cannot be either growing or diminishing in thickness (unless indeed it can be affected by thermal conditions beneath it within the earth's crust).

2. The unfrozen ground may be a recent aquifer or water-bearing horizon that developed on or near the top of the permafrost. Freezing of the active layer may compress this aquifer, giving rise to hydrostatic pressure that prevents its water from freezing even when its temperature falls below zero Centigrade.

3. The permafrost may have resulted from a landslide that buried a mass of snow and ice. In this case it will not be likely to exceed a few feet in thickness, and owes its survival to the low conductivity of the soil.[4]

We must next try to explain the great thickness of permafrost in many places, its extent in depth to hundreds of feet below the level of present-day zero annual amplitude. We know that at various periods in the past the climate over a great part of the northern hemisphere has been very much harsher than it is today. During any one of these cold ages the level of zero annual amplitude, which fluctuates slightly even during short-period climatic cycles, must have extended to a very much greater depth than is possible under present conditions. Furthermore, seasonal changes in soil temperatures probably reach to greater depths with every increase in the range of air temperatures, or in the ratio of precipitation to evaporation, even though the mean annual temperature of the atmosphere may undergo no change. One may reasonably conclude, therefore, that permafrost could become embedded to a very considerable depth during one or more of the harsher ages, and not disappear entirely in the milder period that succeeded. During this milder period soil could accumulate over it and bury it still deeper, but this soil in turn would become permanently frozen when the climate deteriorated again (Fig. 1). In this way the permafrost could become thicker and thicker under successive cold and warm periods until, in the end, it reached a state of equilibrium, when any increase at the surface would be counterbalanced by a thawing at the base brought about by a rise of temperature with pressure.[5]

The depth at which it would reach this state of equilibrium would depend on climate, soil, and other factors, and would therefore vary from

