Permafrost investigations in Northern Ontario and Northeastern Manitoba

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R.J.E. Brown

Technical Paper No. 291

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by

R.J.E. Brown

Since 1950 the Division of Building Research, National Research Council of Canada, has been studying the numerous construction problems caused by permafrost in northern Canada. A basic requirement in solving these problems is knowledge of the distribution of permafrost and the location of its southern limit; information is being obtained continually from field investigations, the scientific and technical literature, and reports from individuals and agencies working in permafrost areas.

Information regarding distribution and character of permafrost is particularly vital in the southern fringe where construction is complicated by patchy distribution of perennially frozen ground and the proximity of its temperature to 32°F. The existence of permafrost in this area is greatly influenced by microclimate and local terrain conditions, which form complex relationships producing variable and unpredictable ground thermal conditions.

At present, the southern fringe of the permafrost region is experiencing increasing economic development with the establishment of new towns, communication lines, mines and oil exploration. In the northern sections of the western provinces of Canada and adjacent portions of the Yukon Territory and Mackenzie District, new roads are being constructed through the southern fringe of the permafrost region. East of Hudson Bay, land communications are not as well developed; the only existing links are two railway lines extending from the Gulf of St. Lawrence northward to the extensive iron ore deposits in the interior of Quebec and Labrador.

Between the four western provinces and Quebec lies Ontario, whose northern area situated in the permafrost region has experienced virtually no economic development. No land communication penetrates this area, the closest link being a railway whose northern terminus is at Moosonee, just bordering the permafrost region at the south end of James Bay. Some of the most difficult terrain in northern Canada is found in northern Ontario and northeastern Manitoba where vast poorly drained peatlands of the Hudson Bay Lowland make overland travel extremely difficult. This factor combined with poor natural harbour possibilities on Hudson Bay and James Bay contribute to the current lack of development. The current lower level of economic development and potential in northern Ontario and northeastern Manitoba, as compared to the southern fringe of the permafrost region elsewhere in Canada, could be changed by future mining and oil exploration activities.

The Division of Building Research continued its survey of the southern fringe of permafrost in Canada in this area in 1965. This programme of investigations was initiated in 1962 in northern Alberta and Mackenzie District coinciding with the construction of the Great Slave Railway (1). In 1963 these field surveys were extended to the provinces of Saskatchewan and Manitoba (2). A field survey was carried out in northern British Columbia and southern Yukon Territory in 1964 (3). Similar surveys in Quebec and Labrador in 1967 and 1968, respectively, completed the investigations across Canada (4).

The study area comprises that portion of northern Ontario lying north of latitude 51°N and northeastern Manitoba north of Lake Winnipeg and east of the Hudson Bay Railroad. It lies in two physiographic regions, the Hudson Bay Lowland in the north and east, and the Precambrian Shield in the west. The absence of large-scale relief features such as occur in the Cordillera in British Columbia and Yukon Territory, and in Quebec and Labrador, results in a less complicated distribution pattern of permafrost. The occurrence of permafrost increases steadily with latitude and there are no complications due to elevation. The southern limit of permafrost in the study area extends roughly parallel to the Hudson Bay coast diagonally from the north end of Lake Winnipeg at latitude 54°N to the south end of James Bay at latitude 51°N. The boundary in the middle of the discontinuous zone, separating the southern fringe from the subzone of widespread permafrost, and the southern limit of the continuous zone also parallel the southern limit in response to the climatic influence of Hudson Bay.

Because of the paucity of economic development in this area, little information on permafrost was available from the literature prior to the survey. These field investigations were carried out in

September 1965 by helicopter when the depth of thaw had reached its maximum and seasonal frost of the forthcoming winter had not begun to form. The survey began at Timmins, Ontario, and extended to Thompson, Manitoba, in a series of north-south traverses across the permafrost zones (Figure 1).

METHODS AND SCOPE OF INVESTIGATIONS

Prior to the actual field investigations, information on the climate and terrain was obtained from the available technical literature (Appendix A). Aerial photographs and large-scale topographic maps of selected areas were examined in the office to identify the various types of terrain and the character of the relief, vegetation and surface drainage. From this preliminary examination, potential permafrost locations were noted for subsequent field investigations.

In the field, detailed investigations were carried out at each stop (Figure 1) to obtain information on the aerial extent of bodies of permafrost, the depth to the permafrost table, and, where possible, the thickness of the permafrost. Supplementary information included the type of vegetation, the thickness of the living surface vegetation cover, the thickness of peat, the type of underlying mineral soil and the character of the ground ice.

The main objective was to delineate, approximately, the areas of permafrost and relate their distribution to the various environmental features such as relief, drainage, vegetation and soil type. With this information it is possible to predict in a qualitative manner where permafrost might be expected in other areas.

Field equipment was limited by weight restrictions imposed by the use of the helicopter and consisted of a 3-ft aluminium Hoffer probe 5/8 in. diameter equipped with a case-hardened serrated steel bit and 3-ft extensions. It was used to determine the depth to permafrost and soil profiles in areas where permafrost did not exist. In frozen ground consisting either of peat or fine-grained mineral soils, it was usually possible to ram and rotate the probe to a depth of 15 or 20 ft and obtain undisturbed cores of the soil in 6-in. increments. Frozen fine to medium sand could be penetrated for a few feet but frozen stony and gravelly soils resisted the probe.

The observations are listed in Table I beginning with Stop No. 1 between Timmins and Moosonee, and ending with Stop No. 41 north of Norway House, Manitoba (Figure 1). Typical types of terrain are illustrated in Figures 2 to 32 inclusive.

The following example is presented to illustrate the use of the symbols in Table I to describe the terrain and permafrost conditions (Figure 16 - ground view and Figure 17 - aerial view). Location No. 15 (Column 1) is situated about 50 miles west of Winisk (Figure 1). It is a low area located in a peat bog (Column 2-L) in which there are depressions and peat plateaux. The right foreground in the ground view (upper right corner - aerial view) is treeless (Column 3 ---). In the ground view, where the man is standing, the tree growth consists of spruce up to 5 ft and tamarack (lower right - aerial view) (Column 3 - S (5) T). The tree growth in the background on the peat plateaux (lower left - aerial view) consists of spruce up to 20 ft high (Column 3 - S (20)). The ground vegetation in the treeless areas consists of sedge and grass, and the ground is wet (Column 4 - SeG (w)). Where the man is standing, the ground vegetation consists of hummocky Sphagnum, lichen and sedge (Column 4 - HSphLnSe). The ground vegetation in the areas of higher tree growth is hummocky Sphagnum, lichen covering 50 per cent of the ground and sedge growing on peat plateaux (HSphLn (50) Se (p)). The peat in the treeless areas is 8 ft - 0 in. thick (Column 5 - 8' - 0"); in the areas with trees it is 4 ft - 8 in. thick (Column 5 - 4' - 8"). The underlying mineral soil is grey sandy silty clay (Column 6 - SaSiC). No permafrost was encountered in the treeless area (Column 7 - No) but it occurs in the areas with trees (Column 7 - Yes). The depth to the permafrost table in the 5-ft high spruce areas varies from 1 ft - 6 in. to 2 ft - 9 in. (Column 8 - 1' - 6" to 2' - 9"), and in the 20-ft high spruce areas it is 1 ft - 6 in. (Column 8 - 1' - 6"). The thickness of the permafrost was not determined (Column 9 ---).

CLIMATE

The study area is located in an interior continental position in North America. The whole area is less than 1,500 feet above sea level and much of the Hudson Bay Lowland has an elevation below 500 feet. Because of the subdued relief the climate varies gradually with latitude in response to general continental controls. These are modified to some degree by the presence of Hudson Bay and James Bay to the north as manifested by the southward trend of isotherms from west to east, and to a lesser extent by the Great Lakes to the south and the high elevations immediately north of Lake Superior (5, 6, 7).

The maritime influence of Hudson Bay and James Bay is modified by the ice cover which forms over these bodies of water for several months during the winter. The climate of the study area is essentially continental in character with long cold winters, and short generally warm summers. In winter, severe cold waves of polar continental air move southeastward from the Prairie Provinces or southward from the Arctic across Hudson Bay with little or no modification. The weather pattern during the summer is characterized by frequent cool periods in the rear of eastward moving cyclones.

Air temperature observations are available for seven stations within the area under consideration (8, 9). Their locations are shown on Figure 33 and monthly and annual averages of daily mean temperatures are given in Table II. The mean annual isotherms for 25°F and 30°F are also shown on Figure 33 (10). The mean annual air temperatures vary with latitude and the southeastward trend of the mean annual isotherms reflects the cooling influence of Hudson Bay. The mean annual air temperature at Norway House, situated at the western extremity of the study area at 54°N, is 29.6°F; whereas at Moosonee (51°N) at the south end of James Bay, it is only $\frac{1}{2}$ degree higher at 30.1°F. At Winisk on Hudson Bay the mean annual air temperature is 22.1°F in contrast to 23°F at Gillam situated 1 degree of latitude north at the western edge of the study area. All but one of the stations, Winisk, lie south of the 25°F mean annual air isotherm. Graphs of the averages of the mean monthly air temperatures for three stations, Moosonee, Trout Lake and Winisk, representative of the southern, central and northern sections of the study area respectively, are shown in Figure 34.

Freezing and thawing indices provide an indication of the amount of heat withdrawn from and added to the ground. On Figure 33 it can be seen that freezing indices vary from 4500 degree days in the southeast to 5500 in the north. Thawing indices vary from 3500 in the south to 2500 in the north and reflect the cooling influence of Hudson Bay in trending to the southeast.

Precipitation observations are available for the seven stations (11, 12). The maximum occurs in the summer months, being mostly frontal but partly convectional in origin. Most of the stations have their maximum precipitation in July, except Moosonee in the southeast and Gods Lake in the west, which have June maxima. Annual totals decrease with latitude and westward away from Hudson Bay and

James Bay. Moosonee has the highest total of 31.02 in.; whereas the two Manitoba stations, Gods Lake Narrows and Norway House, have only 19.36 and 14.12 in. respectively. Graphs of the averages of the mean monthly total precipitation for the three stations, Moosonee, Trout Lake and Winisk are shown in Figure 35.

The same general pattern applies to the mean annual rainfall and snowfall. Moosonee has the highest average annual rainfall of 19.99 inches; Gods Lake Narrows and Norway House have the lowest totals of 11.84 and 9.27 in. respectively. The highest average annual snowfall of 110.3 in. occurs at Moosonee and the lowest, 48.5 in., at Norway House in the extreme southwest. The highest monthly totals of snowfall at all stations occur in November before Hudson Bay freezes over. Annual totals decrease sharply westward away from the influence of Hudson Bay, being 75.2 in. at Gods Lake Narrows and less than 50 in. at Norway House.

Rain has been recorded in all months of the year at all stations except in December, January and February at Pickle Lake and in January at Gods Lake Narrows. August is the only snow-free month at all stations, and only Trout Lake has a trace of it in July. Data on the average depth of snow on the ground each month are available only for the east half of the study area represented by Moosonee, Lansdowne House and Trout Lake (13). Snow accumulation is considerably greater at the latter two stations which are inland. The maximum accumulation usually occurs during late February near Lake Superior, and by mid-March along the shores of Hudson Bay. The ground is usually covered with snow north of the southern tip of James Bay until mid-May after which it disappears rapidly.

In summary, it is evident that air temperatures and precipitation values for the seven stations are influenced by latitude relative to their proximity to Hudson Bay and James Bay. Hythergraphs based on the averages of mean monthly temperatures and mean monthly total precipitations for Moosonee, Trout Lake and Winisk are shown in Figure 36. The higher monthly temperature and precipitation values at Moosonee, the most southerly of the three stations, are evident. The continental character of the climate is borne out by the large difference between summer and winter air temperatures, coupled with summer maximum precipitation. Nevertheless, the maritime influence of Hudson Bay is reflected in the smaller differences between summer and winter monthly precipitation values compared with the Prairie Provinces to the west.

GEOLOGY

The chief geological feature is the contrast between the Precambrian Shield and the Hudson Bay Lowland. The former comprises the west and south portions of the study area and the latter forms a band 100 to 200 miles wide around the coast of Hudson Bay and James Bay in the north and east. This portion of the Shield in Northern Ontario and Northeastern Manitoba is characterized by the typical terrain of rock knobs and ridges, peat-filled depressions, and innumerable lakes. The Hudson Bay Lowland consists of vast tracts of flat peatland with virtually no relief overlying rocks of Palaeozoic and Mesozoic age (Figure 37) (14,15).

The rocks of the Precambrian Shield are mainly acidic, consisting of granodiorite, granite, quartz diorite and granite gneisses, including much granitized sedimentary and volcanic rock. Within this geological province there are small subdivisions of Archaean rocks falling into three categories: (1) mainly sedimentary and derived metamorphic rocks including argillite, slate, arkose, quartzite, greywacke, conglomerate, sedimentary gneiss and schist, and iron formations; (2) mainly volcanic and derived metamorphic rocks including andesite, dacite, basalt, rhyolite, trachyte, minor volcanic breccia and tuff, greenstone schist and hornblende gneiss; and (3) undivided sedimentary, volcanic and metamorphic rocks. Two Precambrian outcrops occur in the Hudson Bay Lowland south of Winisk. One is comprised entirely of Late Proterozoic sedimentary and volcanic rocks - sandstone, quartzite, conglomerate, shale, iron formation and basalt, and the other consists of these rocks and Proterozoic basic intrusive rocks - diabase sills and dykes.

Most of the Hudson Bay Lowland is underlain by rocks of Silurian age consisting mainly of sedimentary rocks - shale, limestone, dolomite, conglomerate, sandstone, volcanic rocks, and possibly salt, oil and natural gas formations. South of the Albany River in the southeast portion of the Lowland the bedrock is Devonian sedimentary and volcanic rocks similar to the Silurian rocks. Small areas of Ordovician sedimentary rocks - limestone, dolomite, shale, argillite, sandstone, quartzite, grit, and possible oil and natural gas formations lie along the southwest and northwest edges of the Silurian formations. Two small areas of undivided Cretaceous sedimentary rocks occur in the extreme south.

During the Pleistocene, the Precambrian Shield was glaciated by ice moving from the north and northeast. Glaciation was intense in most of the Shield area, particularly north and west of Lansdowne House and Pickle Crow. The resulting relief is irregular, with rocky parallel ridges separating poorly drained depressions and innumerable narrow lakes. Drift deposits on the uplands are thin in some places and absent in others where rock barrens of Precambrian granites and gneisses are exposed. On slopes and in the valleys, the drift is deeper. Southeast of Lansdowne House and Pickle Crow, glacial advance from the north covered the Precambrian granites and intrusives with a calcareous drift. Farther east in the Timmins-Cochrane region, the bedrock was only partly covered by drifts (Figure 38) (16, 17).

As the ice retreated, large portions of the study area were submerged. The southeast section was submerged under glacial Lake Ojibway, causing reworking of the till deposits and deposition of lacustrine material. Driftless areas of bedrock were also covered by lacustrine deposits, and therefore the topography is generally unbroken and relatively level, with only occasional hills and ridges. Eskers and outwash plains which cross the area from north to south are partially or entirely covered by the lacustrine deposits (Figure 38) (16, 17).

The west section of the study area was submerged under glacial Lake Agassiz and the consequent deposition of lacustrine clays and sands has had the effect of levelling what was formerly an irregular and rolling Precambrian surface. The lacustrine deposits, shallow on the rocky uplands and deeper in the valleys, extend back along the latter considerable distances from the present-day lakes (Figure 38) (16, 17).

The Hudson Bay Lowland underwent postglacial marine submergence followed by slow uplift which continues at present. Crustal uplift has proceeded recently at the rate of about 3 ft per century, but it seems to be much less in the southern part of James Bay (Reference 18). The surface materials of these marine flats are calcareous clays, derived by glacial action from the underlying Palaeozoic sediments and deposited in sea-water. Beach sand deposits in the form of strand lines on the marine clays occur near the west sides of James Bay and Hudson Bay (Figures 21, 22, 23) (16, 17).

TERRAIN

Relief

The relief of the area under study varies markedly from undulating to hilly in the Precambrian Shield to flat in the Hudson Bay Lowland. The rock knob relief, typical of the Precambrian Shield, reaches a maximum of several hundred feet. In the glacial Lake Ojibway and Lake Agassiz regions, the relief of the Precambrian Shield terrain is subdued by lacustrine depositions. Elevations in the Shield vary from just under 2,000 ft north of Lake Nipigon to about 500 feet above sea level at the boundary of the Hudson Bay Lowland. From this boundary across the Hudson Bay Lowland to the present coast, the elevation decreases very gradually but steadily to sea level at the rate of 2 to 5 ft per mile. The Hudson Bay Lowland is virtually without relief except for the beachlines near the coast and the two areas of Precambrian rock outcrops south of Winisk. The relief is also interrupted by the valleys cut by the numerous large rivers which cross the Lowland (Figure 2) (15).

Local relief consists of alternating elevated areas and depressions (hereafter referred to as "high areas" and "low areas" respectively - Table I). In the Precambrian Shield differences in elevation of high and low areas vary from only a few feet to about 20 ft and more. These high and low areas vary in extent from a few hundred feet to several miles. Occasional low areas a few hundred feet in extent occur within high areas, and vice versa. The ground surface of the elevated areas is smooth and virtually devoid of the micro-relief features that are common in the depressions; these consist of hummocks and peat plateaux rising 3 or 4 ft above the surrounding surface. In the Hudson Bay Lowland, the high areas refer to river banks (Stop Nos. 7, 16, 18) and beach ridges (Stop No. 21). The low areas, which comprise most of the terrain, include a variety of micro-relief features such as hummocks, peat plateaux rising 3 to 4 ft above the surrounding surface, and palsas - Swedish term for low hillock or knoll in peatland containing permafrost - exceeding 10 ft in height.

Drainage

Regional drainage is provided throughout virtually all of the study area by about eight major rivers which cross the Hudson Bay Lowland in a northeasterly direction from the Precambrian Shield to Hudson Bay and James Bay. They cut through the Palaeozoic sedimentary bedrock and through layers of till and marine sediments up to 50-80 ft thick. The upper reaches and tributaries of these rivers in the Shield are interrupted by rapids and falls. The rivers cross the Hudson Bay Lowland in roughly parallel courses with a minimum of cross-drainage. Back from the rivers lie immense areas of poorly drained peatland (Figure 2).

Local drainage in the Shield varies considerably from good to excessive on the high areas to poor in the depressions. Bog conditions are prevalent. In the Hudson Bay Lowland local drainage varies from good on the peat plateaux and palsas to poor in the depressions.

Vegetation

The study area lies entirely within the taiga or boreal forest region, which extends east-west across Canada in a band several hundred miles wide. This vegetation zone has been described by several authors, but generally all of them attribute similar characteristics to it. J.S. Rowe (17) provides a description of the forest regions comprising the area under study; their distribution is shown in Figure 40.

The southeast corner of the study area lies in the Northern Clay Section. Extensive stands of black spruce (*Picea mariana*) cover the gently rising uplands as well as the lowland flats, alternating in the latter position with extensive sedge and heath bogs. Tamarack (*Larix laricina*) grows infrequently with the spruce except in young stands, and extensive areas of spruce-cedar swamp occur also. Improvement in drainage, due to slight changes in relief or to position beside rivers and lakes, is reflected in hardwood or mixed wood stands of aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), balsam fir (*Abies balsamea*), white spruce (*Picea glauca*) and the black spruce. Jack pine (*Pinus banksiana*) has a dominant position on many of the drier sites such as outwash deposits, old beaches and eskers.

The Central Plateau Section lies immediately northwest of the Northern Clay Section. Extensive sand and gravel deposits and low rocky outcrops provide a favourable environment for the prevalent jack pine. Black spruce types are well developed, from those occupying the shallow swamps to those of maximum productivity on the better-drained, level or undulating land. Mixture of the two conifers is common, and white birch (*Betula papyrifera*) and aspen occur within the same association. On the more restricted and favourable sites, such as river banks, lake shores and drumlinized till uplands where conditions of soil texture and drainage are optimum, communities of aspen, white spruce, balsam fir, black spruce, balsam, poplar and white birch are found. Areas of bog and upland rock barren occur throughout, the latter condition aggravated by frequent fires.

The Northern Coniferous Section, lying immediately northwest of the Central Plateau Section, comprises most of the Precambrian Shield portion of the area under study. Black spruce is the predominant tree, forming stands on the thin soils of the uplands as well as on the poorly drained lowlands, and associated on these two positions with jack pine and tamarack, respectively. Frequent fires have favoured the spread of jack pine and are probably responsible also for the general though scattered representation of white birch over the majority of sites. In river valleys, around some of the lakes and on south-facing slopes, where soil and local climatic conditions are more favourable, white spruce, balsam fir, aspen and balsam poplar form mixed stands of good growth.

The Nelson River Section forms a north-south band along the western edge of the study area. Black spruce comprises a large part of the forest cover, but proximity to the numerous and extensive swamps that lie back from the rivers is reflected in a restriction of growth. Where drainage is better, as along the sides of rivers, on islands or on low ridges, good stands of white spruce with some balsam poplar, white birch, aspen, and balsam fir are customary. Extensive and repeated fires have fragmented all the forest cover, and large areas support small growth aspen, white birch, and scattered white and black spruce, or jack pine and aspen, or grassy scrub on rock barrens. Tamarack is present with black spruce in the swamps.

The Manitoba Lowlands Section forms a very narrow strip along the eastern shore of Lake Winnipeg. The prevailing vegetation on the flat, poorly drained land consists of forest patches of black spruce and tamarack, with intervening swamps and meadows. Good stands of white spruce, aspen and balsam poplar, sometimes in mixture with balsam fir and white birch, occur on the better-drained alluvial strips bordering rivers and creeks.

The vegetation of the Hudson Bay Lowlands section has in general a subarctic appearance because of the predominance of an open cover of black spruce and tamarack in the swamps and peatlands. On the river banks, however, where drainage is better, forests of white spruce, balsam fir, aspen, balsam poplar and white birch occur, similar to those in the Northern Clay Section. Jack pine occurs only sparingly in the south. Northwestward the percentage of peatland and of lakes increases, and the prevalent forest is of stunted open-grown black spruce and tamarack. On the west side of James Bay, as on the coast of Hudson Bay in general, black spruce does not appear to be as well adapted to the sea shore environment as white spruce, and the latter species forms the maritime tree line.

