
TERRAIN, VEGETATION & PERMAFROST RELATIONSHIPS,
NORTHERN MACKENZIE VALLEY AND YUKON

PREFACE

This is one section of a three-part contribution to the Task Force on Northern Oil Development, by the Northern Forest Research Centre (Canadian Forestry Service, Department of the Environment), Edmonton, Alberta. This particular contribution, prepared in collaboration with the Department of Agriculture, is concerned with the interrelationships between vegetation, landform and permafrost; another with the mapping of landscape-permafrost features using aerial photo interpretation, checked by ground inspection (C.B. Crampton); and the third with an investigation of the effects of disturbance in permafrost terrain, and the kind and degree of damage to the terrain caused by different agents (R.M. Strang).

STUDIES OF VEGETATION, LANDFORM AND PERMAFROST IN THE MACKENZIE VALLEY:

Terrain, Vegetation and Permafrost Relationships in the Northern Part of the Mackenzie Valley and Northern Yukon

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The data for this report were obtained as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.

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1. SUMMARY

The rapid development of transportation facilities in the north necessitates a knowledge of special circumstances presented by the occurrence of permafrost. In this report the results of a study undertaken by the Department of the Environment (Canadian Forestry Service) in co-operation with Department of Energy, Mines and Resources (Geological Survey of Canada) supported by the Department of Agriculture (Soil Research Institute) in the northern part of the Mackenzie Valley and northern Yukon are described.

The area investigated in two field seasons occupies about 107,000 km^2 (41,000 mi^2), partly in the Interior Plains physiographic province and partly in the Cordilleran province of Canada. Arctic - continental climate prevails, characterized by long, cold winters and short, often warm summers, and low amounts of precipitation. Permafrost is continuous throughout the area, except under permanent water bodies and under wet fenlands in the south. The vegetation is transitional between the boreal coniferous forests and the treeless tundra, consisting mainly of open stands of low spruce with an extensive ground cover of lichen. In the mountains, treeless tundra conditions prevail.

It was found that vegetation succession, active layer and near surface permafrost conditions could be related to specific landforms in broad, climatically influenced Land Regions. The thickness of the active layer is the greatest in the south and decreases northward. However, in the sparsely vegetated parts of the tundra the active layer is no thinner than further south, due to the absence of the insulating vegetation cover.

Earth hummocks are very common features of the surface. They are believed to be formed by the freezing and thawing of the active layer, and hence reflect some characteristics of the near-surface conditions. The height and size of hummocks is related to the texture of the soil materials and to soil moisture within each climatic zone. They are best developed in the most northerly treed region, but they become smaller in the poorly vegetated alpine tundra areas.

The moisture content of the near-surface permafrost can be related to landforms (texture, slope) and vegetation within various Land Regions. The iciest near-surface permafrost occurs in fine grained, but permeable soil materials on gentle slopes or on relatively well drained plains under undisturbed vegetation of spruce - lichen. Massive ground ice, occurring at depth, can be found with increasing frequency from south to north; the presence of such icy bodies is not indicated by the vegetation. It was noted, however, that these occur in areas which were at one time occupied by lakes or ponds.

Peatlands occupy large portions of the land surface. Bogs occur as peat plateaus and palsas elevated by permafrost. Wet fenlands, however, are not frozen above the mineral subsoil in the southern Regions. This causes a great difference in the properties of these peatlands: bogs, although containing up to 90% moisture, provide firm footing as they are frozen beneath the surface. Fenlands, being unfrozen, act as drainage channels or water reservoirs during the summer.

Vegetation-permafrost relationships, ascertained from local studies, were expressed on an areal basis by correlating these relationships with landforms, as mapped by the Geological Survey. This was accomplished by providing the information on a detailed legend of the landforms.

The susceptibility of the surface to disturbance was determined by correlating vegetation, near-surface permafrost, active layer, soil materials, and slope patterns. Surface susceptibility, defined as a reaction to a moderate surface disturbance, was determined for the landforms in the study area and ranked on a six point scale. Maps at a scale of 1:250,000 were prepared, showing the surface susceptibility of the study area.

It was found that the most important function of the vegetation is the insulation of the surface from excessive heat transfer. The quality of vegetation is important: vegetation is usually re-established soon after a disturbance (as fire), but the pioneer vegetation is a poor insulator and thermal subsidence occurs. Ponding on differentially subsided areas further alters the thermal conductivity of the ground, leading to aggravated conditions. Any interdiction of surface drainage on permafrost ground which causes ponding is dangerous. Such interference with drainage can result when building berms or roads across slopes, blocking often indistinct, but active drainage-ways. Blockage of drainage can result when putting a refrigerated pipeline across unfrozen fenlands, with subsequent upstream ponding and thermokarst development.

2. INTRODUCTION

2.1 Nature and scope of study

In the natural state, terrain and vegetation are in a state of balance with the climate of the region. In the north slow changes in vegetation will induce an adjustment by the terrain surface in the underlying frozen soil. Similarly, gradual terrain changes by erosion or uplift through ground ice accumulation cause changes in the vegetation. Sudden and severe changes, however, disrupt this balance and may have catastrophic consequences. Whether these changes occur in the vegetation (e.g. a fire) or in the terrain (e.g. a landslide, blocking of drainage), they will affect each other, and together, the thermal quality of the ground. Readjustment and restoration of the balance and consequent stabilization of the ground surface may be a very slow process in the arctic and sub-arctic environment.

The purpose of the present study is to identify some basic relationships between landform, vegetation and near-surface permafrost in the northern part of the Mackenzie River valley and in the adjacent part of Yukon Territory. These relationships are both regional and local in character. Regional relationships determine the extent and kind of unfrozen terrain within the various climatic zones and the vegetation associated with them in the broad, biogeographical sense. Local relationships, including the history of past disturbances, determine the kind of vegetation, soil, and moisture content of the near-surface permafrost developed on any part of a terrain, as well as the thickness of the seasonally thawed soil layer and the distribution pattern of permafrost and non-frozen terrain.

In this study both regional and local relationships were studied within the limitations imposed by available time. Ecologically significant regions (zones) were recognized, and landforms, as identified and mapped by the Geological Survey of Canada, were characterized in terms of vegetation, soils and permafrost conditions within each ecological zone.

2.2 Specific objectives

The stated objectives of this study are:

1. To determine relationships between landforms, vegetation cover, soils and permafrost conditions in various climatic zones in the northern part of the Mackenzie River valley. These relationships should be meaningful for determining the sensitivity of the terrain to disturbance and may be used as mapping criteria.

2. To identify and map landform - potential (stable) vegetation types.

3. To integrate this work with results emerging from studies of the Geological Survey of Canada, Canadian Wildlife Service, Arctic Land Use Research projects and others to facilitate the devising of a terrain sensitivity classification.

2.3 Relationships to pipeline development

Within specific landforms, vegetation reflects the influence of the near-surface permafrost conditions. The thickness and insulating quality of the ground vegetation is influenced by both the landform and the vegetation community. Such considerations influence the type of activity that the terrain can withstand without deterioration. An understanding of such relationships will help to avoid adverse consequences of disturbances either directly to the terrain surface, or indirectly by the disruption of the natural drainage. With such knowledge, areas of potentially troublesome terrain or local conditions which may cause difficulties can be identified and avoided.

3. STATE OF KNOWLEDGE

The The influence of vegetation on the establishment and maintenance of permafrost has been studied in North America (see summary by Roberts-Pichette, 1972) and in Eurasia (Tyrtikov, 1964). Soil-landform-permafrost studies have been carried out in northern Canada and Alaska (Tedrow, 1966), concentrating chiefly on conditions in the Arctic regions.

By far the greatest part of this information was obtained from the tundra or from the northern boreal forest regions and only very little from the sub-Arctic regions. Thus very little information is directly applicable to the study area which lies almost entirely in the sub-Arctic/boreal forest ecotone.

4. STUDY AREA

4.1 Geographic Location

The area studied lies south of latitude 68° N, extending in rectangular blocks to 65°30' N in the south between the Alaska boundary in the west and longitude 128° W in the east (Fig. 1). Reconnaissance surveys were made in the surrounding areas to the Coastal Plain and northern Mackenzie Delta in the north and to the Sans Sault Rapids-Norman Wells area in the south.

4.2 Physiography

The topography presents great contrasts in both regional and local relief (Fig. 2). Mountains and high plateaus characterize the west where the elevation is generally above 300 m (1000 ft), while the relief is much more subdued in the east, with the lowest portion near the Mackenzie Delta being only some 15 m (50 ft) above sea level.

The study area lies partially in the Interior Plains Province and partly in the Cordilleran Province of the Border Region of Canada.

(Bostock 1964). The Cordilleran Region is characterized by mountain ranges, as the Richardson Mountains, Ogilvie Mountains and the British Mountains and by enclosed plateaus (Porcupine Plateau, Fig. 1). The highest peaks in these mountains exceed 1500 m (5000 ft) in rugged quartzite, sandstone or limestone bedrock materials. The Porcupine Plateau is a mature, dissected, elevated plain with local mountain ranges (Keele Range, Old Crow Range) and lacustrine basins (Old Crow Basin, Bluefish Basin, Bell Basin).

In the Interior Plains Province several physiographic divisions were recognized (Bostock 1964: Fig. 1). The Peel Plain is a relatively flat area with innumerable small ponds. The Grandview Hills, composed of shaly rocks of Mesozoic age, provide the only substantial relief. The Anderson Plain is characteristically rolling, being underlain by Palaeozoic rocks. The Peel Plateau is a dissected, elevated plain consisting of Mesosoic rocks, with local mountain ranges.

4.3 Drainage

The area straddles the Continental Divide: in the eastern part the Mackenzie River and its tributaries drain the area into the Arctic Ocean, and in the west the drainage is to the Pacific Ocean.

The principal stream in the west is the Porcupine River. Its main tributaries are the Eagle, Bell and Old Crow Rivers. The Porcupine River joins the Yukon River at Fort Yukon in Alaska before reaching the ocean. In the east, the Mackenzie River and its tributaries form the drainage system. The main tributaries are the Peel, Arctic Red and Hume Rivers, all reaching the Mackenzie River from the west. The Mackenzie River is building a large alluvial delta before finally reaching the Arctic Ocean north of the study area.

4.4 Glacial geology

The Laurentide ice sheet extended up to the Richardson Mountains on two separate occasions (Hughes 1972). The older advance took place from the east, across the Peel Plain, and the ice reached the Richardson Mountains, but did not cross them. A smaller lobe extended up the Peel River valley, to a point west of the study area. The ice blocked the natural drainage to the east and north, and a number of glacial lakes were dammed, having outlets across mountain passes to the west. During late-Wisconsin time another ice sheet advanced into the area from the east, extending up to the mountains but stopping some distance short of the limit of the earlier ice advance. Glacial lakes were again ponded between the ice sheet and the mountains. As the ice sheet waned, several recessional halts or readvances occurred, marked by belts of hummocky moraines. The minimum date of deglaciation, as indicated by radiocarbon dating, was about 10,000 years ago.

The Richardson Mountains and the Porcupine Plateau were not glaciated by either the continental glacier or by local mountain glaciers (Hughes 1972), possibly due to insufficient precipitation during the glacial periods. Lacustrine basins were formed in the Old Crow, Bluefish and Bell Basins during the Pleistocene period when meltwaters of the eastern ice sheet poured across mountain passes. The existing outlets could not accommodate the vastly increased flow and lakes were established in the lowest portions of the plateau, to be drained as the outlets were sufficiently eroded.

4.5 Climate

The climate of the study area is characterized by long, very cold winters and short, cool summers, with some warm periods. Precipitation is low and unevenly distributed due to the effects of topography. Mountains generally receive more precipitation than the valleys which may lie in a rain shadow (Fig. 3). Old Crow Basin, being enclosed by mountains, is a prime example of such an effect. Some pertinent meteorological data are presented in Table 1.

5. METHODS OF INVESTIGATION

5.1 Field techniques

The survey was carried out in conjunction with terrain studies by the Geological Survey of Canada. Various landforms were identified in the field and vegetation, soil, active layer, and near surface permafrost conditions were related to each landform.

5.1.1 Survey Crew

Logistics problems limited the size of crew to a forest land ecologist and a pedologist working as a team most of the time. Occasionally, the team members accompanied geologists, geotechnical engineers and botanists on transects or on detailed local inspections.

Table 1. Temperature and precipitation normals at climatic stations

	Norman Wells	Fort Good Hope	Fort McPherson	Inuvik	Old Crow*
Annual average temperature	-6.2°C	-7.6°C	-8.2°C	-9.6°C	-5.0°C
Monthly average temperature:					
July	15.9°C	15.8°	14.7°C	13.9°C	20.1°C
January	-28.2°C	-30.0°C	-28.8°C	-30.9°C	-31.1°C
Ave.frost-free period	90 days	71 days	75 days	N.A.	N.A.
Ave.date of last spring frost	May 31	June 6	June 8	N.A.	N.A.
Ave.date of first fall frost	Aug 30	Aug 17	Aug 23	N.A.	N.A.
Average annual precipitation	321 mm	267 mm	296 mm	276 mm	182 mm
Average precipitation, June-Aug	147 mm	111 mm	105 mm	98 mm	90 mm
Average annual snowfall	136 cm	118 cm	161 cm	173 cm	84 cm

* Personal communication, Mr. Burns, Atmospheric Environment Service.

5.1.2 Survey procedures

The survey was carried out by helicopter from field camps. In a new area transects were flown, when large distances were covered with only limited number of stops (up to 6 stops) at selected points. Once such overview was obtained, specific locations were selected from aerial photographs where typical landforms or a combination of landforms were noted. At such points the field crew was set out by helicopter and a day-long foot traverse was made.

5.1.3 Data collection

Aerial surveys consisted of making observations on macro-vegetation (trees, shrubs, etc) in relation to various landforms, noting the presence and extent of hummocks, the elevation of timber line, and the effect of disturbances on vegetation and land surface.

On the ground the vegetation was tallied by species according to cover classes in various life forms (trees, shrubs, etc.) and flowering specimens were collected. Soil pits were dug to permafrost table and samples taken. In selected locations, the pits were extended into the frozen stratum using an electrically operated jackhammer. Disturbed areas were visited and gross changes in vegetation, depth of thawed layer and subsidence were noted.

Organic terrain was investigated by obtaining elevation profiles of various organic landforms at 67 different locations. The frozen material was cored using a small diameter (22 mm), hand-operated permafrost probe to a maximum depth of 4 m (13 ft). A total of 870 samples of known volume were obtained.

5.2 Data analysis

To date only the organic samples have been analysed. Moisture content by volume and weight were obtained by weighing and drying. The dried specimens were ashed to obtain a characterization of specific gravity of peat in relation to degree of decomposition and contamination by mineral soil material.

5.3 Phasing of work

A general reconnaissance survey of the area was carried out in June, July and first half of August in 1971 and 1972. The raw data were organized and preliminary maps drafted during the intervening winter for the area investigated.

Due to insufficient time available, the area had to be covered very hurriedly at an average rate of 950 km^2 (370 mi^2) per field day. Many interesting and important observations were made that could not be followed due to the lack of time.

6. RESULTS

6.1 Ecological zonation: Land Regions

When examining the vegetation of a large area, certain latitudinal and altitudinal zonation is apparent. The vegetation is similar on comparable habitats within the zones, but changes from zone to zone. Thus, the vegetation development on physiographic sites, e.g. on the same landform, slope position, parent soil material, internal and external drainage, will be the same within a zone, but the same physiographic site in a different zone will show different vegetation development. The soil displays similar trends, as the kind and development of soil profiles vary from zone to zone on similar physiographic sites. The depth of the thawed layer, the form and kind of surface expression of permafrost also vary on similar sites from zone to zone, but remain relatively constant on comparable sites within a zone.

The zones can be identified as the Site Regions of Hills (1960), defined as areas in which the same vegetation succession will occur on the same physiographic site, providing the type and degree of disturbance is the same. The Land Regions of the Biophysical Land Classification System are similarly defined (Lacate, 1969), being areas of land characterized by a distinctive regional climate as expressed by the vegetation. In the present study in addition to vegetation, trends in soil development and permafrost features were also used to characterize the Land Regions. The Land Regions in the study area are shown in Fig. 4.

The expected orderly zonation from south to north is complicated by the presence of mountain ranges and broad valleys. This is true not only on the regional, but also on the local scale. Thus within some regions there are some mountainous areas which would belong to another Land Region. Although the complexity of terrain makes the identification of such outliers of other regions impractical, their presence must be recognized. The regions, as shown in Fig. 4, were delineated on the basis of the dominant, most widespread conditions within their boundaries.

In order to compare briefly the different Land Regions, the conditions on a gentle, southeast facing mid-slope can be compared. The composition of the vegetation and successional trends on such slopes differ according to the thermal regime and precipitation pattern of each region and these characteristics can be used to distinguish ecologically significant regions. The climate may also affect the physical characteristics of the land: moisture conditions on similar slopes may be different due to decreased evaporation in colder regions; permafrost-induced microrelief may develop to different degrees. These features can also be used as distinguishing characteristics of the regions.

REGION 0	Vegetation:	Treeless tussock tundra of sedge and cottongrass (Fig. 5)
	Soil:	Bare centered hummocks; microrelief 50 cm
	Active layer:	60-70 cm under hummocks; 15 cm in depressions
	Organic landform:	Peat polygons, fenlands with permafrost
REGION 1	Vegetation:	White spruce - black spruce - lichen (Fig. 6)
	Soil:	Hummocks with 5-10 cm organic horizon; microrelief 50 cm
	Active layer:	60-80 cm under hummocks; 15-20 cm in depressions
	Organic landform:	Peat polygons; fenlands with permafrost
REGION 1(m)	Vegetation:	Black spruce - sedge tussock (Fig. 7)
	Soil:	Hummocks with thin (less than 5 cm) or often no organic horizon on top; microrelief from 30-60 cm
	Active layer:	60-80 cm under hummocks; 20 cm in depressions
	Organic landform:	Peat plateaus, peat polygons; some fenlands with permafrost
REGION 2	Vegetation:	Black spruce - lichen (Fig. 8)
	Soil:	Hummocks with up to 15 cm organic horizon; microrelief 25-40 cm
	Active layer:	80-90 cm under hummocks; 20-30 cm in depressions
	Organic landform:	Peat plateaus, palsas; fenlands without permafrost

REGION 2(m)	Vegetation:	Black spruce - sedge tussock (Fig. 9)
	Soil:	Hummocks with variable organic horizon; microrelief from 25 to 40 cm
	Active layer:	80-90 cm under hummocks; 20-30 cm in depressions
	Organic landform:	Peat plateaus, occasional peat polygons; some fenlands with permafrost
REGION 3	Vegetation:	Black spruce - lichen (Fig. 10)
	Soil:	Weak hummock development under 20 cm organic horizon; microrelief 10 to 15 cm; locally to 40 cm
	Active layer:	80-110 cm under hummocks; 50-80 cm in depressions
	Organic landform:	Peat plateaus, palsas; fenlands without permafrost

In this classification all areas above the arctic or alpine tree line were included in Region 0. Preliminary observations indicate that the vegetation and active layer characteristics of high alpine areas are substantially different from lower alpine and arctic conditions, and may indeed be in a different Land Region. However, available data are not sufficient to characterize these areas and such subdivision may be carried out in the future.

6.2 Stable vegetation

Vegetation development on an area is influenced by physiographic, biotic and climatic factors. When allowed to grow without disturbance, the vegetation reaches a balance with the environment; in this state the plants are able to reproduce themselves for generations until the environment changes. Should this stable condition be disturbed, other vegetation types will succeed one another until the balance is once again reached. Thus an area, with its particular physiographic and climatic conditions, may support the stable vegetation but, at a different point in time the vegetation may be developing toward the stable condition following a disturbance on the same area. Even in the disturbed state, stable vegetation characteristic of a site can be predicted by comparing the vegetation of the site with a similar area in the undisturbed condition.

The stable vegetation can be readily characterized within the Land Regions according to soil and soil moisture conditions. Local physiographic conditions may change the local climate and hence the vegetation development. Such conditions occur on steep, south facing slopes, in protected valleys which may make the site warmer, or on north facing slopes, exposed ridges, snowbank accumulation areas and in frost pockets any of which may make the site effectively colder. Sites which are not so influenced may be called normal, as the vegetation on them expresses the normal effect of the regional climate (Hills, 1960). The stable vegetation occurring on medium to fine grained soils in the various Land Regions of the northern Mackenzie Valley is shown in Table 2.

There are only four coniferous tree species growing in the area, white spruce*, black spruce, a white and black spruce hybrid, and tamarack, but the latter reaches its western limit of distribution in the area and is not found west of Land Region 1m. Similarly, three broadleaved tree species are found; white birch is common in all regions, except in the treeless Region 0. Balsam poplar is present on well drained normal sites in Region 3, but occurs in all other Regions, with the exception of Region 0 on well to imperfectly drained, warmer thannnormal sites and on frequently flooded alluvial flats. Similarly, trembling aspen is restricted to warmer than normal, well drained sites in Regions 1, 1m, 2 and 2m.

The most commonly occurring plant community covering vast areas of imperfectly drained soils is the spruce-lichen forest type, consisting of black spruce in Regions 2 (Fig. 8) and 3 (Fig. 10), and a mixture of black and white spruce in Region 1 (Fig. 6). The trees are the tallest (up to 10 m or 30 feet) and the stands the densest (trees about 4 m or 15 feet apart) in Region 3, but the trees become smaller and the stand more open towards the north, in Region 1 the average height of trees is 4 m (12 feet) and the trees about 7 m (25 feet) apart. Lichens (*Cladina, Cladonia* and *Cetraria* sp.) occur mainly on the well drained portions of hummocks that have been permanently elevated by frost action, with some feathermosses (e.g. *Hypnum, Hylocomium, Pleurozium, Dicranum* sp.). Between the hummocks wet conditions prevail where usually coarse-leaved Sphagnum (*Cymbifolia* group) grow. The organic mat, formed by dead plant debris and living moss, is the thickest in Region 3 on such imperfectly drained sites (average 35 cm), but it gradually becomes thinner in the northern regions. A description of the vegetation in this and other vegetation types is given in Appendix 12-2.

In Regions 1m and 2m spruce-tussock forests cover large areas of poorly to imperfectly drained silty soils (Figs. 7, 9). The sparse tree cover consists of black spruce, with some tamarack in Region 2m. The trees are small, less than 4 m (15 feet) tall, although they may be over 200 years old. The sparse shrub layer consists mainly of *Salix* sp. and *Betula glandulosa*, with some Ericaceous shrubs. Closely spaced

* See Appendix 12-1 for list of scientific names.

tussocks of sedge (mostly *Carex bigelowii*) occur on low hummocks, with Sphagnum (*Acutifolia* group) growing between the hummocks. Lichen is rare; a few *Cetraria cucullata* and *Cladina rangiferina* may occur on some Sphagnum cushions.