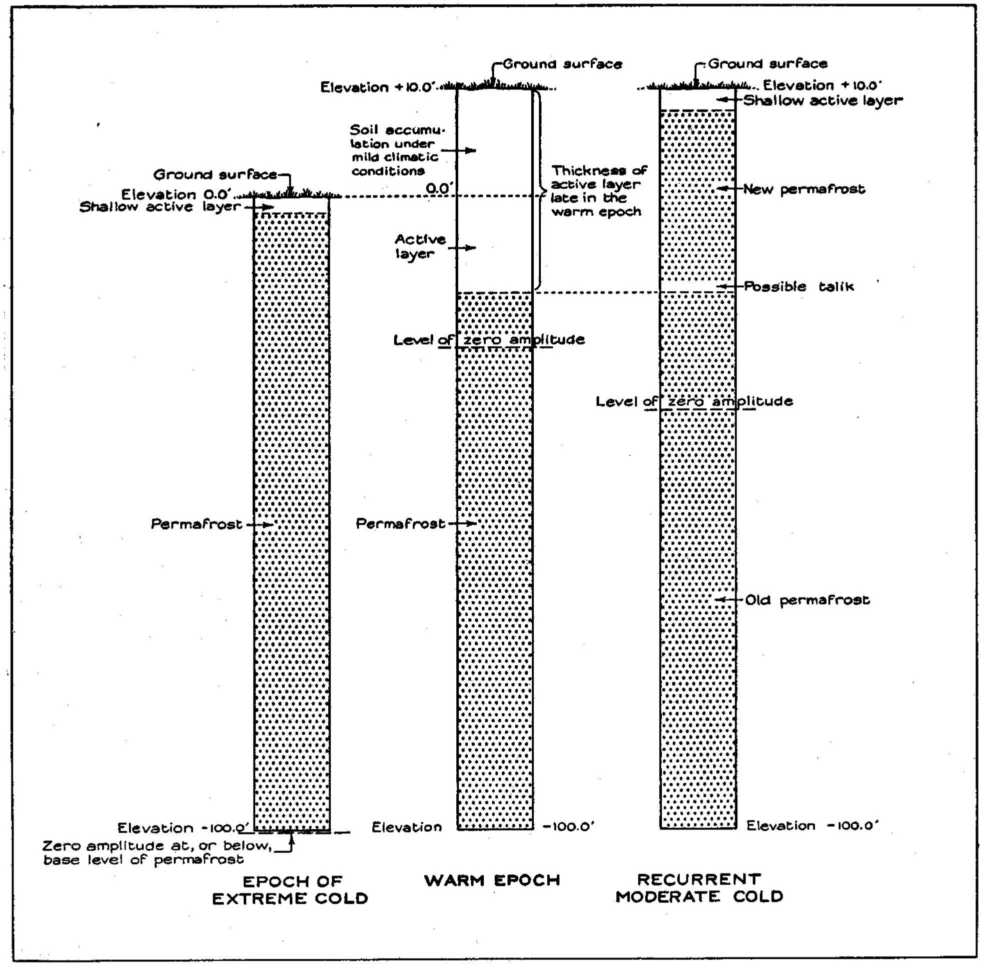



**Fig. 1**—Diagrammatic illustration of the origin and subsequent growth of very deep permafrost.

one region to another. Hence, while it is broadly true, in North America at least, that the thickness of permafrost increases from south to north, it may and apparently does show wide diversity in contiguous districts.

This theory of permafrost growth readily explains the occasional presence of a belt of unfrozen ground—a *talik*—not on top of the present permafrost, but deep within it far below the level of zero annual amplitude. It is hardly conceivable that underground water can force its way through already frozen soil and cause it to thaw out. This unfrozen belt, then, must represent either the lower part of an ancient active layer, which, in the course of a long mild period, became so thick that a recurring cold age failed to freeze it to the bottom, or else it was an aquifer within that ancient active layer that failed to freeze because of high mineralization or hydrostatic pressure. Whichever the cause, borings will show what appears to be one continuous belt of permafrost intersected by a *talik* that may or may not carry water; but in reality there will be two belts of frost, the lower much older than the upper.