The Forest Tundra Section occupies a narrow strip 10 to 50 miles wide along the cost of Hudson Bay. The vegetative pattern is one of tundra barrens and patches of stunted forest. The primary species is white spruce, which predominates over black spruce under the maritime influence of Hudson Bay, and tamarack accompanied by alder and willow shrubs. The general environment for tree growth is precarious because of the harsh climate, especially the strong winds and low air temperatures, and the continuous permafrost conditions. There is evidence that the treeline has fluctuated widely in the past.

Throughout the area under study, variations occur in the vegetation corresponding to changes in local relief. The "low areas" are characterized by bog vegetation - open bogs with scattered stunted black spruce growing on thick accumulations of Sphagnum and sedge peat. The best spruce growth occurs on the peat micro-relief features such as peat plateaux, and particularly the palsas, where local drainage is relatively good. The tallest spruce grow to about 40 ft but the majority of trees are less than 25 ft tall. The vegetation of the Hudson Bay Lowland has been described by Hustich (17). Spruce islands occur in large numbers in the peatlands of the Hudson Bay Lowland (Figure 4). Patterned fen and string bog-like features are also abundant in all stages of development both north and south of the southern limit of permafrost (Figure 5). Tamarack is common, either mixed with black spruce, or in pure stands. Vast tracts of dense tamarack occur in the Hudson Bay Lowland between the major rivers, the maximum tree height averaging about 20 ft (Figure 2). Scattered jack pine growing to about 20 ft are encountered in drier bogs. The ground cover consists predominantly of Sphagnum, with patches of feather and club mosses, lichen and Labrador tea. In some areas of the Hudson Bay Lowland, lichen covers 50 per cent or more of the ground surface (19). Sedge predominates in the wet treeless areas and the aforementioned tamarack forests.

The "high areas" with moderate to good drainage include river banks (Figures 2, 3), and beach ridges (Figures 21, 22, 23) in the Hudson Bay Lowland and mineral soil and rocky areas in the Precambrian Shield. The tree growth consists mainly of white spruce, black spruce and jack pine, scattered aspen, balsam poplar and tamarack with undergrowth of willow and alder. The tallest trees grow to about 40 ft in the Hudson Bay Lowland, and higher in the Shield, in dense stands averaging about 5 ft between trees. Areas with subdued relief and poorer drainage have white spruce as the major cover, with occasional aspen. Improved drainage, coarser grained soils and more irregular relief results in an increase in aspen and a decrease in white spruce. The ground vegetation consists of various berry plants, grasses, Labrador tea, discontinuous cover of feather and club mosses, and some lichen. The beach ridges in the Hudson Bay Lowland are frequently characterized by the ground surface being completely covered with lichen (Figures 22, 23).

Scattered burned-over areas occur in the study area. Following a fire in the high areas it appears that aspen is the main species to regenerate on medium to fine-grained soils, and jack pine the main post-fire species on sandy areas. Burned trees are prevalent in many areas of the Hudson Bay Lowland and the Precambrian Shield. Many of the large mature palsas show evidence of recent forest fires as evidenced by the dense cover of burned trees. In these areas, the burned areas are confined frequently to the well-drained drier palsas, the surrounding wet areas remaining virtually untouched by fire (Figures 8, 9, 10, 11).

Soils

Throughout the study area the soils vary from coarse-grained sands and gravels to fine-grained silts and clays. Their character is strongly influenced by their nature of origin, the coarse-grained soils being associated with till, glaciofluvial and shoreline deposits, fine-grained soils with lacustrine and marine deposits. Following deposition of these materials, profile development has produced pedological variations.

Rowe (17) has described the pedological characteristics of the soils in each of his forest sections. In the Northern Clay Section grey wooded soils have developed on the calcareous upland clays and modified tills, with podzolic and peaty gleysols on the flats. A podzol profile is usual on sand ridges.

In the Central Plateau Section grey wooded profiles are usual. There are local areas of very calcareous soils supporting stands of stunted black spruce. The coarser outwash and terrace deposits are leached of their lime, and podzolization is more active in them. Peaty gleysols and peaty podzols are found on the low areas.

The Northern Coniferous Section experienced intensive glaciation and soil development is poor except in the deeper drift of slopes and valleys. Podzol profiles have developed in these locations, while the less well drained areas are peat filled.

To the west, the Nelson River Section has developed on lacustrine clays and sands deposited in glacial lake Agassiz. Podzolic profiles normally develop on well-drained areas; podzolic gleysols are typical of poorly drained slopes; and moss and peat characterize the lowlying spruce-and-tamarack-covered peat bogs.

In the Manitoba Lowlands Section along the east shore of Lake Winnipeg, the influence of the limestone parent materials can be seen in the soils which tend toward rendzinas and high lime meadow and peat profiles. In areas long under forest, shallow grey wooded profiles have developed on this highly calcareous substratum.

Organic soils predominate in the Hudson Bay Lowland, some associated with perennially frozen ground. In well-drained locations on alluvium and on ridges, weak brown wooded soil profiles have developed.

PERMAFROST

Northern Ontario and Northeastern Manitoba are located almost entirely in the discontinuous permafrost zone (Figure 41) (20), but the narrow tundra strip along the coast of Hudson Bay lies in the continuous permafrost zone. The distribution of permafrost in the study area is notable for several reasons. First, the southern limit of permafrost in Canada dips farthest (excluding occurrences at high elevations in the mountainous Cordillera of western Canada) at the south end of James Bay near Moosonee. Second, the discontinuous zone is narrower than anywhere else in Canada, being only about 250 miles wide in contrast to about 500 miles in the Mackenzie River region. Third, the continuous permafrost zone reaches its most southerly extent in Canada at the north end of James Bay.

Within the permafrost region in the study area, perennially frozen ground varies from scattered islands in the south to continuous distribution in the north. In the southern fringe of the discontinuous zone, permafrost islands vary in extent from less than 50 ft to several acres. The thickness of these patches varies from a few inches to 1 or 2 ft at the southern limit of the permafrost region to tens of feet where the distribution becomes widespread in the northern portion of the discontinuous zone. No information is available on the thickness of permafrost at any stations in Ontario, but thicknesses of 50 ft and more have been encountered at Thompson and Kelsey in northeastern Manitoba near the southern boundary of widespread discontinuous permafrost. Northward, the permafrost becomes increasingly widespread and thicker, reaching depths of 100 to 200 ft at Churchill, Manitoba just north of the study area. The continuous zone is much thinner here than elsewhere in Canada; it is confined to a narrow coastal strip. Because of its proximity to Hudson Bay, the permafrost, although continuous, is probably thin (perhaps only 100 ft or less) and wedges out at the shore.

The helicopter traverse crossed the southern limit of permafrost at three locations in Northern Ontario and approached it in northeastern Manitoba (Figure 1). On the first northward leg of the traverse, permafrost was encountered first at Stop No. 5 about 50 miles north of Moosonee. The next leg, extending southward from Winisk to Ogoki, lay just within the Hudson Bay Lowland. Permafrost was encountered at Stop Nos. 21 and 22 north of Attawapiskat River but none was found at Stop Nos. 23, 24 and 25 south to Ogoki. A small area of coalescing palsas and peat plateaux covering several acres was observed, however, 20 miles north of Mississa Lake between Stop Nos. 23 and 24. Westward in the Precambrian Shield on the third leg of the traverse, permafrost was encountered first at Stop No. 30 about 30 miles south of Trout Lake. Between Island Lake and Norway House in Manitoba, permafrost was encountered at all the stops. This leg of the traverse did not extend sufficiently southward to cross the southern limit of the permafrost region. Although the most southerly occurrences of permafrost encountered on the various legs of the traverse lie north of the southern limit shown on the map, it is probable that occurrences of permafrost could have been found in other peatland areas not examined.

All occurrences of permafrost, examined in the discontinuous zone were encountered in peatlands or bogs (Figure 42). In the Hudson Bay Lowland all of the terrain consists of peatland except the river banks, beach ridges, and areas of rock outcrop south of Winisk. In the Precambrian Shield, all permafrost occurrences were encountered in peat bogs. In the peatlands and peat bogs (low areas), the vegetation consists mainly of two associations:

1. Little or no tree growth, marsh sedge 1 to 2 ft high and thin moss, predominantly of the feather and other non-Sphagnum types, and scattered patches of Sphagnum. These areas are almost always very wet.

2. Dense or scattered stunted black spruce and tamarack, thick often very hummocky Sphagnum, lichen varying in coverage from scattered patches to virtually continuous cover, and Labrador tea. Some of these areas are wet and some are fairly dry.

In the Precambrian Shield, most of the peat bogs are only a few hundred feet in extent, being closely confined by rock knobs. These bogs usually support vegetation described in association No. 2. A few bogs, which were more extensive, more frequently support vegetation described in association No. 1. East of Lake Winnipeg in the glacial Lake Agassiz lacustrine deposits, there are extensive peatlands as in the Hudson Bay Lowland with similar vegetation and permafrost characteristics.

Because the relief of the study area is subdued, even in the Precambrian Shield, no modifications to the general pattern of permafrost distribution due to high elevations were encountered.

Several of the major rivers flowing eastward into James Bay - Albany, Attawapiskat and Ekwan - have north- and south-facing banks. It could be expected that permafrost might exist in the north-facing banks of these rivers but none was encountered on the survey.

High Areas

Four high areas, all in Ontario, were investigated for permafrost covering the range of terrain conditions encountered on the river banks and beach ridges in the Hudson Bay Lowland. On the river banks (Stop Nos. 7, 16, 18 in Table I; Figures 2, 3) the tree growth consists of dense spruce up to 40 ft in height and tamarack. Undergrowth of willow and alder grows to a maximum height of about 10 ft. At Stop No. 7 the ground cover consists of feather moss, grass and sedge growing on a 3-in. layer of forest litter. The mineral soil is a wet silty clay to a depth of 6 ft 3 in. overlying fine grey sand. At Stop No. 16 the surface peat layer is 1 ft 6 in. thick overlying a layer, 3 ft 6 in., of brown sandy clay. Below, the soil is beach sand with stones and shells. At Stop No. 18 the mineral soil consists of a 2-ft layer of brownish yellow silt, possibly less, overlying a 1-ft layer of beach material with shells, below which is stony till.

Stop No. 21 is typical of the beach ridges in the Hudson Bay Lowland which are some distance inland and support a mature forest growth (Figures 22, 23). It is located about 100 miles from the coast and supports vigorous spruce growing in open stands to a height of 25 ft. The ground cover consists of a continuous lichen mat 3 in. thick and large scattered clumps of Labrador tea. The underlying beach material consists of sandy gravel.

No high areas were investigated in the Precambrian Shield. It is presumed that no permafrost occurs in these areas based on observations made in the Shield in western Manitoba and Saskatchewan (2).

Low Areas

During the survey, 39 low areas covering the range of terrain conditions in the study area were investigated for permafrost. They vary in extent from a few hundred feet to several miles. As mentioned previously, several distinct associations of vegetation with related drainage occur.

Generally the tree growth consists of scattered to dense spruce varying in height from 2 to 40 ft, and tamarack. Alder and willow undergrowth was infrequent occurring at only about seven sites. Burned trees were found at eight sites. The ground vegetation is a mosaic of Sphagnum, feather and other mosses, Labrador tea, grass and marsh sedge in various combinations. The micro-relief ranges from flat to very hummocky. Individual hummocks vary in size to a maximum of 3 ft high and of 4 ft wide. Variations in elevation from one association to another range through several feet. Peat plateaux rising 3 to 4 ft above the surrounding poorly drained areas are prevalent. Palsas up to 12 ft or more in height occur in large numbers in the Hudson Bay Lowland. Surface and subsurface drainage is variable. Standing water is usually associated with marsh sedge areas and many of the lowest lying Sphagnum areas. The individual hummocks, peat plateaux, and palsas are drier. Depth to the mineral soil (thickness of moss/lichen and peat) in 47 observations varied from a minimum of 1 ft to a measured maximum of 10 ft 2 in. One-half of the observations exceeded 7 ft in thickness. Hustich (18) has ascribed an average value of annual peat accumulation in the Hudson Bay Lowland of about 1.2 mm or 1/20 in. based on numerous observations.

Fine-grained soils, silts and clays, predominate but sand and stony materials were encountered at several locations. Gravel was not present at any site but bedrock was found directly under the peat at one stop. Permafrost was encountered at 23 of the 41 stops on the survey. A total of 27 observations of permafrost were made at the 23 stops. Sphagnum comprises the cover at 21 of the permafrost sites and at 25 sites where no permafrost was encountered. Lichens (Cladonia sp. and Cetraria sp.) grow at 47 sites, and are absent at 18 sites. Of the 47 sites where lichen was found, permafrost was encountered in 22 and not in the remaining 25. In the 18 sites where no lichen was growing, 4 had permafrost and 14 did not. These observations are presented in the following Table:

	Permafrost	No Permafrost
Sphagnum	21	25
No Sphagnum	6	13
Lichen	22	25
No Lichen	4	14

The depth of the permafrost table was determined at 26 sites. It occurred above the mineral soil in the peat in 24 of these locations. The average depth to permafrost of 26 determinations was 1 ft 9 in. The minimum depth to the permafrost table encountered throughout the investigations was 1 ft 0 in. and the maximum depth was 3 ft 0 in. The depth of the permafrost table at most of the sites was encountered between the depths of 1 ft 6 in. and 2 ft 0 in.

Permafrost thickness was determined at 12 sites. The thinnest permafrost encountered was 3 in. at Stop No. 17 south of Fort Severn and Stop No. 35 northeast of Gods Lake in Manitoba. In the palsa at Stop No. 5 located at the southern limit of the discontinuous zone, the permafrost was 4 ft 2 in. thick. In most cases where the thickness of the permafrost layer could be ascertained, it was located entirely within the peat layer.

Ice was encountered in many of the holes advanced into permafrost. Much of it occurred in layers, the thickest about 1 in. One exception to this was a layer of ice 3 ft thick encountered in the palsa examined at Stop No. 5. Ice was also found in the form of small pellets and other random inclusions.

The relationship of permafrost occurrence to tree species was also noted. Tamarack was encountered at 22 locations where permafrost observations were made. Permafrost occurred in 10 of these but not in the remaining 12.

Subsurface investigations in permafrost (excluding palsas which are described separately) were carried out at numerous locations including the following:

Stop No. 13 (about 5 miles west of Winisk, Ont.) (Figures 18, 19).

Soil profile: 0 to 3 ft 6 in. - peat;
below 3 ft 6 in. - grey clayey sand;
below 1 ft 0 in. in dry peat plateau and below 3 ft 0 in. under water in surrounding areas there is permafrost.

Stop No. 20 (about 5 miles east of Fort Severn, Ont.) (Figures 20, 21).

Soil profile: 0 to 1 ft 0 in. - peat;
below 1 ft 0 in. - clayey silty fine sand;
below 2 ft 0 in. there is permafrost.

Stop No. 37 (west of Island Lake, Manitoba) (Figures 28, 29).

Soil profile: 0 to 7 ft 0 in. - peat;
below 7 ft 0 in. - grey clay;
below 2 ft 0 in. there is permafrost.

Stop No. 41 (north of Norway House, Manitoba).

Soil profile: 0 to 2 ft 4 in. - peat;
2 ft 4 in. to 3 ft 6 in. - organic silt;
below 3 ft 6 in. - brown clayey silt;
1 ft 5 in. to below 5 ft 9 in. - permafrost.

Micro-relief in the form of hummocks, peat plateaux, and frequently palsas, was encountered at virtually all of the sites examined for permafrost occurrence. The Sphagnum was hummocky regardless of whether or not permafrost was present. Peat plateaux and palsas always indicated the existence of permafrost and both types of features appeared to be related in origin and development. In the Hudson Bay Lowland, numerous areas of coalescing palsas were observed which were virtually indistinguishable from peat plateaux. West of Winisk, for example, the peat plateaux in the early stage of development at Stop No. 13 (Figures 18, 19) are similar in situation and appearance to the youthful palsas examined at Stop No. 5 (Figure 6). Similarly, about 20 miles west of Winisk, mature peat plateaux with lichen cover (Figure 7) were observed to be similar in origin and appearance to coalescing palsas examined at Stop No. 9 and elsewhere (Figures 8, 9).

The peat plateaux and palsas in the Hudson Bay Lowland are the sites of the worst forest fires because they are the driest areas and support the most vigorous tree and lichen growth. A peat plateau which had experienced a very recent burn was examined at Stop No. 19 south of Fort Severn (Figure 11). The peat plateau was 3 ft high with recently burned dead spruce up to 15 ft. The ground cover consisted of charred Sphagnum and burned lichen, with a few patches of unburned Sphagnum. The fire had burned the top $\frac{1}{2}$ in. of Sphagnum and the top 1 in. of lichen down to the wet basal layer. The depth to the permafrost table in the peat was 1 ft 6 in., which was the same as in surrounding unburned Sphagnum-covered areas. It appeared that the unburned peat protected the permafrost from the heat of the fire and the increased solar heat input due to the burned black surface.

In the Precambrian Shield, particularly in the glacial Lake Agassiz region of Manitoba, peat plateaux are very extensive (Stop Nos. 37 to 41 inclusive). Mature peat plateaux occur as far south as Norway House, which is climatically similar to Moosonee where no such features were found. (The higher freezing index at Norway House is probably a significant factor.) Generally, the lichen cover is less extensive in this region, up to 25 per cent, compared to the Hudson Bay Lowland, where it exceeds 50 per cent in many areas.

Palsas

Palsas are very prevalent in the Hudson Bay Lowland. Palsas encountered at Stop No. 5 constitute the most southerly occurrence of permafrost on this leg of the helicopter survey. These palsas are small, being in the early stage of development. They vary in size from a few square feet to the largest measuring 31 ft long by 12 ft wide by 2 ft high and are surrounded by water. Living vegetation was absent except for a few willow shrubs and sedge plants, consisting of bare sedge peat. Subsurface exploration in the largest palsa revealed a layer of peat 5 ft 2 in. thick overlying grey clayey silt with fine sand down to the 7 ft 4 in. depth. Below this depth the soil is stony. The depth to the permafrost table varied from 1 ft 1 in. in the middle of this palsa to 2 ft 1 in. at the water's edge. The permafrost core varies in thickness from 4 ft 2 in., including a layer of ice 3 ft thick in the middle of the palsa and tapering to 7 in. at the water's edge. The permafrost wedges out a few inches beyond the edge of the palsa under the water. No permafrost occurs in the surrounding areas under water.

Mature palsas were encountered at Stop No. 9 north of Attawapiskat (Figures 8, 9). They stand about 10 ft above the surrounding peatland surface and support a tree growth of scattered spruce up to 10 ft. The presence of many burned trees both standing and lying on the ground indicated a previous dense growth of mature spruce. The ground cover consisted of almost continuous lichen and dense Labrador tea. The lichen has undergone considerable biological oxidation and the ground surface is very hummocky and cracked. The peat varied in thickness from 4 ft 9 in. to 2 ft in local hollows overlying grey silty clay with a mixture of sand and stones. The depth to the permafrost table was 2 ft 8 in. but no permafrost was found in the local hollows. Ice was found in the peat and mineral soil.

At Stop No. 11 near the Ekwan River about 60 miles northwest of Stop No. 9 a lower palsa about 6 ft high was examined (Figures 12, 13). No trees grow on this palsa but the presence of burned trees indicated a former vigorous growth. The ground surface consisted of a hummocky lichen cover which was oxidized. The peat was 10 ft 2 in. thick overlying clayey fine sand and silt with a few stones. The depth to the permafrost table was 1 ft 5 in. and ice lenses 1 in. thick were encountered.

A large high mature palsa about 20 ft high was examined at Stop No. 22 between the Ekwan and Attawapiskat Rivers about 100 miles west of James Bay (Figure 10). The tree growth, consisting of spruce up to 30 ft high, was the most vigorous of all the palsas examined. The large number of dead mature trees lying on the ground indicated previous dense tall growth. Several depressions up to 20 ft in diameter and about 12 ft deep occurred in the palsa supporting scattered spruce 2 ft high. The ground cover of the palsa consisted of hummocky Sphagnum, scattered lichen and Labrador tea. In the depressions the ground cover was Sphagnum, sedge and ground birch, and water stood at the ground surface. The peat in the palsa was about 7 ft thick and in the depressions also about 7 ft overlying grey clayey silt with stones. The depth to the permafrost table was 2 ft 3 in. in the areas of growing trees and 2 ft 9 in. in the burned areas. No permafrost was encountered in the depressions.

In addition to the palsas described above, many other palsas in all stages of development were observed in the Hudson Bay Lowland. Between Stop Nos. 7 and 8, between the Albany and Attawapiskat Rivers near the coast of James Bay, there are many small scattered palsas. Farther north between Stops 8 and 9, north of the Attawapiskat River, all palsas were observed in the centres of shallow ponds. Numerous palsas were also seen between Stop Nos. 11 and 12 in the vicinity of the rock outcrops at Sutton Lake and Hawley Lake. South of Fort Severn in the northern part of the discontinuous permafrost zone between Stop Nos. 15 and 16 extensive palsas up to 10 ft were observed in which the permafrost probably exceeds 30 ft in thickness. Large coalescing palsas were observed between Stop Nos. 19 and 20 near Fort Severn. Small developing palsas occur in a few lakes in the tundra coastal strip on Hudson Bay between Fort Severn and Winisk.

Densely forested palsas occur north of the Attawapiskat River between Stop Nos. 21 and 23. Inland from James Bay and south of the Attawapiskat River between Stop Nos. 23 and 24, several old palsas, partially destroyed by thawing and slumping, were observed. No newly forming palsas were seen in this area south to Mississa Lake at the southern limit of the permafrost similar to those described at Stop No. 5 near Moosonee.