On well drained sites, which are relatively rare in all Regions, white spruce is common, growing in a mixture with white birch and black spruce in the south and in pure, open stands with lichen in the northern Regions. The lichen is mainly *Cladina* sp. but in Regions 1 and 1m *Cetraria* sp. and *Stereocaulon* sp. are locally dominant. The organic mat is generally thin or absent, and the seasonally thawed layer is usually in excess of 150 cm, even in the northern Regions.

On wet, poorly drained sites open forests of black spruce and tamarack develop, often having a relatively dense shrub layer (shrub birch, willow, ericaceous shrubs) and sedge. Sphagnum may occur locally, but in the moister regions (2m, 1m) the small-leaved Sphagnum species (*Acutifolia* group) may form a nearly continuous carpet. The organic mat buildup is variable, but is generally less than 30 cm.

Special conditions exist on alluvial soils in the major river valleys. These sites are generally in warmer, protected valleys and are periodically enriched with alluvial deposits. This inundation, at intervals which depend on position in the valley, causes the development of a vegetation-soil-permafrost system in all regions that is peculiar to these sites.

On frequently flooded sites horsetail and some annual plants can establish themselves. These sites are not underlain by permafrost. Areas which are less frequently, or less severely flooded usually support tall willows in the northern Regions and a mixture of willow and river alder in Regions 2 and 3. As the ground is free of plants which could develop an insulating organic mat, permafrost is absent. Areas that are subjected to less flooding or are not scoured by ice floes support stands of balsam poplar (Fig. 11), sometimes in admixture with willow. The ground is still bare of moss vegetation and permafrost is absent, or occurs at depth where it does not influence the tree roots. On portions of the flood plain which are subject to less frequent or less damaging flooding, white spruce-feathermoss stands develop. The trees are usually tall (up to 20 m (70 feet) in Region 3 and 15 m (50 feet) in Region 1) and the diameter at breast height may reach 20 inches in the south. Some white spruce trees can reach great age; 300-year-old trees are not rare, and some individuals may be considerably older. The insulating effect of the mosses induces the development of permafrost, the active layer being about 30 cm in Region 1 and 50 cm in Region 3. Should the riverbed shift sufficiently to exclude floods from such an area, the absence of the periodically deposited calcareous sediments permits the invasion of Sphagnum mosses and ericaceous shrubs, and eventually a spruce-lichen forest will develop on the imperfectly drained sites, similar to those growing on non-alluvial soils in the region.

Table 2. Stable vegetation types in the Land Regions of the Northern Mackenzie Valley.

	COOLER*			NORMAL*			WARMER*		
	Well drained	Impf. drained	Poorly drained	Well drained	Impf. drained	Poorly drained	Well drained	Impf. drained	Poorly drained
Land Region 0	Tussock	Tussock	Sedge	Tussock	Tussock	Sedge-Sphagnum	Shrub birch	Shrub birch alder	Sedge
Land Region 1	bS-lichen	bS-Sphagnum	Lichen-heath	wS-lichen	wS-bS-lichen	bS,tL-sedge	wS-lichen	wS-alder	Shrub birch-tL
Land Region 1m	bS-lichen	bS-tussock	Lichen-heath	wS-bS-lichen	bS-tussock	bS-tL-Sphagnum	wS-lichen	wS-alder	Shrub birch-tL
Land Region 2	wS-bS-wB	bS-lichen	Lichen-bS	wS-wB-bS	bS-lichen	bS-tL-sedge	wS-wB-tA-bPo	wS-feather moss	Shrub birch
Land Region 2m	bS-wS-wB	Tussock-bS	Lichen-bS	bS-wB-wS	bS-tussock	bS-tL-Sphagnum	wS-wB-tA-bPo	bS-lichen	Shrub birch-tL
Land Region 3	wS-bS-wB	bS-lichen	Lichen-bS	wB-wS-bPo	bS-lichen	bS-tL-sedge	wS-wB-tA	wS-feather moss	Alder-willow

*Local climates created by topographic variations.

The altitudinal limit of trees on mountains is influenced by the overall climate and shows a gradual lowering toward the north. In addition, many local factors are effective in influencing the tree line, such as rainfall, exposure to wind, soil material and mineralogy, stoniness, etc., making the precise determination of the tree line difficult and of little value on the regional scale. The approximate altitudinal limit of trees is shown in Fig. 12, based on average conditions, discounting the lowering or elevating of the tree line due to local circumstances. The tree line species is usually white spruce, if the slope is well drained. On gentler slopes (usually less than 8%) black spruce or tamarack may grow up to the alpine tree line.

6.3 Vegetation after disturbance by fire

Disturbances disrupt the balance between the vegetation, land and permafrost that developed during the stable condition. The destruction of the stable vegetation may cause drastic changes in the land surface and an entirely new assemblage of plants may colonize the area. Thus if the insulating organic mat is destroyed, the permafrost table will be lowered, resulting in subsequent subsidence of the ground. On flat areas this may result in ponding, and on slopes the melted material may flow downslope, creating an entirely different environment than before. Hence the composition of the vegetation following a disturbance will depend on the kind and severity of the disturbance, as well as on availability of seed. The greater the disturbance and the greater the changes in the land surface itself, the greater the difference will be in the vegetation of the disturbed and undisturbed state.

Disturbance of vegetation can be caused by natural agents, as fire, slope erosion, land slide, etc., or by man. As the vegetation response to disturbance caused by man is the subject of another study (Strang, in press), only the most common disturbance, fire, is discussed here.

The immediate effect of fires is the killing of the vegetation. Trees, shrubs, mosses and lichens are killed and partially consumed by the flames. The roots of some species (white birch, willow, alder, etc.) may survive, and the vegetation in wet spots usually remains alive. The insulating effect of the ground cover is destroyed or severely reduced and, within two seasons the active layer becomes 50% to 100% deeper than before the fire. On the imperfectly drained sites in Regions 1, 2 and 3 the regeneration will be spruce (mainly white spruce) and white birch, with wild rose, alder willow and shrub birch in the understory. Initially there may be an extensive moss (*Polytrichum juniperinum* and *Ceratodon purpureus*) and liverwort (*Marchantia polymorpha*) cover, but these largely disappear as the shade from other species is established. In the following generation white birch content is much reduced, and the tree cover consist of relatively closely spaced white and black spruce.

Feathermosses and, in the wet spots, Sphagnum mosses begin to invade the area, and the ground lichens (*Cladina* sp., *Cetraria* sp.) will be established on the hummocks. As the moss layer is once again being built up, the permafrost table rises to its normal level, and the active layer becomes thinner. These conditions are more favourable to black spruce than white spruce in Regions 2 and 3, and the stable black spruce - lichen forest is re-established (Strang, in press). This cycle may take 2 to 3 generations of 100 to 150 years, the longer being in the north.

In the moister regions, a somewhat different cycle is evident. Fire kills the trees and most of the ground vegetation, but the sedge and cottongrass tussocks survive and thrive in the absence of competition. As the permafrost table is lowered, the site becomes moister, favouring tussock growth and making the re-establishment of black spruce or tamarack very difficult (Fig. 13). In these regions there are extensive areas of fire-induced tundra of tussocks (Region 1m) or tussock-dwarf birch (mainly in Region 2m). It is estimated that hundreds of years may elapse before the stable black spruce (tamarack) - tussock forest and the normal permafrost table are re-established.

The vegetation succession on burned high ice areas is complicated by subsidence and mass soil movement following the destruction of the organic mat and the lowering of the permafrost table. On level ground, local areas which contain more ice than their surrounding areas will subside more as the ice melts, creating shallow depressions where water will collect. This further increases the thermal conductivity of the soil and the permafrost melts deeper. The result is a depression, its size and depth being determined by the amount of ice in the original land. The first plants to invade will be cottongrass (*Eriophorum brachyantherum, E. angustifolium*) along with some *Carex* species. Eventually, moss species that grow submerged in water will invade (*Drepanoclaudus* sp., *Hypnum* sp.) and the peat buildup will begin. Finally *Sphagnum* mosses will be established on the wet peat, and with the invasion of the cushion-forming *Sphagnum* species (*S. fuscum, S. rubellum*), the permafrost table will be raised and the concurrent ice formation will elevate the land to near its former level. This process may take several centuries. It may be noted that the land, having been a depression, will be highly icy, and will be vulnerable to a similar cycle after the next fire.

On slopes the lowering of the permafrost table following the fire creates a layer of soil saturated with water, resting on frozen substrate. Should the slope be steep enough (15% or more, depending on texture, ice content), the thawed layer may slide down slope, exposing the subsoil (Fig. 14). Should this subsoil be high in ice, a flow-slide may be initiated where the material becomes a slurry and flows downhill. If the material is not too icy, herbaceous plants as *Petasites palmatus, Equisetum* sp., *Senecio congestus* will colonize the landslide scar, followed by willow and alder. In the south (Land Regions 2, 2m and 3) balsam poplar and later white spruce follow, while in Regions 1 and 1m white birch and white spruce are the tree species. In Region 0 alder and willows are characteristic of landslide scars. On the waste material of flow slides similar trends are prevalent, but the individual stages may take far longer, as the land surface has to be stabilized and desiccated sufficiently to allow plant growth.

Flow slides that have been active for decades were noted. Many flow slides were stabilized only to be re-activated by fires (Fig.15), as shown by charred trees in the slump material. Examination of older, stabilized flow slides suggest that such slides become stable if the headwall reaches a less icy material, or if the overhanging organic mat can effectively insulate the headwall after slumping and covering the headwall. However, on burned areas there is no insulating organic mat, and hence this form of stabilization of flow slides cannot operate.

6.4 Active layer

The active layer is a surface layer of soil and rock which lies above the permafrost and freezes in winter and thaws in summer (Brown, 1970). The term, active layer is appropriate because most physical, chemical and biological activity takes place in this seasonally thawed layer. Phase changes from ice to water and back to ice, moisture changes through the thermal season, decomposition of organic matter and weathering of mineral soil, movement of soil through frost action, biological activity of soil flora and fauna, as well as root penetration by plants all take place in this layer exclusively, or to a far greater degree than further down in the perennially frozen portion. It must be added that the entire thawed layer is not utilized by plants, as most growth is concluded by late July, long before the full development of the active layer is reached. By far the greatest portion of plant roots are concentrated in the top 10 cm (4 inches) of the soil which is generally thawed by early June in the south and late June in the north.

The thawing of the surface begins as the snow melts and proceeds rapidly in the soil saturated by snowmelt. By the end of June, however, the surface organic layers are dry and insulate the soil against rapid heat transfer, resulting in a slow thawing of the soil. It was found that the thickness of the thawed layer increased very little after mid-August.

The thickness of the active layer depends on the regional climate, local climate, vegetation cover, presence of organic mat (living and dead moss and vegetal matter), soil moisture and texture. Table 3 gives the average thickness of the active layer in various regions on normal (neither exposed nor protected) sites under stable vegetation.

6.5 Soils

Soil profile development is generally quite weak. Two of the main factors involved are (1) the cool temperatures and short summer season which retard chemical and biological activity and (2) the presence of permafrost in the majority of soils which effectively limits internal drainage and leaching, and also promotes profile disruption. Maximum development occurs in well drained coarse textured materials. Where permafrost is not a factor, profiles may be developed with whitish eluviated (Ae) and reddish brown B horizons. These soils (degraded distric and eutric brunisols[1]) are more common in the south where generally warmer temperatures and higher precipitation prevail. In the northern regions the eluviated horizons may be absent as a result of decreased leaching, but strong brown Bm horizons persist in well oxidized soils. This kind of soil (eutric or cryic eutric brunisol) is common to coarse texture till and gravel materials in all regions, but becomes less pronounced in Region 0. Well drained coarse textured soils, particularly those not affected by permafrost, do not make up a large proportion of the project area.

Surface materials are dominantly medium and fine textured. The tills on the southeastern portion average loam to clay loam in texture, but become more clayey to the north and west with the tills on the Peel Plateau commonly having in excess of 40% clay. The unglaciated regions tend to have very silty surface materials, probably from a loessial source at least in the southern portion. These materials are nearly all characterized by high permafrost tables which result in impeded drainage. This situation is prevalent over the majority of the study area, with the result that nearly all the medium and fine textured soils are imperfectly drained and have a hummocky surface as a consequence of cryoturbation processes. The hummocky permafrost affected soils present taxonomic problems and they have not been classified from a pedological point of view because Canadian soil classification system at present does not adequately account for these soils.

6.5.1. Earth hummocks

Earth hummocks are very common in the area (Fig. 5). It is estimated that about 75% of the surface of mineral soils (excepting bedrock) is mounded into earth hummocks in all Land Regions, with the exception of Region 3 where they occur less frequently. Earth hummocks are mounds, generally less than 1 m (3 feet) high and have a diameter between 1.25 and 2 m (4-7 feet), resembling the earth hummocks of Lundquist (1969) and non-sorted nets of Washburn (1956). The consist of mineral soil with variable quantities of organic matter mixed in as streaks or lumps, but

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[1] Soil nomenclature follows "The System of Soil Classification for Canada", Nat. Soil Surv. Comm., 1970.

Table 3. Average thickness of active layer under stable vegetation in different Land Regions on various soil texture and drainage classes.

LAND REGION	SILTY CLAY LOAM			SAND			ORGANIC SOIL	
	Well dr.	Impf. dr.	Poorly dr.	Well dr.	Impf. dr.	Poorly dr.	Impf.dr.	Poorly dr.
Region 0		70 cm	50 cm	100 cm	70 cm	60 cm	25 cm	50 cm
Region 1		70 cm	70 cm	150 cm	75 cm	80 cm	30 cm	100 cm
Region 1m		70 cm	70 cm	150 cm	75 cm	80 cm	40 cm	100 cm
Region 2	120 cm	80 cm	*150 cm	200 cm	100 cm	*200 cm	40 cm	Unfrozen
Region 2m	120 cm	80 cm	*150 cm	200 cm	100 cm	*200 cm	40 cm	Unfrozen
Region 3	150 cm	100 cm	*200 cm	200+cm	150+cm	*200 cm+	50 cm	Unfrozen

* Under sedge vegetation.

without an ice core (Fig. 16). The permafrost between the hummocks and under them is usually highly icy in the upper 10 to 25 cm (4 to 10 inches). Hummocks are not usually found on either well drained sandy soils or on poorly drained mineral soils, regardless of texture.

It was noted that trees are usually located between or on the sides of the hummocks and, in Regions 1 and 2 particularly, are frequently leaning away from the hummocks. This would indicate that the hummocks were active during the life of the trees and presumably still are. Soil profiles are remarkably similar if minor variations from one to another are overlooked. The following generalities appear warranted for the mature stage (Fig. 17):

1. There is a formation of "earth hummocks" or mounds,

2. The permafrost table is roughly a mirror image of the surface microtopography.

3. A "bowl" of relatively high ice content material underlies the active layer of the hump, rising up into the organic filled micro-depressions.

4. Soil horizons are discontinuous in horizontal as well as vertical direction.

5. Buried organic matter is associated with the base of the active layer. Small inclusions of organic matter are common within the active layer, often being contiguous with the inter-hummock depression.

6. Thin (two to ten centimeter) granular, brown, surface mineral horizons with plentiful fine roots grade to an amorphous lower horizon characterized by few roots and dull gray and brown colors. Both of these horizons and the organic inclusions may show signs of cryic movements.

The micro relief features produced by the earth hummock formation vary in size and form with soil texture, drainage, Land Regions. Keeping all other factors constant, the relief or height of the hummocks is lowest in Region 3, increases to a maximum in Region 1, and tends to decrease slightly in Region 0 (Table 4). This appears to be a response initially to decreasing annual temperatures and a higher permafrost table and, in Region 0, to be a response to decreasing moisture. Within a uniform climatic area (on similar textures) maximum development is achieved in the imperfectly to poorly drained sites and it decreases in the drainage extremes. All the mineral soils in Regions 2, 1, and 0, with the exception of the outwash materials, are affected to some extent. Texture, and water holding capacity strongly influence the size and shape of the mounds with the silty clay loam to silty clay materials forming the largest hummocks, up to 70 or 80 centimeters in height and 2 to 3 meters in diameter. As clay content increases above 40%, the hummocks tend to become smaller in diameter, lower in relief but with steeper sides and a more abrupt break between the hummock and the depression elements of the micro-topography. Also, the tops of the mounds tend to be flatter than the more conical shapes of the siltier materials. As the particle distribution shifts to a dominance of coarser fractions (sandier) the hummocks become lower and often more irregular in outline.

6.5.2. Surface organic horizons

The character of the surface organic horizon depends on the vegetation. Under the normal black spruce - lichen forest a 10 to 20 centimeter forest peat horizon is common on the hummocks with 30 to 40 centimeters of sphagnum moss in the depressions. The larger roots (greater than a few millimeters) tend to be concentrated in the lower portion of the organic horizon, particularly on the edges of the hummocks with only the finer roots in contact with the mineral material.

The more poorly drained positions have thicker organic horizons (to 20 to 30 centimeters) with the lower part often being blackish and not as fibric as the upper reddish brown portion. Dark organic mineral (Ah) horizons may be present ranging in depth from up to 10 centimeters in the south to 1 centimeter or less in the north. Alternatively, as the site becomes better drained the organic horizon becomes thinner and in the extreme case of freely drained sands and gravels may consist only of a thin discontinuous lichen crust. There is also a general thinning of the organic horizon from south to north (Regions 3 to 1) concomitant with decreasing vegetative vigour. In Region 0 (non-forested; tundra and alpine) the dry tops of the hummocks are commonly bare of moss or lichen cover, but the mineral soil is not markedly different from the adjacent forest area and, in fact, usually appears to be more stable with more pronounced horizon differentiation. A notable exception is the "fire-induced" tundra soils which will be dealt with later. As has been mentioned earlier, the vegetative cover is a controlling factor in the rate and depth of thawing. As would be expected these soils that are bare of vegetation are the quickest to thaw as soon as the snow cover is gone and also are the earliest to approach maximum depth of thaw. This situation is usual in Region 0 and at first it appears anomalous that the colder region should have soils that warm up more quickly than the more vegetated counterparts. The lack of insulating cover explains why soils in the alpine tundra may have as deep an active layer as those below the tree line.

Table 4. Relationship of height of microrelief with Land Region, drainage, and texture.

Region	Texture	Well drained	Imperfectly drained	Poorly drained
0	fine	-	60 cm	20 cm
	medium	-	20 cm	10 cm
	coarse	0-10 cm	10	<10
1	fine	-	70 cm	30 cm
	medium	10 cm	30 cm	20 cm
	coarse	<10 cm	10 cm	<10 cm
2	fine	20 cm	60 cm	30 cm
	medium	10 cm	30 cm	20 cm
	coarse	0	<10 cm	<10 cm
3	fine	10 cm	20 cm	10 cm
	medium	0	10 cm	<10 cm
	coarse	0	0	0

6.5.3 Soils of unglaciated areas

In general, there was not a marked difference between the kinds of soil in the unglaciated and glaciated areas. Part of this might be due to the presence of the silt loam (loessial?) deposit over most of the southern half of the Porcupine Plateau. However, the unglaciated portion of the study area does present several variations. One is a variable depth of unconsolidated materials, either as weathering products or loess. It appears that a minimum depth of 75 to 100 centimeters of loose regolith is required for full development of the micro-relief features.

A special feature which is most apparent in, but not entirely confined to, the unglaciated regions is the phenomenon of the "fire-induced" tundra. These are the tussock tundra areas below tree line but could also include shrub tussock and black spruce - tussock sites which appear to be different stages of the same situation. They occur on smooth, gentle (less than 5%) slopes in materials of high silt content and appear to be primarily a phenomenon associated with poor drainage. A combination of a poorly structured thixotropic tending material, and an irregular permafrost table close to the surface seem to be the cause. Apparently a hummocky relief can be attained supporting a forest vegetation. A subsequent fire which destroys the forest and at least some of the surface cover results in an increased depth of thaw and more moisture. The hummock collapses because of structural instability, the mineral material becomes saturated throughout, and tussock forming sedge or cotton grass take over. Trees cannot become part of this succession until the re-establishment of micro-topography and associated micro sites of improved drainage. It is estimated that this process could take up to 500 or more years. In extreme cases, the centre of the collapsed hummocks could be covered with mosses. This could be a primary stage as well, but in either case it may be more or less permanent.

Another example of variation in soil character is that due to changes in mineralogy. These effects are most visible on moderately well to well-drained sites and become weaker as restricted drainage assumes greater importance. A particular note here is the presence of carbonates, or the dominance of calcium on the soil exchange complex. Again this is most prevalent in, but not necessarily confined to, the unglaciated area. The effect on vegetation is the first noticeable difference, with an increase in white spruce and feather mosses at the expense of black spruce and sphagnum mosses. While micro-relief may develop on suitable textures, the relief may not be quite as pronounced as in the non-base-saturated soil. The soils develop a more stable structure (probably from calcium - organic - clay complexes) and the whole area often appears to have a "drier" appearance. This likely comes as a result of both different vegetation and a surface that is, in fact, better drained because of the better structural or soil aggregate formation. Because of the more stable structures, these soils are not as prone to degrade to a tundra condition after fire. Another major difference is the development of dark organic mineral (Ah) surface horizons. When free carbonates are present, as in case of weathering carbonate rock, a black turfy horizon will develop above the tree line and below tree line a dark felted organic layer will be present. These areas are very significant from a wild life point of view because the kind of organic accumulations and friable structures (and therefore surface drainage) are ideal or favoured sites for small burrowing rodents. This then controls the rest of the food chain as well. As the soil affects the distribution of these animals, they in turn affect the soil. Burrowing activities have a mulching or cultivating effect and the organic rich micro-environments created must also affect the soil microfaunal population, etc. These soils were encountered in two principal areas, (1) the hill country southeast of Old Crow (Pear Lake area) and (2) the ridge dividing the Old Crow and Bluefish Basins from the Old Crow River east to the Driftwood River. Dark organic mineral surface horizons are also noted in the Peel and Anderson plains on moderately calcareous till materials.

The Bluefish and Old Crow Basins, south and north of Old Crow respectively, are somewhat special ecological areas. These flat, sparsely treed areas, are characterized by peculiar square or rectangular lakes. The orientation of lake borders is approximately parallel with and perpendicular to the prevailing wind direction of approximately 040 and 220 degrees. The presence of old lake borders and buried soil horizons suggest a cyclic nature to these lakes, yet there are at present, in Bluefish Basin at least, no very large lakes although outlines can be seen of those that existed in the past.