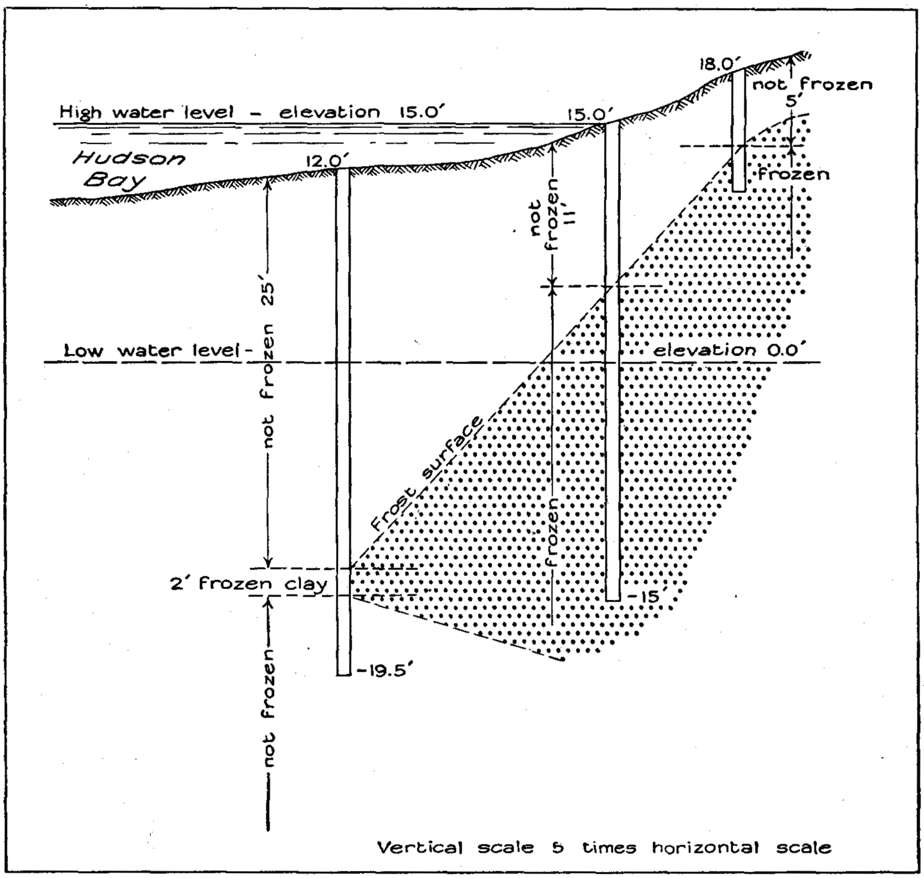
*Age of Permafrost in Canada*

How old is the deepest permafrost which, as we have just shown, must have originated in some period when the climate was colder than it is today? Muller says, "It is now generally agreed by most authors that permafrost first appeared during the refrigeration of the earth's surface at the beginning of the Pleistocene or Ice Age, perhaps a million years ago."[6] Even if we agree, however, that it did make its appearance at that time, it is still far from certain that this early permafrost did not disappear entirely during one or other of the warm interglacial periods that succeeded the first onset of the ice. If this were the case, then the oldest permafrost existing today would date from the closing phases of the Ice Age rather than from its opening ones, i.e. from the Iowan-Wisconsin glaciation rather than from the Nebraskan. One thing seems certain, viz., that no permafrost can originate underneath huge masses of snow and ice; for these masses, so thick that friction and pressure tend to keep the ice on the bottom at its melting point, can do no more than serve as an insulating blanket superimposed on any frost that may already exist in the ground. That is why the deepest permafrost yet found in America lies in an area of northern Alaska that experienced the extreme cold of the last glaciation without being covered by any insulating ice-sheet.

In the glaciated areas of Canada permafrost may date, then, either from some cold period that preceded the blanketing of the land beneath the ice sheets, or else from some period, rather less cold, perhaps, that followed the final recession of the ice. In many cases an exact determination of its age will be difficult and perhaps impossible. There are, however, large areas of permafrost concerning whose age we can have little doubt. Just as a large lake does not freeze entirely throughout its depth, so the waters of Hudson Bay never freeze right to the bottom, but at all seasons circulate from within a few feet of the surface to its bed. We believe that there can be no permafrost under this bed, and our belief is corroborated by McLachlan's borings at Churchill. There, where the mean annual temperature is -7.6° C., and permafrost attains a depth of about 140′, it nowhere extends out more than a few hundred yards under the water of the harbour (Fig. 2); it disappears completely, indeed, under the shallow Churchill River.[7] The present land at Churchill, however, as well as the littoral of Hudson Bay for many miles inland (in some places as far as the present 500′-600′ level) was submerged beneath the sea during the Pleistocene; apparently the land was slowly depressed by the weight of glacial ice and did not rise again until that ice melted. Consequently, even if permafrost had existed in this depressed area during some earlier epoch, it could hardly have survived the last glaciation. Its subsoil must have become permanently frozen since the post-glacial uplift; and only further inland, beyond the limits of the Pleistocene sea, may the permafrost be of greater age.

We may add, perhaps, two other cases in which permafrost must have developed quite recently. We know from borings near Norman Wells that it is absent from the bed of the Mackenzie River, yet it underlies the newly-formed islands in the delta of the river. It is present also in the islands of the Canadian Arctic, not in their interiors only, but along their shore-lines which over wide areas seem even yet not to have ended their emergence from the sea.[8]

**Fig. 2**—Borings on beach at Churchill Harbour, October 3-10, 1929, showing effect of sea on permafrost. Vertical scale 5 times horizontal scale. (Reproduced from unpublished plan by D. W. McLachlan in the files of the Department of Transport, Ottawa.)



In Russia, too, scientists have ascertained that permafrost is forming during the present climate, notably in the recently built river islands and bars in the northern part of Siberia. Its formation is therefore not localized to a few favourable areas in Canada, but is a widespread process resulting from present climatic conditions throughout all or most of the Arctic. If we can provide some clue to the air temperatures that give rise to permafrost, we will have a clearer picture, not only of its areal extent, but also of the boundary that, for practical purposes, separates the permafrost-free area from those in which a permanently frozen soil must always be taken into account in any use we may wish to make of the land.

*Permafrost and Mean Annual Temperature*

Sumgin, a Soviet investigator, has stated that while the mean annual temperature of any place must be below zero Centigrade (the normal freezing-point of water) before permafrost can originate, it may nevertheless be quite close to that figure. Other Russians demand a mean annual temperature not higher than -3.3°, -4°, or even -6° C.[9] In Canada the Meteorological Division of the Department of Transport has conjectured that the "southern limit of permanently frozen soil closely coincides with the annual mean isotherm of -5° C."[10] This term "southern limit" may need a little clarification. It means, presumably, a line drawn across the breadth of the map of Canada through the southernmost stations that report an unbroken expanse of frozen subsoil. Such a line permits a more accurate comparison with mean temperature graphs than any other; but it leaves out of consideration numerous localities farther south where permafrost underlies only part of the land surface—the patches or "islands" of permafrost that have persisted, because of insulation, where the mean annual temperature is today not low enough for the ground to remain frozen from one year to another. These cannot be embraced within a single line because they are discontinuous; nor for our present purpose would it seem of any value to include them, since they occur in such widely diverse places, and often under such anomalous circumstances, that they cannot be related precisely to any atmospheric conditions.