Farther west in the Precambrian Shield, palsa development was observed at several locations. In the vicinity of Stop Nos. 33 and 34, which are located near the western edge of the Hudson Bay Lowland, palsas were observed to be developing in small shallow lakes similar to those described above.

The most intensive study of palsas in the Hudson Bay Lowland was carried out by Sjörs. His observations are described in three papers and he discusses the various theories which have been advanced on their origin (21-23).

Another type of feature associated with permafrost, polygons and polygonal cracks were observed in the tundra strip where the permafrost appears to be continuous. Areas of narrow cracks forming polygons about 50 ft in diameter occur just east of the Winisk River in sedge-covered treeless areas. Polygonal cracks were also observed in the bottom of a lake about 1 mile in diameter between Hawley Lake and Winisk. Five miles east of Stop No. 20 on the Hudson Bay coast several polygonal cracks occur in the beach deposits.

Air Photo Patterns

Vertical air photo coverage is available for all of Northern Ontario and Northeastern Manitoba at a scale of 5,000 ft: 1 in. or 3,333 ft: 1 in. (taken at altitudes of 30,000 and 20,000 ft respectively). Examination of the air photographs reveals a variety of patterns throughout the area under study because of the variations in relief, vegetation, soils and drainage. The most notable feature of the air photographs is the variety of patterns in the peatlands of the Hudson Bay Lowland. The lack of relief and poor drainage contribute to the jumbled appearance of surface vegetation and other terrain features. Within this broad framework, the recognition of such permafrost features as peat plateaux and palsas is hindered by their small size on the available photographs, and their similarity to other terrain features which have no permafrost. Three photographs have been selected from the Hudson Bay Lowland showing some of the patterns including permafrost features (Figures 43, 44, 45). One photograph is included from the glacial Lake Agassiz region in Manitoba east of Norway House where permafrost was encountered in an extensive peatland (Figure 46).

I. The first aerial photograph (Figure 43) is located at Stop No. 9 about 35 miles northwest of Attawapiskat. The entire area is peatland in which three main patterns are evident:

1. Medium grey with smooth texture covering the central and southwest portions of the photograph on both sides of the stream which flows from west to east. This is a low, wet, poorly drained flat sedge-covered area. The black peppery flecks are small pools of water less than 50 ft in diameter. No permafrost occurs in this area.

2. Fine network of closely spaced dark grey to black flecks in a light grey mesh-like matrix covering the northwest and eastern quarter of the photograph. This type of area termed "patterned fen with flarks" by Sjörs (Reference 22), is low, wet, poorly drained and flat, and consists of shallow pools up to 100 ft in diameter separated by low narrow sedge-covered peat ridges about 1 ft high. The dark grey circular areas in the southeast corner are spruce islands up to several hundred feet in size. No permafrost was encountered in this type of terrain.

3. Light grey circular and irregularly shaped areas with white patches adjacent to the stream and bordering Pattern 2 in the southeast portion of the photograph. These areas are large mature palsas 15 ft high and high peat plateaux and coalesced palsas (Figures 8, 9). The light grey tone is caused by the dense cover of Labrador tea growing on the lichen cover of the palsas. Permafrost occurs in these features.

II. The second aerial photograph (Figure 44) is located at Stop No. 10 about 30 miles northwest of the previous photograph. The entire area is peatland in which two main patterns are evident:

1. Medium to light grey tone with smooth to slightly grainy texture. This pattern occurs in irregularly shaped areas scattered throughout the photograph and along the stream in the northeast portion. These low, flat, wet patches are treeless and covered with sedge. The black peppery flecks are small pools of water. Low scattered spruce up to 2 ft high grow on Sphagnum-lichen covered bog at the edges of these areas. The

dark grey to black along the stream in the northeast portion of the photograph is dense spruce growing on well-drained mineral soil banks. No permafrost was encountered in this pattern.

2. Most of the photograph, comprising the areas between the patches of Pattern 1, is a network of closely spaced dark grey to black flecks in a medium- to light-grey meshlike matrix. This area termed "patterned fen with flarks" is similar to Pattern 2 of the previous photograph but is slightly coarser in texture. A high concentration of spruce islands in the form of dark grey circular and irregularly shaped areas is super-imposed on this pattern. The entire pattern is generally wet although the spruce islands are relatively the best drained portions. No permafrost was encountered in this pattern, even in the spruce islands, although it could possibly exist in these features.

III. The third aerial photograph (Figure 45) is located 60 miles west of Winisk near the treeline. The entire area is peatland in which two main patterns are evident:

1. Light grey to white with fine to medium texture. This pattern occurs in irregularly shaped areas varying greatly in size from $\frac{1}{2}$ mile to several hundred feet. These areas are peat plateaux, ridges and mounds rising 5 to 10 ft above the neighbouring ponds and small lakes. The light grey areas support low stunted spruce growing on Sphagnum-lichen, and the white areas are lichen. Permafrost occurs in this pattern (Figure 7).

2. Network of closely spaced dark grey to black irregularly shaped flecks and minute spots in a medium grey mesh-like matrix producing a pattern similar to Pattern 2 of the first and second aerial photographs (Figures 43, 44). This is also patterned fen with flarks but no spruce islands occur here. This pattern is found mainly along the west edge of the photograph but small areas are scattered throughout. It is unlikely that permafrost exists in this pattern.

IV. The fourth aerial photograph (Figure 46) is located about 8 miles east of Norway House. This area is located in the glacial Lake Agassiz plain. Precambrian rock outcrops are scattered throughout this area interspersed with extensive peatlands containing peat plateaux and string bogs. Three distinctive patterns are visible on the aerial photograph.

1. Irregularly shaped white areas partially covered with dark grey to black coarse-textured patches. These areas are Precambrian rock outcrops with spruce trees growing on them. No permafrost occurs in this pattern.

2. Large oval to circular medium to dark grey areas with coarse to medium texture. These areas are peat plateaux 3 to 4 ft high supporting fairly dense spruce tree growth. The coarse-textured areas have the densest tree growth and are the most probable locations of permafrost (Figures 30, 31, 32). Small light grey treeless sedge-covered depressions occur within the large circular areas on the east side of the photograph.

3. Light grey elongated areas with fine to medium texture interspersed between the darker areas of Pattern 2. These low wet areas have scattered stunted spruce trees and ground cover of sedge and moss. Permafrost does not exist in this pattern. Two elongated areas of string bog occur in this pattern as dark grey sinuous bands, one extending diagonally across the photograph from southwest to northeast, and the other across the southern edge of the photograph.

DISCUSSION

The chief problem arising from permafrost investigations in Northern Ontario and Northeastern Manitoba is the prediction of permafrost conditions from existing climatic and terrain features. An accompanying problem is the assessment of the relative influence of climate and terrain on the formation and maintenance of a permafrost condition (perennially below 32°F).

The patchy distribution and thinness of the permafrost in the southern part of the study area is characteristic of the southern fringe of the discontinuous zone, where permafrost exists in a delicate thermal state close to 32°F. Observations in Canada and other countries indicate the existence of a broad relation between mean annual air and ground temperatures in permafrost. Many investigations have estimated the mean annual air temperature required to produce and maintain a perennially frozen condition in the ground, but there is some disagreement on this matter. In Canada the southern limit of permafrost, as known at present, coincides roughly with the 30°F mean annual air isotherm. The difference between mean annual air and mean annual ground temperatures, and variations in this difference from one location to another, are caused by climatic factors other than air temperature, in combination with surface and subsurface terrain factors. The complex energy exchange at the ground surface, which is influenced by these factors, and the snow cover which reduces the influence of winter air temperatures, cause the mean annual ground temperature measured at the level of zero annual amplitude to be several degrees warmer than the mean annual air temperature (20, 24, 25).

The mean annual air temperature in the study area varies from 30.2°F at Pickle Lake to 22.1°F at Winisk (Figure 33). The location of the 30°F mean annual air isotherm is also shown on Figure 33 and corresponds roughly with the southern limit of permafrost (Figure 41). Between the 30°F and 25°F mean annual air isotherms in the southern fringe of the discontinuous zone, permafrost occurs mostly in scattered patches and islands in peatlands and peat bogs, and possibly in heavily shaded areas and in some north-facing slopes. North of the 25°F isotherm, permafrost is widespread and found in most types of terrain. As mentioned previously, this subzone of widespread discontinuous permafrost is very narrow in the study area, particularly in the northeastern corner of Ontario.

In the southern fringe of the permafrost region, permafrost can exist only in certain types of terrain described previously, provided the climate is sufficiently cool - i.e. the mean annual air temperature 30°F or less. Southward, permafrost occurrences are rare and small in size and generally are not found in the same types of terrain because the climate is too warm. Such occurrences were found in the Prairie Provinces (2) but none was encountered in the area under study. In the vicinity of the 25°F mean annual isotherm, the average difference of 6°F between the mean annual air and ground temperature produces a mean annual ground temperature of a fraction of a degree below 32°F, in most types of terrain.

From the 25°F mean annual air isotherm northward, permafrost becomes increasingly widespread and thick, and the mean annual ground temperature decreases. The influence of climate on the existence of permafrost becomes increasingly important and variations in the terrain cause variations in the depth to permafrost, its areal extent and thickness (26, 27).

The continuous permafrost zone throughout Canada except in the study area lies north of the 17°F mean annual air isotherm which corresponds roughly to a mean annual ground temperature of 23°F. In Northern Ontario and Northeastern Manitoba, however, the narrow strip along the coast of Hudson Bay appears to lie in the continuous permafrost zone, according to field observations, but it lies south of the 20°F mean annual air isotherm. This discrepancy may be related in some manner to the fact that the area is situated north of the treeline. On the other hand, further field observations may reveal discontinuities in the permafrost placing it in the discontinuous zone.

The only available ground temperature observations are at Thompson and Kelsey in Northeastern Manitoba at the western edge of the study area (28, 29). They are located in the middle of the discontinuous zone near the 25°F mean annual air isotherm. Permafrost occurs in scattered islands with maximum known thicknesses of about 50 ft. The mean annual air temperature at both stations is 25°F and mean annual ground temperatures in permafrost range from 31°F to 32°F.

In previous investigations carried out in western Canada, questions regarding the origin and persistence of permafrost and the factors governing development of various types of terrain were raised (1, 2, 3). The same questions apply to the area under discussion referring to the reasons for permafrost occurring only in certain types of terrain in the southern fringe of the discontinuous zone. In peatlands and peat bogs, in which all of the known permafrost occurrences in the Hudson Bay Lowland (excluding the narrow coastal strip in the continuous zone) and Precambrian Shield in the study area are found, the thermal properties of the peat appear to determine the presence of permafrost.

The mechanism of permafrost formation in peat terrain appears to be related to changes in the thermal properties of the peat through the year (30, 31). During the summer the surface layers of peat become dry through evaporation. The thermal conductivity of the peat is low and warming of the underlying soil is impeded. The lower peat layers gradually thaw downward and become wet as the ice layers in the seasonally frozen layer melt. In the autumn there tends to be more moisture in the surface layers of the peat because of a decreased evaporation rate. When it freezes the thermal conductivity of the peat is increased considerably. Thus the peat offers less resistance to the cooling of the underlying soil in winter than to the warming of it in summer. The mean ground temperature under peat will therefore be lower than under adjacent areas without peat. When conditions under the peat are such that the ground temperature remains below 32°F throughout the year, permafrost results and is maintained as long as the thermal conditions leading to this lower temperature persist.

Other factors such as micro-relief, drainage and snow cover influence the ground thermal conditions and may be involved in the production of permafrost islands. Such a close relationship exists between these and other environmental factors that it is difficult to single out the significant effect of each of these factors on the permafrost.

Permafrost Indicators

Consideration was given to the use of the various components of the environment as indicators of the presence of permafrost. Tree types by themselves cannot be employed as reliable indicators of permafrost. Spruce is the predominant tree on peatlands and peat bogs in the Hudson Bay Lowland and Precambrian Shield; it grows both on permafrost sites and sites with no permafrost. Tamarack also grows with the spruce on many sites where permafrost was present and where it was absent. Extensive pure stands of tamarack grow in the Hudson Bay Lowland between major rivers. No permafrost occurs in these vast, flat areas because of the poor drainage conditions. Thus these extensive stands of tamarack could be considered as an indicator of the absence of permafrost.

Most permafrost sites have Sphagnum and lichen, but these plants are unreliable indicators because they grow extensively in areas where permafrost does not exist. Various attempts have been made to correlate the distribution of permafrost in peat terrain with the occurrence of lichen (32). This supposition was examined in detail in a previous paper and proved invalid (33). Nevertheless, macrolichens are so prolific in the Hudson Bay Lowland, and to a lesser extent in the peat bogs of the Precambrian Shield (19) that special note was taken on the helicopter survey of their occurrence in relation to permafrost distribution. On the first leg of the survey, lichen covering 25 per cent and more of the peatland terrain, and thus qualifying as Radforth's muskeg H factor, was noted in the vicinity of Stop No. 1 more than 100 miles south of the southern limit of permafrost. North of Stop No. 5, lichen covering 25 to 50 per cent or more of the ground surface was observed at many sites where permafrost was absent (Figures 14, 15). At some sites, permafrost occurred where lichen was absent and it was not found in some areas covered with lichen (see table on page 30). Those various situations were also encountered on the other legs of the traverse.

In areas where permafrost is forming, lichen growth does not usually begin until many years have elapsed, even decades or centuries (34). On the coast of Hudson Bay, the shoreward limit of lichen growth was observed to be about the second or third beachline back from the water's edge. Assuming an uplift of about 3 ft per century, the second or third beachline has been above water for at least several decades. Permafrost would begin to form in the present climatic conditions soon after exposure to the atmosphere and decades before lichen growth begins. Similarly in the case of young palsas, lichen does not begin to grow on them until many years after the perennially frozen core has developed. Thus, the absence of lichens on these newly formed features does not indicate the absence of permafrost.

The type of mineral soil does not appear to have any bearing on the existence of permafrost. Fine-grained soils were encountered at sites where permafrost was present and where it was absent. Sandy soils and stony materials were also found at sites with permafrost and sites without it. It is rarely possible to determine the mineral soil type in the peatlands from the surface vegetation. The same type of permafrost and associated conditions prevail on all types of soil in relation to the vegetation, microrelief and drainage conditions.

The occurrence of permafrost in the discontinuous zone appears to be closely related to drainage. The importance of water conditions is shown by the absence of permafrost in areas where the water table is at the ground surface, even if the ground cover consists of Sphagnum. Permafrost occurs, however, in the microrelief peat features such as mounds, ridges, plateaux and palsas which rise above the wet areas. It is suggested that these features are morphological variations of the same process, i.e. the same mechanism is responsible for the formation of peat plateaux and palsas. The European literature appears to support this contention (34, 35, 36). They appear to pass through a life cycle of development and degradation and all stages occur in the Hudson Bay Lowland.

Initially, these features appear as low mounds or upwarpings of peat protruding above water level in the middle of shallow ponds only a few inches deep (Figure 6). The mechanism of their formation and control of their distribution is uncertain, but it is suggested that the pond freezes to the bottom in winter and the underlying saturated peat is domed up at random locations by intensive frost action and ice lens growth. When elevated above the pond level, the dry layer of exposed peat insulates the underlying frozen mass from summer thawing, thus marking the initiation of a perennially frozen or permafrost condition. The elevation of the peat surface above the general level of the surrounding flat level surface devoid of relief exposes it to winter winds which reduce or remove the insulating snow cover. Winter frost penetration is therefore greater than in the surrounding low, flat areas, thus contributing to further permafrost accumulation.

As the peat continues to accumulate year after year accompanied by the increase in permafrost thickness each winter, the mounds grow and coalesce to form plateaux. In the youthful stage, there is little or no living vegetation on the peat surface. During maturity, Sphagnum and other mosses and lichens become established, along with Labrador tea and spruce (Figures 7, 8, 9). Old age and degradation begin when the insulating ground cover ruptures due to biological oxidation and general deterioration, and thawing penetrates into the underlying perennially frozen core. The surface of the palsa or peat plateau becomes very uneven because of differential thawing of the underlying ground ice and large blocks of thawed peat break off the margins. It is not certain whether rejuvenation can occur.

The critical factors in palsa and peat plateau formation are possibly climate, water supply, and snow cover. Little work has been done on the climatic requirements for the formation of these features but some information is available in the Scandinavian literature. It has been recorded in Sweden that palsas occur where the air temperature remains below 32°F during more than 200 days per year. They also appear to be present only where the precipitation - virtually all in the form of snow - during the period of November to April is less than 12 inches (37). It appears from the air temperature and precipitation data for the stations in the study area that these criteria are satisfied. Although palsas are much more prevalent in the Hudson Bay Lowland than in the Precambrian Shield, peat plateaux grow farther south climatically in the latter region. They occur extensively in the vicinity of Norway House which has approximately the same mean annual air temperature as Moosonee. A contributing factor may be the difference in freezing index which is about 5000 degree days at Norway House and less than 4500 at Moosonee. In addition, the snowfall at Norway House is only half of that at Moosonee.

Drainage conditions and water supply are very important factors in the development of palsas and peat plateaux. The ponds in which they begin to grow probably should be sufficiently shallow to freeze to the bottom in winter so that a frozen zone may develop below. The process of growth is not clear, but the gradual updoming of the peat proceeds possibly because of its high capillarity, which draws considerable quantities of water to the freezing front from the surrounding wet areas. These conditions occur widely in the Hudson Bay Lowland where palsas and coalescing palsas forming peat plateaux grow to heights of 10 to 15 ft. In the Precambrian Shield peat plateaux are common, especially in the glacial Lake Agassiz region, but grow to heights of only 3 or 4 ft. Reasons for this limitation are uncertain but may be related to less availability of water compared to the Hudson Bay Lowland, and less exposure to strong winter winds and reduction of snow cover due to the relief and more vigorous tree growth.

Snow cover is considered one of the critical factors in palsa development once formation of the feature has begun. According to Lundgvist (37) the amount of snowfall in the region through the winter may not exceed a certain quantity - i.e. 12 in. In addition, a differentiation occurs in that the snow cover on the palsas is significantly less than on the surrounding terrain. Winter observations have not been made in the Hudson Bay Lowland to test the validity of these assumptions.

A considerable number of papers has been published on palsas and associated features in recent years, some of which have been referred to in the text. Because of the importance of these features in the permafrost environment of Northern Ontario and Northeastern Manitoba, a special bibliography of other papers on palsas follows immediately after the list of references. Some references to string bogs are also included.

CONCLUSION

Climate is the most important factor influencing the formation and continued existence of permafrost. This is borne out by the location of the mean annual air isotherms relative to the distribution of permafrost, and indicates the existence of a broad relationship. South of the 30°F isotherm permafrost was not found in the study area although it might have been encountered if more sites had been examined. Between the 30°F and 25°F isotherms, permafrost is patchy and restricted to certain types of terrain. North of the 25°F isotherm, permafrost is widespread and in fact appears to be continuous along the Hudson Bay coast not far to the north.

Permafrost occurs only in the peatlands and peat bogs of the Hudson Bay Lowland and Precambrian Shield; none was encountered in the high areas. Even in the peat terrain, permafrost does not exist where water lies at or near the ground surface. It is restricted to the positive microrelief peat features - plateaux and palsas which abound in the Hudson Bay Lowland and are prevalent in the peatlands and peat bogs of the Shield. Drainage is therefore one of the main terrain factors influencing the existence of permafrost.

The role of vegetation in the distribution of permafrost is complex. The tree growth, predominantly spruce and tamarack, is not an indicator of permafrost distribution because these trees grow on sites where permafrost is both present and absent. The only direct correlation between tree growth and permafrost occurrence is in the extensive tamarack stands between the major rivers in the Hudson Bay Lowland. The absence of permafrost here is due to the lack of drainage and the tamarack reflect these conditions rather than the absence of permafrost. The Sphagnum and lichen cannot be used as indicators of the existence of permafrost.

One of the most difficult problems is explaining the distribution of permafrost peat features in the peatlands and peat bogs. There does not appear to be any obvious explanation of why these features occur in some peatland areas and not in others with apparently similar conditions. Local small variations in winter winds and snow cover may be sufficient to tip the net effect of all the environmental factors either towards or away from the initiation of these features.

A major difference between this survey in Northern Ontario and Northeastern Manitoba and the previous surveys in western Canada is the different means of transportation. In the latter area, the existence of a road network in the study areas and the use of an automobile made it possible to examine virtually every peat bog and other potential permafrost site along the route. In contrast to this, it was not possible to stop at every such site in the helicopter because of the greater time required to land and the frequent lack of a sufficiently large open area. Thus, some permafrost occurrences may have been missed in the southern part of the region. Nevertheless the broad patterns of permafrost distribution were established. The advantage of helicopter travel, naturally, was the opportunity afforded of seeing a much greater expanse of country at an altitude of 500 to 100 ft than it is possible to see on the ground from a road.

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TITLES OF COLUMNS AND EXPLANATION OF SYMBOLS IN TABLE I

Column 1 - Reference number of observation point listed in numerical order of helicopter stops beginning with Stop No. 1 between Timmins and Moosonee, Ontario and ending with Stop No. 41 north of Norway House, Manitoba.

Column 2 - Relief H - relatively elevated area, or river bank
L - relatively low area or depression.

Column 3 - Trees S - spruce, T - tamarack,J - jackpine, A - alder, W - willow, (40) - number in brackets is height in feet of tallest trees, (b) - burned over, d - dense growth, s - sparse or scattered growth.

Column 4 - Surface Features - Sph - Sphagnum moss, M - moss other than Sphagnum, Ln - lichen, (25) - percentage of ground surface covered by lichen, Lt - Labrador tea, G - grass, Se - sedge, B - ground birch, (w) - standing water or wet, (p) - peat plateau, P - palsa.

Column 5 - Thickness of peat (i.e. depth from ground surface to top of mineral soil). F - forest litter, (w) - wet.

Column 6 - Soil Type - G - gravel, Sa - sand, Si - silt, C - clay, X - scattered stones, O - organic, B - bedrock, (w) - wet.

Column 7 - Existence of permafrost.

Column 8 - Depth to permafrost table.

Column 9 - Thickness of permafrost.

Column 10 - Figure number in report.