On the steeply sloping land forms (mountains) which are generally above tree line the regolith and soils are often relatively thin. Features such as stripes and terraces (Washburn, 1956) are common. Soils with a significant coarse fragment content (greater than 15%) generally show sorting. Sorted nets and sorted circles are common on the ridge crests. Relatively few solifluction features were noted and these seem to be confined to slopes of greater than 20%.

6.6 Massive ground ice

Massive ground ice bodies and icy sediments, similar to those described by Rampton and Mackay (1971) occur scattered throughout the area, with increasing frequency toward the north. They consist of layers of pure ice (Figs. 15, 18), often alternating with very icy sediments, or occur as relatively dry mineral soil (mainly clay) in pure ice matrix in a mortar (ice) and brick fashion. They are invariably capped by frozen soil which is similar to the permafrost in the area. The vegetation reflects the active layer conditions which developed in the near surface permafrost and does not reveal the presence of massive ice bodies lying at depth.

The great majority of massive ice exposures examined in the study area occur in lacustrine deposits (silt, silty clay loam, clay), or under drained ponds identifiable by mollusk shell and marl layers. The topographic position of ground ice in till is such that these areas may have been subject to ponding, although no sediments were deposited. Such positions are encountered on the eastern slopes of the Richardson Mountains where temporary pondings were induced by the continental ice sheets. No massive ice was encountered in the unglaciated uplands of northern Yukon, the only ice bodies found were on lowlands, in alluvial or lacustrine sediments.

The presence of ice lenses may be inferred from thermokarst topography; an area characterized by generally level surface with steep-sided depressions which are filled with shallow lakes. The postulated genesis of such areas assumes the presence of icy sediments at depth, which will collapse upon melting and produce pits. In several instances, natural exposures of ground ice were observed. In one instance on the plateau in a thermokarst area, fossil freshwater mollusks and marl were found about 60 cm (2 feet) below the surface, showing that it once was the bottom of a pond which was drained and elevated in relation to the newer thermokarst ponds.

Most thermokarst ponds are ringed with dead trees that have fallen into the ponds or with living trees leaning towards the pond and are on the point of falling (Fig.19). This phenomenon is interpreted as an indication of active collapse of the area surrounding the thermokarst ponds.

6.7 Organic terrain

6.7.1 Definition

Organic terrain presents a particular environment where the living and dead vegetation constitutes the land forming a dynamically aggrading and degrading land, vegetation and permafrost system. For the purposes of this study, organic terrain is defined as a wetland where the organic matter accumulation is in excess of 50 cm (18 inches). This definition excludes a vast portion of 'muskeg' which is defined as an organic terrain composed of peat and the related mineral sublayer and is considered in relation to topographic features and vegetation (Radforth, 1952). Because the thickness of the peat is not limited, nor is the moisture condition defined, such muskeg would include, in addition to wet peatlands, all imperfectly drained areas that have stable vegetation and all poorly drained soils in the study area. This situation develops because the low thermal regime of the area permits the survival of the normally moisture-loving plants even on slopes, developing a thin (20-25 cm, or up to 10 inches) organic layer. The "muskeg" as defined above, includes heterogeneous areas having greatly different physical, hydrologic and vegetational characteristics. The concept of "muskeg" was considered to be unsuited for describing areas at the levelof detail used in this study.

6.7.2 Morphology

In the study area two broad types of organic terrain occur, bog peatlands and fenlands. The bog peatlands are sufficiently raised above the level of the neighbouring wetland that their surface receives only rainwater and is largely unaffected by the water of the nearby wetlands or by runoff from the mineral landscape. In the study area all bogs are perennially frozen below the active layer, with the permafrost extending into the mineral soil beneath the peat. Fenlands are located in topographic depressions which are usually gently sloping, allowing seepage water to percolate downslope. The fens are affected by runoff water from the nearby mineral areas and by the downslope movement of this water. Fenlands are not frozen in Land Regions 3, 2 and 2m, but are frozen below the active layer in the other, more northerly regions.

Several types of bogs and fens were recognized in the area. By far the most common type of bog is the peat plateau (Brown, 1970), which is frozen peatland raised about 1 m (4 ft) above the neighbouring fens or pools (Fig. 20). They are generally level, with minor irregularities, although in some areas they may be broadly domed. Ice lenses or layers are rare, but thin, generally less than 15 cm (6 inches) layers of ice may be found at the base, between the peat and the mineral soil.

Locally another type of frozen bog, palsas, may be found as islands or peninsulas in wet fens. These are steeply doming peatlands, often reaching 3 to 4 meters in height (Fig. 21). They are generally small, usually less than 45 meters (150 feet) in diameter. The height of palsas is attributed to ice accumulation in the mineral soil under the palsa (Zoltai and Tarnocai 1971) although thin (up to 20 cm or 8 inches) of clear ice layers may occur in the peat.

A third type of frozen bogs are the peat polygon areas (Fig. 22) occurring in the northern Land Regions (Regions 0, 1, 1m). These are essentially peat plateaus with a polygonal trench pattern caused by the development of ice wedges in the peat. Occasionally, especially in Region 2, a polygonal pattern can be seen in waterlogged fens. Coring shows that there is no ice wedge under the trench, and the trench may be regarded as a fossil remnant of an old polygonal peat area.

The second type of organic terrain, the fenlands, can also be subdivided into different types. One such broad type occurs in ponds which are filling in with plant remains. Other types occur on very gentle slopes (estimated at less than 1 in 5000) as rivers of grass (sedge) where slowly seeping water saturates the entire deposit. Often, especially in Land Region 2, low, narrow ridges develop at right angles to the direction of seepage, forming string (ribbed) fens (Fig. 23).

6.7.3 Distribution

Organic terrain, as defined above, is common in the forested Land Regions in the glaciated areas, generally east of the mountain ranges.

In Land Regions 3 and 2 about 30% of the land surface is covered by deep organic deposits. About half (15%) occurs as bog peatlands, mainly in peat plateaus and associated bog pools, with the occasional palsa "islands" or peninsulas in the bog pools. Another 10% of the Region is covered by fens, having deep organic deposits. Many fens, especially in Region 2, show a surface patterned by low ridges (strings). Thin organic veneer (less than 60 cm or 2 ft) occurs in some seepage channels (runnels) on slopes.

Organic terrain is less common in Land Region 1, covering only about 10% of the area. About half of this occurs as thin organic veneer, usually found in runnels, the rest being equally divided between bog peatland and fenland. The bogs occur as peat plateaus, often with polygonal surface pattern caused by the presence of ice wedges. Some fens have strings on their surface, but many show a thickening of these strings into narrow peat plateaus, indicating that a transition from fens to peat plateaus is taking place.

Very little organic terrain is found in Land Region 0, partially because of the generally steep topography, but mainly because of the slow growth of peat-forming plants. Less than 3% of the Region was mapped as organic terrain, all in peat plateaus with polygonal surface pattern.

Organic terrain is scarce in the unglaciated uplands of Region 2m, 1m and 1, being less than 1% of these regions. However, organic terrain occupies about 30% of the basins of glacial lakes occurring in the area: Old Crow Flats, Bluefish Basin and Bell Basin (Hughes 1972). Here the organic materials occur in peat plateaus, frequently with polygonal surface pattern, while the fenlands are less common. To explain the scarcity of peatlands in the areas unaffected by glaciation, it is postulated that here the drainage system is so well developed that few depressions exist which could be filled with organic matter.

6.7.4 Vegetation

The vegetation on the frozen peatlands (bogs) is dominated by ground lichens (*Cladina* sp. and *Cetraria* sp.) and low heath (*Ericaceae*) shrubs (see description in Appendix 2). Scattered, low black spruce and, rarely, tamarack occur on unburned peatlands in all Regions except Region 0. After fire, the heath shrubs take over, with a scattering of trees. Should the peat plateau be located in a position exposed to wind, trees may not be established for several generations. Eventually the ground lichens will recover, usually several decades after the fire.

Fens forming on ponds being filled by peat are dominantly sedge, with brown mosses (*Hypnum* sp., *Drepanocladus* sp.). Coarse-leaved Sphagnum species (*Cymbifolia* group) may grow near a collapsing peat plateau. On the broad, very gently sloping fens, sedges dominate in mixtures with dwarf birch, willow, tamarack and black spruce.

6.7.5 Properties of peat

The depth of peat deposits varies with the configuration of the underlying mineral surface and with position on the particular organic terrain. The peat in a filled-in pond is generally the thickest near the centre, and the shallowest near the periphery of a particular peatland or fenland. On the frozen bog peatlands a minimum depth of 1 m (3 feet) and a maximum of 4 m (13 feet) was encountered. Only the upper 50 cm of the bog deposits was derived from *Sphagnum* and ericaceous plants growing on bogs, the rest is composed of plant remains growing in fens, or pond fillings. Structurally the peat is generally somewhat decomposed, being mesic in the terminology of the Canadian Soil Survey (1970), where the individual plant remains are still discernible, but rubbing destroys most fibres.

The moisture content of all frozen bog peatlands is similar. The moisture in the active layer can be as low as 10% by volume during the summer. Moisture in the frozen peat averages 75% by volume (about 1000% by weight) which is about the same as in the nearby fen, or somewhat lower. Although the moisture content of peat polygon areas is similar, the ice wedges add greatly to the volume of stored frozen water. The width of an ice wedge at the top is about 1 m (3 feet) and the wedge often extends below 4 m (13 feet) below the surface (Fig. 24). As the diameter of peat polygons averages 15 meters (45 feet), it is estimated that about 15% of the surface of a peat polygon area is in ice wedges.

The peat in bog peatlands is most acid near the surface (pH about 4.5), but the acidity decreases with depth to about pH 6 near the base. The fen peat in seepage areas is usually neutral (around pH 7), but it is somewhat acid (about pH 6) in infilled ponds surrounded by peat plateaus.

6.7.6 Peatland dynamics

The internal structure of frozen bog peatlands shows that they developed from fens, in an environment free from permafrost. Similar trends are evident in the area today, as many wetlands were noted where the development is transitional from fen to bog. Thus, often the ridges in string fens are first to become covered by bog vegetation of *Sphagnum* mosses (*S. fuscum, S. rubellum*) and Ericaceous shrubs. This elevates the surface above the water level in the fen and the insulating qualities of this vegetation allows the formation and preservation of permafrost. In time the strings become wider until the entire surface of the former fen becomes peat plateau. In other fens small cushions of *Sphagnum* become established, which similarly fosters the formation of permafrost. By gradually expanding the peat plateau finally covers most of the fen surface.

On the margins of many peat plateaus the degradation of the permafrost is evidenced by slumping and collapsing. Such conditions are frequently found in Land Regions 3, 2 and 2m. Many other peat plateaus show evidences of aggrading in narrow marginal ridges around fens, encroaching on the fens (Fig. 25). This is particularly evident in Regions 1 and 1m, although the same peat plateau complex may have aggrading and degrading margins, in all Regions.

The development of peat polygon areas is problematical. Observations, especially in Regions 1 and 1m indicate that ice wedges may have developed in already existing peat plateaus. In Region 0, however, a sequence of development from low centre polygons to high centre peat polygons was noted. Ice wedges first develop in mineral soil, and soil displaced by the ice wedge form a dam ponding shallow water inside the polygon. Sedge and cottongrass grow vigorously, and the peat buildup begins. Eventually *Sphagnum* moss will invade, raising the centre of the polygon in relation to the trench over the ice wedge.

6.8 Landform maps

The genetic landforms at a scale of 1:125,000 with added information on relief and soil texture are being mapped by the Geological Survey of Canada, Department of Energy, Mines and Resources. The geomorphological maps of the unglaciated areas (west of the Richardson Mountains) are being prepared by the same agency, based on bedrock materials, slope, and surface materials. To date (December 1972) six map sheets have been published, but the field work is largely completed for the surficial geology and geomorphological aspects of the entire area.

The published maps (Appendix 12-4) are accompanied by a legend characterizing the landforms, soil, vegetation and permafrost conditions in each mapping unit in different ecological Land Zones (i.e. Land Regions). In reading the map the following sequence should be followed:

1. Determine the map unit of the entire area of interest. Find this map unit in the legend, and read the information on the nature of the deposits and their thickness; topography (landform, slope, local relief) and drainage pattern; area of surface water included; ground ice conditions.

2. Determine the Land Zone in which the area of interest is located. Within *individual zones* (Land Regions) the soil texture is given in both agricultural and engineering usage. The kind and height of permafrost induced microrelief and depth of thaw (active layer) is shown. The proportion of internal drainage classes occurring on the map unit in the Zone is expressed as a percentage of the map unit. Vegetation in a stable and disturbed state are shown by regions for each broad drainage class.

This procedure may be illustrated by an example. Supposing that information is required on the area tMpv just east of Fort McPherson (Appendix 12-4, Fig. 36). The legend shows that this unit is a moraine plain (Column 2), composed of clayey or silty glacial till (Column 3) where the thickness of the till over bedrock varies between 1 and 20 meters (Column 4). The surface is flat to gently sloping ($0-3^{o}$ slopes), with local relief up to 5 meters (Column 5). The surface drainage is mainly by downslope seepage in subparallel runnels which are not deeply incised (Column 6). Included surface water (ponds, rivers, creeks) may cover up to 5% of the map unit (Column 7). Ground ice occurs as thin seams in the upper 2-3 meters, but rarely thick ice lenses may occur at depth (Column 8).

Upon checking the index map of Land Zones on the legend, it is found that the area lies in Land Zone (Region) 1, and this line is followed in the legend for the tMpv map unit. Column 10 gives the texture of the material as clay loam, or as silty, sandy clay in engineering terms (Column 11). The typical microrelief is hummocks, between 20 and 60 cm high (Column 12), depending on soil moisture and exposure conditions. The depth of active layer (Column 13) is generally between 50 and 80 cm. Column 14 shows that only about 20% of the mapping unit is well drained, with 40% imperfectly drained and another 40% poorly drained, the latter in runnels and flats. The stable vegetation on well drained sites (Column 15) is white spruce - lichen, with black and white spruce - lichen on the imperfectly drained sites. On the poorly drained sites tamarack - black spruce - sedge communities are found. After disturbance by fire white birch - white spruce occupies the well drained sites (Column 16), with white birch - white spruce - willow on the imperfectly drained sites. The poorly drained sites will be initially occupied by a sedge - alder - willow community. Column 17 shows that this mapping unit is common in Land Zone (Region) 1, covering about 25% of the mapped portion of the zone. In Column 18 some information is given on hazards to construction within this mapping unit.

Should a map of the potential vegetation be required, the information on stable vegetation could be applied to the surficial geology and landform units. As the scale of mapping would prohibit the identification of the different drainage classes, certain generalizations would have to be made. Using the above example, all areas of tMvp in Zone (Region) 1 could be mapped as dominantly spruce - lichen with a high proportion of spruce - sedge type. The present vegetation actually occurring on any one area may differ from the potential or stable vegetation due to fire history, cultural practices, availability of seed or other local and temporal influences. Thus the present vegetation could not be mapped from the information given in the legend of the surficial geology and geomorphology maps and is the subject of another project (Forest Man. Inst., in press).

6.9 Surface susceptibility

One of the objectives of this study was to contribute to the development of a terrain sensitivity rating, based on terrain performance following various disturbances. Data on vegetation, active layer and near surface permafrost were made available through the Geological Survey of Canada, and a series of maps were published on terrain sensitivity and performances (Monroe, 1972), based on ice content of the material, steepness of slopes and the performance (bearing strength) of the freshly thawed and unfrozen materials. These maps provide a general rating of terrain sensitivity in which the role and effect of each specific aspect is averaged and often submerged. Thus the relationships of vegetation cover to near-surface permafrost condition were in some cases masked by the presence of icy layers at depth or by other considerations. To emphasize the land-vegetation interface, the surface sensitivity of various land units was determined and a matching series of maps was produced[1], showing the susceptibility of the land to surface damage, based on surface and near-surface land, vegetation, soil and permafrost characteristics.

6.9.1 Definitions

A disturbance will upset the natural environmental balance, often resulting in substantial changes in the land surface, e.g. subsidence, ponding, landslide, etc. For the purpose of this study, susceptibility to surface damage can be defined as the reaction of the surface and subsurface to a disturbance. These reactions may be determined and ranked in order of magnitude of deviation from the undisturbed condition. Those lands which are particularly prone to severe reactions can be identified. In this study the direct effects of disturbances are excluded, e.g. the changes caused by a bulldozer blade or ruts caused by vehicle tracks (Fig. 26). However, if these acts cause the death or compaction of the insulating vegetation and cause subsequent subsidence or sheet erosion, these reactions are evaluated as surface sensitivity.

In addition to terrain characteristics, the magnitude of changes subsequent to disturbances depends on the kind, severity, time-intensity and seasonal timing of the disturbance (Fig. 27). In order to present a realistic evaluation of surface changes following a disturbance, the ratings are based on the effects of one particular disturbance and therefore are valid only for the specified disturbance. This disturbance consists of a single pass with a bulldozer, blade down to cut off the tops of hummocks in the winter or early spring, followed by traffic limited to less than four passes by a seismic crew. This kind of moderate disturbance was widely noted in the study area in seismic lines constructed before more effective land use regulations prohibited the scalping of the ground, generally before 1965.

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[1] Available on Open File by request to the Environmental-Social Program, Northern Pipelines, 151 Slater Street, Ottawa, Ontario K1P 5H3

6.9.2 Susceptibility ratings

The major factors contributing to the ecological and thermal balance of the surface are vegetation, thickness and moisture content of the active layer, ice content of the near-surface permafrost, particle size and mineralogy of the soil material, and the slope to the land surface. Other features, such as snow accumulation, surface and subsurface drainage are dependent on the above features. Regional climate plays a dominant role, but local climates, induced by topography and aspect, must be taken into consideration.

During the survey, data on the thickness or organic mat, active layer, and near-surface permafrost characteristics were collected and related to landforms and vegetation in different Land Regions. Each landform was characterized on this basis, and by relating observations on the consequences of disturbances to these landforms, a rating of surface susceptibility was established. As near-surface conditions are substantially different after fires which destroy the vegetative mat, different ratings were given for stable vegetation and after fire conditions.

The kind of reaction will vary according to near surface conditions. The most common reaction is subsidence; in most cases the land surface is stabilized at this level. In some severe cases, however, thermokarst development takes place, enlarging the originally affected area (Fig. 28). Slopes can magnify the effects of the reaction (Fig. 29). The removal of the vegetative mat by fire or by artificial means can be devastating on steep slopes (Fig. 30). The reaction of land without permafrost in the surface 2 m to disturbance is usually minimal. Thus wet fenlands are rated as not susceptible, although they have highly undesirable engineering qualities (Monroe, 1972).

6.9.3 Maps of surface susceptibility for a moderate disturbance

In nature the terrain is far more complex than a single rating could express it. Hence the ratings shown for various areas are general guides only, based on expectation under conditions that typically occur on the given land-vegetation complex. Variations due to local conditions are unavoidable, due to the small scale of mapping and imperfect knowledge of all factors involved. Caution is therefore urged when interpreting the maps, they should be used only for indicating broad, regional conditions and not in a local context.

Maps were prepared at a scale of 1:250,000 showing surface susceptibility of the study area to a specific, moderate disturbance. The ratings are expressed in descriptive terms from 1 (not susceptible) to 6 (most susceptible), corresponding in severity to terms used by Crampton (in press), with the addition of another rating at the low end of the scale (not susceptible) and at the high end of the scale (extremely susceptible).

Fire is a disturbance which can cause subsidence, lowering of the permafrost table and, on many slopes, a drying of the active layer. Thus an additional disturbance a few years after a fire will have less effect on the surface than in an unburned area. The general guide used in producing the maps, taking the effects of fire into account, is shown in Table 5. However, this guide was not applied mechanically as, before arriving at a rating for an area, each area was examined on aerial photographs and the proportions of various land and vegetation types that determine near-surface permafrost conditions were determined.

7. DISCUSSION

In the study area, where almost all mineral soils are underlain by permafrost, the vegetation-permafrost relationships are not manifested simply by the presence or absence of certain plants. The influence of vegetation on permafrost consists mainly of changes in the thickness of the active layer and the moisture (ice) content of the near-surface permafrost. On a broader scale, the distribution of vegetation and associated active layer conditions on various landforms causes distinctive vegetation patterns. Some of these aspects are discussed briefly below.

7.1 Timber

The timber resources of the study area are limited. Tall trees (over 20 m or 60 ft) of large diameter (38 cm or 15 inches) are restricted to alluvial soils, although some large trees may occur on short, steep slopes in Land Region 3. However, most large trees are over 200 years old, showing that the rate of growth and annual volume increment are low and many are rotten.

It is possible that small sawmills satisfying local needs may utilize the timber. The timber will be of poor quality, as spiral grain and butt rot appear to be common in the trees. Large poles may find ready market in the north as pilings. The use of wood as fuel is steadily declining. It may be concluded the present timber and the potential for future growth in the area is low and contributes little to the economy of the area.

7.2 Vegetation-active layer relationships

The general statement may be made for the treed Land Regions that the thicker the active layer, the taller the trees and, relatively, the denser the forests, provided that the soil drainage is adequate. Dense white birch, white and black spruce stands are widespread on well to imperfectly drained sites after fire when the active layer is relatively thick. Later, as the moss layer is again developed, white birch disappears or is present only as scattered individuals in a low, open spruce-lichen forest. Similarly, in Region 2 and 2m dense stands of white

Table 5. Surface susceptibility of common landforms in glaciated terrain to a moderate disturbance.