Map 2* shows the mean annual isothermal lines for the part of Canada relevant to this study.[11] A comparison between this map and Map 1, which shows permafrost, will indicate that the isothermal lines sufficiently resemble the line marking the southern limit of continuous permafrost to confirm the belief that the frozen zone is in some way related to present-day temperatures. Furthermore, as the Meteorological Division suggested, its southern limit in Canada roughly coincides with the isotherm for -5° C.[12] We dare not make this relationship too precise, however, as long as reports of permafrost are so lacking in detail. We must remember, also,

*Maps 1 and 2 are to be found following page 76.

that any isotherms we may plot of as vast and unpopulated a territory as northern Canada cannot be truly accurate without detailed reports from a much larger number of weather stations than exist at the present time, and that a great deal of interpolation was required to produce the lines for Map 2. Hence, despite the support the map appears to give to the Meteorological Division's theory, it is worth suggesting that permafrost may be less closely related to the mean temperature for the entire year than to the ratio between the winter's mean temperature combined with its length, and the corresponding mean temperature and length of the summer, winter being taken as the period of frost and summer the period of thaw.

Map 1 shows the southern boundary of permafrost as it exists today, but this boundary will fluctuate, of course, with every modification in the climate. The many "islands" of permafrost that survive south of it indicate that it once extended over a much wider area, perhaps in the not too distant past. Recent research suggests that the greatest advance made by glaciers during the past 2,000 years, or longer, has occurred within the past 200 years, but that they began to recede all over the world in the late nineteenth century.[13] It was toward the close of that century, too, or the beginning of the present one, that the temperature of the West Greenland Current began to rise slowly, and that the thickness of the cold surface layer of water in the Arctic Sea started to decrease.[14] In line with these indications of a widespread amelioration of climate in the northern hemisphere the Russians claim that in the Archangel region of northern Russia the southern boundary of permafrost has moved almost 100 kilometers (60 miles) farther north during the past 96 years.[15] If their claim is true, then almost certainly the permafrost line has receded north in Canada also. Although the gain in temperature is minute, the gain in the permafrost-free land over a wide area becomes quite significant; and if the trend continues it opens up a vista of economic expansion into regions which today still remain outside the pioneer fringe.

Coniferous trees shown are growing where permafrost is 12" from surface. Site of geographical-magnetic expedition camp, south of Amundsen Gulf, N.W.T., Canada.

*(Photo: J. L. Jenness, from Geographical Bureau, Ottawa)*

(Photo: R.C.A.F.)

Lake-strewn terrain west of Hudson Bay at Eskimo Point, N.W.T. A typical example of imperfect drainage.

*Permafrost and Vegetation*

In order to grow, all natural vegetation depends ultimately upon the temperature and rainfall conditions of its environment; these determine such major regions as desert, grassland and forest. Each of these in turn shows local variations which can largely be traced to the effect of local climate, to differences in the character of the soil as influenced by the underlying geological structure, to surface deposits and drainage, and to topographical differences in run-off and exposure.

In permafrost regions as elsewhere, it is the interplay of all these factors that decides the character of the local vegetation. A permanently frozen soil does not create barrenness on the surface soil above, but it exercises a selective role upon such vegetation as the climate and soil permit. Plants will grow above it that can withstand the climatic factors, that can tolerate the cool night temperatures and mature in the short growing season.

Permafrost seems to affect vegetation mainly in two ways. Wherever the active layer is shallow, the frozen ground represses all deep-rooted species and limits growth to those that have shallow roots. Of Canadian trees, spruce (both black and white), balsam poplar and the birches are all shallow-rooted, and all will grow above permafrost. However, A. E. Porsild, Chief Botanist of the National Museum of Canada, tells me that in the newly-formed islands of the Mackenzie River delta balsam poplar does not reach large size when permafrost lies very close to the surface. Tamarack, black spruce and larch seem to have the ability to form auxiliary roots if their bottom roots are killed by permafrost; they too need only a shallow thawed layer in the growing season. The pines, however, both the jack-pine and the lodge-pole pine, root deeply and thrive only where the active layer is comparatively thick; hence they will not grow in muskeg or in heavy clay soils, but indicate the presence of sand or gravel.