TABLE I

NORTHERN ONTARIO AND NORTHEASTERN MANITOBA PERMAFROST SURVEY

1	2	3	4	5	6	7	8	9	10
				ONTARIO					
1	L	S(5) J(10) d	H Sph M Ln(15) Lt G Se	5'-6"(w)	Si Sa (w)	No	-----	-----	
2	L	----- S(2) d	M G Se (w) H Sph Ln G Se	>9'-9"	-----	No	-----	-----	
3	L	T(2) s	M G Se	-----	-----	No	-----	-----	
4	L	T(5) s S(25) T A W d	H Sph M G Se (w) H Sph M	2'-2"	Sa C Si X (w)	No	-----	-----	
5	L	T(5) s -----	Se G H Sph Ln Se P	5'-2"	C Si Sa X	No Yes	----- 1'-1" TO 2'-1"	----- 0'-7" TO 4'-2"	Figure 6
6	L	S T(5) s S(5) s S(30) d	Se G H M Sph H Sph Ln (>25) G Se (w) H Sph Ln	----- 7'-2" >3'-0"	C Sa Si	No	-----	-----	
7	L H	W(3) S(5) s S(40) T A W d	G Se (w) M G Se	2'-0" 0'-3" (F)	C Si Si C Sa (w)	No	-----	-----	Figure 2 Figure 3
8	L	S(5) T W(1) s S(30) T d	Se (w) H Sph M Ln Lt G Se (w)	1'-6"	C Sa Si X	No	-----	-----	Figure 8 Figure 9
9	L	S(10) (b) s S(10) T W(b) s	Ln(100) Lt P H Sph Ln Lt G Se	4'-9" 4'-3"	Si C Sa X -----	Yes	2'-8" 2'-0"	----- -----	
10	L	----- S(20) d	M G Se (w) H Sph Ln(50) Lt G (w)	6'-6"	C Si Sa	No	-----	-----	
11	L	S(15) s S(b) d	H Sph Ln(50) Lt B Se H Ln(100) P	8'-6" 10'-2"	C Sa Si X	No Yes	----- 1'-5"	----- -----	Figure 12 Figure 13
12	L	S(25) d	H Sph Ln(50) Lt B	9'-6"	X(w)	No	-----	-----	Figure 14 Figure 15
13	L	T(5) s	G Se (p)	3'-6"	C Sa	Yes	1'-0" TO 3'-0"	-----	Figure 18 Figure 19
14	L	S(40) T d W s	H Sph Ln(33) G Se	1'-9" 3'-0"	Si Sa	Yes No	1'-9" -----	----- -----	
15	L	----- S(5) T S(20)	Se G (w) H Sph Ln Se H Sph Ln(50) Se (p)	8'-0" 4'-8"	Sa Si C	No Yes Yes	----- 1'-6" TO 2'-9" 1'-6"	----- ----- -----	Figure 16 Figure 17
16	H	-----	-----	1'-6"	Sa C	No	-----	-----	
17	L	S(30) T (b) s	H Sph Ln(50) G Se	4'-0"	Si Sa	Yes	-----	0'-3" TO 0'-6"	
18	H	-----	-----	-----	Si Sa C X	No	-----	-----	
19	L	S(15) (b) d	H Sph Ln (p)	-----	-----	Yes	1'-6"	-----	Figure 11
20	L	W(1) s	M Se G	1'-0"	C Si Sa	Yes	2'-0"	-----	Figure 20 Figure 21

TABLE 1 (Cont'd)

1	2	3	4	5	6	7	8	9	10
21	L	ST (15) d	H Sph Ln (50) Lt B	4'-0"	Si Sa X	Yes	1'-6"	-----	Figure 22
		ST s	Se (w)	4'-0"	Si Sa X	Yes	1'-6"		
	H	ST (20) d	(p)	-----	-----	Yes	1'-6"	-----	Figure 23
		S (25) s	Ln (100)	1'-0"	Sa G	No	-----	-----	
22	L	S (30) (b) d	H Sph Ln Lt P	7'	C Si X	Yes	2'-3" TO 2'-9"	-----	Figure 10
		S (2)	Sph Se B (w)			No	-----	-----	
23	L	ST (5) (b)	H Sph Ln (50) Lt Se (w)	7'-0"	Sa	No	-----	-----	
24	L	S (5) s	H Sph Ln Lt B	>7'-0"	-----	No	-----	-----	
		S (30) d	H Sph Ln Lt						
25	L	ST (5) s	H Sph Ln Lt Se (w)	2'-3"	Si Sa	No	-----	-----	Figure 24
		S (30) d	H Sph Ln Lt						Figure 25
26	L	S (15) (b)	H Sph Ln (20) Lt	>7'-0"	-----	No	-----	-----	
27	L	S (5) T J (b) s	H Sph Ln Lt M G Se (w)	4'-0"	Sa X	No	-----	-----	
		S (25) d	H Sph Lt Se	>7'-0"					
28	L	-----	M Se (w)	>7'-0"	-----	No	-----	-----	
		S (30) J T	H Sph Ln Lt Se						
29	L	S (40) J T A W (10) d	Ln Lt Se M	4'-3"	O C Si	No	-----	-----	
30	L	S (40)	H Sph Ln (20) Lt Se	>7'-0"	-----	Yes	2'-0"	0'-9"	Figure 26
		-----	G Se			No	-----	-----	Figure 27
31	L	S (40)	H Sph Ln Lt	>7'-0"	-----	Yes	1'-8" TO 1'-10"	1'-6"	
32	L	S (20) T	H Sph Ln Lt B (w)	7'-0"	Sa C Si	Yes	2'-2" TO 2'-6"	-----	
33	L	S (20)	H Sph Ln Lt G Se (p)	>7'-0"	-----	Yes	1'-9"	6'-3"	
				MANITOBA					
34	L	-----	Sph G Se B	>7'-0"	-----	No	-----	-----	
		S (15) T (b)	H Sph G Se B			Yes	1'-7" TO 2'-0"	-----	
35	L	S (20)	H Sph Ln (25) Lt G Se	>7'-0"	-----	Yes	1'-9" TO 2'-0"	3" TO 4"	
36	L	S (10)	H Sph Ln Lt	>7'-0"	-----	Yes	1'-8"	3'-1"	
37	L	-----	H Sph M G Se B (w)	4'-0"	C	No	-----	-----	Figure 28
		S (25)	H Sph M Ln Lt (p)	7'-0"		Yes	2'-0"	1'-0"	Figure 29
38	L	S (20)	H Sph Ln (5) M Lt	6'-3"	B	Yes	1'-6"	2'-4"	
39	L	S (20)	H Sph Ln (5) Lt	>7'-0"	-----	No	-----	-----	
		S (30)	H Sph Ln (5) Lt (p)			Yes	1'-7"	5'-11"	
40	L	S (20) s	H Sph Ln Lt M	>7'-0"	-----	No	-----	-----	Figure 30
		S (30) d	H M Sph Ln Lt (p)			Yes	1'-9"	> 5'-3"	Figure 31
									Figure 32
41	L	S (25)	H Sph Ln Lt	2'-4"	O C Si	No	-----	-----	
			H Sph Ln Lt (p)			Yes	1'-5"	>4'-4"	

TABLE II

(a) Location and elevations of meteorological stations

ONTARIO	Latitude (N)	Longitude (W)	Elevation (ft)
Lansdowne House	52° 14'	87° 53'	840
Moosonee	51° 16'	80° 39'	34
Pickle Lake	51° 28'	90° 15'	1245
Trout Lake	53° 50'	89° 52'	720
Winisk	55° 14'	85° 07'	42
MANITOBA			
Gods Lake Narrows	54° 33'	94° 29'	610
Norway House	53° 59'	97° 45'	720

(b) Monthly average of daily mean air temperatures (^{o}F)

ONTARIO	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lansdowne House	-7.9	-2.0	9.5	27.1	41.8	56.0	62.7	60.1	49.0	38.0	18.7	0.3	29.4
Moosonee	-5.1	-0.4	10.5	27.5	41.3	53.5	60.1	58.8	50.1	39.0	22.2	4.2	30.1
Pickle Lake	-6.0	-1.0	12.3	28.8	43.7	56.0	63.3	59.6	50.0	38.6	16.5	0.1	30.2
Trout Lake	-11.0	-6.5	6.0	23.7	38.4	52.2	60.7	58.5	47.6	35.3	16.0	-2.8	26.5
Winisk	-13.5	-11.3	-2.7	15.1	33.6	44.8	53.1	52.1	45.0	34.8	17.2	-2.6	22.1
MANITOBA													
Gods Lake Narrows	-11.8	-6.7	5.2	25.0	42.8	53.0	64.2	59.3	48.4	34.0	12.0	-3.0	26.8
Norway House	-9.7	-3.6	8.4	30.1	46.2	56.8	65.1	61.7	49.1	37.3	14.0	-0.3	29.6

(c) Average monthly precipitation (inches)

ONTARIO	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lansdowne House	1.10	1.07	1.25	1.50	2.12	3.05	3.49	2.91	2.90	2.27	1.68	1.37	24.71
Moosonee	1.87	1.84	1.64	1.73	2.85	3.63	3.14	3.20	3.23	2.86	2.82	2.21	31.02
Pickle Lake	1.49	1.23	1.38	1.24	2.40	3.40	3.95	3.18	2.88	2.27	1.69	1.40	26.51
Trout Lake	0.97	0.83	0.66	1.04	1.87	2.95	3.94	3.62	2.95	2.07	1.86	1.13	23.89
Winisk	1.00	0.90	0.90	0.81	1.60	2.00	3.00	2.80	2.60	1.80	1.70	1.51	20.62
MANITOBA													
Gods Lake Narrows	1.00	0.82	1.02	0.73	1.44	2.92	2.44	2.35	2.13	1.53	1.70	1.28	19.36
Norway House	0.64	0.38	1.04	0.54	0.91	1.64	2.05	2.13	1.53	0.98	1.26	0.82	14.12

(d) Average monthly rainfall (inches)

ONTARIO	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lansdowne House	0.02	0.01	0.10	0.43	1.58	3.03	3.49	2.91	2.74	1.20	0.24	0.05	15.80
Moosonee	0.07	0.06	0.27	0.73	2.41	3.60	3.14	3.20	3.22	2.17	0.89	0.23	19.99
Pickle Lake	0	0	0.07	0.42	2.08	3.40	3.95	3.18	2.83	1.64	0.23	0	17.80
Trout Lake	T	T	0.02	0.27	1.10	2.94	3.94	3.62	2.77	1.30	0.13	0.10	16.19
Winisk	T	T	T	0.01	0.90	1.90	3.00	2.80	2.50	1.20	0.35	0.01	12.67
MANITOBA													
Gods Lake Narrows	0	0.04	0.10	0.14	1.11	2.83	2.44	2.35	2.05	0.76	0.09	0.02	11.84
Norway House	T	T	0.05	0.33	0.85	1.64	2.05	2.13	1.38	0.71	0.10	0.03	9.27

(e) Average monthly snowfall (inches)

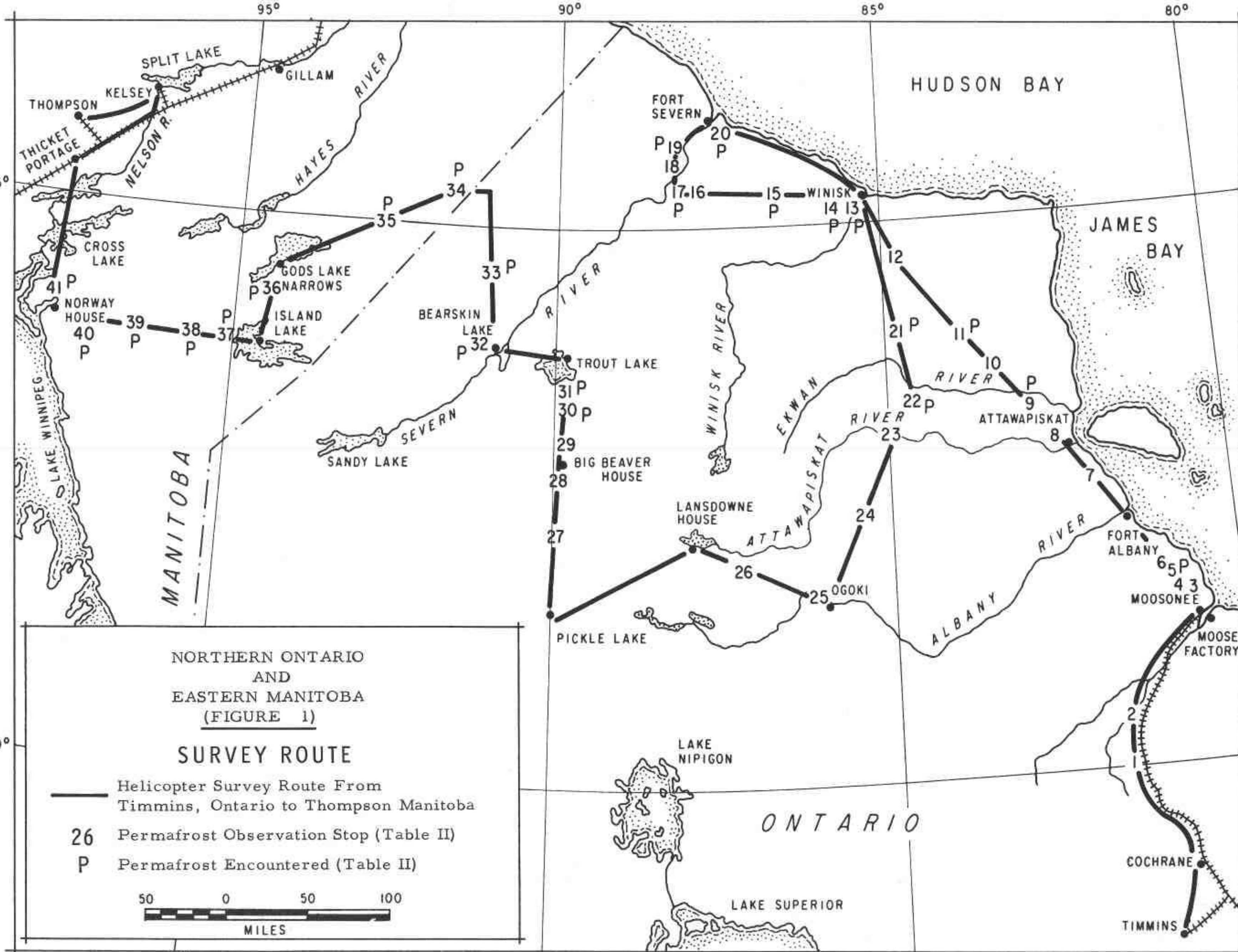
ONTARIO	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lansdowne House	10.8	10.6	11.5	10.7	5.4	0.2	0	0	1.6	10.7	14.4	13.2	89.1
Moosonee	18.0	17.8	13.7	10.0	4.4	0.3	0	0	0.1	6.9	19.3	19.8	110.3
Pickle Lake	14.9	12.3	13.1	8.2	3.2	T	0	0	0.5	6.3	14.6	14.0	87.1
Trout Lake	9.7	8.3	6.4	7.7	7.7	0.1	T	0	1.8	7.7	17.3	10.3	77.0
Winisk	10.0	9.0	9.0	8.0	7.0	1.0	0	0	1.0	6.0	13.5	15.0	79.5
MANITOBA													
Gods Lake Narrows	10.0	7.8	10.1	5.9	3.3	0.9	0	0	0.8	7.7	16.1	12.6	75.2
Norway House	6.4	5.8	9.9	2.1	0.6	0	0	0	1.5	2.7	11.6	7.9	48.5

(f) Normal monthly depth of snow on ground (inches) at end of month (Arithmetic Mean)*

ONTARIO	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Winter Max.
Lansdowne House	25	31	27	10	-	-	-	-	-	4	11	19	37
Moosonee	19	24	17	3	-	-	-	-	-	-	8	14	29
Trout Lake	28	33	27	10	-	-	-	-	-	2	15	24	30

* Reference 13

N.B. Underlined values obtained from earlier table (reference not available).


HUDSON BAY
JAMES BAY
ONTARIO
MANITOBA
SPLIT LAKE
GILLAM
KELSEY
THOMPSON
THICKET PORTAGE
NELSON R.
HAYES RIVER
CROSS LAKE
GODS LAKE NARROWS
ISLAND LAKE
NORWAY HOUSE
LAKE WINNIPEG
BEARSKIN LAKE
SEVERN RIVER
SANDY LAKE
TROUT LAKE
BIG BEAVER HOUSE
PICKLE LAKE
FORT SEVERN
WINISK
WINISK RIVER
EKWAN RIVER
ATTAWAPISKAT RIVER
ATTAWAPISKAT
LANSDOWNE HOUSE
OGOKI
ALBANY RIVER
FORT ALBANY
MOOSONEE
MOOSE FACTORY
COCHRANE
TIMMINS
LAKE NIPIGON
LAKE SUPERIOR
NORTHERN ONTARIO
AND
EASTERN MANITOBA
(FIGURE 1)
SURVEY ROUTE
Helicopter Survey Route From Timmins, Ontario to Thompson Manitoba
26 Permafrost Observation Stop (Table II)
P Permafrost Encountered (Table II)
50 0 50 100
MILES

BB4244-1

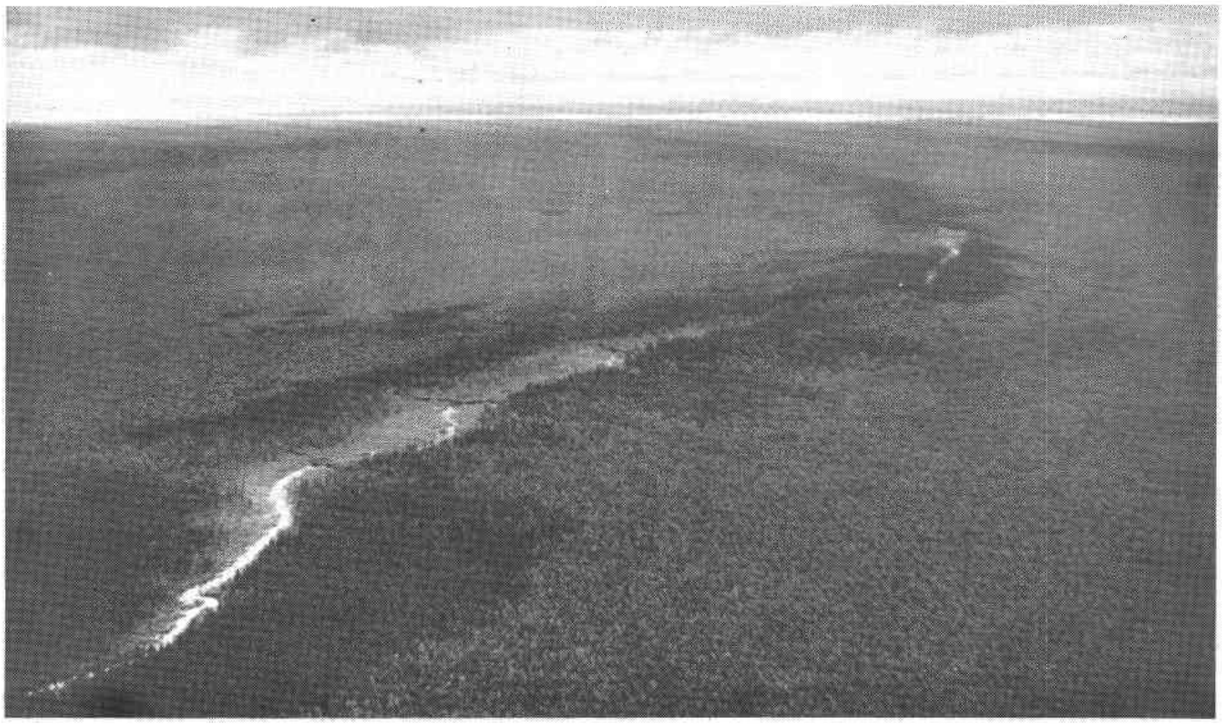


Figure 2 - Aerial view looking east toward James Bay from altitude of 1, 000 ft of dense tamarack swamp between river valleys bordered by dense spruce. Location between Stop Nos. 3 and 4 in Hudson Bay Lowland. No permafrost was encountered in this type of terrain. 14 September 1965.

Figure 3 - Stop No. 7 - Dense spruce on silty clay river bank in Hudson Bay Lowland similar to growth along rivers in Figure 2. No permafrost was encountered in this type of terrain. 14 September 1965.

Figure 4 - Aerial view looking east from altitude of 600 ft in Hudson Bay Lowland of typical patterned fen with flarks (pools). Note string bog-like formations and spruce islands in background. No permafrost was encountered in this type of terrain. 16 September 1965.

Figure 5 - Aerial view from altitude of 800 ft of typical wet string bog-like terrain in Hudson Bay Lowland located between Stop Nos. 4 and 5. No permafrost was encountered in this type of terrain. 14 September 1965.

Figure 6 - Stop No. 5 - Small youthful palsas containing permafrost in wet peatland with no permafrost located at the southern limit of discontinuous zone in Hudson Bay Lowland. The peat in the large palsa in the foreground is 5 ft 2 in. thick overlying grey clayey silt with fine sand. The depth to the permafrost table in the centre of this palsa is 1 ft 1 in. and the permafrost layer is 4 ft 2 in. thick. 14 September 1965.