Symbol	Landform	Land Region 0		Land Region 1		Land Region 2		Land Region 3	
		Not burned	Burned	Not burned	Burned	Not burned	Burned	Not burned	Burned
f0v	Organic veneer	3*	–	2	–	2	–	2	–
f0	Fenland	4	–	4	–	1	–	1	–
p0	Peatland	4	4	4	4	4	4	4	4
siApk	Alluvial plain with thermokarst; silt	5	–	5–1	–	5–1	–	4–1	–
Lp, Lpk, GLp, GLpk	Lacustrine plain; silt, clay	5–6	5–6	5–6	4	5	4	5	4
Mp, Mv, Mpv, Mm	Ground moraine, slopes $<3^{\circ}$; loamy till	5	4–5	5	3–4	4–5	3	4–5	3
Mp^1, Mv^1, Mvp^1, Md	Ground moraine, slopes 3–8°; loamy till	5–6	5	5–6	4	5	3	5–4	3
Mp^2, Mv^2, Mpv^2	Ground moraine, slopes 8–12°; loamy till	6–5	5	5–6	4	5	3	5–4	3
Mh, Mr	Ridged ground moraine; loamy till, minor gravel	3–5	3–5	3–5	3–4	3–5	3–4	–	–
Gp,Gt,Gc, Gh,Gr	Glaciofluvial plains and ridges; sand, gravel	2	2	1	1	1	1	1	1
Ug, Pg	Glaciated uplands and piedmont; till,minor clay	6–4	5	6–5	4–5	–	–	–	–
Cv, Cx	Colluvial complexes, silt, loam, minor stony sand	6–4	6–4	5–6	5	5	5	5	5

* 1 – not susceptible; 2 – somewhate susceptible; 3 – moderately susceptible; 4 – strongly susceptible; 5 – highly susceptible; 6 – extremely susceptible.

birch often cover south-facing hillsides where the active layer relatively is thick due to greater insolation (Fig. 31). Trembling aspen, when present in Regions 2, 2m and 3, is invariably restricted. to areas where the permafrost table is well below the rooted zone: on steep, south-facing slopes and on well drained sandy, gravelly areas. In general, the shallow rooted species (black and white spruce) are able to grow on thin active layer, although they become smaller and more scattered as the permafrost table rises. Deeper rooted tree species (poplar, aspen, white birch) are restricted to thicker active layer, although a few individual white birch trees may survive in thin active layer.

7.3 Permafrost distribution

All lands are underlain by permafrost, except the wet fenlands in Regions 2, 2m and 3. Shallow coring (to 5 m or 15 ft) in fenlands showed that both the wet peat and the underlying mineral soil are unfrozen in the thermal season. This causes an intricate pattern of frozen and unfrozen ground in peatlands where the change from soft, unfrozen, wet ground to firm, frozen ground occurs abruptly (Fig. 32). Generally, the proportion of unfrozen fens is greater in the south than in the north. In Region 1 and 1m most fenlands are frozen below the depth of about 50 cm at the time of maximum summer thaw, but some are not underlain by permafrost within probing depth (5 m). In Region 0 all fenlands tested were found to be underlain by permafrost.

Permafrost is absent beneath bodies of water which do not freeze to the bottom in the winter. Thus a permafrost - unfrozen material interface exists around fens, ponds and shores of rivers. It is at such interfaces that changes in the extent of permafrost take place. Melting of permafrost causes collapse and sinking of the shores of ponds and fens, while permafrost encroaches on some fens at the margins or on islands. Minor changes at the interface, such as the death or uprooting of a tree, a small change in the water level of a pond or fen may initiate the thermal erosion of a shore. Similarly the establishment of different plants, e.g. cushions of *Sphagnum* on a fen, will serve as a nucleus of permafrost development. Thus very small natural changes can induce large, although local, effects on such a dynamic system. Major changes, such as fire, bulldozing, etc. will certainly have analogous effects on a larger area and accelerated temporal scale. Such disturbances may initiate new permafrost - unfrozen material interfaces which will have profound effects on the finely balanced natural system.

7.4 Lineated slopes and subsurface drainage

When viewed from high in the air, or from aerial photographs, all slopes in the study area show a lineated pattern where narrow lines extend downslope from the ridges (Fig. 33). These lineations are close to one another and suggest drainage lines as they sweep downslope and around mid-slope obstructions. On the ground, however, they are often difficult to locate as there is little topographic expression of the lines and the contrast which is clear from above, becomes diffuse. Vegetation helps to locate them: the vegetation on lineations consists of scattered tamarack and black spruce, with a variable cover of shrubs (*Betula glandulosa*, *Alnus rugosa* or *A. crispa*, *Salix* sp.) and sedges with some mosses. The area between the lineations is usually covered by vegetation characteristic of the imperfectly drained slopes: open stands of black spruce with abundant ground lichen (*Cladina* sp.) and some *Sphagnum* mosses between the earth hummocks. The vegetation suggests that areas between the lineations are better drained than the lineations where water is usually seeping downslope even in late summer. Probings show that permafrost underlines both the wet portion and the better drained portions, but the active layer is thicker on the wet lineations.

Preliminary observations suggest that the wet, somewhat depressed lineations are runoff channels (runnels) which drain surplus water from the slopes. In the spring, when the snow melts the ground is frozen and the snowmelt cannot percolate into the ground hence most of the snowmelt is lost as surface runoff. This runoff is channelled downslope in the runnels which function mainly during periods of surplus surface water. In this area, where the mean annual precipitation is between 380 mm and 250 mm (15 to 10 inches), half of which is in the form of snow, there is little surplus water that would carve out well defined drainage courses on the permafrost slopes. Thus the runnel pattern is interpreted as indicating temporary runoff channels which carry the greatest amount of water in the spring and a lesser seepage flow during the rest of the thermal season as the seasonal frost melts.

The movement of groundwater at depth is limited by permafrost. The presence of open system pingos north of the Porcupine River shows that under certain conditions groundwater flows may take place. A few springs were noted in the mountains, some of which flow through the winter, as interpreted from vast quantities of aufeis around them. These springs may reflect residual orogenic thermal conditions in the mountains.

Water may move more readily in the unfrozen fenlands. Some fens resemble overgrown pools where very little water movement takes place. Other fens, forming the majority, were formed on very slight slopes and transmit seepage water. A number of string fens were noted, especially in Region 2, which resemble rivers of grass (Fig. 34). Although their genesis is not clear, there is evidence that they serve as temporary rivers and catchment basins during spring thaw (Thom, 1972).

7.5 Permafrost-landform relationships

Certain permafrost conditions are closely related to the landform (slope, material) in which they occur, as influenced by vegetation. Distinction should be made between near-surface permafrost and ice accumulations at depth because of the different conditions the represent.

7.5.1 Near-surface permafrost

Near-surface permafrost, extending about 50 cm (20 inches) beneath the permafrost table, is most influenced by temporal and seasonal changes. Fluctuations in the permafrost table due to vegetation changes or long term climatic changes affect this layer. Water migrates into the frozen material due to a thermal gradient (Hoekstra 1966) and accumulates near the permafrost table. As the most troublesome property of permafrost is associated with its moisture content, remarks will be limited to this aspect.

Samples of water saturated, unfrosen, fine grained material were obtained from beneath fens and their moisture content found to be about 40% by weight of dry material, or 45% by volume. Moisture content of frozen, fine grained soil with fine seams of segregated ice averages 105% by weight and 56% by volume, showing that migration of moisture into the frozen soil can take place. In addition, ice accumulation is frequently found immediately below the permafrost table (Fig. 35) where the moisture content exceeds 200% by weight and 65% by volume. In this paper, high ice permafrost is defined as frozen subsoil material in which water must be present in ice form at all times to maintain its natural mechanical properties.

Landforms having good drainage have the least ice content. Such conditions obtain on sloping sandy-gravelly materials and on steep slopes of any materials. Consolidated bedrock seldom contains free ice, but shale and other clastic bedrock may contain as much moisture as fine grained soils.

The iciest near-surface permafrost is generally found in fine grained, but permeable soil materials, such as silt, silt loam or clay loam. The moisture content in these materials is the highest on gentle (up to 10%) slopes and on elevated flats.

7.5.2 Massive ground ice

Massive ground ice occurs as lenses or layers of pure ice or very icy sediments (Fig. 15, 18) often having a moisture content in excess of 95% by volume. In the study area such massive ground ice is associated with lacustrine or glaciolacustrine basins or local pondings. At five locations the massive ground ice was overlain by post-glacial ponded deposits as shown by marl, freshwater mollusk, beaver-chewed wood and peat.

The origin of massive ground ice occurring on the western Arctic coast is explained by the expulsion of ground water during the freezing of saturated sands (Mackay 1970). In addition, the occurrence of segregated ice under lacustrine or ponded deposits suggests a process similar to pingo formation. Closed system pingos are formed as permafrost aggrades into the unfrozen strata under a draining lake (Lundquist 1969).

Some, if not all massive ground ice occurrences in the study area is in areas where pondings have taken place. It is possible that these massive ice occurrences were formed by the same process that forms the pingos, the only difference being that the massive icy beds in the study area do not have the dimensions of the closed system pingos of the Mackenzie delta.

If the above generalization is correct, massive icy beds should be expected to occur in areas which were ponded in post-glacial times. Such areas are plains of glacial and post-glacial lakes, alluvial deposits and bog pools. In two locations, temporary pondings with segregated ice were found in connection with ancient beaver activity. Ponds may have existed in areas which do not now appear to be basins, but were in fact pond basins before the present drainage system was established. It is interesting to note that massive ground ice was not encountered on the mature landscape of the unglaciated portion of Yukon Territory.

7.6 Extrapolation of results

The results presented in this report are directly applicable to the areas studied and to similar areas in the Canadian western arctic and subarctic areas. Exploratory studies in the vegetated eastern arctic regions of the Canadian mainland show that similar relationships to those found in the west exist there, although they differ in detail. The basic relationships between vegetation and permafrost, landform and permafrost, moisture content of permafrost are similar, but different in extent due to differences in soil, bedrock, vegetation and climatic conditions.

8. CONCLUSIONS

8.1 Land Regions

The area was divided into ecologically significant sections, Land Regions, on the basis of vegetation successional trends, permafrost and active layer development on comparable landforms. Vegetation-landform-permafrost relationships are similar within these regions.

8.2 Vegetation-permafrost

Shallow rooted, coniferous trees are able to grow on thin active layer. Thicker active layer (on slopes, floodplains, or after fire) allows the growth of deeper rooted, broadleaved species and the establishment of denser forests of coniferous species.

8.3 Vegetation disturbance

In undisturbed areas,the vegetation, including ground cover, is fully developed. The active layer, its thickness, moisture content and slope of repose is in balance with the vegetation and climate. Disturbance by fire or other means will upset this balance. Thickening of the active layer follows the destruction of the ground cover with possible ponding, subsidence or downslope sliding of the surface.

8.4 Organic terrain

Two types of organic terrain occur in the area where the thickness of peat exceeds 50 cm (20 inches): bogs and fens. Bogs, occurring as peat plateaus, palsas or peat polygons, are always perennially frozen 30 to 50 cm (13 to 20 inches) beneath the surface. Fens are unfrozen in summer, except in the most northerly regions.

8.5 Runnel pattern

All slopes in the study area show downslope lineations of wet seepage channels, accented by the vegetation cover. These runnels act as seasonal runoff channels, operating mainly in the spring when the snowmelt cannot percolate into the ground and is drained by the runnels. Some seepage flow continues during the summer.

8.6 Subsurface drainage

In this area, which is almost completely underlain by permafrost, the only subsurface drainage takes place in the unfrozen fens. Water movement is by slow seepage during the summer, but during spring runoff some fens carry increased volumes of water on the surface.

8.7 Moisture content of permafrost

The moisture content of permafrost varies with materials, slope, and depth within Land Regions. Slope and depth being equal, organic materials and silty soils have the highest moisture content, and sands have the least. Fine grained soils usually contain more moisture in the permafrost near the surface on flat or gently sloping locations.

8.8 Massive ground ice

Massive ground ice and icy sediments occur with increasing frequency from south to north. Most occurrences are restricted to areas which were subject to post-glacial ponding, but were later drained. This suggests that the ice bodies were formed by a process similar to pingo formation.

8.9 Earth hummocks

Earth hummocks are very widely distributed in all but the most southerly Land Region. Cross-sections show that they were formed by soil displacement through cryostatic pressure. In the northern regions this process is still active, as shown by leaning trees on hummocks.

8.10 Landform maps

Surficial geology and geomorphology maps were used to give areal expression to vegetation-landform relationships. The map units, as mapped by the Geological Survey of Canada, were characterized with regard to soil moisture, active layer, earth hummock development, stable vegetation types and vegetation after disturbance.

8.11 Surface susceptibility

The reaction of surface to disturbance varies with materials, slopes and vegetation in each Land Region. A generalized map shows areas of different surface susceptibility to a particular moderately light disturbance, indicating that the proportion of susceptible land is greater in the north than in the south.

9. IMPLICATIONS AND RECOMMENDATIONS

9.1 Matters relating to pipeline construction

9.1.1 Vegetative mat

The role of an insulating organic mat over permafrost is well known and cannot be overemphasized. The removal, severe compaction or rutting of the organic mat will expose the upper part of the permafrost to heat and melting will occur. It is therefore recommended that on areas underlain by permafrost

1. *no vehicular traffic, wheeled or tracked, be allowed on thawed natural surface, and*

2. *all roadbed or berm construction must proceed by dumping fill on undisturbed surface, and*

3. *insulating cover, natural or artificial, be restored on natural surfaces if this cover is destroyed or damaged for any reason, and*

4. *no bulldozing, ditching and scalping of surface be allowed unless the insulating cover is restored before the surface is exposed to melting. Well drained granular or bedrock materials serving as source of fill may be exempted.*

9.1.2 Ponding

The thermal qualities of water are different from soil materials, frozen or unfrozen. A body of water will transmit heat and if allowed to accumulate on the surface, will cause melting of the permafrost. If any artificial structure hinders the natural drainage, ponding will result, leading to subsequent thermokarst development through subsidence on icy materials. It is therefore recommended that on areas underlain by permafrost

1. *no structure must disrupt natural drainage and cause prolonged ponding, and*

2. *all gravel pits, quarries and borrow pits must be provided with drainage and the slopes be stabilized when no longer required.*

9.1.3 Pipeline in discontinuous permafrost

Discontinuous permafrost means the horizontal alternation of frozen and unfrozen subsoil. Excavating of high ice material in a frozen area in the discontinuous permafrost zone would have the same effect as in the continuous zone. It is therefore recommended that

1. *similar construction techniques be applied to perennially frozen ground regardless of its geographical occurrence.*

Placing a cold (below 0°C) pipeline into an unfrozen wetland (fen) will cause the freezing of the material in its immediate vicinity. Moisture will migrate into this frozen peat as it migrates into palsas due to a thermal gradient. Hence two effects are foreseen: 1. a cold pipeline laid across a fen will become an impermeable dam, interfering with drainage through the fen and cause ponding, and 2. the cold line, with a mantle of frozen peat whose volume is greatly increased by attracted and frozen water will be forced upward by ice accumulation, much as natural palsas are, causing stress on the pipeline at the permafrost-unfrozen material interface. It is therefore recommended that

2. *special attention be paid to placing cold pipelines into unfrozen, wet material to avoid the creation of icy dams and rupturing of the line by artificial palsa formation.*

9.1.4 Terrain sensitivity and susceptibility maps

Certain land characteristics which make the terrain particularly subject to damage were identified by the Geological Survey of Canada, and features which make the terrain susceptible to surface damage were identified in this report. Generalized maps were produced in both instances showing large blocks of areas of various sensitivity. It is recommended that

1. *areas that are shown on maps as highly susceptible to terrain and surface damage be avoided, and, if this is not possible, be treated with special care, and*

2. *the sensitivity maps be used judiciously and in no case be taken as the final word: combination of local circumstances may create a more difficult situation than is indicated for the areas as a whole.*

9.2 Matters related to judgment

9.2.1 Prevention vs. repair

It is our contention that it is far easier to control a potentially difficult situation by preventive measures than trying to repair the damage. Engineering expertise, although continually increasing, may not be available to economically solve a difficult situation, while knowledge to prevent such situations is available. It must be emphasized that environmental considerations are advanced not only to protect the environment for its own sake, but mainly because it is a good engineering practice.

9.2.2 Build for worst condition

In the sub-arctic regions of Canada the terrain is variable, as conditions can change in very short distances. This is especially true in the discontinuous permafrost area where frozen and unfrozen ground may alternate within a few feet. While technology may exist to build pipelines or other structures to suit the terrain, it is a fact of life that construction methods cannot be as flexible as the terrain demands. Thus a decision must be made in marginal areas on the construction method: whether to bury a hot pipeline or place it on a berm; whether to permit summer operations or restrict it to winter; whether to allow vehicle traffic on natural surfaces in the summer or not. In our opinion the decision must be governed by the most severe condition within a construction section.

9.2.3 Where to apply special construction methods

The question where to apply special construction methods suitable to permafrost conditions and where southern methods can be applied will have to be decided. Proceeding from the north southward, the first unfrozen patches are in very wet fens. Further south, the well drained and granular materials become frost-free. Still further south, the southwest to southeast facing slopes will have no permafrost. The last mineral soils to contain permafrost are the poorly drained flats and lower slopes. Organic soils may contain patches of permafrost far beyond the limit of permafrost in mineral soils.

The above sequence implies that mineral soils having permafrost in the south are likely to be high in ice content, as the occur in poorly drained topographic positions. It is recommended therefore that

> *special construction methods adapted to permafrost terrain be applied as far south as permafrost occurs in mineral soils*

9.2.4. Enforcement

Some environmental damage can be prevented by decisions made around a table, but in the final analysis it is the person in the bulldozer's seat who makes the operation a success or disaster. It is imperative that all field personnel be instructed on how to operate in the north and the reasons why. Stiff fines by the companies, suspensions of operations by government agencies must be applied to violators, but the most effective weapon is knowledge. This knowledge must be passed on to enforcement, supervisory, construction and maintenance personnel at all levels.

10. NEEDS FOR FURTHER STUDY

10.1 Problem areas

During the reconnaissance survey certain problem areas were identified but time did not permit to study them in any satisfactory detail. The significance of these possible problems could not be fully assessed, but it is felt that more knowledge is necessary to evaluate their effects on pipeline construction and maintenance and to initiate preventive measures.

10.1.1 Frost heaving

Observations indicate that a great deal of mixing and churning has taken place in the active layer, and that this is related to ice content of near-surface permafrost. It is not known whether such soil movements are active at the present, or they are fossil features in certain parts of the study area. Conditions favourable to cryoturbation, and the timing of cryoturbation should be investigated to permit the development of effective protective measures.

10.1.2 Mechanical properties of soils

Incomplete analyses suggest that many thawed soils in the study area are lacking cohesive strength, possibly because of mineralogical and chemical properties. Some chemical properties may be due to soil forming processes in cold climates. This aspect should be investigated in relation to soil stability and bearing capacity.

10.1.3 Subsurface drainage

Snowmelt and precipitation during the thermal season cannot percolate through the soil, although some water may be incorporated into the permafrost near the surface. The present knowledge on the drainage and water seepage in the active layer is very incomplete. The amounts of water, the possible development of subsurface drainage channels, the timing of seepage after a rain and the release of water from the thickening active layer should be investigated. Such knowledge is essential to prevent the blocking of drainage by berms, roads, etc. that would cause ponding and thermal erosion.

10.1.4 Thermodynamics of peatlands

In the discontinuous permafrost zone all peatlands contain unfrozen "windows" of peat. On the same bog the permafrost may be aggrading or degrading. The thermodynamics of this process is not known, but such knowledge is essential if the introduction of cold pipelines into unfrozen peat, or hot pipeline into frozen peat is considered.

10.2 Proposal for additional studies

It is proposed that the process of cryoturbation be studied at four selected locations (Wrigley, Sans Sault Rapids, Fort McPherson, Inuvik) in relation to vegetation cover, fire succession, slope position and soil texture. Chemical, mineralogical and physical parameters of the soil will be determined by intensive sampling. Moisture and temperature conditions in the active layer and near-surface permafrost will be determined. The dating of movements will be obtained by the radiocarbon method and by dendrochronology.

It is further proposed that the thermodynamics of peatlands be studied in relation to the hydrology (frozen and unfrozen), morphology and genesis of different types of peatlands in different climatic zones.

11. REFERENCES

Bird, C. D. 1972. Botanical studies near the Mackenzie River, N.W.T. Manuscript, Dept. Biol., Univ. of Calgary, Calgary, Alberta. 235 p.

Bostock, H. S. 1965. A provisional physiographic map of Canada. Geol. Surv. of Canada, Paper 64-35, 24 p.

Brown, R. J. E. 1970a. Permafrost in Canada. Univ. of Toronto Press, 234 p.

________ 1970b. Occurrence of permafrost on Canadian peatlands. Proc. Third Int. Peat Congr., Quebec, 174-181.

Crampton, C. B. In press. Studies of vegetation, landform and permafrost in the Mackenzie Valley: Landscape survey in the upper and central Mackenzie River Valley. Environmental-Social Program, Northern Pipelines. 83 p. and maps.

Forest Management Institute. In press. Vegetation types of the Mackenzie River basin. Canadian Forestry Service, Environment Canada, Ottawa. 90 p. and appendices.

Frye, T. C. and L. Clark. 1937. Hepatica of North America. Univ. of Wash., Seattle, Wash.

Grout, A. J. 1936. Moss flora of North America. Publ. by author, Newfane, Vt.

Hills, G. A. 1960. Regional Site Research. Forestry Chron., 36:401-423.

Hoekstra, P. 1966. Moisture movement in soils under temperature gradients withtthe cold-side temperature below freezing. Water Resources Res., 2:241-250.

Hughes, O. L. 1972. Surficial geology of northern Yukon Territory and northwestern District of Mackenzie, Northwest Territories. Geol. Surv. of Canada, Paper 69-36, 11 p.

Hulten, E. 1968. Flora of Alaska and neighboring territories. Stanford Univ. Press, Stanford, Cal.

Isoviita, P. 1966. Studies on *Sphagnum* L. 1. Nomenclatural revision of European Taxa. Ann. Bot. Fenn. 3:199-264.

Lacate, D. S. 1969. Guidelines for biophysical land classification. Dept. Fisheries and Forestry, Canadian Forestry Service., Publ. No. 1264, 61 p.

Lindquist, J. 1969. Earth and ice mounds: a terminological discussion. In: The periglacial environment. T. L. Péwé, Ed., McGill-Queen's Univ. Press, 203-215.

Mackay, J. R. 1970. The origin of massive icy beds in permafrost, Western Arctic Coast, Canada. Can. J. Earth Sci., 8:397-422.

Monroe, R. L. 1972. Terrain Classification and sensitivity maps. Geol. Surv. of Canada, Open File 121, Preliminary maps 106M, 106N, 106O, 106K, 106J, 106I.

National Soil Survey Committee. 1970. The system of soil classification for Canada. Canada Dept. of Agric. 249 p.

Radforth, N. W. 1952. A suggested classification of muskeg for the engineer. Engineering Journal, 35:1199-1210.

Rampton, V. N. and J. R. Mackay. 1971. Massive ice and icy sediments throughout the Tuktoyaktuk Peninsula, Richards Island and nearby areas, District of Mackenzie. Geol. Surv. of Canada, Paper 71-21, 16 p.

Roberts-Pichette, P. 1972. Annotated bibliography of permafrost-vegetation-wildlife-landform relationships. Can. Dept. Envir., Forest Manag. Inst., Info. Rept. FMR-X-43, 350 p.