The second way in which permafrost affects vegetation is through its influence on drainage. Because it provides an impervious base to subsurface water, it confines drainage to the shallow active layer. Consequently low-lying terrain is generally water-logged, and filled with large swamps or with lakes of varying shapes and sizes that spill from one to another in very indefinite drainage patterns.[16] In such areas ground-water eliminates all but the most water-loving species, even when the permafrost lies deep enough to permit a greater variety of growth. Mosses and grasses thrive, and, within the forest zone, black spruce and tamarack push through them; but white spruce, poplar and birch require drier soils, and pines are wholly intolerant of water-laden ground. Along the Hudson Bay Railway and elsewhere a very sharp line of colour separates the bright green birches and poplars on the slightly raised mounds from the blackish spruces and tamaracks in the surrounding swamps. Half of northern Canada, on a rough estimate, consists of water and not land; and the luxuriance of the vegetation in the swamps and muskeg is surprising. Porsild believes, however, that were the soil not so waterlogged, it would revert to barren desert on account of the climate. And it is the permafrost that keeps it waterlogged.

Most of the species of trees that grow within the forested part of the permafrost zone can be differentiated on the air photographs that now provide the basis for nearly all northern maps; but because the same trees thrive also on ground that is not permanently frozen it would hardly seem possible, as Belcher suggests,[17] to use their distribution for defining the areas that are underlain by permafrost. It is conceivable that aspen might be used for the purpose, if Leahy is right in believing that it is intolerant of frozen ground;[18] but unfortunately it is neither a climax species nor is it easy to distinguish from balsam poplar either from the air or in air photographs. While the type of forest can certainly give a clue to the amount of moisture in the ground and the nature of the soil, so far at least it has not provided any satisfactory guide for the delimitation of permafrost itself.

*Conclusion*

Certain other aspects of permanently frozen ground, e.g., those connected with engineering, lie outside the scope of this paper. We may, however, suggest two or three lines of research that should increase our understanding of its actions and define its distribution more clearly.

First of all, we need much greater knowledge of its southern limits, particularly in the Labrador Peninsula. At present our only available record from the interior of the peninsula comes from a place, Kivivic Lake, about 2500′ above sea level. Much of the region is totally uninhabited, but if seasonal travellers would probe the ground during middle or late August, the time of maximum thaw, and record any occurrence of permafrost, they would greatly assist in defining its limits. As it is now, we have hardly the faintest clue to these limits because the isothermal lines themselves are largely hypothetical.

Another field for investigation is the influence of great masses of water on permafrost. At Norman Wells, on the Mackenzie River, J. M.