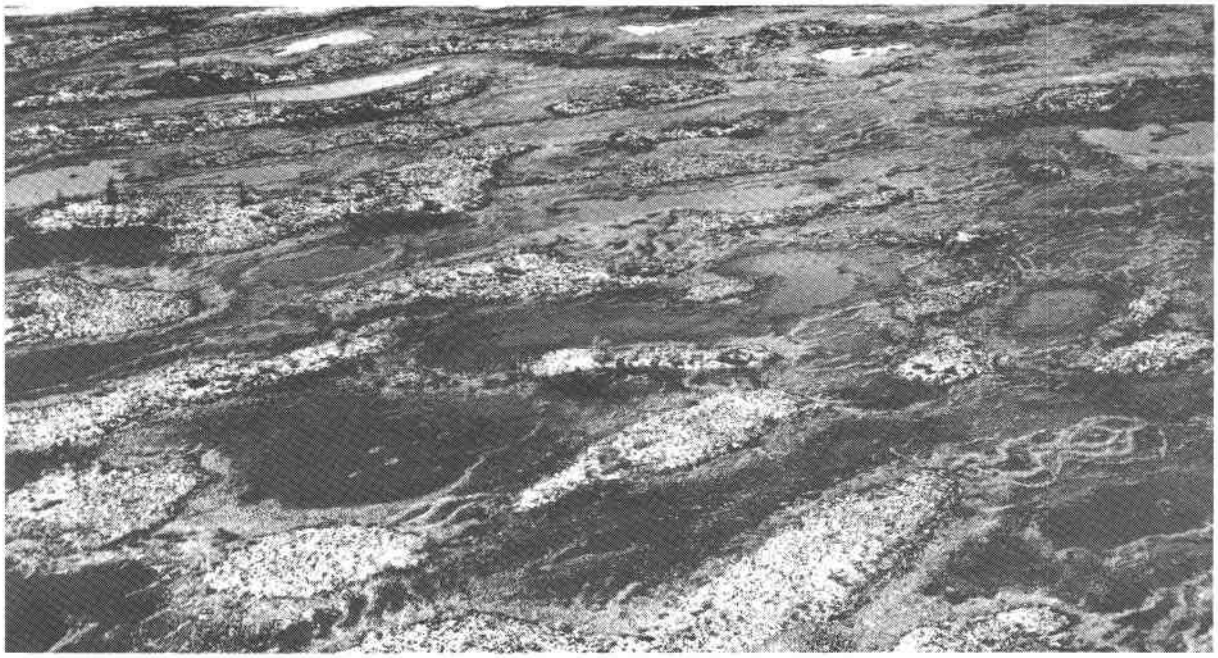


Figure 7 - Aerial view from altitude of 500 ft of mature palsas, coalesced palsas and peat plateaus interspersed with ponds and small shallow lakes in Hudson Bay Lowland 20 miles west of Winisk. 17 September 1965.

Figure 8 - Stop No. 9 - Mature coalesced palsas forming peat plateaus in Hudson Bay Lowland. Note burned spruce trees and dense cover of Labrador tea. Ground surface is very hummocky and covered with Sphagnum and lichen below which is peat to a depth of 4 ft 9 in. overlying grey silty clay with sand and stones. The depth to the permafrost table is 2 ft 8 in. No permafrost occurs in the sedge-covered depression in foreground. 16 September 1965.

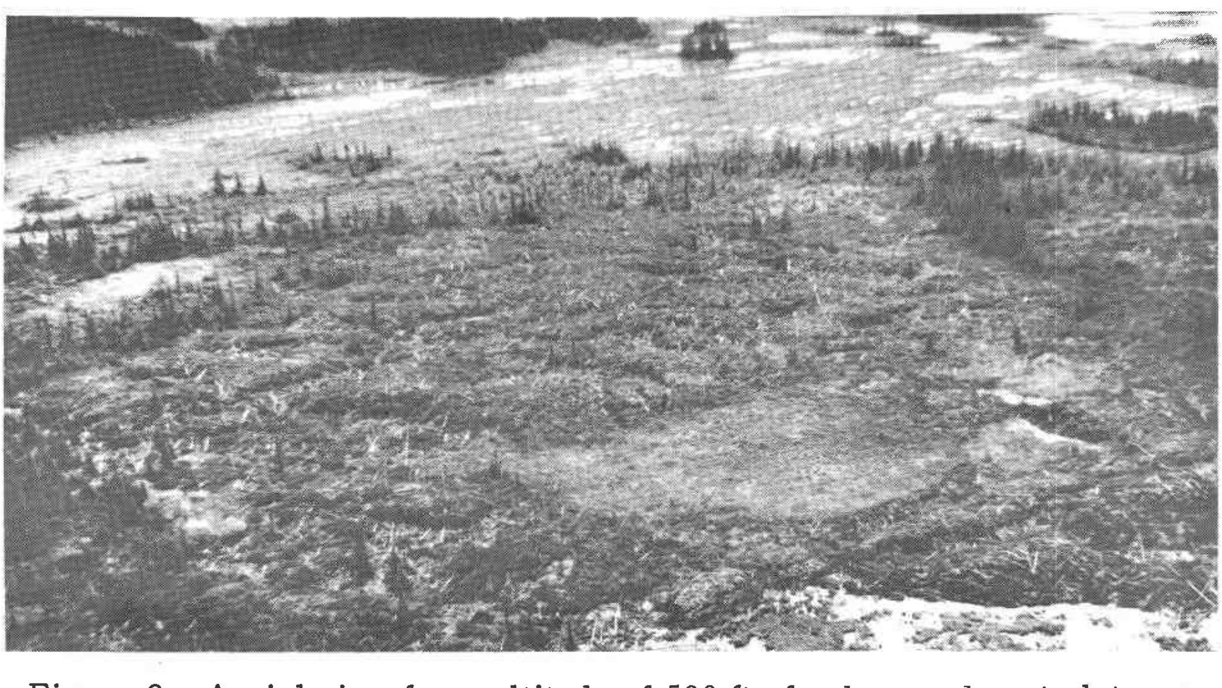


Figure 9 - Aerial view from altitude of 500 ft of palsas and peat plateaus at Stop No. 9. Note wet patterned fen with spruce islands in background. 16 September 1965.

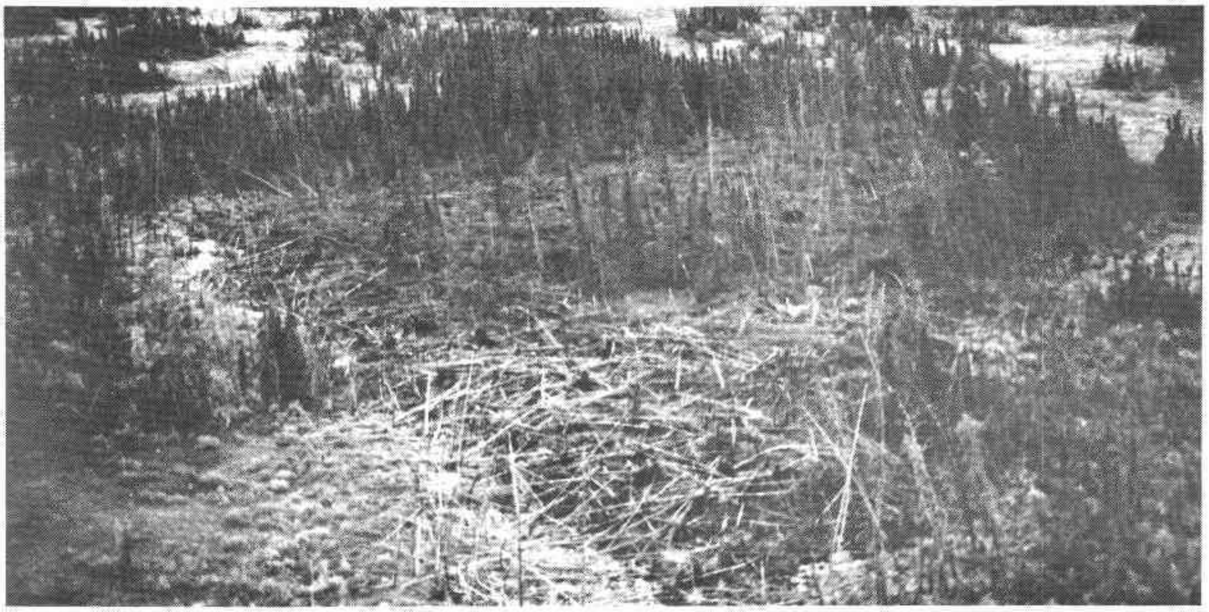


Figure 10 - Stop No. 22 - Aerial view from altitude of 300 ft of mature palsa in Hudson Bay Lowland. The surface of the palsa is covered with burned spruce trees. The peat is 7 ft thick overlying grey clayey silt with stones. No permafrost occurs in the surrounding terrain. 19 September 1965.

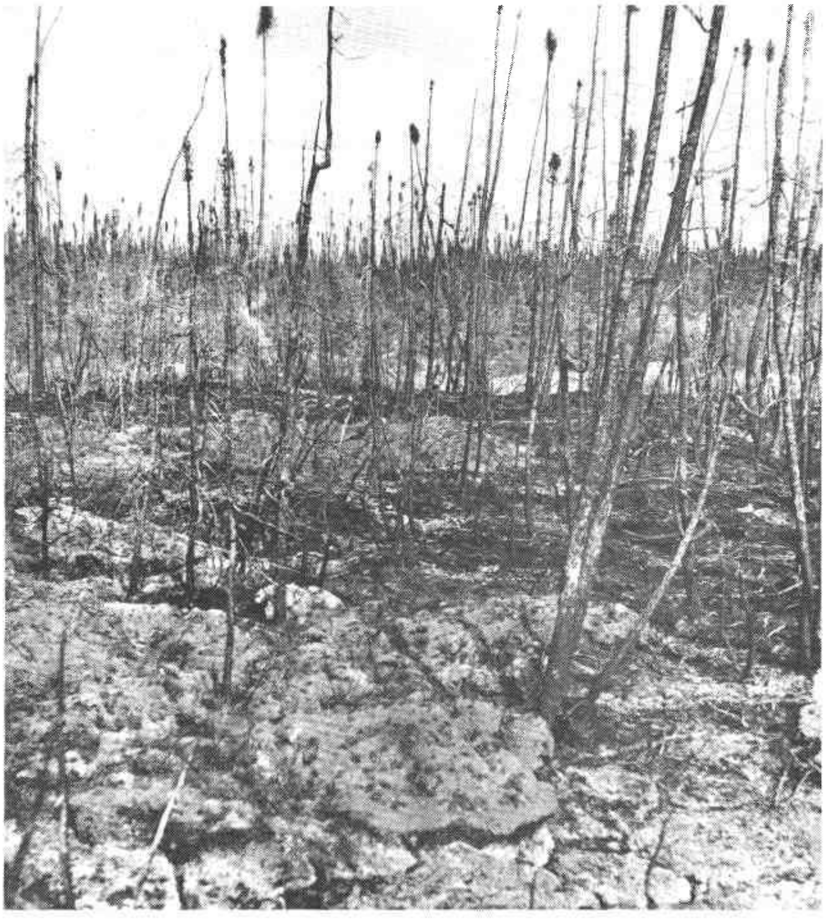


Figure 11 - Stop No. 19 - Recently burned over palsa in Hudson Bay Lowland. Black areas in right background are covered with charred Sphagnum and white area in right foreground is burned lichen. Sphagnum hummocks on left were not affected by fire but trees were burned. The depth to the permafrost table is 1 ft 6 in. in the burned and unaffected areas. 17 September 1965.

Figure 12 - Stop No. 11 - Small palsa in Hudson Bay Lowland shows as low ridge in background. The peat is 10 ft 2 in. thick overlying clayey fine sand and silt with a few stones. The depth to the permafrost table is 1 ft 5 in. No permafrost occurs in the surrounding lichen covered areas. 16 September 1965.

Figure 13 - Aerial view from altitude of 300 ft of palsa near Stop No. 11. No permafrost occurs in surrounding lichen covered areas. 16 September 1965.

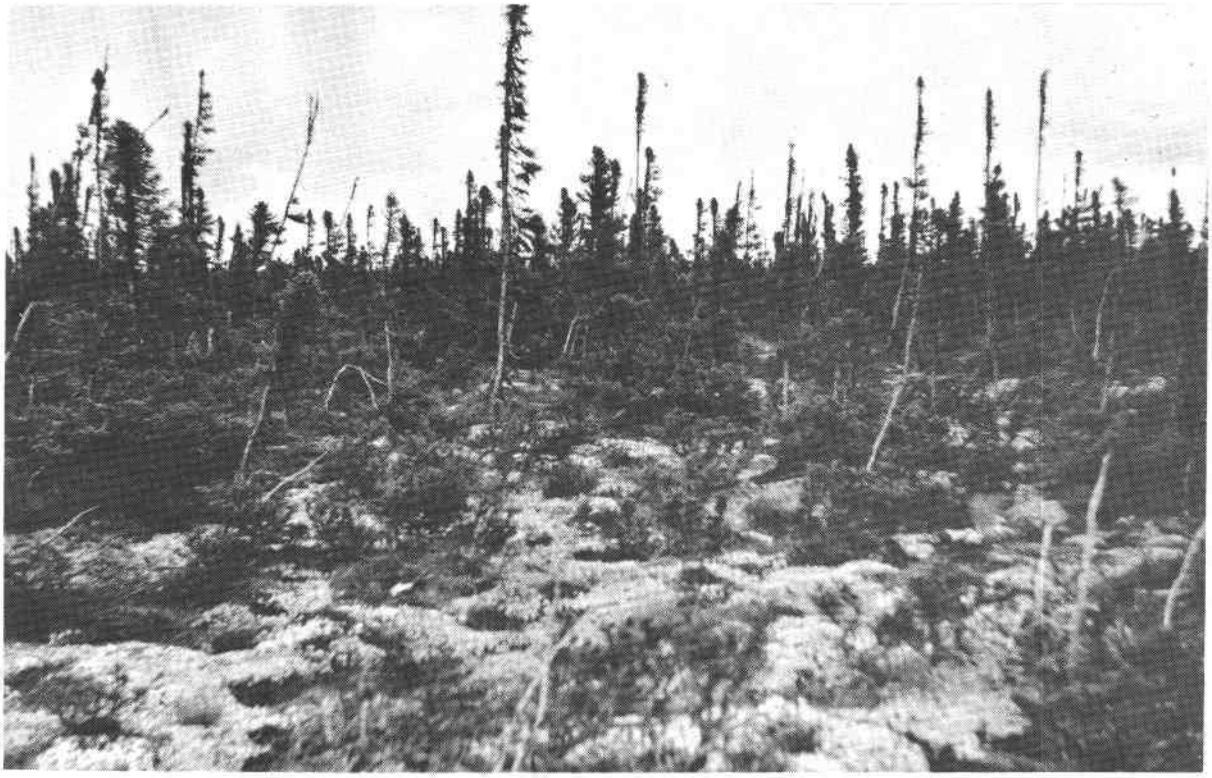


Figure 14 - Stop No. 12 - The peat in this lichen covered peatland in the Hudson Bay Lowland is 9 ft 6 in. thick overlying wet stony soil. No permafrost was encountered in this terrain. 16 September 1965.

Figure 15 - Aerial view from altitude of 300 ft of terrain at Stop No. 12. 16 September 1965.

Figure 16 - Stop No. 15 - Peat terrain west of Winisk in Hudson Bay Lowland. See page 4 for detailed description. 17 September 1965.

Figure 17 - Aerial view from altitude of 200 ft at Stop No. 15. 17 September 1965.

Figure 18 - Stop No. 13 - Peat terrain in narrow coastal strip of Hudson Bay Lowland north of treeline at Winisk. Peat in low peat plateaus in foreground is 3 ft 6 in. thick overlying grey clayey sand. The depth to the permafrost table is 1 ft in the peat plateaus and 3 ft beneath the water surface. 17 September 1965.

Figure 19 - Aerial view from altitude of 400 ft at Stop No. 13. Note peat plateaus in lower portion of photograph. 17 September 1965.

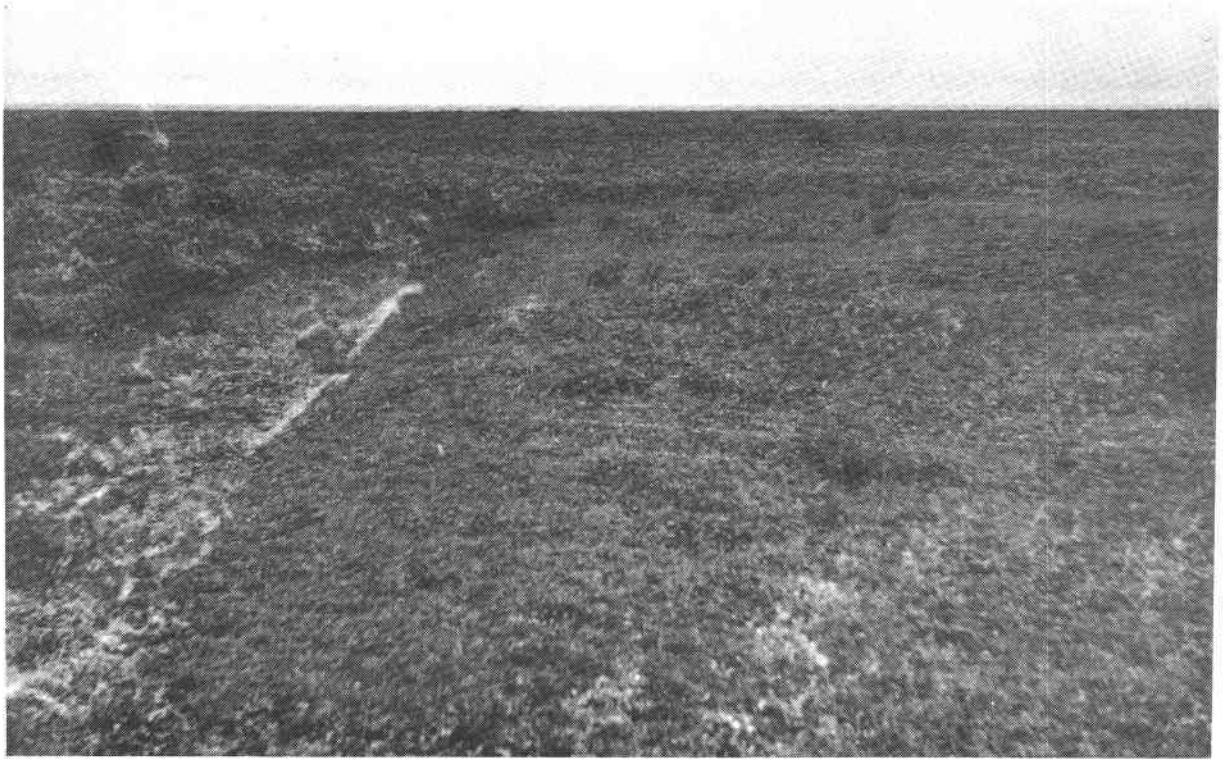


Figure 20 - Stop No. 20 - Narrow coastal strip of Hudson Bay Lowland near Fort Severn north of treeline. The tundra vegetation consists of willow growing up to 1 ft high and sedge on peat 1 ft thick overlying clayey silty fine sand. The permafrost is presumed to be continuous and the depth to the permafrost table is 2 ft. 17 September 1965.

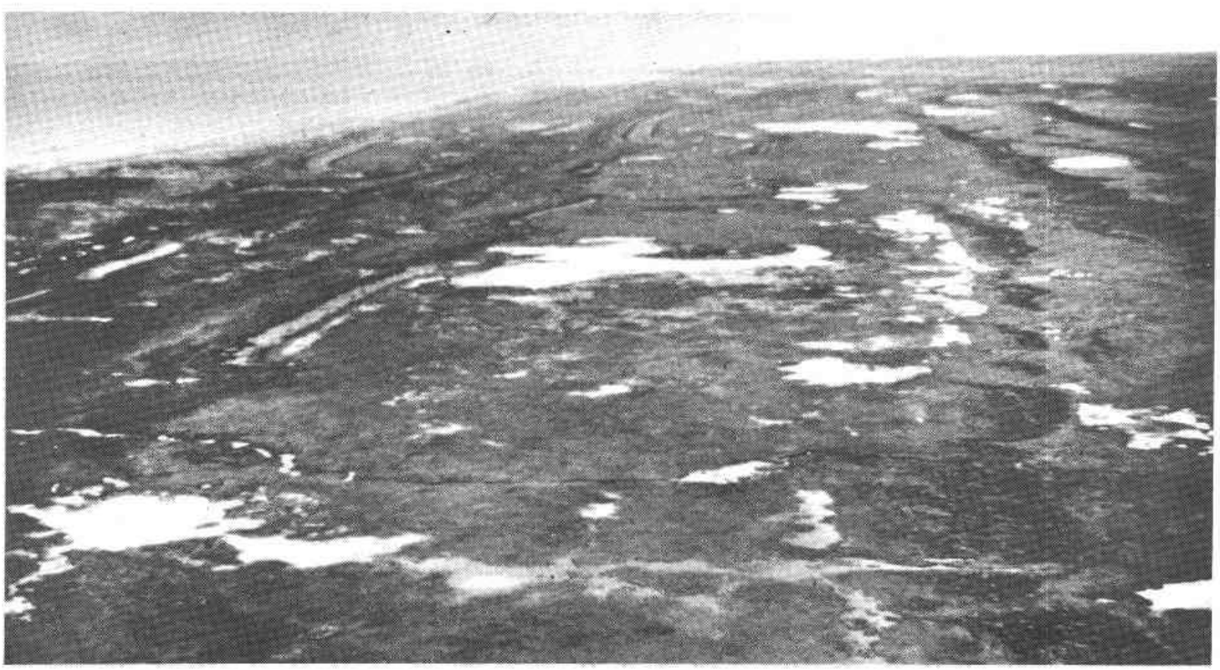


Figure 21 - Aerial view from altitude of 600 ft of terrain near Stop No. 20. Although this photograph is not clear, it shows the tree-covered beach ridges (black strips right foreground) inland from Hudson Bay (left background). 17 September 1965.

Figure 22 - Stop No. 21 - Beach ridge 100 miles from Hudson Bay in Hudson Bay Lowland supporting dense spruce 25 ft high and ground vegetation of dense Labrador tea and continuous cover of 3 in. thick lichen overlying peat 1 ft thick below which is sandy gravel. No permafrost was encountered in this type of terrain. 19 September 1968.