Strang, R. M. In press. Succession in unburned subarctic woodlands. Can. J. Forest Sci.

________ In press. Studies on vegetation, landform and permafrost in the Mackenzie Valley: The effects of disturbances; some case histories. Environmental-Social Program, Northern Pipelines. 37 p. and appendices.

Thom, B. G. 1972. The role of spring thaw in string bog genesis. Arctic, 25:236-239.

Tyrtikov, A. P. 1959. Perennially frozen ground and vegetation. Principles of geocryology (permafrost studies), Part I, General geocryology, Chapter XII. Acad. Sci. U.S.S.R. Moscow 1959 p. 399-421. (Translation by Nat. Res. Council of Canada).

Zoltai, S. C. and C. Tarnocai. 1971. Properties of a wooded palsa in northern Manitoba. Arctic and Alpine Res., 3:115-129.

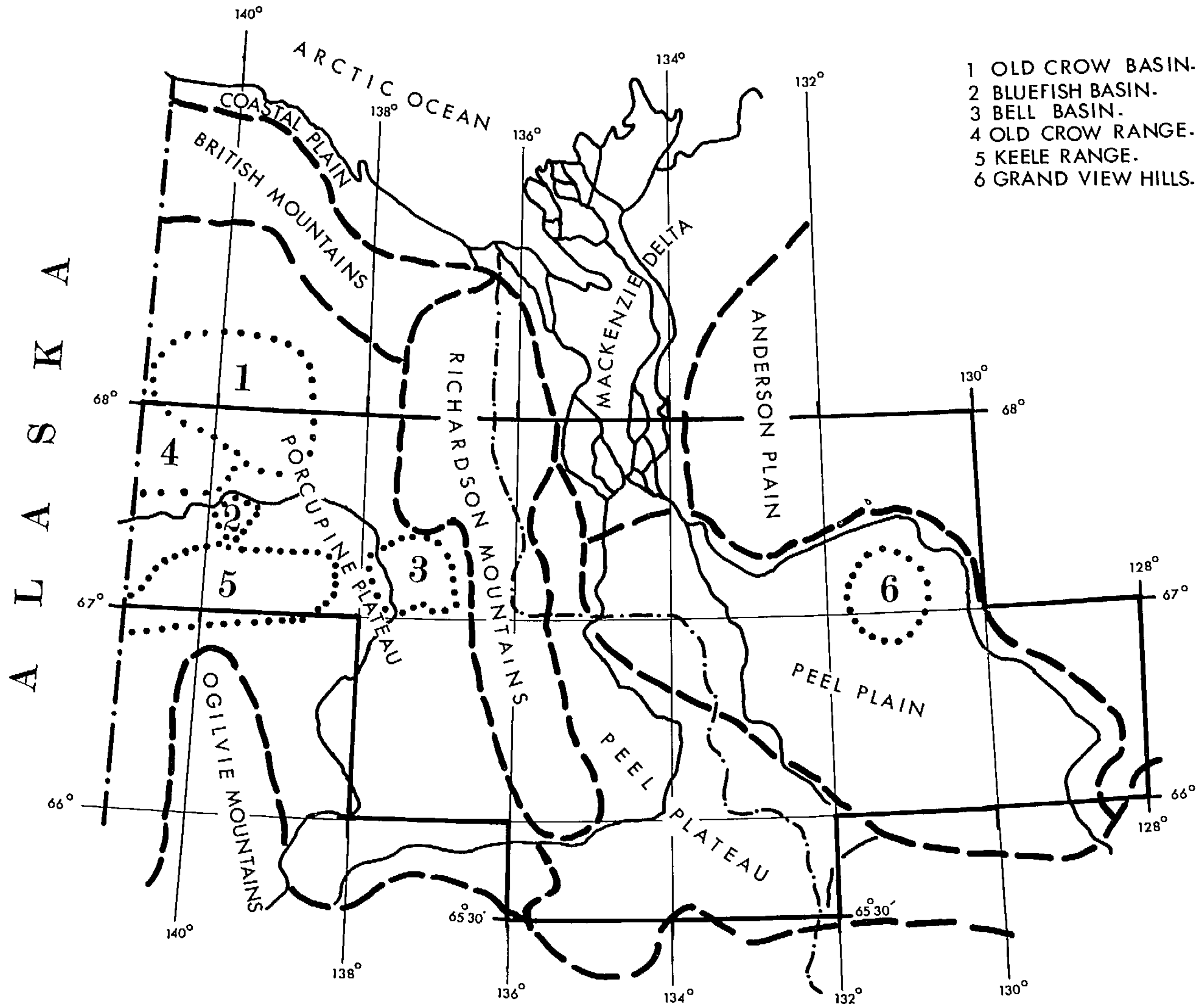


Figure 1. Physiographic divisions of northern Yukon Territory and the northern Mackenzie River valley. Modified after Bostock (1964).

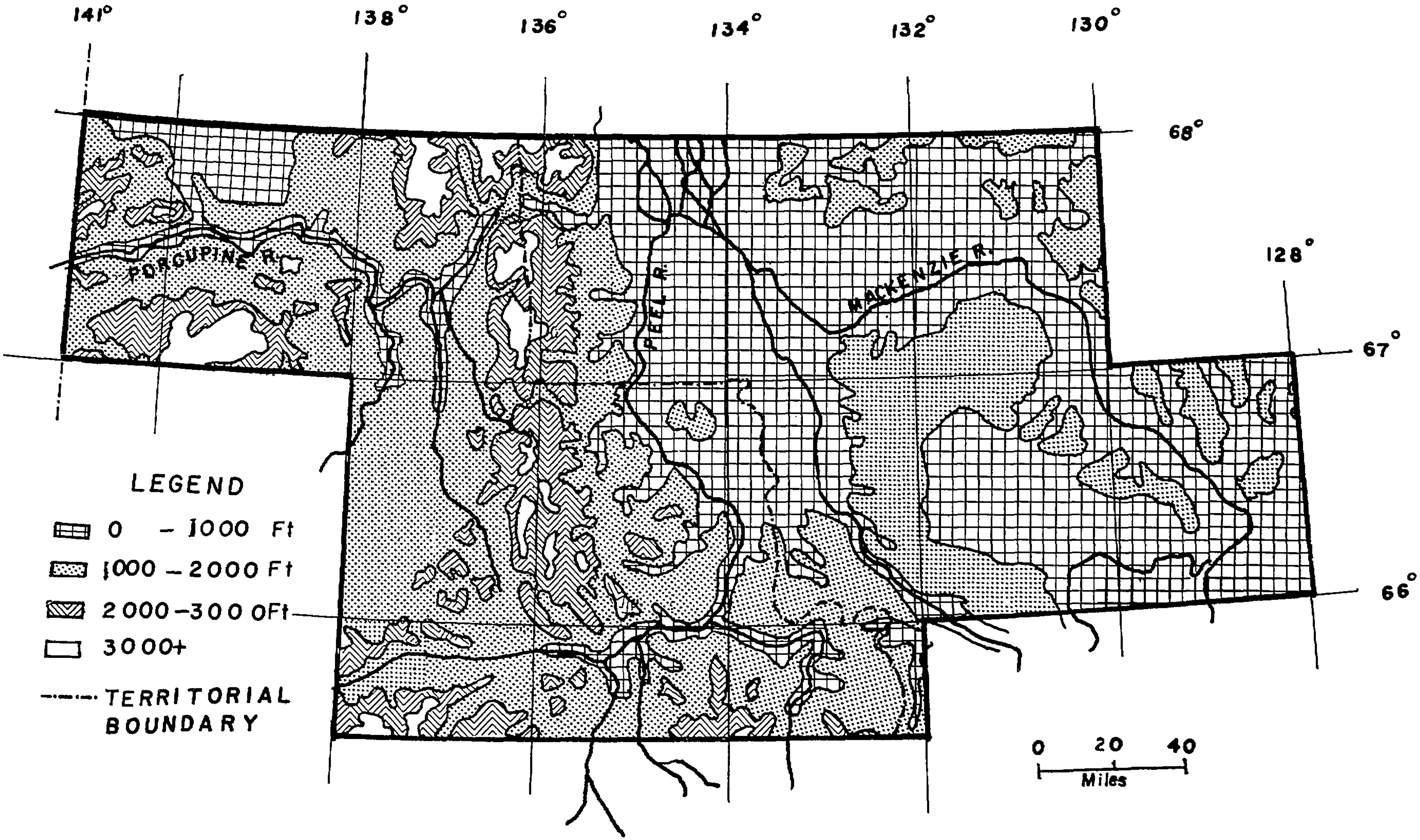


Figure 2. Relief map of the study area.

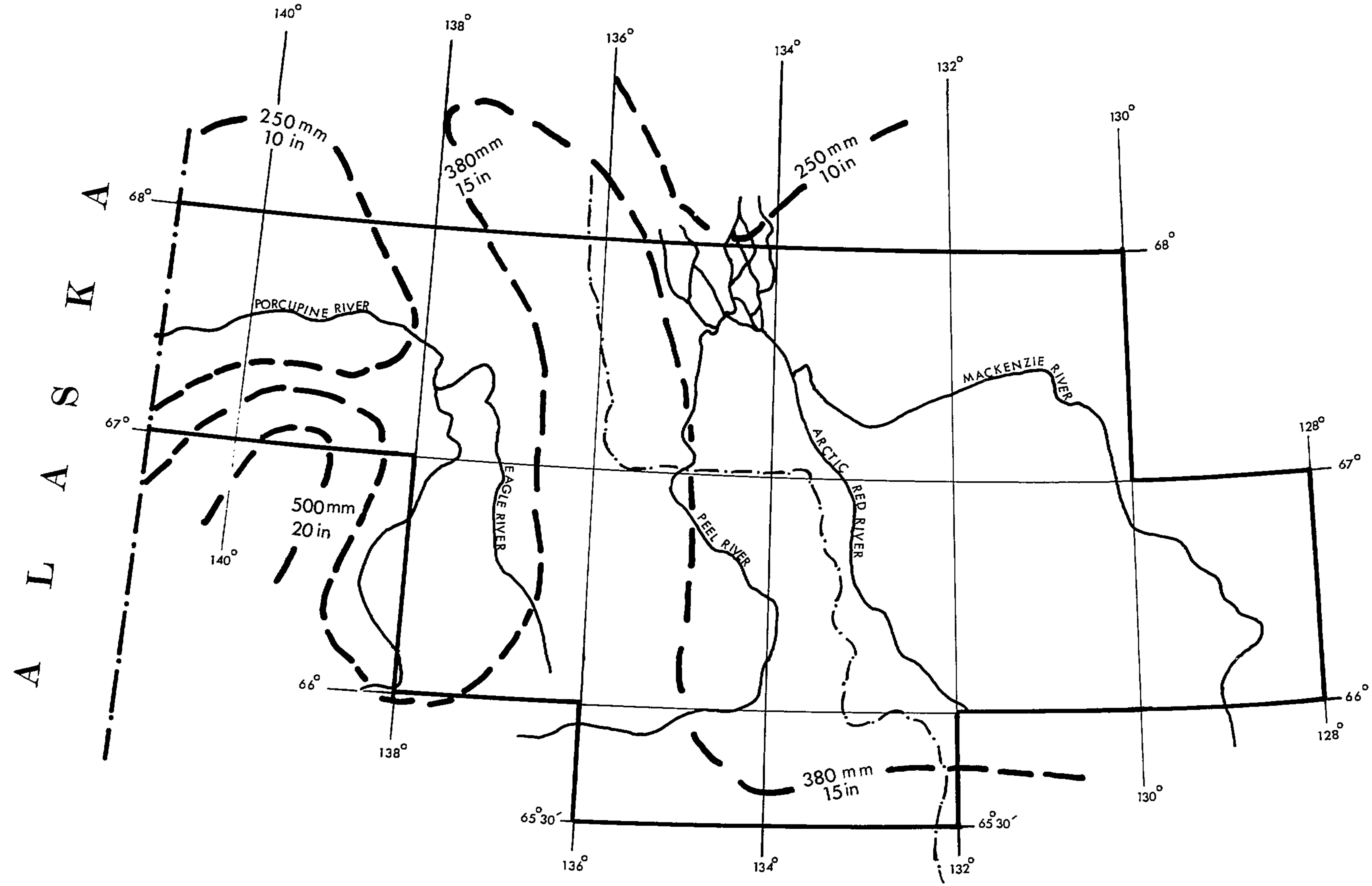


Figure 3. Distribution of mean annual precipitation. (From: Mackenzie Valley - Beaufort Sea Climatological Study; Environment Canada, in press).

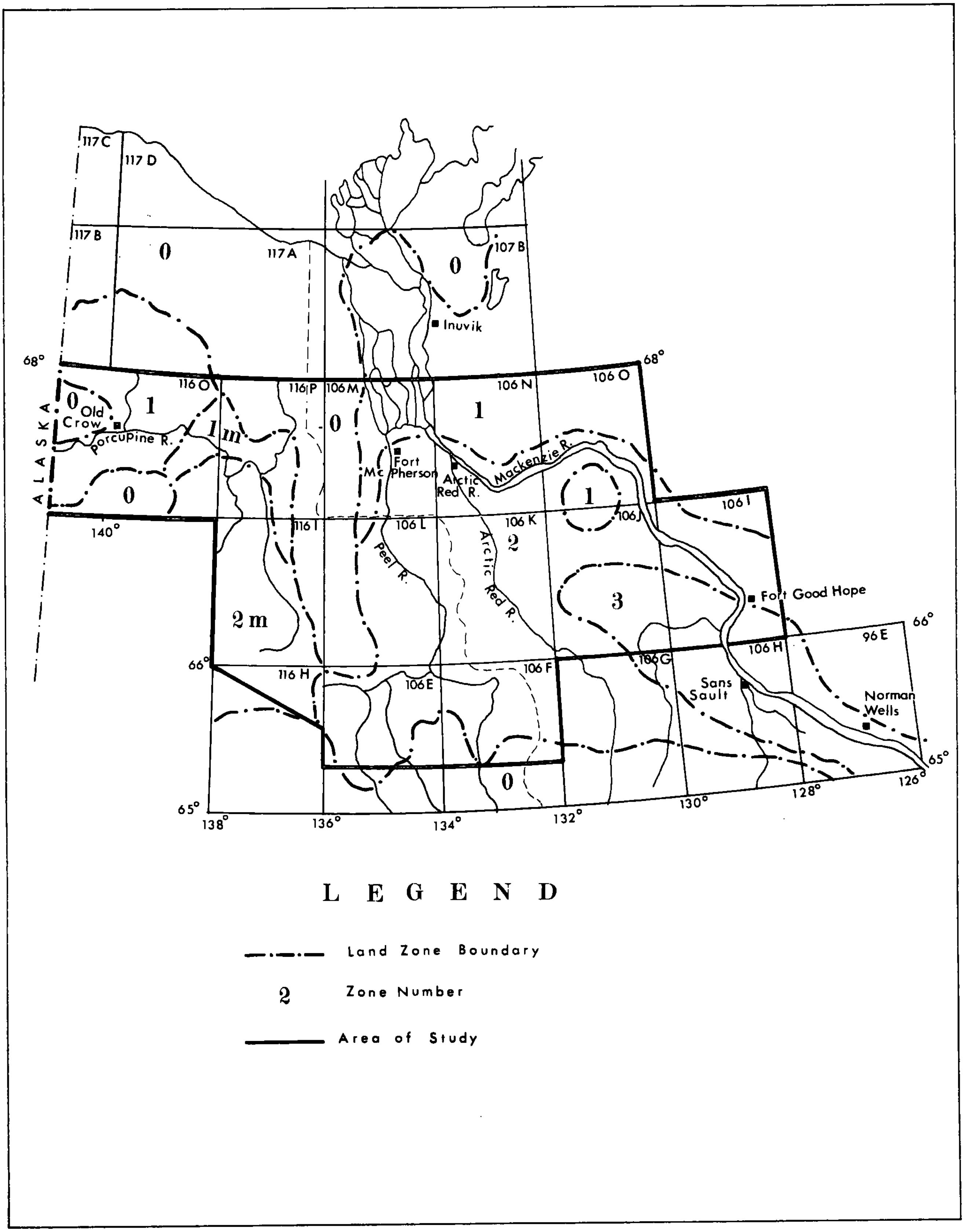


Figure 4. Land Regions in the study area.

Figure 5. Aerial view of hummocky tussock tundra in Land Region 0. Location: Lat. 67°17'N and Long. 135°59'W

Figure 6. Mature white spruce - black spruce - lichen forest in Land Region 1. Location: Lat. 66°48'N and Long. 128°30'W.

Figure 7. Mature black spruce - tussock forest in Land Region 1m. Location: Lat. 67°10'N and Long. 136°23'W.

Figure 8. Mature black spruce - lichen forest in Land Region 2. Location: Lat. 67°11'N and Long. 130°15'W

Figure 9. Mature black spruce - sedge tussock forest in Land Region 2m. Location: Lat. 66°25'N and Long. 136°51'W

Figure 10. Mature black spruce - lichen forest in Land Region 3. Location: Lat. 65°39'N and Long. 128°50'W.

Figure 11. Vegetation on a floodplain: willow - alder in the foreground, balsam poplar on higher level, white spruce on the highest terrace in the valley. Location: Snake River, Lat. 65°58′N and Long. 133°08′W.

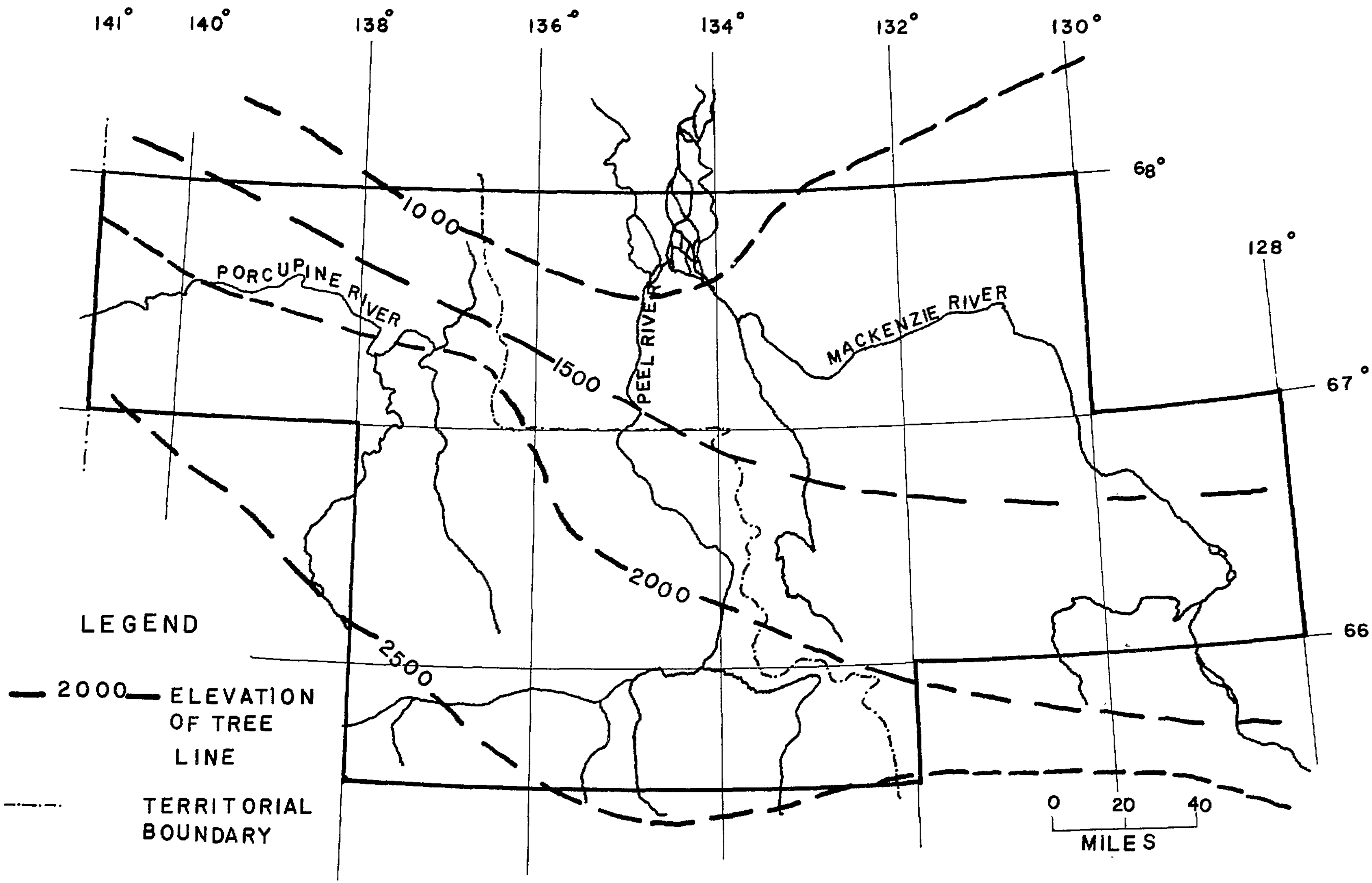


Figure 12. Iso-lines connecting elevations at which the alpine tree line occurs in the study area.

Figure 13. Vegetation pattern caused by fire in a black spruce - sedge tussock forest. Note pseudo-tundra in foreground. Location: Lat. 67°04'N and Long. 136°33'W

Figure 14. Landslide scars on recently burned steep slopes. Location: Lat. 66°32'N and Long. 134°41'W

Figure 15. Flow slide with massive ground ice, activated after fire. Location: Lat. 65°49'N and Long. 135°08'W

Figure 16. Cross section of a hummock. Note cryoturbated organic material in soil above permafrost table. Location: 65°55'N and Long. 129°25'W

Figure 17. Section through an earth hummock to the permafrost table. Note the thin organic mat with roots on top of hummock; thick (15 cm.) organic mat between hummocks; depression of permafrost table under the hummock, July 16, 1971. Location: Lat. 67°37'N and Long. 11°15'W

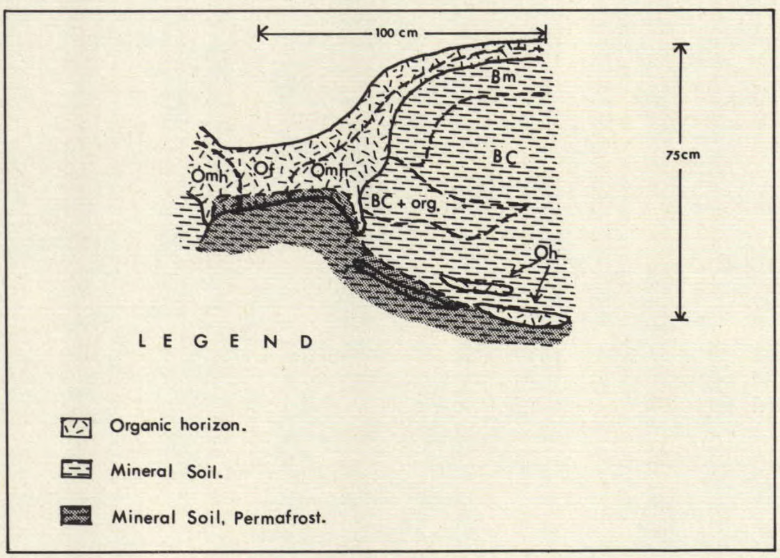


Figure 17a. Cross section of a hummock in imperfectly drained clay loam till in Land Region 1.