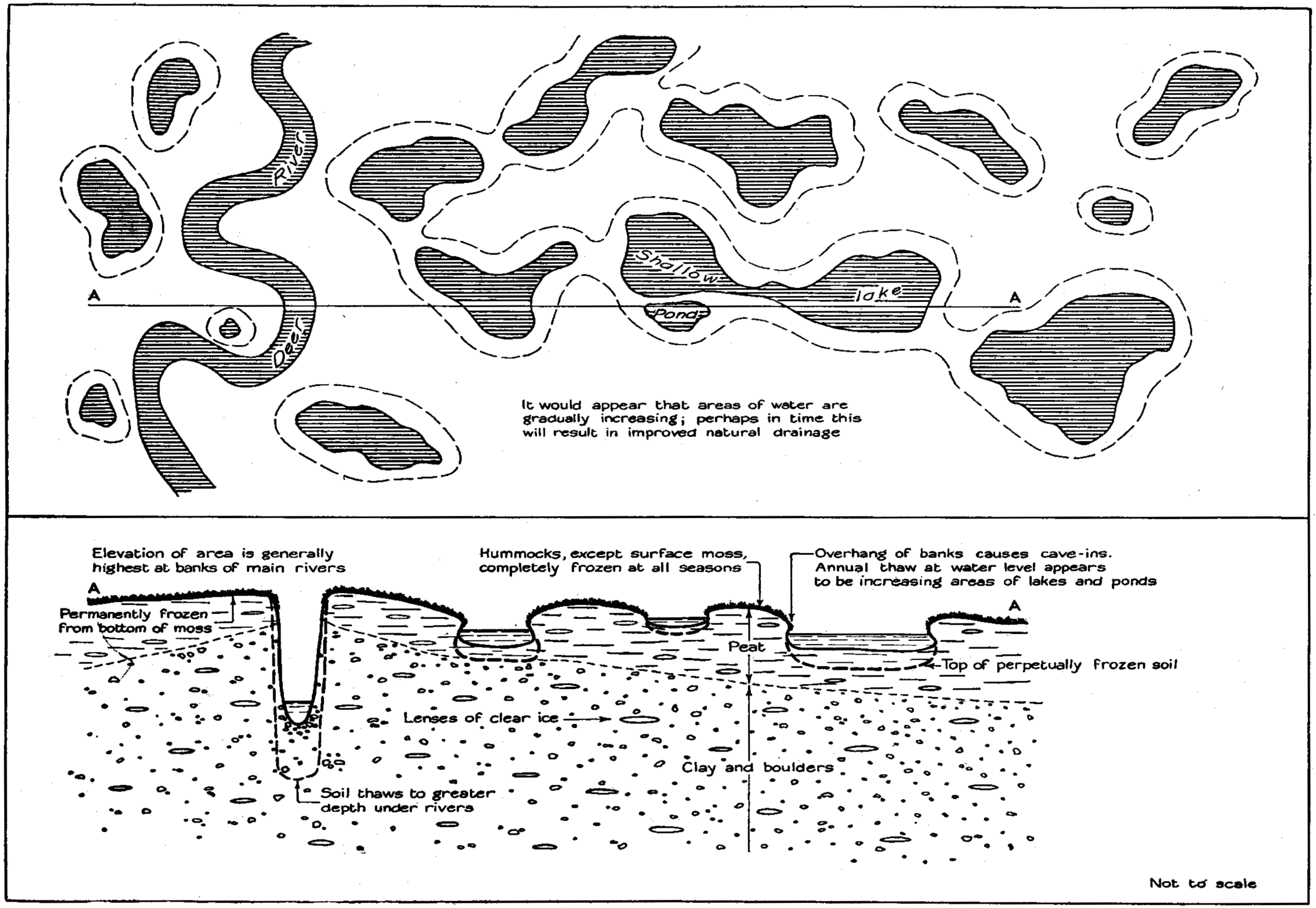



**Fig. 3**—Diagrammatic illustration of summer conditions in the "Intermediary Region" south of Churchill, Manitoba. (Slightly adapted from Charles, J. L. Op. Cit.)

Fulton noted that in wells 100′, 200′, and 350′ from the water's edge permafrost reached thicknesses of about 60′, 135′ and 267′ respectively,[19] and he drew the logical conclusion that the water of the river has caused these differences. McLachlan observed similar influence by the sea at Churchill (Fig. 2). Since virtually all settlements in the north are located on river banks, and on sea and lake shores, information should be obtained, if only for constructional reasons, to show how far this influence extends through different types of terrain. For example, some area on the coastline of Hudson Bay, or on the shore of Great Bear or Great Slave Lake, where there is considerable diversity of soil and rock might be selected; there a series of test holes could be made at equal intervals back from the water's edge, in order to take monthly temperature readings at similar depths in each hole. Again, wherever dams are being built, a similar series of temperature tests could be made before and after the raising of the water level.

A third study might follow up Charles' suggestion concerning the effect of permafrost on drainage patterns (*see* reference No. 16). He remarked that "northerly from Wabowden, lat. 54° 50′, the 'islands' [of permafrost] increase in number and surface area, progressively, to a point 20 miles north of Gillam—the crossing of the Limestone River—lat. 56° 30′. The area between lat. 54° 30′ and 56° 30′ might be termed an intermediary region between the definitely agricultural land and the subarctic tundra . . . north of lat. 56° 30′, the entire region appears to be underlaid with a stratum of perpetually frozen soil, extending to various depths increasing northward."[20] Throughout this "intermediary region," he believed, the drainage pattern may be changing, due in part to the permafrost that lies so close to the surface, and in part to the flatness of the topography (Fig. 3). His theory could be readily checked by means of an aerial and ground survey. A map could be made, on a scale large enough to show the intricacies of the present drainage pattern, (e.g., 1:25,000) of the area on both sides of the Hudson Bay Railway between Wabowden and the Limestone River; and the area could be re-photographed at ten-year intervals. By comparing the photographs and maps, it should be possible to detect any normal erosive changes, and determine all unusual alterations in the courses of the rivers and the outlines of the lakes and ponds. Furthermore, the area could be used as a laboratory in which to discover whether the Russian claim of a permafrost recession applies also to the North American continent. The major blocks of frozen and unfrozen ground could be plotted on the map and checked by ground surveys at the same ten-year intervals. If these prove that the permafrost is receding in this area, it will probably be retreating also all along its southern boundary, throughout Canada and Alaska.