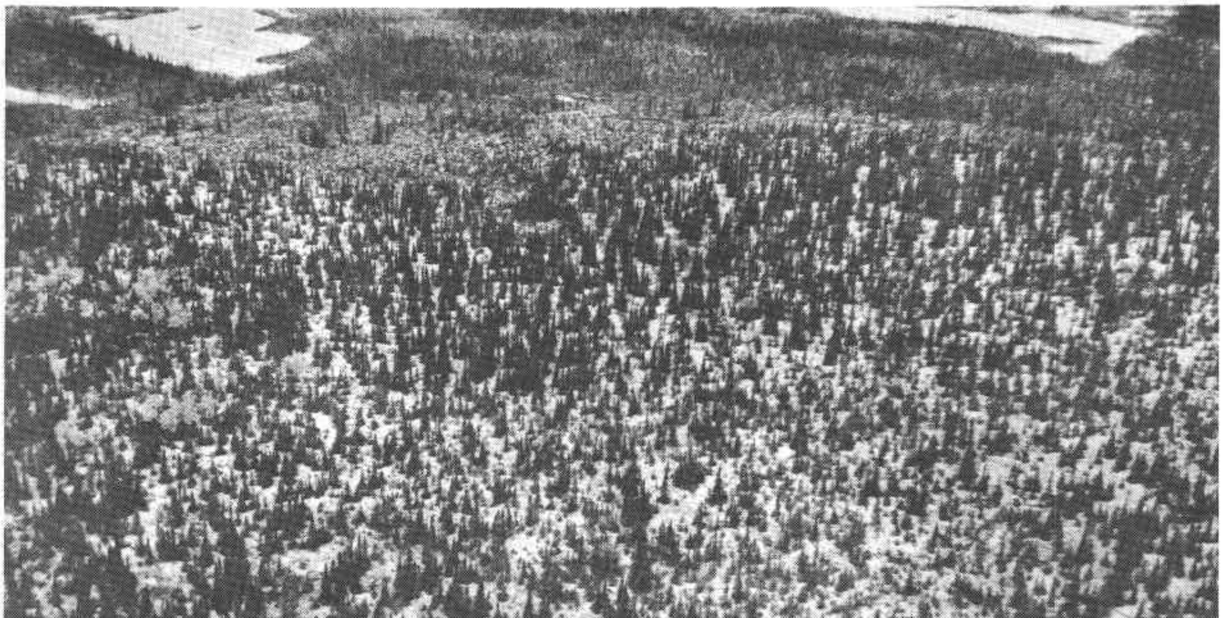


Figure 23 - Aerial view from altitude of 300 ft of beach ridge at Stop No. 21. Note dense spruce growth and continuous lichen cover. 19 September 1968.

Figure 24 - Stop No. 25 - Dense spruce up to 30 ft high with ground cover of hummocky Sphagnum, lichen patches, Labrador tea and sedge below which is peat 2 ft 3 in. thick overlying silty fine sand at Ogoki in the Hudson Bay Lowland. No permafrost was encountered at this location. 20 September 1968.

Figure 25 - Aerial view from altitude of 200 ft of terrain at Stop No. 25. Note lichen patches in centre of photograph in area of sparser tree growth. 20 September 1968.

Figure 26 - Stop No. 30 - Dense spruce up to 40 ft high with ground cover of hummocky Sphagnum, lichen (almost 25 per cent coverage), Labrador tea, and sedge in some hollows below which is peat exceeding 7 ft in thickness located south of Trout Lake in the Precambrian Shield. Permafrost occurs in scattered patches up to 1 ft thick at depths of 2 to 3 ft below the ground surface. No permafrost was encountered in the wet sedge covered depression on the left. 21 September 1968.

Figure 27 - Aerial view from altitude of 200 ft of terrain at Stop No. 30. Note lichen patches. 21 September 1968.

Figure 28 - Stop No. 37 - Dense spruce up to 25 ft high on peat plateau with ground cover of hummocky Sphagnum, other mosses, lichen and Labrador tea below which is peat 7 ft thick overlying grey clay located near Island Lake in the Precambrian Shield. Permafrost 1 ft thick occurs at a depth of 2 to 3 ft below the ground surface. Low wet treeless depressions with ground cover of sedge and ground birch below which is peat 4 ft thick overlying grey clay are interspersed with the peat plateaus. No permafrost occurs in the depressions. 28 September 1968.

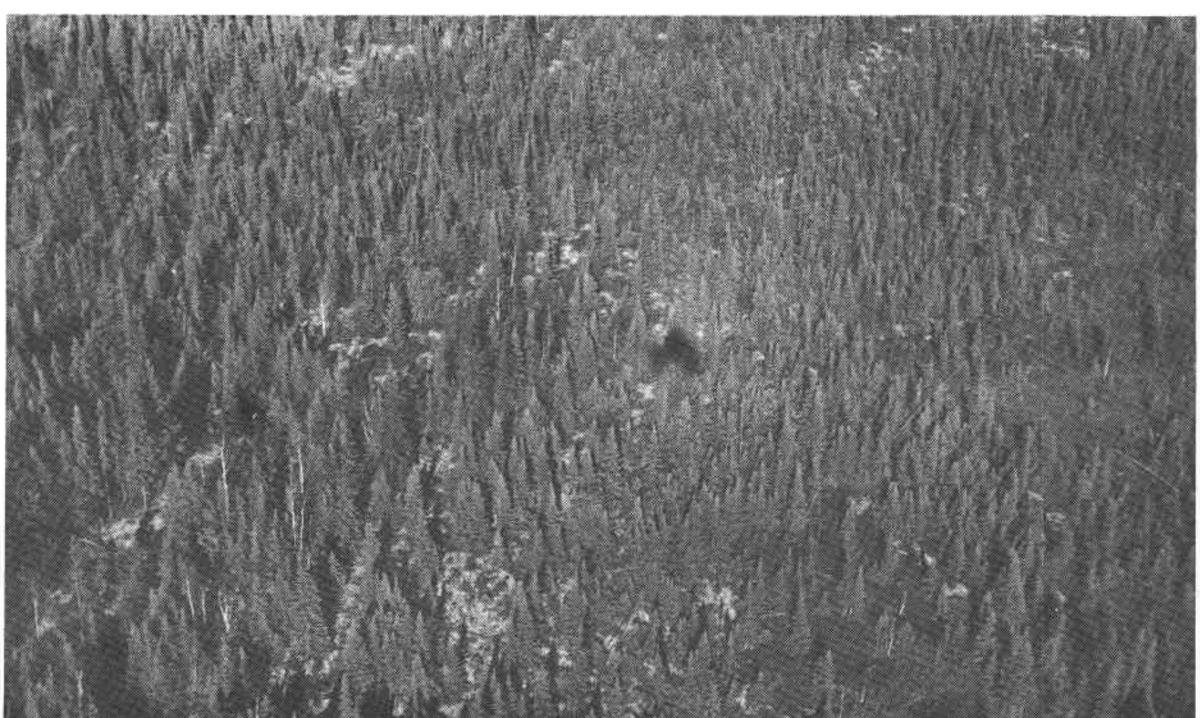


Figure 29 - Aerial view from altitude of 200 ft of terrain at Stop No. 37. 28 September 1968.

Figure 30 - Stop No. 40 - Dense spruce up to 30 ft high on peat plateau with ground cover of hummocky Sphagnum, other mosses, lichen and Labrador tea below which is peat exceeding 7 ft in thickness located east of Norway House in the glacial Lake Agassiz region of the Precambrian Shield. The permafrost table is 1 ft 9 in. below the ground surface and the permafrost extends below the 7 ft depth. No permafrost occurs in the sedge covered depression in the foreground. 28 September 1968.

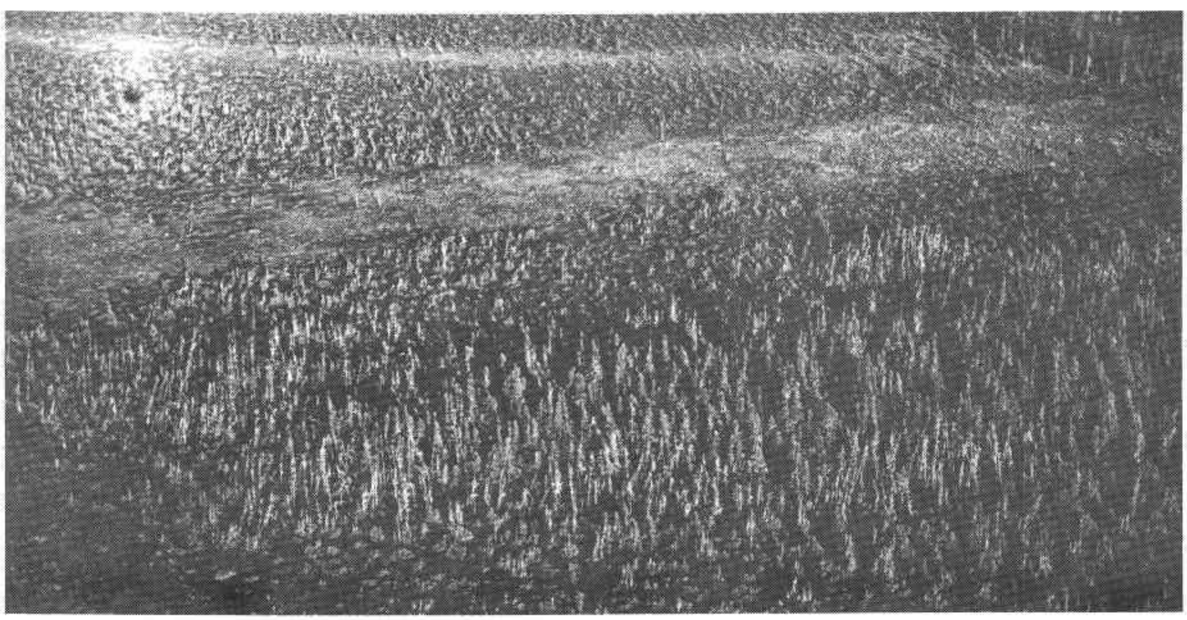


Figure 31 - Aerial view from altitude of 300 ft of terrain at Stop No. 40. The area of tallest tree growth extending across the centre of the photograph marks the position of the peat plateau at Stop No. 40. Peat plateau development in the surrounding areas of sparser tree growth is limited and no permafrost was encountered. 28 September 1968.

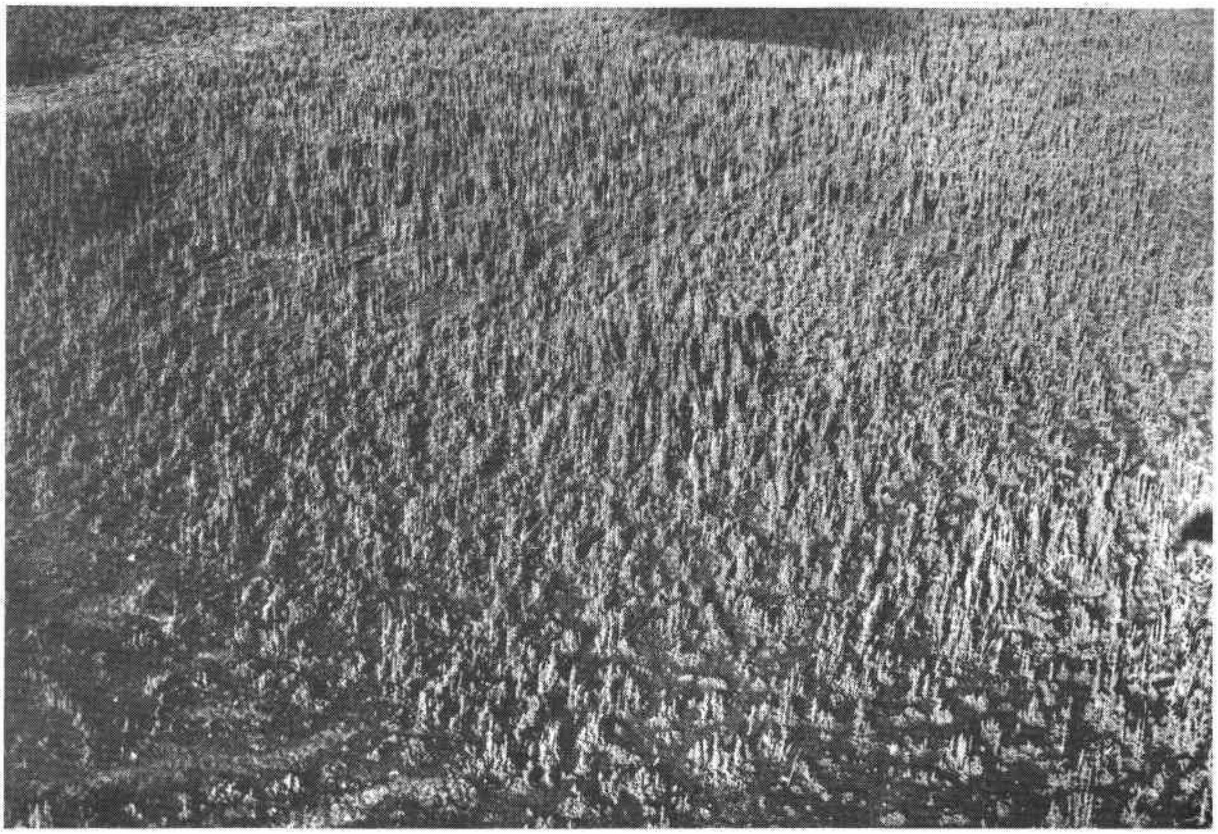
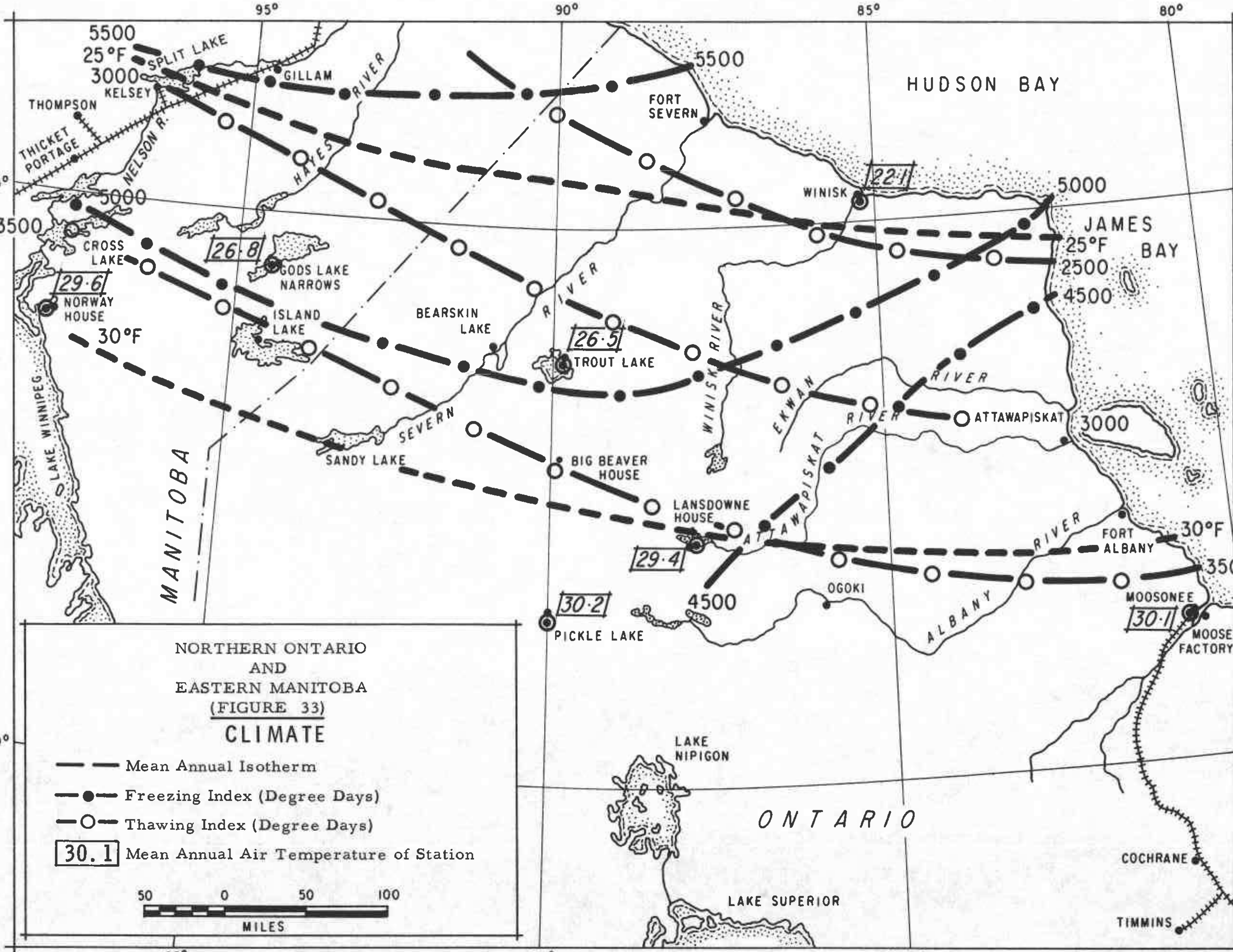


Figure 32 - Aerial view from 400 ft at Stop No. 39 located a few miles east of Stop No. 40 in the glacial Lake Agassiz region of the Precambrian Shield. Tree growth and ground cover conditions are similar to Stop No. 40. The peat exceeds 7 ft in thickness. Peat plateaus are abundant but permafrost about 5 ft thick was encountered only in the areas of densest tree growth in the upper left hand corner and slightly right of centre of the photograph. 28 September 1968.



(After Thompson, 1966)

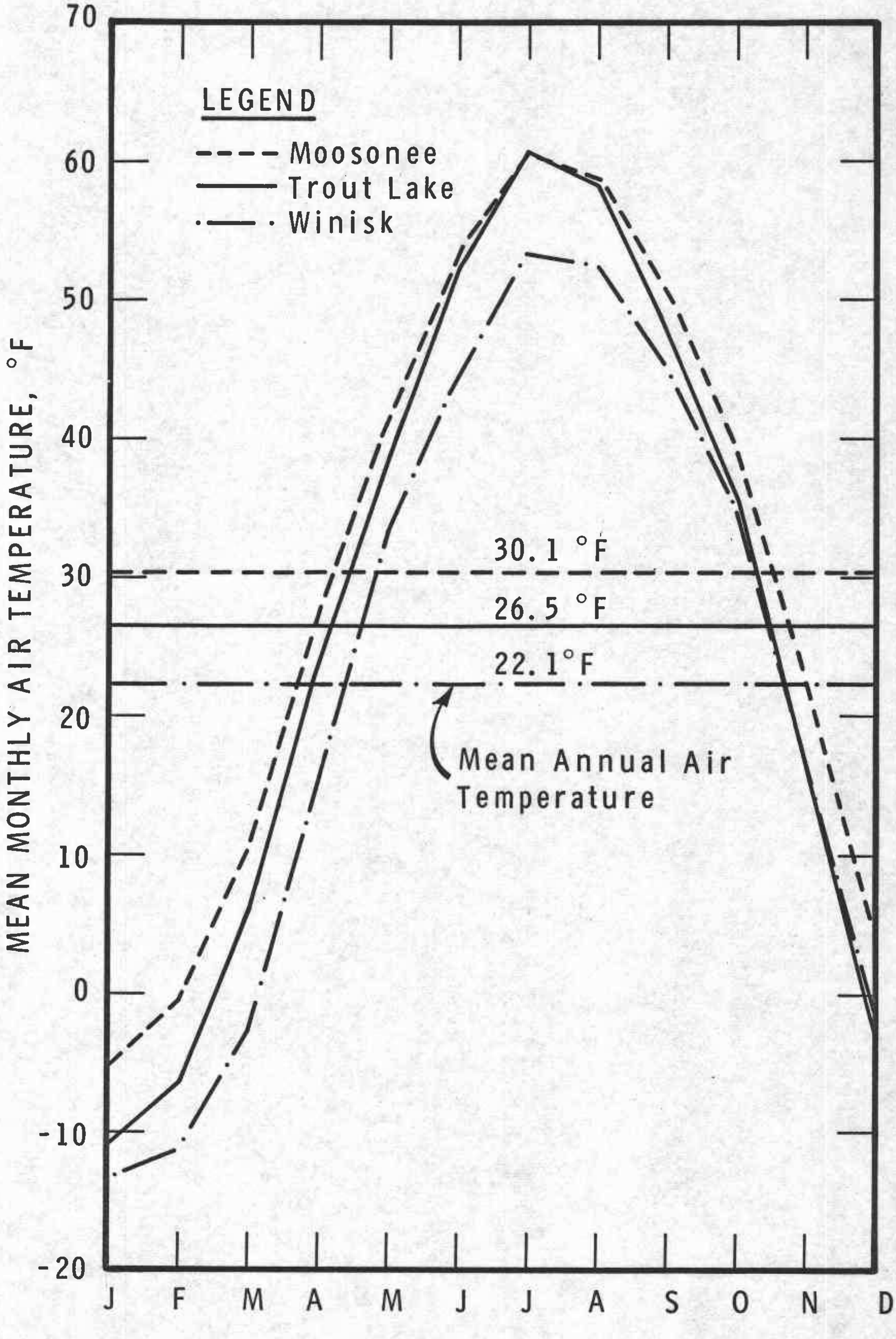


FIGURE 34

AVERAGES OF MEAN MONTHLY AIR TEMPERATURES FOR 3 STATIONS IN NORTHERN ONTARIO: MOOSONEE, TROUT LAKE AND WINISK.