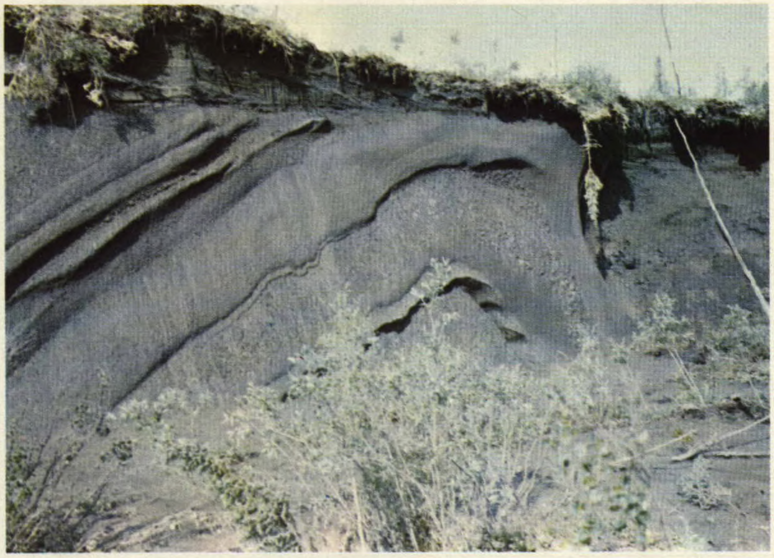


Figure 18. Icy lacustrine sediments in the head wall of a flow slide. Location: Lat. 67·05′N and Long. 131·12′W

Figure 19. White spruce leaning over a thermokarst pond on the Mackenzie Delta. Location: Lat. 67·51′N and Long. 134·34′W

Figure 20. Peat plateaus raised above the nearby unfrozen fens. The diameter of the small peat plateau at left center is about 120 m. (350 ft.) Location: Lat. 66°35'N and Long. 133°40'W

Figure 21. Palsa, raised 3.5 m. (14 ft.) above nearby fen. Location: Lat. 65°38'N and Long. 128°55'N

Figure 22. Polygons in peatland, Land Region 1. Location: Lat. 67°39'N and Long. 133°40'W

Figure 23. String fen with small peat plateaus at nodes. Location: Lat. 67°32′N and Long. 134°12′W

Figure 24. Ice wedge in peat over alluvium. Location: Lat. 66°58′N and Long. 137°33′W

Figure 25. Filled-in lake with concentric peat ridges. Location: Lat. 67°15′N and Long. 137°10′W

Figure 26. Damage to active layer in peat caused by wheeled traffic in summer.
Location: Lat. 66°21'N and Long. 137°32'W

Figure 27. Different reaction to disturbances, according to the season, elapsed time and subsequent intensity of use. No reaction to recent disturbance in foreground, adjacent water-filled and partially over grown track shows severe reaction. Location: Lat. 67°27'N and Long. 134°05'W

Figure 28. Old seismic line in silt with about 1 m. subsidence. Note trees leaning toward line, indicating lateral spread of thermokarst conditions. Location: Lat. 65°52'N and Long. 136°55'W

Figure 29. Old flow slide scar, flow slide partially reactivated by seismic line too close to the escarpment. Note that little reaction is shown elsewhere on the line. Location: Lat. 67°16'N and Long. 136°49'W

Figure 30. Land slip following fire. Note characteristic accumulation of trees at base, some still upright. Location: Hume River, Lat. 66°02'N and Long. 129°34'W

Figure 31. White birch on well drained southwest facing slopes; stunted black spruce on northeast slopes. Location: 66°33'N and Long. 134°21'W

Figure 32. Peat plateaus (unburned on left, burned on right) separated by unfrozen string fen channel. Location: Lat. 66°56'N and Long. 133°40'W

Figure 33. Runnel pattern on till slope. Location: Lat. 66°48'N and Long. 134°30'W

Figure 34. A 'river of grass': seepage channel overgrown by sedge. Location: Lat. 67°47'N and Long. 134°00'W

Figure 35. Digging highly icy near-surface permafrost with an electrically powered jackhammer. Location: Lat. 65°47'N and 134°56'W

12. APPENDICES

12.1 Scientific names of plants

The following is a list of scientific names of plants appearing in the main body of the text. The nomenclature is as follows: flowering plants after Hultén (1968); Sphagnum after Isoviita (1966); mosses after Grout (1939); Hepactica after Frye and Clark (1937); lichens after Bird (1972).

Scientific name	Common name	Abbreviation
Picea glauca (Moench) Voss	White spruce	wS
Picea mariana (Mill.) Britt. Sterns & Pogg.	Black spruce	bS
Larix laricina (Du Roi) K. Koch	Tamarack	tL
Populus balsamifera L.	Balsam poplar	bPo
Populus tremuloides Michx.	Trembling aspen	tA
Betula papyrifera Marsh. ssp. *humilis* (Regel) Hult.	White birch	wB
Betula glandulosa Michx.	Shrub birch	Bi
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung	Alder	
Alnus crispa (Ait.) Pursh ssp. *crispa*	Green alder	
Sphagnum fuscum (Schimp.) Klinggr.		
Sphagnum rubellum Wils.		
Polytrichum juniperinum Hedw.		
Ceratodon purpureus (Hedw.) Brid.		
Marchantia polymorpha L.		
Cetraria cucullata (Bell) Ach.		
Cladina rangiferina (L.) Harm.		
Eriophorum brachyantherum Trautv. & Mey.	Cottongrass	
Eriophorum angustifolium Honck. ssp. *subarcticum* (Vassilijev) Hult.	Cottongrass	
Carex Bigelowii Torr.	Sedge	
Petasites palmatus (Ait.) Gray	Coltsfoot	
Senecio congestus (R.Br.) DC.		

12.2 Common vegetation types

The floristic composition of some common vegetation types are given on the following pages.

The information is presented by various layers: tree layer (higher than 2 m), shrub layer (2 m to 0.3 m), dwarf shrub layer (lower than 0.3 m), herb-grass layer, moss-lichen layer and bare ground. The estimated cover by the various layers is expressed as percentages. The cover of individual species is shown as percentage of the appropriate vegetation layer.

Location: $66^{o}32'$ & $136^{o}30'$ (Land Region 0)
Vegetation type: Low shrub tundra
Landform: Sandstone ridge, well drained. Elevation 2000 ft., tree line at 2000 ft.

Dwarf shrub layer 40%
- 30 *Betula glandulosa*
- 30 *Arctostaphylos rubra*
- 10 *Vaccinium vitis-idaea* ssp. *minus*
- 5 *V. uliginosum* ssp. *alpinum*
- 20 *Salix* sp.
- 5 *Empetrum nigrum* ssp. *hermaphroditum*

Lichen-moss layer 20%
- 30 *Cetraria nivalis*
- 30 *Alectora* sp.
- 30 *Polytrichum juniperinum*
- 10 *Cetraria cucullata*

Herb-grass layer 10%
- 60 *Carex* sp.
- 40 *Pedicularis kanei* ssp. *kanei*

Bare 40%

Location: $66^{o}59'$ & $128^{o}30'$ (Land Region 1)
Vegetation type: wS-bS-lichen
Landform: Silty loam till on 4% E slope, imperfectly drained.

Tree layer 10%
95 *Picea glauca* (15 ft. high)
3 *Picea mariana*
2 *Larix laricina*

Shrub layer 5%
90 *Rhododendron lapponicum*
10 *Salix* sp.

Dwarf shrub layer 20%
40 *Vaccinium uliginosum* ssp. *alpinum*
20 *Arctostaphylos rubra*
20 *Vaccinium vitis-idaea* ssp. *minus*
10 *Ledum palustre* ssp. *decumbens*
10 *Dryas integrifolia*

Herb-grass layer 2%
100 *Eriophorum* sp.

Moss-lichen layer 90%
25 *Cladina arbuscula*
15 *C. alpestris*
15 *C. mitis*
15 *Cladonia amaurocraea*
10 *Cladina rangiferina*
10 *Cetraria nivalis*
5 *Aulacomnium* sp.
5 *Dicranum* sp.

Location: $67^{o}30'$ & $139^{o}46'$ (Land Region 1)
Vegetation type: Spruce-moss
Landform: 10% S slope on lacustrine, calcareous loam, well drained.

Tree layer 65%
100 *Picea glauca* (35-45 ft. tall)

Shrub layer 40%
100 *Salix* sp.

Dwarf shrub layer 40%
65 *Arctostaphylos rubrum*
30 *Potentilla fruticosa*
5 *Vaccinium vitis-idaea* ssp. *minus*

Herb layer 25%
80 *Lupinus arcticus*
15 *Equisetum squarrosum*
5 *Arnica* sp.

Moss layer 40%
40 *Hypnum crista-castrensis*
30 *Dicranum* sp.
20 *Pluerozium schreberi*
10 *Ptilidium ciliare*

Bare 30%

Location: $67^{\circ}08'$ & $136^{\circ}27'$ (Land Region 1m)
Vegetation type: Black spruce-tussock
Landform: 5% W slope on long pediment, silty clay. Somewhat imperfectly drained. Abour 200 ft. below tree line.

Tree layer 15%
100 *Picea mariana*(4-8 ft tall)

Shrub layer 2%
100 *Betula glandulosa*

Dwarf shrub layer 25%
55 *Ledum palustre* ssp. *decumbens*
15 *Rubus chamaemorus*
15 *Chamaedaphne calyculata*
10 *Vaccinium vitis-idaea* ssp. *minus*
5 *Oxycoccus microcarpus*

Lichen-moss layer 60%
5 *Cladonia cornuta*
5 *Cladina mitis*
5 *C. alpestris*
5 *C. rangiferina*
10 *Cetraria cucullata*
40 *Sphagnum fuscum*
30 *S. warnstorifianum*

Herb-grass layer 40%
50 *Eriophorum brachyantherum*
50 *Carex* cf. *Bigelowii*

Location: $65^{o}47'$ & $134^{o}38'$ (Land Region 2)
Vegetation type: Spruce-lichen
Landform: Silty loam till on 3% W slope, imperfectly drained.

Tree layer 20%
100 *Picea mariana* (10-15 ft. high)

Shrub layer 35%
40 *Betula glandulosa*
60 *Picea mariana*

Dwarf shrub layer 30%
30 *Vaccinium uliginosum* ssp. *alpinum*
20 *V. vitis-idaea* ssp.*minus*
50 *Ledum palustre* ssp. *decumbens*

Moss-lichen layer 25%
30 *Cladonia amaurocraea*
20 *Cladina alpestris*
30 *Sphagnum* sp.
20 *Dicrenum* sp.

Grass layer 20%
100 *Carex Bigelowii*

Location: 65°45' & 135°22' (Land Region 2)
Vegetation type: Lichen-heath
Landform: Peat plateau, imperfectly drained organic soil.

Tree layer 5%
- 90 *Picea mariana* (10-15 ft. high)
- 10 *Larix laricina*

Dwarf shrub layer 30%
- 60 *Ledum palustre* ssp. *decumbens*
- 20 *Betula glandulosa*
- 20 *Vaccinium vitis-idaea* ssp. *minus*

Lichen-moss layer 65%
- 80 *Cladina alpestris*
- 20 *C. arbuscula*

Location: 67°20' & 134°51' (Land Region 2)
Vegetation type: White birch-spruce (fire origin)
Landform: Silty clay loamy till on 4% N slope, well to imperfectly drained.

Tree layer 10%
70 *Betula papyrifera* ssp. *humilis* (35 ft. high)
30 *Picea mariana* (25 ft. high)

Shrub layer 7%
60 *Alnus crispa* ssp. *crispa*
40 *Betula glandulosa*

Dwarf shrub layer 50%
30 *Ledum palustre* ssp. *decumbens*
60 *Vaccinium vitis-idaea* ssp. *minus*
10 *Lycopodium annotinum* ssp. *pungens*

Moss-lichen layer 35%
80 *Sphagnum fuscum*
20 *Dicranum* sp.

Location: $65^{o}31'$ & $128^{o}26'$ (Land Region 3)
Vegetation type: Spruce-lichen
Landform: 3% E slope on lucustrine silty clay loam, imperfectly drained.

Tree layer 55%
95 *Picea mariana* (20-25 ft. high)
5 *Betula papryifera*

Shrub layer 20%
60 *Alnus crispa*
20 *Salix* sp.
20 *Ledum palustre* ssp. *groenlandicum*

Dwarf shrub layer 10%
70 *Vaccinium uliginosum* ssp. *alpinum*
30 *V. vitis-idaea* ssp. *minus*

Lichen-moss layer 85%
35 *Cladina alpestris*
10 *C. mitis*
45 *Hypnum crista-castrensis*
10 *Sphagnum rubellum*

Herb layer 5%
50 *Saussurea angustifolia*
50 *Pyrola secunda* ssp. *obtusata*

12.3 Representative soils

12.3.1 Grandview

Location: 67°23' N, 131°5' W (N side of Grandview Hills - Map 106 O)

Land Region: 2 Map Unit: G_c

Topography: Channeled undulating upland with few undrained depressions

Elevation: 150 m (500 feet)

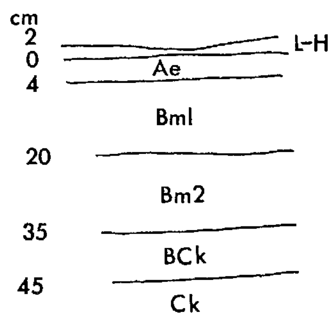
Slope: 0 to 20%

Vegetation: Open stand of *Picea glauca* and *Betula papyrifera* with scattered *Alnus crispa, Salix* sp. and *Vaccinium vitis-idaea*; discontinuous ground cover of feather mosses and lichens.

Parent Material: Glaciofluvial sands and gravels.

Drainage: Well drained.

Microrelief: Not present.



Horizon	Depth (cm.)	Description
L-H	2-0	Dark gray (10YR 3/1 d) loose organic material; discontinuous; abrupt, smooth boundary; 0-3 cm thick.
Ae	0-4	Pinkish gray (5YR 6/2 d) coarse sandy loam; single grained; loose, friable; plentiful fine random, plentiful medium horizontal roots; medium acid; abrupt, smooth boundary.
Bml	4-20	Yellowish red (5YR 4/8 m) sandy loam to loamy sand; single grained; friable; plentiful medium, few fine roots; medium acid; gradual, wavy boundary.
Bm2	20-35	Strong brown (10YR - 7.5YR 5/6 m) loamy sand; single grained; loose; few fine vertical roots; neutral; clear, smooth boundary.

Horizon	Depth (cm)	Description
BCk	35-45	Dark brown (7.5YR 3/2 m) gravelly sand; single grained; friable; plentiful fine roots and root remains; moderately effervescent; clear, smooth boundary.
Ck.	45-55+	Grayish brown fine gravel; single grained moderately to strongly effervescent.

	Particle size distr. of <2 mm fraction						
Horizon	sand	silt	clay	($CaCl_2$)	% C	$CaCO_3$	% Base Sat.
Ae	68	30	2	5.3	0.78	-	25
Bm_1	76	14	10	5.3	0.44	-	20
Ck	89	8	3	7.2	-	15	100

12.3.2 Arctic Red River 2

Location: 67°27' N, 133°47' W (1 ½ miles W of Arctic Red River - Map 106 N)

Land Region: 2 - 1 Map Unit: tMm

Topography: Subdued gently rolling hummocky upland with local undrained depressions.

Elevation: 75 m (200 feet)

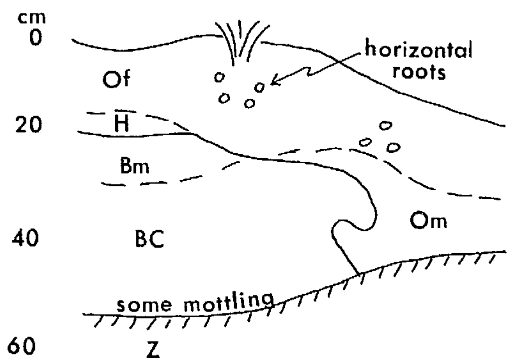
Slope: Crown of slope exposed to south.

Vegetation: Well stocked stand of *Betula papyrifera* with some *Picea mariana;* shrub layer includes *Alnus crispa* and *Salix* sp.; a continuous cover of low shrubs consists mainly of *Vaccinium uliginosum* with *Ledum palustre* ssp. *groenlandicum*, *L. palustre* ssp. *decumbens*, *Vaccinium vitis-idaea* and *Viburnum* sp.; feather mosses form the major ground cover with a good lichen (*Cladonia* spp.) cover on the hummocks and some *Sphagnum* sp. in the depressions. The thick organic layer and old trees would indicate a mature forest.

Parent Material: Medium to fine textured till.

Drainage: Well to poor within the rooting zone.

Microrelief: Strong relief to 50 cm and higher with generally steep sides.



Section through the edge of a hummock

= permafrost table

Horizon	Depth (cm)	Description
Of	10-2	Dark reddish brown (5YR 2/2 m) fibric organic horizon with a very high content of fine random roots, also abundant large horizontal roots near shoulders of hummocks, may include pieces of rotting stems and roots; extremely acid; clear, wavy boundary; 5-25 cm thick.
H	2-0	Black (5YR 2/1 m) humic horizon commonly containing charcoal; weak granular; abundant fine roots; very strongly acid; abrupt, wavy boundary; 0-2 cm thick.

Horizon	Depth (cm)	Description
Om		Black (5YR 2/1 - 2/2 m) peaty horizon consisting of humic material and roots; abundant fine and medium roots; extremely acid; abrupt, irregular boundary; 0-20 cm thick.
Bm	0-10	Brown to dark brown (7.5YR 4/4 m) clay loam; moderate to strong fine granular; friable, abundant fine roots; strongly acid; a few stones; clear, wavy boundary; 0-10 cm thick.
BC	10-30	Very dark grayish brown (2.5YR 3/2m) loam to clay loam; weak medium platy to amorphous; wet, sticky; moist, firm; few fine roots; 5% coarse fragments; neutral; 0-50 cm thick.
Z	30-45	Very high ice horizons with scattered mineral and organic inclusions.
BCz + Hbx	45-75	Frozen mineral and buried organic horizons.
BCkz	75-80+	Dark grayish brown loam; some organic material; 20% coarse fragments; weakly effervescent.

The temperature at the base of the O layer was 6.5^{o}C and at the base of the Bm horizon was 3^{o}C on July 21, 1971.

Horizon	Particle size distribution of < 2 mm fraction			L.L.	P.L.	Unified	pH $CaCl_2$	% C	$CaCo_3$ Equiv.	% Base Sat.
	sand	silt	clay							
Of							4.0	39.8		20
Bm	26	46	28				5.0	2.3		55
BC	27	48	25	29	20	CL	7.0	1.6		100
BCkz	34	46	20				7.2		5.2	100

12.3.3 Road River

Location: 66°50' N, 135°23' W (N of Road River on Peel Plateau - Map 106L)

Land Region: 2 - 1 Map Unit: tMm

Topography: Subdued hummocky (rolling) upland with drainage to local depressions.

Elevation: 400 m (1300 feet)

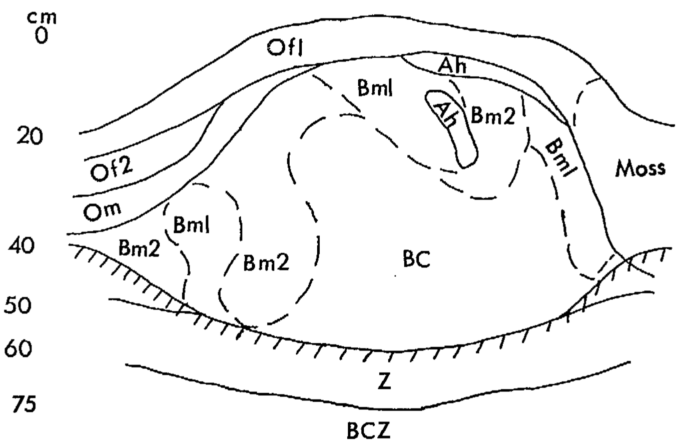
Slope: 4% to W

Vegetation: Continuous but open tree layer of *Picea mariana*; a rather sparse high shrub layer of *Betula glandulosa, Alnus crispa* and *Salix* sp.; moderately dense low shrub layer consisting of *Ledum palustre* ssp. *decumbens, L. palustre* ssp. *groenlandicum; Vaccinium uliginosum; V. vitis-idaea, Rubus chamaemorus* and *Spirea beauverdiana*: there is a complete ground cover of lichens (mostly *Cladonia* spp.) and feather mosses on the hummocks and dominantly *Sphagnum* mosses in the depressions with a minor sedge component.

Parent Material: Fine textured till? of shale origin.

Drainage: Imperfect to poor within rooting zone.

Microrelief: Continuous earth hummock development 40 to 60 cm high and 70 to 110 cm in diameter.



Section through the centre of a hummock

⁄⁄⁄⁄⁄⁄ - permafrost table

Horizon	Depth (cm)	Description
Of1		Reddish brown (5YR 5/4 - 4/6 m) fibric horizon composed of fine roots, mosses, and lichen remains; abundant medium and large horizontal roots; extremely acid; clear, wavy boundary; 0-8 cm thick.
Of2		Similar to Of1 except that has no lichen material; 0-5 cm thick.