## REFERENCES

[1]Brunt, D. "Some Factors in Microclimatology," *Quarterly Journal, Royal Meteorological Society.* Vol. 72, April-July, 1946, pp. 185-188.

[2]Verbal information. Cf. also McLachlan, D. W. "The Development of the Hudson Bay Project," the *Engineering Journal,* April 1933, p. 10.

[3]In March, 1944, the Imperial Oil Company dug eight holes at Norman Wells, capped them, and began to record the daily temperatures in each hole 3′ below the surface. The lowest temperature recorded in the winter of 1946 was -13.3° C., but in the preceding winter of 1945 only -5° C. This illustrates how greatly one winter's penetration of cold can differ from another's, and explains why at Port Nelson the frost did not work its way downward at a uniform rate.

[4]The Ottawa press of August 1947 carried a report that "underground ice" had just been uncovered in nearby Hull, Quebec, a city whose mean annual temperature is several degrees above the freezing-point. Here the soil normally freezes each winter to a depth of only 3′ to 5′ depending on the amount of snow cover, whereas the "underground ice" was 15′ below the surface under about 10′ of heavy clay. Investigation proved, however, that it was not true ice, but a mass of half-congealed snow from the previous winter that had accumulated at the base of a clay pit and been buried by the collapse of its wall. It did not become true permafrost; but it demonstrates that landslides, often perhaps on a grand scale, have caused the burial of much winter ice and snow below the level of summer thaw.

[5]At Norman Wells the rise of temperature with depth was calculated by J. M. Fulton, Imperial Oil Company Engineer, as 0.0258° F/ft., a rate somewhat higher than the average of 0.0155° F/ft. given in Peele's *Mining Engineers' Handbook.* He believed that his rate was modified near the surface by the belt of permafrost (letter of J. M. Fulton, June 14, 1945.)

[6]Muller, S. W. (compiled by) "Permafrost or Permanently Frozen Ground and Related Engineering Problems." Washington, 1945, p. 4.

[7]McLachlan, D. W. *Op. cit.,* p. 10, and plans of his borings in the files of the Department of Transport, Ottawa.

[8]Cf. Washburn, A. L. "Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions Arctic Canada," *Memoir 22,* Geological Survey of America, 1947, p. 69 et. seq.

[9]Muller, *Op. cit.,* p. 4.

[10]Personal communication from Thomson, Andrew, Controller of that office, June 21, 1946.

[11]Map specially prepared by Meteorological Division, Toronto.

[12]Note particularly how both lines loop around the northeast end of Great Slave Lake.

[13]Steers, J. A. Unpublished notes. Cf. Flint, R. F. *Glacial Geology and the Pleistocene Epoch,* New York 1947, p. 499.

[14]Dunbar, M. J. "Greenland—An Experiment in Human Ecology," *The Commerce Journal,* March, 1947.

[15]*Ottawa Citizen,* Jan. 12, 1946, quoting a Moscow despatch.

[16]J. L. Charles has suggested that the water slowly accumulates on the lower ground, that the swamps and lakes are gradually increasing in size through the undermining of pond walls, and that in many areas along the Hudson Bay Railway the present drainage pattern may soon become considerably modified. (Charles, J. L. "Perpetually Frozen Subsoil in Northern Canada, Office of the Chief Engineer, Winnipeg, Man., March 29, 1940," unpublished MS, Canadian National Railway.)

[17]Belcher, D. J. Department of Civil Engineering, Cornell University 1946.

[18]Leahy, A., Soil Specialist, Dominion Experimental Farm, Ottawa, personal communication, Nov. 6, 1946.

[19]Fulton, J. M. *Op. cit.* These wells, it should be remarked, were at considerable distances apart.

[20]Charles, J. L., *Op. cit.*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