BR 4244-3

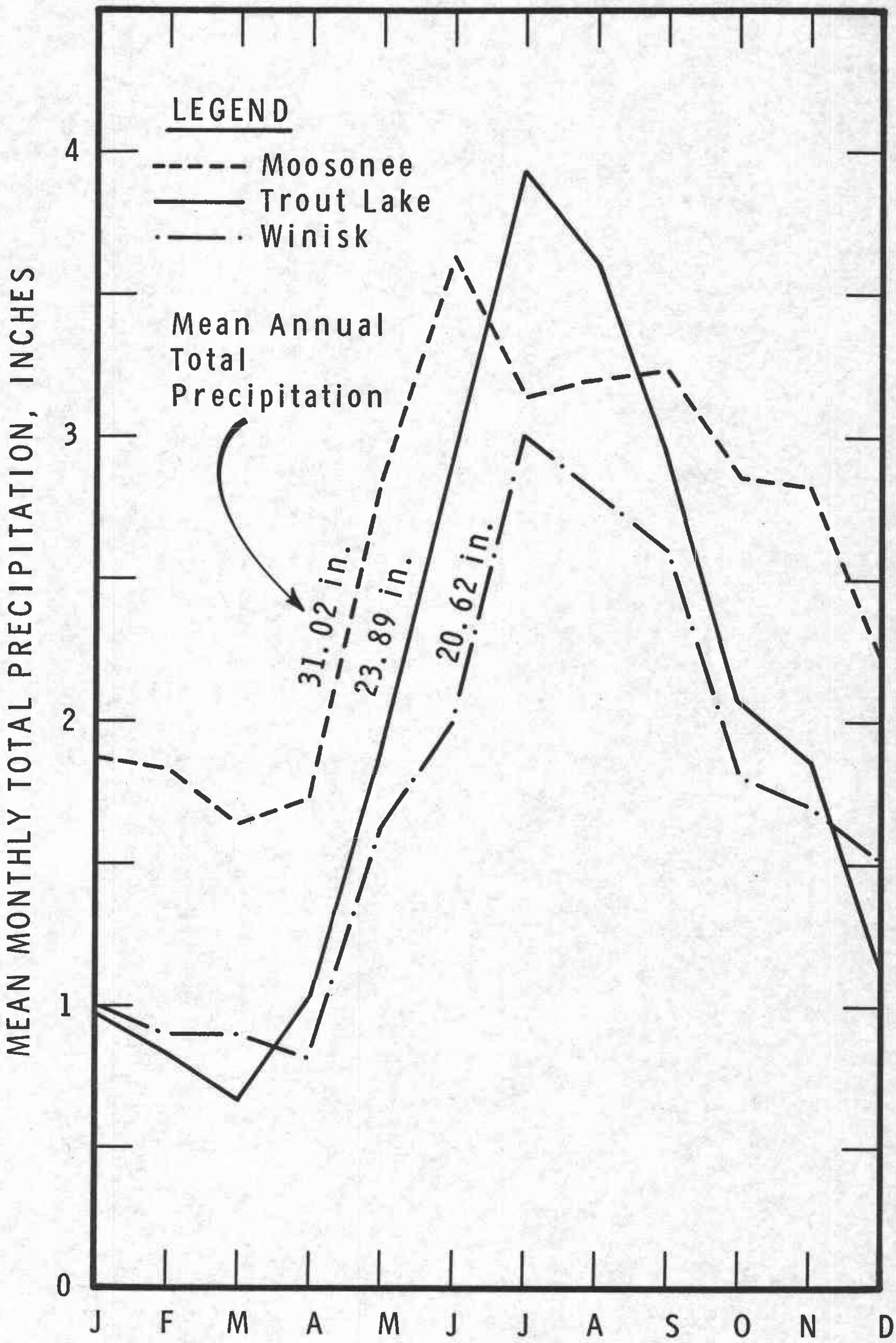


FIGURE 35

AVERAGES OF MEAN MONTHLY TOTAL PRECIPITATIONS FOR 3 STATIONS IN NORTHERN ONTARIO: MOOSONEE, TROUT LAKE AND WINISK.

BR 4244-4

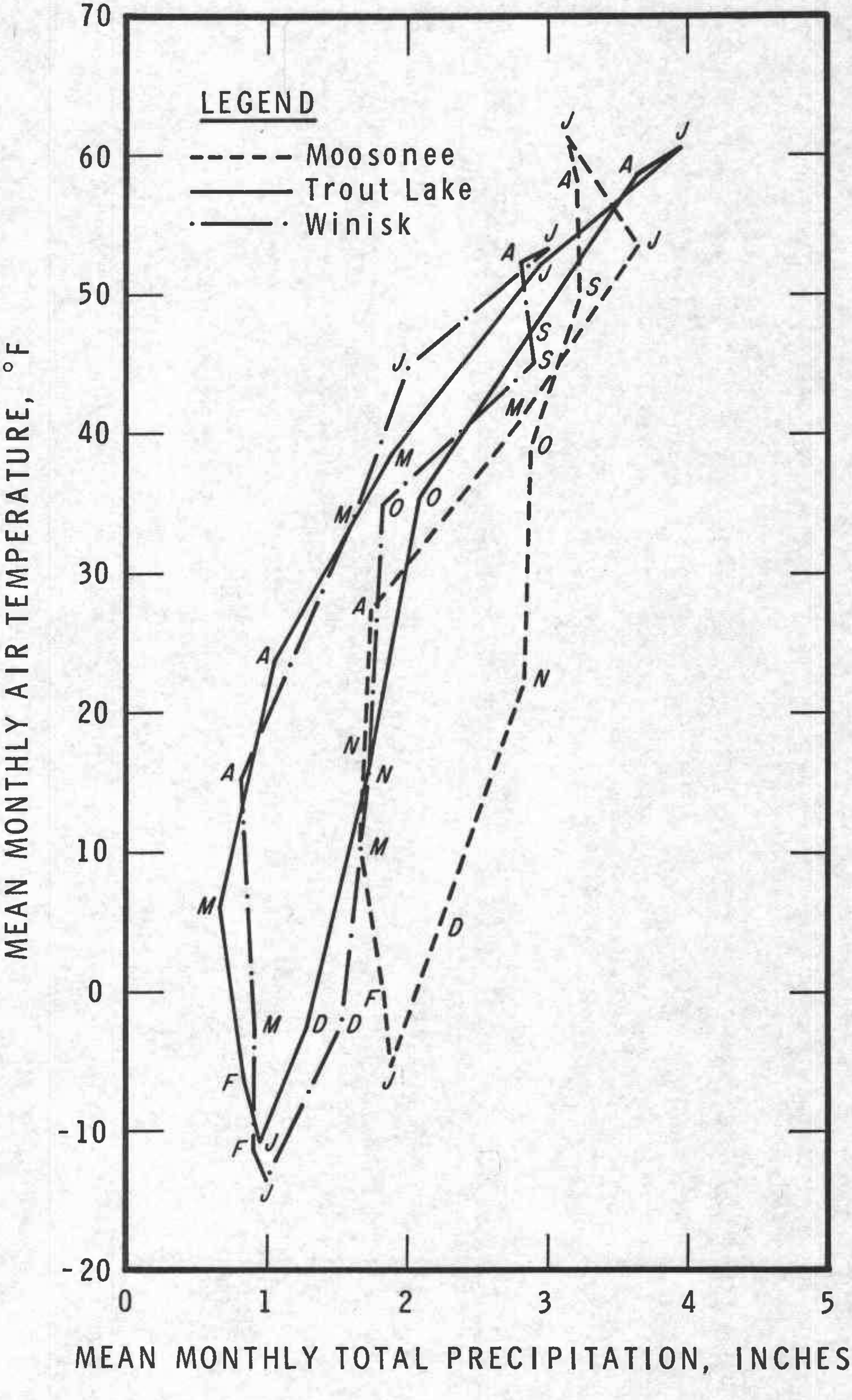
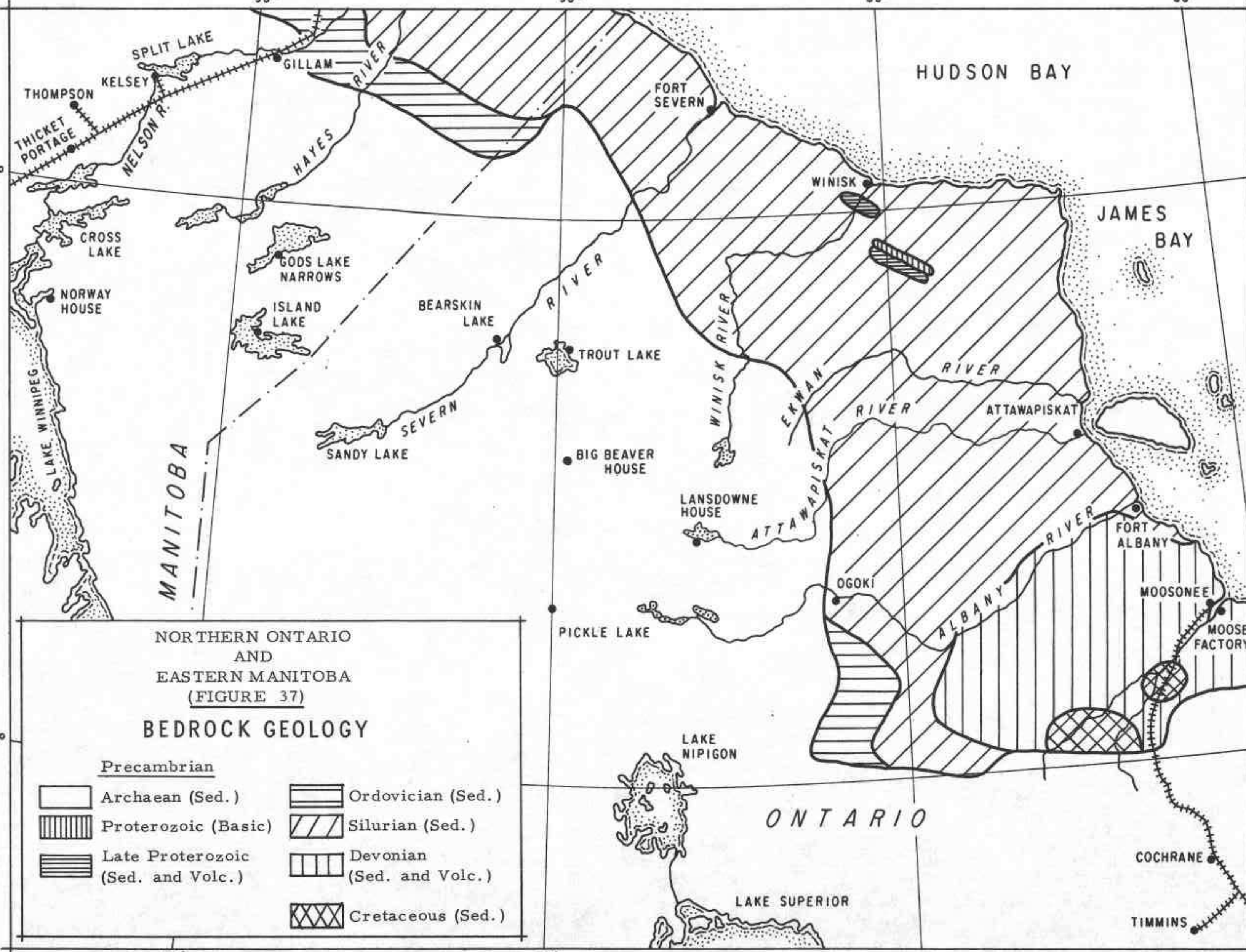


FIGURE 36

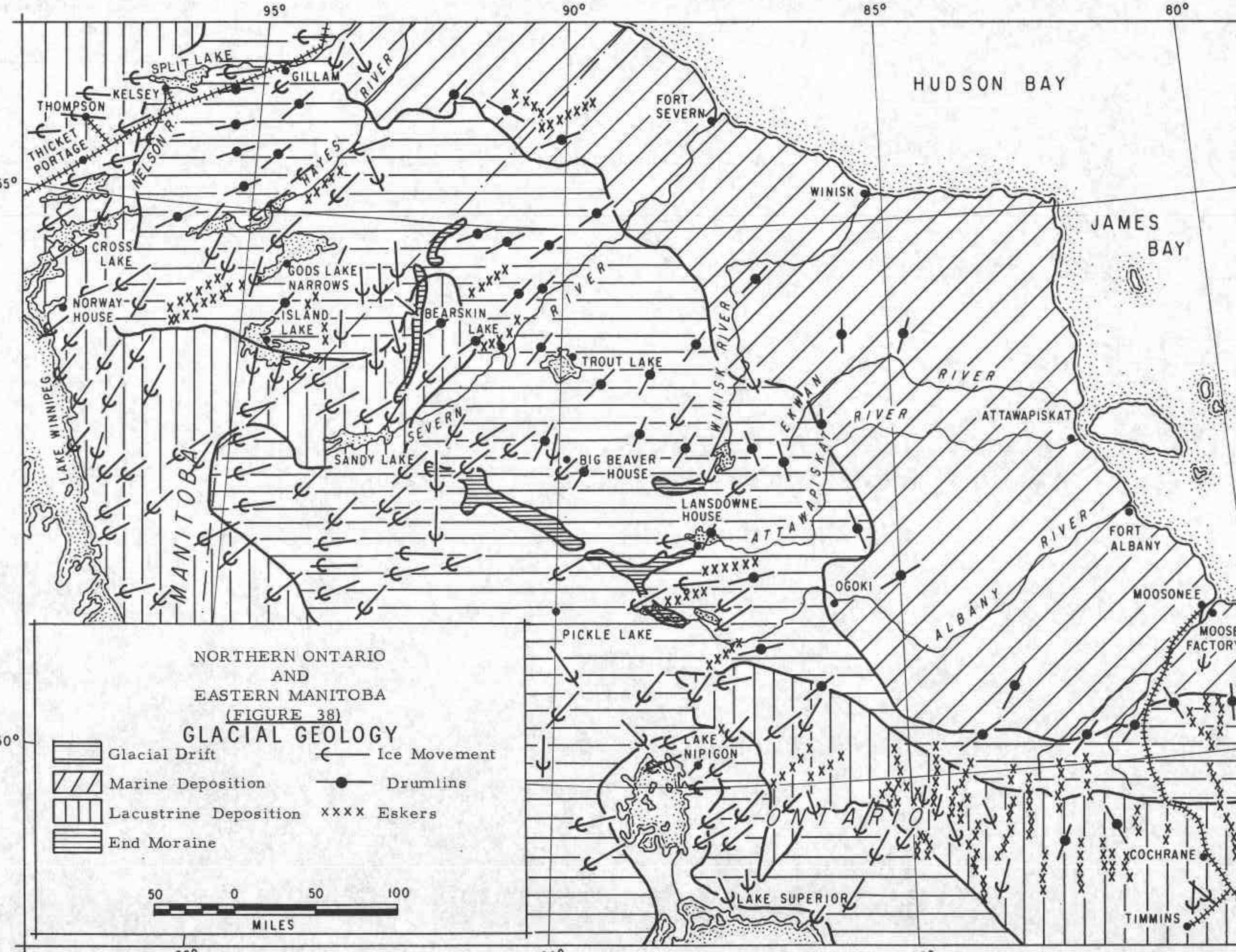
HYTHERGRAPHS BASED ON AVERAGE OF MEAN MONTHLY AIR TEMPERATURES (°F) AND MEAN MONTHLY TOTAL PRECIPITATIONS (INCHES) FOR 3 STATIONS IN NORTHERN ONTARIO: MOOSONEE, TROUT LAKE AND WINISK.

BR 4244-5

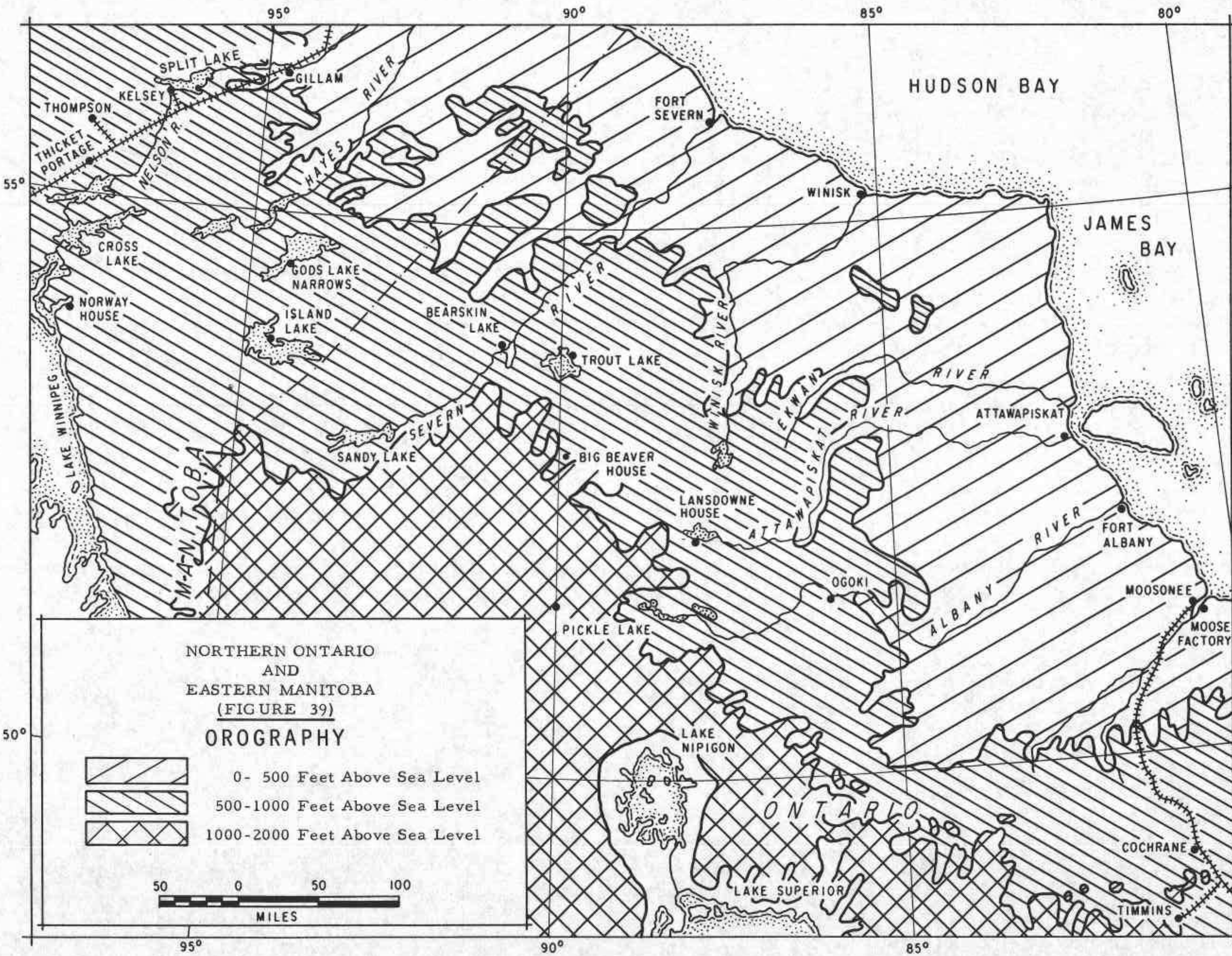


(After Geological Map of Canada, 1962)