Horizon	Depth (cm)	Description
Om	-	Dark reddish brown (5YR 2.5/2 m) mesic horizon; abundant roots of all sizes, extremely acid; abrupt, wavy boundary; 0-10 cm thick.
Ah	0-3	Very dark brown (10YR 2/2 - 3/2 m) silt loam, weak fine granular; moist friable, wet not sticky; abundant fine random roots; very strongly acid; clear, wavy boundary; 0-5 cm thick.
Bm1	variable	Dark brown (10YR 3/3 w) clay loam; strong fine granular to medium subangular blocky, friable; abundant fine random roots; strongly acid; clear, broken boundary; 0-20 cm thick.
Bm2	variable	Very dark grayish brown (10YR 3/2 m) clay loam; some dark gray (10YR 4/1 m) and dark brown (7.5YR 4/4 m) areas; moderate, medium subangular blocky; firm to friable; few to plentiful fine black roots; strongly acid; clear, broken boundary; 0-40 cm thick.
BC	variable	Dark gray (10YR 4/1 m) clay loam; common fine to medium prominent dark brown (7.5YR 4/4 m) mottles in upper portion grading to few near lower boundary; amorphous; firm; very few fine roots; a few stones; medium acid; abrupt, wavy boundary; 0-50 cm thick.
Z	60 cm from top of hummock	Greater than 90% ice with some streaks of organic and mineral material; 15 cm thick.

Horizon	Particle size distribution of < 2 mm fraction			L.L.	P.L.	Unified	pH	% C	$CaCO_3$	% Base Sat.
	sand	silt	clay							
Of1							3.6		-	
Om							3.3		-	
Ah							4.0	6.7	-	24
Bm1	19	48	33				4.5	4.2	-	51
Bm2	21	47	32				4.5	4.0	-	59
BC	20	50	30	33.7	28.4	ML to CL	4.7	3.2	-	66
BCz							6.2	12.2	-	90

12.3.4 Bell River

Location: 67°20' N, and 137°37' W (N of Bell River - Map 116 P)

Land Region: 1m Map Unit: L

Topography: Rolling upland with good regional drainage.

Elevation: About 330 m (1100 feet).

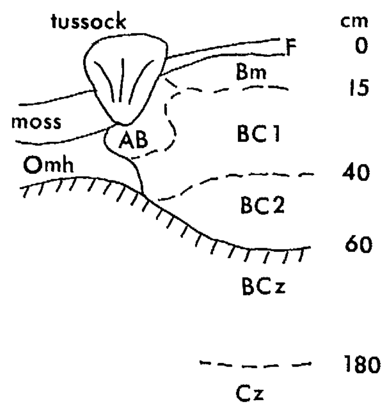
Slope: 5% to SE

Vegetation: Sparse *Betula papyrifera*; continuous high shrub layer of *Betula glandulosa* and *Salix* sp.; continuous low shrubs include *Ledum palustre* ssp. *decumbens*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Arctostaphylos rubra*, *Rubus chamaemorus*, and *Spirea beauverdiana*; sedge tussocks are common and mosses form about 30% of the ground cover. Very little lichen is present. This is a fire induced situation with a mature black spruce-lichen forest present just up slope.

Parent Material: Fine textured weathering products (possibly some aeolian) over sedimentary rocks.

Drainage: Moderate to poor within rooting zone.

Microrelief: Continuous earth hummocks 25 to 40 cm high and about 100 cm in diameter.



Section through the edge of a hummock

= permafrost table

Horizon	Depth (cm)	Description
F	2-0	Dark reddish brown (5YR 2.5/2 m) organic material with charcoal, discontinuous, abrupt, wavy.
Omh	variable	Black (5YR 2.5/1 m) saturated organic horizon with abundant fine to large roots; very strongly acid; wavy, abrupt boundary. 0-15 cm thick.

Horizon	Depth (cm)	Description
AB	variable	Dark grayish brown (10YR 3/2 w) silt loam to silty clay loam; fine granular; friable, slightly sticky; abundant fine roots; strongly acid; clear, irregular boundary; 0-10 cm thick.
Bm	0-15	Dark yellowish brown (10YR 4/4 m) silt loam to silty clay loam; strong fine granular grading to medium subangular blocky; friable to firm; abundant grading to few fine roots; strongly acid; gradual, wavy boundary; 0-15 cm thick.
BC1	15-40	Dark gray (10YR 4/1 m) and dark brown to brown (7.5YR 4/4 m) silt loam to silty clay loam; amorphous; firm; very few to no roots; strongly acid; gradual, wavy boundary; 0-30 cm thick.
BC2	40-60	Dark grayish brown (10YR 4/2 w) clayey silts with streaks of organic matter; moderate medium granular often with lenticular structures due to fine ice lenses; slightly sticky; strongly acid; abrupt, wavy boundary.
BCz1	60-85	Similar to above with 30% visible ice as fine lenses.
BCz2	85-170	Grayish brown organic clayey silts (similar to above) with common organic inclusions; 70% visible ice in veins up to 2 cm thick.
BCz3	170-180	Organic clayey silts with 30% visible ice.
Cz	180-225+	Gray (5Y 4/2) clayey silt matrix with 40% sandstone fragments; 15% visible ice.

Horizon	Particle size distribution of < 2 mm fraction: sand	silt	clay	L.L.	P.L.	Unified	pH	% C	$CaCO_3$	% Base Sat.
Bm	10	60	30				4.7	2.4	-	
BC1	11	60	29				4.7	3.3	-	
Cz	11	62	27				6.7		-	

12.3.5 Palmer Lake

Location: 66°05' N, 136°17' W (S of Palmer Lake - Map 116 I).

Land Region: 2 Map Unit: B

Topography: Gently sloping upland surface (pediment) with restricted drainage, mainly as downslope seepage.

Elevation: 500 m (1550 feet).

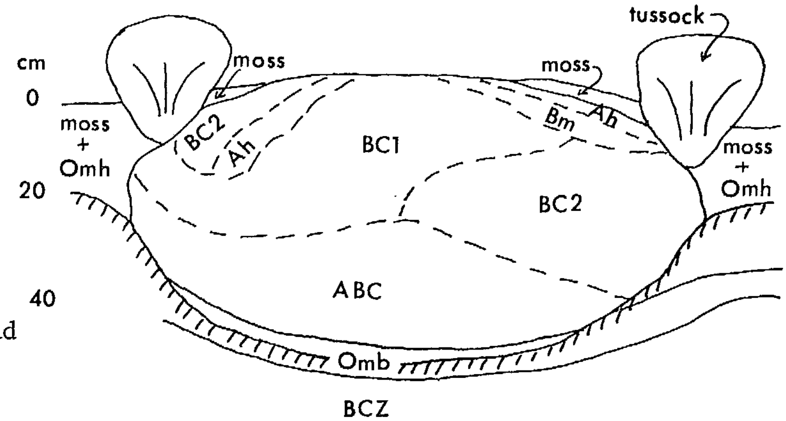
Slope: 2% to W

Vegetation: Sedge tussock dominated with minor *Sphagnum* sp., feather mosses and lichens in the ground layer; low shrubs such as *Ledum palustre* ssp. *decumbens* and *Vaccinium vitis-idaea* (minor *Rubus chamaemorous*) are common; *Betula glandulosa* forms a scattered high shrub layer with a few small *Picea mariana* and *Larix laricina*. About 5% of the area is bare hummock tops. This is a fire-induced tundra situation.

Parent material: Silts (an aeolian contribution is probable).

Drainage: Generally poor.

Microrelief: Note diagram. Usually negative with respect to the tussocks but is actually 10 to 30 cm relief on the mineral surface in broad low hummocks.



Section through an entire hummock

ттттт = permafrost table.

Horizon	Depth (cm)	Description
Omh		Very dark brown (10YR 2/2 m) organic material; slippery consistency; abundant fine and medium roots; clear, irregular boundary; extremely acid; 0-15 cm thick.
Ah		Very dark grayish brown (10YR 3/2 m) organic loam; weak fine graunular to amorphous; friable; few to plentiful fine roots; extremely acid; clear, wavy boundary; 0-5 cm thick.

Horizon	Depth (cm)	Description
BC1		Brown to dark brown (10YR 4/3 m) silty clay loam; some yellowish brown (10YR 5/6) and gray (10YR 5/1) streaks; amorphous; firm, rubbery; few fine roots; extremely acid; clear, irregular boundary; 0-20 cm thick.
BC2		Gray (10YR 5/1 - 4/1 m) silty clay loam, with 30% dark brown (10YR 4/3) streaks and blotches; amorphous; firm, rubbery; very few fine roots; extremely acid; clear, irregular boundary; 0-30 cm thick.
ABC		Variable colored with very dark brown and grayish brown (10YR 3/2, 4/3, 4/1, 2/2 m) silt loam; weak medium platy and granular; friable; plentiful fine roots; some pure organic inclusions; clear, wavy boundary; extremely acid; 0-40 cm thick.
Omb		Very dark grayish brown (10YR 3/2 m) buried organic material; slippery when wet; 3-6 cm thick.
BCz	50 cm from top of hummock	Grayish mineral with some organic inclusions; very high ice.

Horizon	Particle size distribution of <2 mm fraction			L.L.	P.L.	Unified	pH $CaCl_2$	% C	% Base Sat.
	sand	silt	clay						
Omh							3.7		
Ah							4.0	17.5	4.5
BC1	3	60	37	36.1	33.1	OL	3.9	5.8	5.5
BC2	3	62	35				4.1	4.9	11
ABC							4.0	9.2	

12.3.6 Jiggle Lake

Location: 67°42' N, 132°03' W (near Jiggle Lake - Map 106 N)

Landform: Peat plateau with polygonal pattern.

Vegetation: Burned over, but previously had *Sphagnum* mosses and *Cladonia* lichens with *Rubus chamaemorus*, *Ledum palustre decumbens*, *Andromeda polifolia*, *Empetrum nigrum*, *Oxycoccus microcarpus*, some *Vaccinium vitis-idaea* and scattered *Betula glandulosa* with scarce *Picea mariana*.

Classification: Cryic Fibrisol

Horizon	Depth (cm)	Description
Of1	0-27	Dark reddish brown (5YR 3/3 m) fibric sphagnic peat.
Om	27-48	Dark reddish brown (5YR 2/2 m))mesic moss peat.
Of2(z)	48-68	Dark reddish brown (5YR 2/2 m) fibric sphagnic peat. 67% ice*.
Omf(z)	68-95	Very dusky red (2.5YR 2/2 m) mesic moss and roots. 70% ice.
Of3(z)	95-117	Yellowish red (5YR 4/6 m) fibric sphagnic peat; 65% ice.
Om2(z)	117-195	Dark reddish brown (5YR 2/2 m) woody mesic sedge peat; 74% ice.
Marl(z)	195-203	Light gray (10YR 2/2 m) marl, shells; 60% ice.
Oh(z)	203-270	Black (5YR 2/1 m) woody humic peat; 69% ice.
Cg(z)	270	Fine sand and silt.

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* Ice percentages on a volume basis.

Horizon	pH ($CaCl_2$)	Pyrophosphate (10YR chart)	Fibre unrubbed	Fibre rubbed	% Ash	W.H.C.	Bulk Density	% C	C/N	Exch. Acidity me/100 g	% Base Sat.
Of1	3.7	8/1	95	70	3.2	14.8		42.2	66	82	16
Om1	3.7	5/3	80	10	6.8	7.2	0.19	44.7	42	76	21
Of2z	4.0	8/1	95	60	4.1	15.2	0.06	42.4	66	78	27
Omfz	4.7	8/2	80	10	7.6	9.6		45.4	33	52	51
Of3z	5.7	8/0	100	75	9.9	16.3		36.5	46	16	76
Om2z	5.8	7/3	80	15	12.4	8.5		41.5	25	22	86
Marl	Moderately effervescent with HCl.										
Ohz	5.6	4/3	50	10	38.4	5.0		28.5	15	18	95

12.4 Surficial geology map

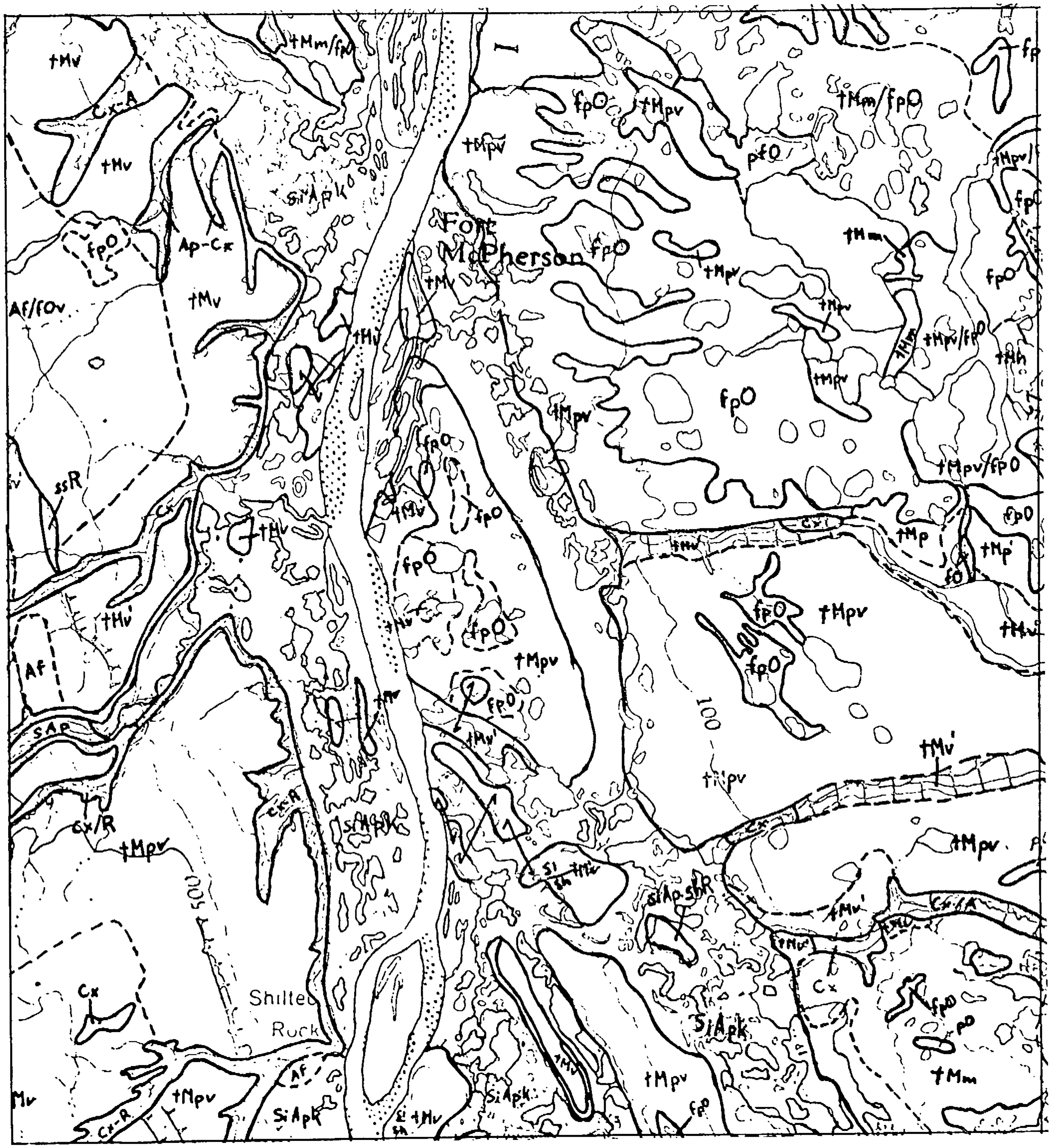

Figure 36. Portion of Map 106 M, showing surficial geology and geomorphology; produced by Terrain Sciences, Dept. Energy, Mines and Resources.

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Studies of vegetation, landform and permafrost in the Mackenzie valley: terrain, vegetation and permafrost relationships...

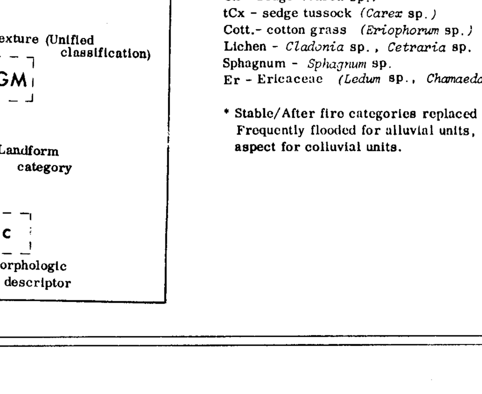
LEGEND AND NOTES (SHEET 1) TO ACCOMPANY SURFICIAL GEOLOGY AND GEOMORPHOLOGY MAPS 106 E, F, G, L, 116 I, J, N(E 1/2) & O, P.

(descriptions are for map-units of organic, eolian, glaciolacustrine, glaciofluvial, glacial and colluvial origin; see Sheet 2 for descriptions of map-units in unglaciated upland areas)