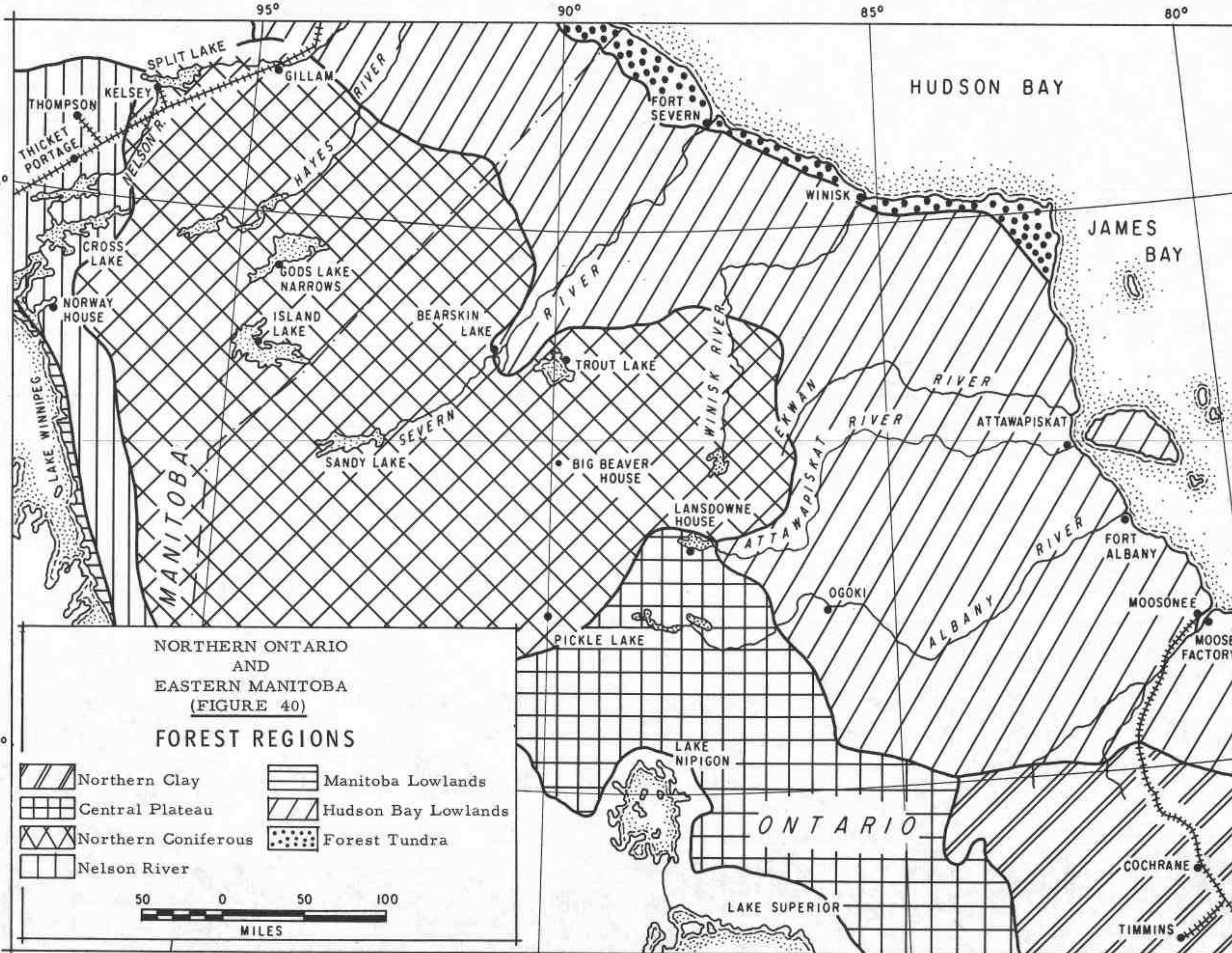
8R,1244-6



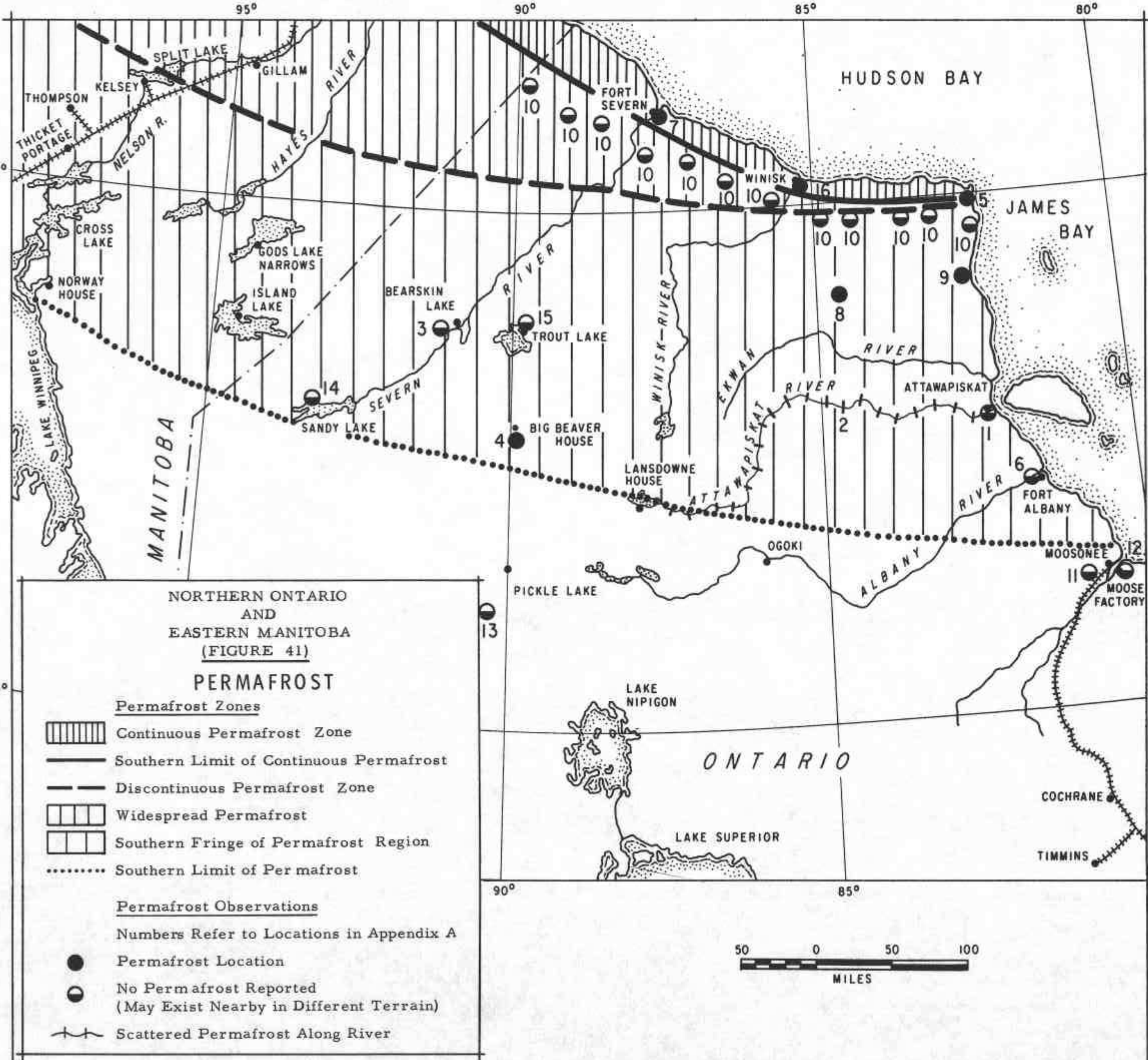
(After Atlas of Canada, 1957)
(After Glacial Map of Canada, 1958)



(After Atlas of Canada, 1957)



(After J.S. Rowe, 1959)



HUDSON BAY
JAMES BAY
FORT SEVERN
WINISK
SPLIT LAKE
GILLAM
KELSEY
THOMPSON
THICKET PORTAGE
NELSON R.
HAYES RIVER
CROSS LAKE
GODS LAKE NARROWS
ISLAND LAKE
NORWAY HOUSE
LAKE WINNIPEG
BEARSKIN LAKE
TROUT LAKE
SEVERN RIVER
SANDY LAKE
BIG BEAVER HOUSE
WINISK—RIVER
EKWAN RIVER
ATTAWAPISKAT RIVER
ATTAWAPISKAT
LANSDOWNE HOUSE
FORT ALBANY
ALBANY RIVER
MOOSONEE
MOOSE FACTORY
OGOKI
PICKLE LAKE
LAKE NIPIGON
LAKE SUPERIOR
ONTARIO
MANITOBA
COCHRANE
TIMMINS
95°
90°
85°
80°
55°
50°
50 0 50 100
MILES
NORTHERN ONTARIO
AND
EASTERN MANITOBA
(FIGURE 41)
PERMAFROST
Permafrost Zones
Continuous Permafrost Zone
Southern Limit of Continuous Permafrost
Discontinuous Permafrost Zone
Widespread Permafrost
Southern Fringe of Permafrost Region
Southern Limit of Permafrost
Permafrost Observations
Numbers Refer to Locations in Appendix A
Permafrost Location
No Permafrost Reported
(May Exist Nearby in Different Terrain)
Scattered Permafrost Along River

BR 4244-10

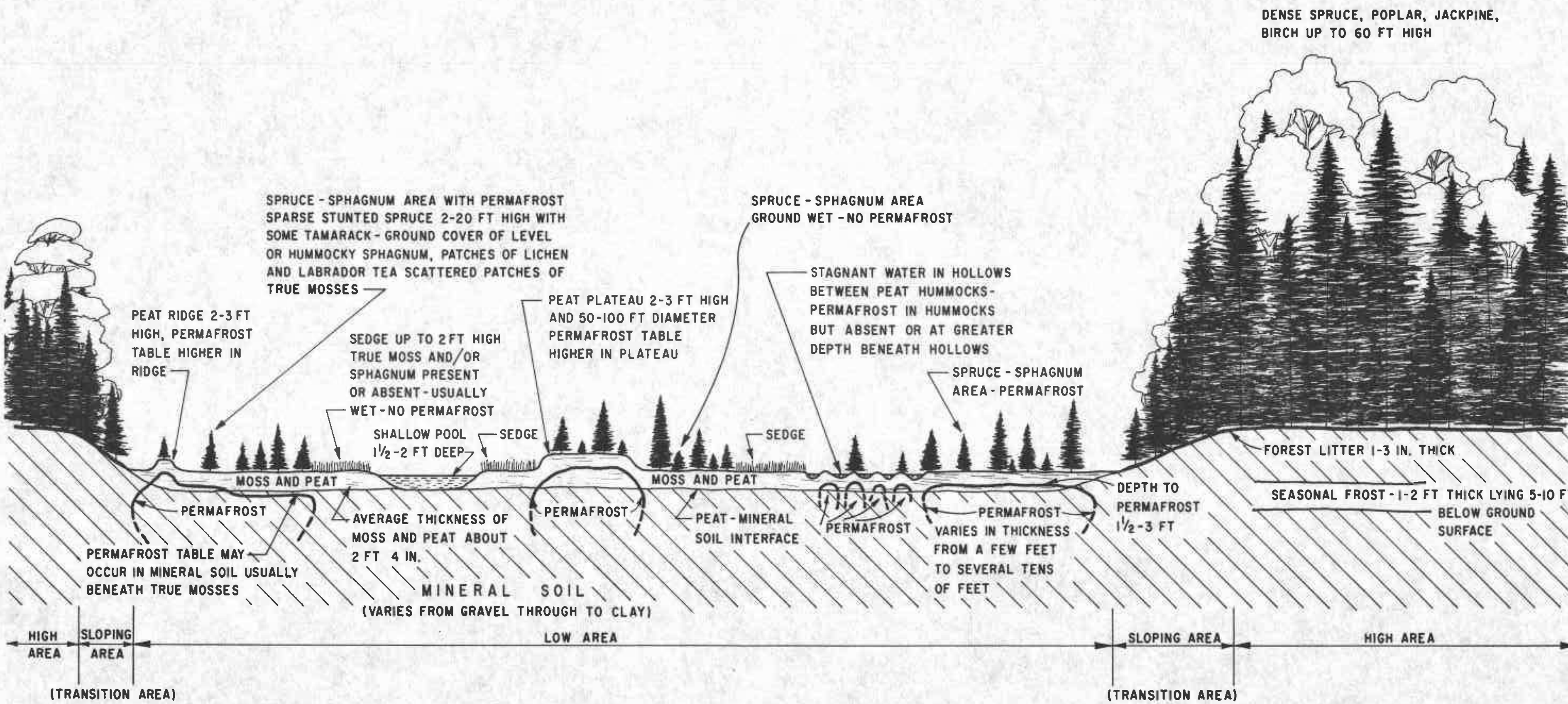


FIGURE 42

PROFILE THROUGH TYPICAL PEAT BOG IN SOUTHERN FRINGE OF DISCONTINUOUS ZONE SHOWING VEGETATION, DRAINAGE AND MICRO-RELIEF, AND ASSOCIATED PERMAFROST DISTRIBUTION.

BR 3119-11

Figure 43 - Section of RCAF air photo A14961-128 at Stop No. 9 in the Hudson Bay Lowland northwest of Attawapiskat.

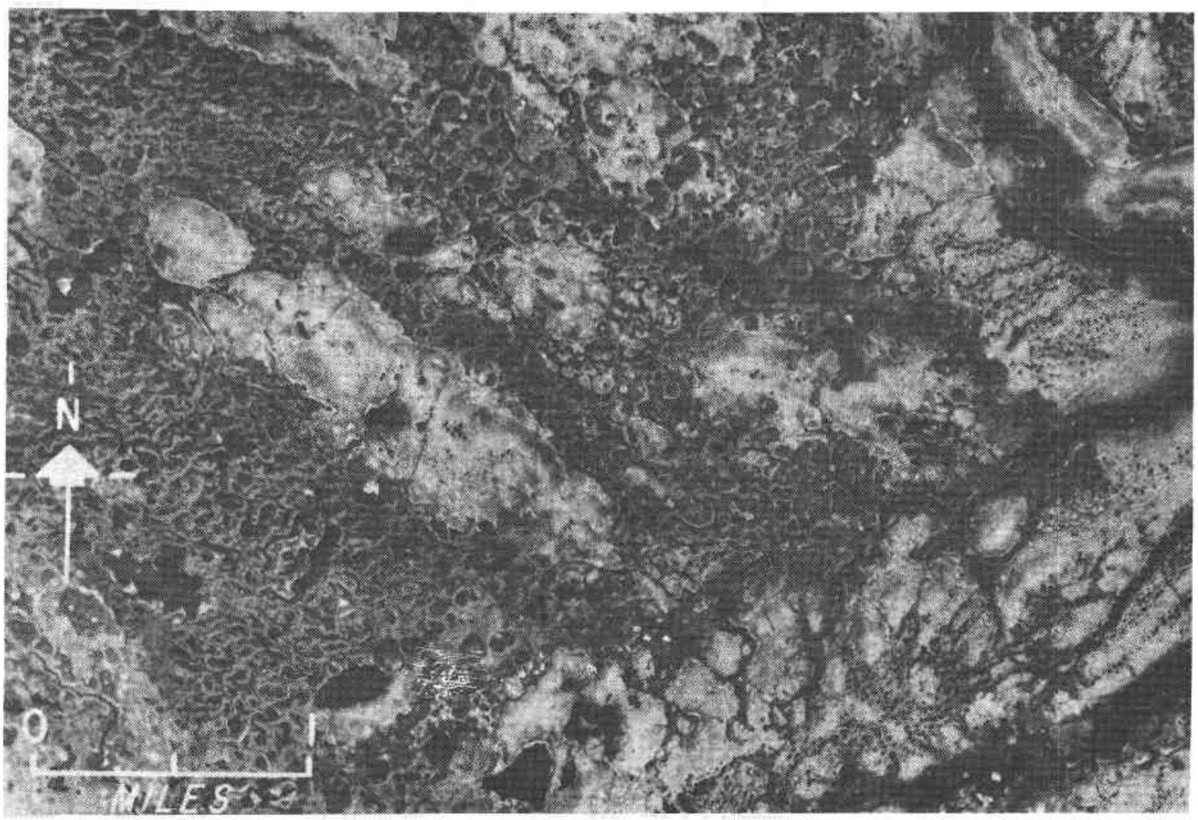


Figure 44 - Section of RCAF air photo A15135-23 at Stop No. 10 about 30 miles northwest of the area shown in Figure 43.

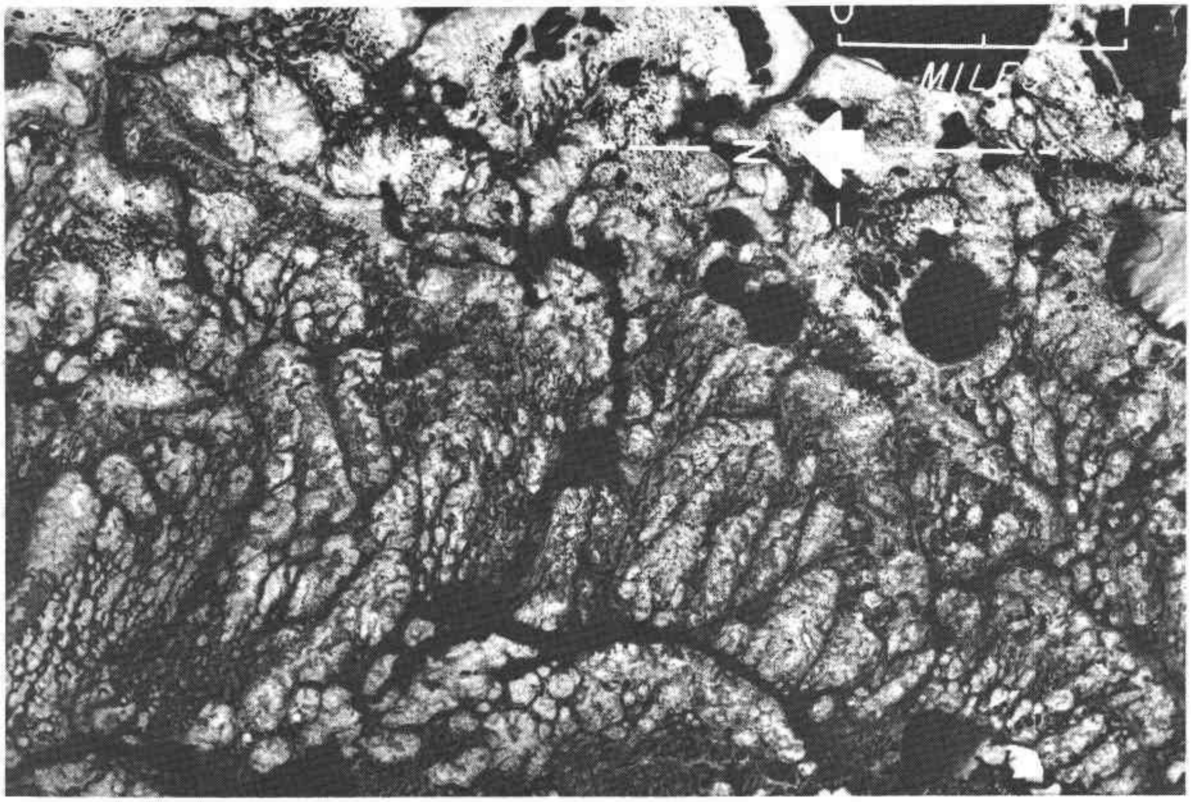


Figure 45 - Section of RCAF air photo A14137-65 west of Winisk in the Hudson Bay Lowland.

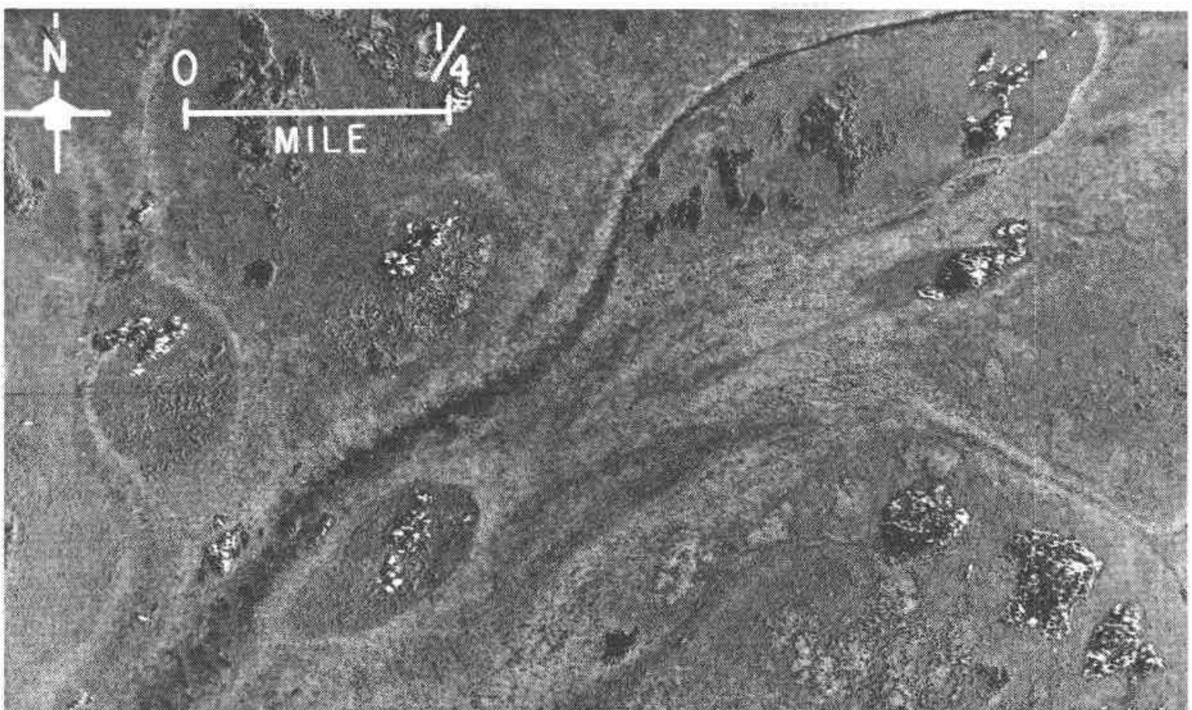


Figure 46 - Section of RCAF air photo A10126-13 at Stop No. 40 about 8 miles east of Norway House.

APPENDIX A

In addition to the permafrost investigations carried out by helicopter in the study area, information on occurrences of permafrost has been obtained from the technical literature, questionnaires and personal interviews. The locations and sources of information are listed below in alphabetical order and shown on Figure 41. The information is presented as it was obtained from the source and the reliability of the observations has not been verified. Observations at one site from several sources may conflict with each other. The absence of permafrost at a particular site does not necessarily preclude the existence of permafrost nearby in a different type of terrain. Permafrost information obtained from these sources in the portion of the study area located in northeastern Manitoba was presented in Appendix A of "Permafrost Investigations in Saskatchewan and Manitoba" by R.J.E. Brown, Division of Building Research Technical Paper No. 193, NRC 8375, September 1965.

1. Attawapiskat

   No permafrost reported (4).

2. Attawapiskat River

   Spruce islands with cores of permafrost occur in bogs near the river and its tributaries (6, 7, 8). Patches of frozen ground of unknown thickness encountered in bogs near river at depth of about 1 ft (1).

3. Bearskin Lake

   No permafrost encountered in clay soils overlain by peat (4).

4. Big Beaver House

   Permafrost encountered in organic material at depth of 5 ft below ground surface (5).

5. Cape Henrietta Marie

   Permafrost encountered in sand and gravel beach material (3).

6. Fort Albany

   No permafrost reported (2).

7. Fort Severn

Permafrost encountered at depth of 6 ft below the ground surface and extends to depth of 13 ft (1).

8. Hawley Lake

Numerous palsas with permafrost cores occur in this area. No permafrost encountered in wet peatland areas between palsas (7).

9. Lake River

Patches of frozen ground of unknown thickness encountered in bogs near settlement at depth of about 1 ft (1).

10. Mid Canada Line

Stations built on elevated permafrost free mineral soil areas in peatlands (3).

11. Moose Factory

No permafrost encountered in excavations (4).

12. Moosonee

No permafrost encountered (4).

13. Osnaburgh House (Lake St. Joseph)

No permafrost reported (1).

14. Sandy Lake

No permafrost encountered to depth of 7 ft in till (4).

15. Trout Lake

No permafrost reported (4).

16. Winisk

Permafrost encountered to depth of 20 ft in site investigations for Mid Canada Line station.

SOURCES OF INFORMATION

1. Canada, Geographical Bureau, Department of Mines and Resources, Ottawa, Ontario. Jenness, J.L. Permafrost questionnaire - 22 July 1946.

2. Canada, Post Office Department.

3. Canada, Department of Transport.

4. Hudson's Bay Company.

5. Martin, G.M., Big Beaver House, Ontario.

6. Sjörs, H. "Bogs and Fens in the Hudson Bay Lowlands," Arctic, Vol. 12, No. 1, Mar. 1959, p. 3-19.

7. Sjörs, H. "Forest and Peatlands at Hawley Lake, Northern Ontario," Contributions to Botany, 1959, Bull. 171, National Museum of Canada, p. 1-31.

8. Sjörs, H. "Surface Patterns in Boreal Peatlands," Endeavour, Vol. XX, No. 80, Oct. 1961, p. 217-224.