MAP[1] UNIT	NAME	SURFICIAL DEPOSIT: Material	SURFICIAL DEPOSIT: Estimated Thickness	LANDFORM: Topography	LANDFORM: Drainage Pattern	% Water	GROUND ICE	LAND[3] ZONE	SOILS[4]: Texture U.S.D.A.	SOILS: Unified Classification	SOILS: Micro-relief cm	SOILS: Depth of thaw cm	SOILS: Drainage (deciles)	VEGETATION: Stable	VEGETATION: After Fire	VEGETATION: Occurrence **	COMMENTS
fOv	Organic veneer (mapped mainly as a secondary unit with tMp, tMv)	Peat - typically woody sedge peat	20-60 cm	Shallow channels, runnels and depressions; Slope 0-3°, Relief to 1 m	Surface seepage in channels, depressions	0-5	Organic veneer lies mainly within the active layer; (for ice in mineral soil below, see associated map unit).	0									Similar to fO; areas with mappable fOv component (+10%) should be avoided in construction of roads, pipelines, etc.
								1, 1m	woody sedge peat over L-C mineral	Pt / CL-ML	Sedge tussocks 10-50	50-100	Poor to wet 10	Cx-Bi-tL	Cx-Wi	1	
								2, 2m	woody sedge peat over L-C mineral	Pt / CL-ML	Sedge tussocks 10-50	50-150	Poor to wet 10	Cx-Bi-tL	Cx-Bi-tL	1	
								3	woody sedge peat over L-C mineral	Pt / CL-ML	Sedge tussocks 10-30	100-200	Poor to wet 10	Cx-Bi-tL	Cx-Bi-tL	1	
fO	Organic (fenland)	Peat - typically woody sedge peat	2-3 m	Flat to very gently sloping, in part with reticulate network of low ridges. Slope 0-2°, Relief to 1 m	No organized drainage; water at surface throughout summer months	5-20	Commonly unfrozen to 2+ m (see "Depth of Thaw" for respective zones) little data available on segregated ice content at greater depths.	0									Poor drainage, plus high compressibility and low strength of the material make it unsuitable for any type of construction.
								1, 1m	Mesic sedge peat	Pt	0 to tussocky	150 to unfrozen	Wet 10	Cx-Cott. or Cx-Bi-tL	Cx-Cott.	1	
								2, 2m	Mesic sedge peat	Pt	None Some sedge tussocks	200 to unfrozen	Wet 10	Cx-Cott. or Cx-Bi-tL		2	
								3	Mesic sedge peat	Pt	0	Unfrozen	Wet 10	Cx-Cott. or Cx-Bi-tL		2	
pO	Organic (peatland)	Peat - typically sedge and woody sedge peat overlain by sphagnum peat	2-4 m	Flat to very gently sloping, typically with numerous shallow steep-sided (2-3 m) depressions occupied by lakes, ponds and bogs.	Depressions interconnected by seepage channels	5-20	Commonly up to 20%, locally up to 60% segregated ice within peat; typically 30-100 cm, locally up to 3 m total thickness segregated ice in mineral soil immediately below peat. Peat in wet depressions commonly thawed to 1 m + (Zones 1, 2) or unfrozen (Zones 2, 3),	0	Fibric to mesic peat	Pt	Polygon trenches to 100 cm	20-30	Imp. 10	Lichen-Sphagnum	Sphagnum-Er	1	Subsidence of up to 1 m common, and subsidence up to 3 m possible, when vegetation is removed; alternation of permanently frozen peat plateaus and thawed depressions and water bodies presents serious problems in construction of roads, pipelines, etc.; material highly compressible when thawed.
								1, 1m	Fibric to mesic peat	Pt	Some polygon trenches to 100 cm	20-30	Imp. 10	Lichen-bS	Sphagnum-Er	1	
								2, 2m	Fibric to mesic peat	Pt	Some sphagnum hummocks	25-30	Imp. 10	Lichen-bS	Sphagnum-Er	2	
								3	Fibric to mesic peat	Pt	Some sphagnum hummocks	25-30	Imp. 10	Lichen-bS	Sphagnum-Er	2	
gAp, s,gAp, si,gAp, si/g Ap	Alluvial floodplain of high energy streams	Sand, gravel, in part with silt veneer	1-5+ m sand and/or gravel, 0-2 m silt	Flood plain and low bordering terraces scarred by braided channels. Slope 0-3°, Relief to 2 m	Intermittent drainage through braided channels	0	Permafrost lacking in active unvegetated parts of floodplain; elsewhere cement ice only, except in silt veneer which commonly has 10 to 25% segregated ice as thin (1 mm - 2 cm) seams							Occasionally flooded	Frequently* flooded		Subject to periodic flooding; constitutes potential reserve of gravel but extraction presents serious possibility of deleterious changes in stream course and downstream changes in stream regimen.
								0	S + G	SM-GM	polygons to 50 cm	50-150	Imp. to well	Wi	Bare	1	
								1, 1m	S + G	SM-GM	0	50-200	Imp. to well	Wi-Al	Bare	1	
								2, 2m	S + G	SM-GM	0	50-200	Imp. to well	Wi-Al	Bare	1	
								3	S + G	SM-GM	0	50-200+	Imp. to well	bPo-Al-Wi	Bare	1	
siAp, si,sAp	Alluvial floodplain of low energy streams	Silt, fine-grained sand	3-5+ m	Flood plain and low bordering terraces commonly with meander scars. Slope 0-3°, Relief to 1 m	No integrated drainage system; impeded by meander scroll ridges where present	0-20	Permafrost lacking in unvegetated part of floodplain; elsewhere 10 to 25% segregated ice by volume as thin (1 mm - 2 cm) seams. Ice wedges in polygonal pattern (diameter of polygons 6-25m) common in Zone 2.	0								1	Subject to periodic flooding; melting of ice wedges produced polygonal network of depressions when vegetation is removed.
								1	VFSL to SiL	SM to CL-ML	0	50 to unfrozen	Imp. 4, Poor 6	wS, Cx tL	Wi-Al, Cx Wi	1	
								2, 2m	VFSL to SiL	SM to CL-ML	0	100 to unfrozen	Imp. 4, Poor 6	wS-bS, Cx-tL	Wi-Al, Cx-Wi	1	
								3	VFSL to SiL	SM to CL-ML	0	100 to unfrozen	Imp. 4, Poor 6	wB-bPo-wS, Cx-tL	Wi-Al, Cx-Wi	1	
si Apk, si,sApk	Thermokarst alluvial floodplain (associated with low energy streams only)	Silt, fine-grained sand	3-5+ m	Level floodplain, in part with meander scars, and with numerous channels and thermokarst ponds. Slopes 0-3°, short steep slopes to 45°, Relief to 5 m	Seepage to ponds and lakes, to adjacent streams by connection channels	20-50	20 to 50% segregated ice by vol. in upper 2-3m (and probably to greater depth)	0									Thermokarst processes active around pond margins; melting of ice wedges produces polygonal network of depressions when vegetation is removed; subject to periodic flooding; highly unsuitable as construction sites.
								1	VFSL to SiL	SM to CL-ML	Hummocks and trenches 0-40	40-200+	Mod. well 1, Imp. 4, Poor 5	wS, wS-bS-lichen, Cx-Wi		2	
								2	VFSL to SiL	SM to CL-ML	Hummocks 0-50	50-200+	Mod. well 2, Imp. 4, Poor 4	wS, wS-bS-lichen, Cx-Wi		1	
								3	VFSL to SiL	SM to CL-ML	Hummocks 0-20	100 to unfrozen	Mod. well 2, Imp. 4, Poor 4	wS, wS-bS, Cx-tL	wB-bPo-wS, bPo-Al, Cx-Wi	1	
gAt, si,gAt, si/g At	Alluvial terrace of high energy streams	Sand, gravel in part with silt veneer	1-5+ m sand and/or gravel, 0-2 m silt	Level to gently sloping terrace, in part with shallow channels and steep scarps. Slope 0-3°, [illegible]	Surface drainage without integrated drainage system	0-5	Cement ice only except in silt veneer which commonly has 10 to 25% segregated ice as thin (1 mm - 2 cm) seams.	0	S + G	SM-GM	Polygons to 50 cm	75-125	Mod. well 2, Imp. 6, Poor 2	Lichen-Er, Cs-Wi, Cx	Er, Cx-Wi, Cx	1	Offer good construction sites where silt veneer is thin; potential aggregate source.
								1, 1m	FS-SiL (often over gravel)	SM to CL-ML	Hummocks 0-20	75-150	Mod. well 3, Imp. 5, [illegible]	wS, wS-bS-lichen, [illegible]	wB-wS, Al-Wi, [illegible]	1	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cv	[illegible]	[illegible]	[illegible]	[illegible] mountainous, Slopes to 45°	[illegible]	[illegible]	[illegible]	[illegible]									[illegible] (elev. 800m+) of Richardson Mountains indicate active creep of colluvial veneer.
E, sEr, sEv	Eolian deposits	Sand, mainly fine to medium grained	1-20 m	Thin veneer or dune ridges within or adjacent to areas of Gp, GLp. Slope to 20°, Relief to 10 m	Mainly subsurface seepage; no organized drainage	0	No data; probably cement ice only below active layer; segregated ice highly probable in subjacent glaciolacustrine silts where eolian deposits occur within areas of GLp.	0									Offers restricted well-drained sites within large areas of poorly drained units GLp, GLpk; subject to wind erosion when vegetation mat is removed. Gulleying commonly occurs upon removal of the vegetation mat in areas where eolian sand forms a thin veneer over ice-rich till or lacustrine sediments.
								1									
								2	LS-S	SP	0	50-300	Well 7, Imp. 2, Poor 1	ws-wh, bS-wS, bS-tL-Cx	wS-wB-grass, wS-sB-bS, Cx-tL	1	
								3	LS-S	SP	0	50 to unfrozen	Well 7, Imp. 2, Poor 1	tA-wS, wS-wB, bS-tL-Cx	tA, wB, tL-Wi	1	
Lp, si,cLp	Glaciolacustrine plain	Glaciolacustrine silt and clay; discontinuous organic cover	1-20 m + silt and clay	Flat to gently sloping, Slope 0-2°, Relief to 3 m	Surface seepage through fen-filled depressions	0-20	No data; should be treated as Lpk until data available.										Active-layer detachment slides, followed by development of retrogressive-thaw flow slides, common on colluvial slopes (Cx) developed on this unit (and on lesser areas of steep slope not mapped as Cx), especially following fire or other disturbance of vegetation. Gulleying commonly results even on gentle slopes upon removal of vegetation due to combined hydraulic and thermal erosion and disruption of the drainage network. West of the Richardson Mountains this unit is underlain by unconsolidated basin-fill sediments. The subjacent non-glacial sediments in the lacustrine plains of the unglaciated area typically have a much lower ice content.
								0	SiL-SiC (some FS)	CL-ML	Hummocks 20-60	50-90	Imp. 4, Poor 6	bS-tCx, bS-Er-tCx	tCx, tCx-Wi	1	
								1m	SiL-SiC (some FS)	CL-ML to ML	Hummocks 20-50	50-100	Imp. 2, Poor 8	wS-bS-lichen, tL-bS-Cx	wB-wS-Wi, Cx-Wi-Al	1	
								2, 2m	SiL-SiC (some FS)	CL-ML to ML	Hummocks 20-75	50-100	Imp. 5, Poor 5	bS-lichen-tCx, bS-tL-tCx	wS-wB-Wi, tCx-Wi-tL	1	
								3	SiL-SiC	CL-ML to CL	Hummocks 10-50	50-200	Imp. 5, Poor 5	bS-lichen, tL-bS-Cx	bS-lichen, tL-Wi-Cx	1	
Lpk, si,cLpk	Glaciolacustrine thermokarst plain	Glaciolacustrine silt and clay; discontinuous organic cover	1-20 m + silt and clay	Flat to gently sloping, numerous shallow thermokarst lakes and ponds. Slope 0-5°, Relief to 6 m	Seepage centripetal to ponds and lakes, intermittent seepage through fen-filled depressions between ponds and lakes	25	Commonly up to 10-25% segregated ice as thin (1 mm - 2 cm) seams in upper 1-3 m; segregated ice as reticulate network to 40% by volume, or thick tabular bodies of nearly pure ice at greater depth.										Thermokarst processes active around pond margins; active-layer detachment slides followed by development of retrogressive-thaw flow slides, common on colluvial slopes (Cx) developed on this unit (and on lesser areas of steep slope not mapped as Cx), especially following fire or other disturbance of vegetation. Gulleying is common even on gentle slopes upon removal of vegetation. West of the Richardson Mountains this unit is underlain by unconsoldiated basin-fill sediments. The subjacent non-glacial sediments in the lacustrine plains of the unglaciated area typically have a much lower ice content.
								1	SiL-SiC (some FS)	CL-ML to ML	Hummocks 20-60	50-90	Mod. well 1, Imp. 4, Poor 5	wS-bS-wB, wS-bS-lichen, bS-Cx	wS-wB, bS-Wi-Al, Cx-Wi	2	
								1m	SiL-SiC (some FS)	CL-ML to ML	Hummocks 20-50	50-90	Mod. well 1, Imp. 4, Poor 5	bS-wB, bS-tCx, bS-tCx	wB-Al, tCx, tCx	2	
								2, 2m	SiL-SiC (some FS)	CL-ML to ML (some SM)	Hummocks 20-75	50-150+	Mod. well 2, Imp. 5, Poor 3	wS-wB-bS, bS-lichen-tCx, bS-tL-tCx	wS-wB, wS-wB-Wi, tCx-Wi-tL	2	
								3									
GLp†, s/si,c Lp	Glaciofluvial-lacustrine plain	Glaciolacustrine silt and clay overlain by glaciofluvial sand with minor silt, rare fine gravel. Discontinuous organic cover	1-35 + m sand, minor gravel, 3-15 + m silt and clay	Flat to gently sloping, Slope 0-2°, Relief to 3 m	Drainage mainly subsurface	0-20	No data; should be treated as GLpk until data available.	0									Active-layer detachment slides followed by development of retrogressive-thaw flow slides common on colluvial slopes (Cx) developed on this unit (and on lesser areas of steep slope not mapped as Cx), especially following fire or other distrubance of vegetation. Rotational slope failures common along banks of larger streams where sand and silt is thicker than 10 m. Gulleying is common even on gentle slopes upon removal of vegetation. The subjacent non-glacial sediments in the lacustrine plains of the unglaciated area typically have a much lower ice content.
								1									
								2	FSL to SiL	SM to CL-ML	Hummocks 10-30	50-150	Imp. 6, Poor 4	bS-lichen, bS-tL-Cx	wS-wB-Wi, Cx-Wi-tL	1	
								3	FSL to SiL	SM to CL-ML	Hummocks 0-30	50-200	Imp. 6, Poor 4	bS-lichen, tL-bS-Cx	bS-wB, tL-Wi-Cx	1	
GLpk†, s/si,c Lpk	Glaciofluvial lacustrine thermokarst plain	As GLp	1-35 + m sand, minor gravel, 3-15 + m silt and clay	Flat to gently sloping, numerous shallow thermokarst lakes and ponds. Slope 0-5°, Relief to 6 m	Seepage centripetal to ponds and lakes, intermittent seepage along fen-filled depressions between ponds and lakes.	25	Commonly up to 10 to 25% segregated ice as thin (1mm - 2 cm) seams in upper 2-3m of sand, but massive segregated ice rare in the sand; very high ice content (to 75% by vol.) as reticulate network or thick tabular bodies in underlying silt and clay.	0									Thermokarst processes active around pond margins; active-layer detachment slides followed by development of retrogressive-thaw flow slides common on colluvial slopes (Cx) developed on this unit (and on lesser areas of steep slope not mapped as Cx), especially following fire or other disturbance of vegetation. Rotational slope failures common along banks of larger streams where sand and silt is thicker than 10 m. Gulleying is common even on gentle slopes upon removal of vegetation. The subjacent non-glacial sediments in the lacustrine plains of the unglaciated area typically have a much lower ice content.
								1									
								2	FSL to SiL	SM to CL-ML	Hummocks 10-50	50-150+	Mod. well 2, Imp. 6, Poor 2	wS-wB-bS, bS-lichen, bS-tL-Cx	wS-wB, wS-wB-Wi, Cx-Wi-tL	1	
								3	FSL to SiC	SM to CL-ML to CL	Hummocks 10-40	50-200+	Mod. well 2, Imp. 6, Poor 2	wS-wB, bS-lichen, tL-bS-Cs	wS-wB-Al, bS-wB, tL-Wi-Cx	1	
Gp, gGp, s,gGp; Gt, gGt, s,gGt	Glaciofluvial plain; Glaciofluvial terrace	Sand, gravel, locally with veneer of eolian silt or sand	2-15 + m	Flat to gently sloping, Slope 0-2°, Relief to 5 m	Drainage mainly subsurface	0-5	Typically cement ice only, polygonal pattern on some areas of unit in Zones 0, 1 suggests possible wedge ice.	0	G + S (local silty veneer)	GW-SW	-	50-150	Well 5, Imp. 4, Poor 1	Bi, Bi-Wi, tCx-sphagnum	Cx, Wi, tCx	1	Offers good construction sites; major source of aggregate where material is gravel rather than sand.
								1	G + S (local silty veneer)	GW-SW	Hummocks 0-10	75-150	Well 5, Imp. 4, Poor 1	ws-lichen, bS-lichen, tL-Bi-Cx	wB-Wi-wS, wB-bS-Wi, Cx-Bi	1	
								2	G + S (local silty veneer)	GW-SW	Hummocks 0-10	75-150+	Well 6, Imp. 3, Poor [illegible]	wS, bS-wS-lichen, bS-tL-Cx	wS-wB-grass, wS-wB-bS, Cx-tL	1	
								3									
Gc	Glaciofluvial plain, channelled	Sand, gravel; silt, peat in channels	2-15 + m	Flat to gently sloping interrupted by shallow channels and low scarps. Relief to 10 m, exceptionally to 30 m	Drainage mainly subsurface with seepage along channels	0-5	As GP, but with locally high segregated ice within silt and below peat in channels.	0									Same as Gp, Gt (above) except in channels which may contain peat and ice-rich silt. Where unit grades into units GLp, GLpk, the surface deposit is typically sand rather than gravel and may be underlain by ice-rich silt.
								1									
								2	G + S	GW-SW	Hummocks 0-10	75-150+	Well 7, Imp. 2, Poor 1	wS-wB, bs-wS-lichen, bS-tL-Cx	wS-wB-grass, wS-wB-bS, Cx-tL	1	
								3									
Gh, Gr, Gm, gGh, gGr, s,gGh, s,gGr	Hummocky, ridged glaciofluvial deposits (includes eskers and esker complexes)	Sand, gravel		Hummocks and ridges, relief to 40 m, Slope 5-15°	Drainage mainly subsurface	0	Typically no segregated ice in well drained sites, but segregated ice may be present in association with silt layers beneath depressions.	0	G + S	GW-SW	Polygons to 50 cm	50-150	Well 8, Imp. 2	lichen-Bi, tCx	bare, tCx	1	Offers good construction sites; major source of aggregate where material is gravel rather than sand.
								1	G + S	GW-SW	0	50-150+	Well 8, Imp. 2	wS-wB, bS-wS	wB-wS-grass, wB-wS-bS	1	
								2	G + S	GW-SW	0	150+	Well 8, Imp. 2	wS, bS-wS-lichen	wS-wB-grass, wS-wB-bS	1	
								3									
tMp, tMv, tMpv	Moraine plain	Glacial till - typically clay, silt, minor sand and gravel. Locally up to 90% > 2 mm	tMp:2-20 m, tMv:0-3 m, tMpv:1-20 m	Flat to gently sloping (0-3%) except as indicated by the slope superscript, Relief to 5 m	Downslope seepage in shallow subparallel runnels	0-5	Commonly 10 to 25% segregated ice as thin (1 mm - 2 cm) irregular discontinuous seams in upper 2-3 m. Thicker 10 cm to 3 m + ice lenses at depth occasionally in Zones 0, 1, 2, rare in Zone 3.	0	SiC (Some L-C)	ML	Hummocks 30-60	50-75	Imp. 9, Poor 1	Cott.-tCx, tCx-sphagnum		1	Potential subsidences on removal of vegetation typically less than 1 m (but note that unit may have up to 10% unmapped fO or pO, and that locally ice content at depth may be high); because of drainage by numerous subparallel runnels, roads or berms normal to slope direction require numerous culverts to avoid impoundment of surface water.
								1	CL (some L and C)	CL	Hummocks 20-60	50-80	Mod.well 2, Imp. 4, Poor 4	wS-lichen, bS-wS-lichen, tL-bS-Cx	wB-wS, wB-wS-Wi, Cx-Al-Wi	3	
								2	CL (some L)	CL	Hummocks 10-40	50-150	Mod. well 2, Imp. 5, Poor 3	bS-wS-wB, bS-lichen, tL-bS-Cx-Al	wS-wB-bS, 2S-wB-Wi, Cx-Al	3	
								3	CL (some L)	CL	Hummocks 0-30	50-200	Mod. well 2, Imp. 5, Poor 3	wS-bS-bro, bS-lichen, tL-bS-Cx	wB-wS-Al, bs, tL-Wi-Cx	2	
tMp^1, tMv^1, $tMpv^1$, tMp^2, tMv^2, $tMpv^2$	Moraine plain	Glacial till	tMp^1:2-20 m, tMv^1:0-3 m, $tMpv^1$:1-20 m, tMp^2:2-20 m, tMv^2:0-3 m, $tMpv^2$:1-20 m	$Slope^1$ 3-8°, $Slope^2$ 8-12°	Downslope seepage in shallow subparallel runnels	0-5	As tMp	0	SiC (some L-C)	ML	Hummocks 30-60	50-75	Imp. 9, Poor 1	Cott.-tCx, tCx-sphagnum		2	Potential subsidence on removal of vegetation typically less than 1 m; potential for creep of active layer, especially in slope category^2. Because of drainage by numerous subparallel runnels, roads or berms normal to slope direction require numerous culverts to avoid impoundment of surface water.
								1	CL-C	ML-CL	Hummocks 20-85	50-150	Mod. well 3, Imp. 6, Poor 1	wS-lichen, bS-wS-lichen, tL-bS-Cx	wB-wS, wB-wS-Wi, Cx-Al-Wi	1	
								2	CL-SiC (locally some L)	ML-CL	Hummocks 20-60	50-100	Mod. well 5, Imp. 4, Poor 1	bS-wS-wB, bS-lichen, bS-tL-Cx	wS-wB-bS, wS-bS-Wi, Cx-L	1	
								3	CL	CL	Hummocks 0-30	50-200	Well 5, Imp. 4, Poor 1	wS-bS-wB, bS-lichen, tL-bS-Cx	wB-wS-Al, bS, tL-Wi-Cx	1	
tMd	Drumlin morain plain	Glacial till	2-20 + m	Moraine plain with individual drumlins, to fluted moraine plain. Slope 2-10°, Relief to 20 m	Parallel seepage or streams in fluted moraine, to trellis pattern or deranged drainage in moraine plain with drumlins	0-15	As tMp	0	SiCL-C (some L-C)	ML	Hummocks 30-60	50-75	Imp. 9, Poor 1	Cx, tCx-sphagnum		1	Similar to tMp; crests of drumlins and drumlinoid ridges typically well-drained, intervening depressions poorly drained; construction of roads, etc. easier parallel to than normal to orientation of drumlins.
								1	CL-L	CL to CL-ML	Hummocks 20-60	50-90	Mod. well 2, Imp. 4, Poor 4	wS-lichen, bS-wS-lichen, tL-bS-Cx	wB-wS, wB-wS-Wi, Cx-Al-Wi	1	
								2	GL-CL	GC-CL	Hummocks 0-30	50-150	Well 3, Imp. 4, Poor 3	bS-wS-wB, bS-lichen, bS-tL-Cx	wS-wB-bS, wS-wB-Wi, Cx-tL	1	
								3	L-CL	CL-ML to CL	Hummocks 0-30	50-200	Mod. well 3, Imp. 4, Poor 3	wS-wb-bPo, bS-lichen, tL-bS-Cx	wB-wS-Al, bS, tL-Wi-Cx	1	
tMm	Subdued hummocky moraine	Glacial till	5-30 m	Broad hummocks 10 to 30 m high, 100 to 500 m across. Slopes to 10°	Deranged; centripetal to local depressions	5-30	Commonly up to 10%, locally up to 40% segregated ice as thin (1 mm to 2 cm) irregular discontinuous seams in upper 2-3 m. Thicker (10 cm to 3 m +) ice lenses at depth common in Zones 0, 1, occasional in Zone 2.	0	SiCL-C (some L-C)	ML	Hummocks 30-60	50-75	Imp. 8, Poor 2	Cott.-tCx, tCx-sphagnum		1	Summits of broad hummocks typically well drained, similar to tMp; lower slopes and intervening depressions may have high ice content, with potential for subsidence of several meters on removal of vegetation; retrogressive-thaw flow slides occur on colluvial slopes (Cx) developed on this unit west of Peel River.
								1	CL-C	CL	Hummocks 20-75	50-150	Mod. well 3, Imp. 5, Poor 2	wS-lichen, bS-wS-lichen, tLbS-Cx	wB-wS, wB-wS-Wi, Cx-Al-Wi	2	
								2	CL-SiCL (locally some L)	CL (some CL-ML)	Hummocks 20-60	50-100	Mod. well 5, Imp. 3, Poor 2	bS-wS-wB, bS-lichen, bS-tL-Cx	wS-wB-bS, wS-wB-Wi, Cx-tL	1	
								3									
tMh, t,gMh; tMr, t,gMr	Hummocky moraine; Ridged moraine	Glacial till, minor gravel; Glacial till, minor gravel	15-50 + m; 15-50 + m	Individual to coalescent hummocks 15 to 50+ m high; Slopes to 20° exceptionally 30°. Individual and compound straight to sinuous ridges 15 to 50+ m high; Slopes to 20° exceptionally 30°	Deranged, centripetal to local depressions	0-15	Highly variable depending upon topographic position; crests of prominent ridges and hummocks well drained and ice-free to depths of 2-5 m; lower slopes as for tMm.	0	LG-CL	GC-GM to CL	Hummocks 15-50	50-90	Mod. well 2, Imp. 6, Poor 2	Bi-Cx, Cott.-tCx, tCx-sphagnum		1	Crests of prominent ridges and hummocks offer restricted good construction sites. Ice content and potential for subsidence may be high in depressions.
								1	GL-CL (local gravel deposits)	GC-GM to CL	Hummocks 0-60	50-150	M.well-well 5, Imp. 4, Poor 1	wS-lichen, bS-wS-lichen, tL-bS-Cx	wB-wS, wB-wS-Wi-Al, Cx-Al-Wi	1	
								2	GL-CL (local gravel deposits)	GC-GM to CL	Hummocks 0-50	50-120	M.well-well 6, Imp. 3, Poor 1	wS-wB-bS, bS-lichen, bS-tL-Cx	wS-wB, wS-wB-Wi, Cx-tL	1	
								3									
Ug	Upland, glaciated	Glacial till - minor glaciofluvial sand and gravel, glaciolacustrine silt and clay, peat	1-5 m thicker in depressions	Rolling bedrock controlled topography with relief to 150 m. Slopes to 15°	Downslope seepage in subparallel runnels; permanent streams in valleys	0-5	As tMp, tMv on hilltops and gentle slopes with locally very abundant (up to 40% by vol.) segregated ice in silt and clay filled depressions.	0									
								1	CL-C (locally silts & gravels)	CL (some CL-ML)	Hummocks 20-60	50-100	Mod. well 4, Imp. 4, Poor 2	wS-lichen, bS-wS-lichen, tL-bS-tCx	wB-Wi-wS, wB-wS-Wi-Al, tCx-Al-Wi	3	
								2	CL-SiCL (locally some L)	CL (some CL-ML)	Hummocks 20-60	50-100	Mod. well 3, Imp. 5, Poor 2	wS-lichen, bS-wS-lichen, tL-bS-Cx	wB-wS, wB-wS-Wi, Cx-Al-Wi	1	
								3									
Pg	Piedmont, glaciated	Mainly glacial till; widely distributed glaciolacustrine silt and clay in valleys	1-15 + m	Broadly rolling piedmont slopes on east flank of Richardson Mtns.	Dendritic (to east) with major streams deeply incised	0	As tMp in uppermost 1-3 m; massive segregated ice common in both till and glaciolacustrine sediments at greater depth.	0	SiCL (some L-C)	ML-CL	Hummocks 30-60	50-75	Imp. 8, Poor 2	Cott.-tCx, tCx-sphagnum		2	Active-layer detachment slides and subsequent retrogressive-thaw flow slides common on colluvial slopes (Cx) developed on this unit.
								1									
								2									
								3									
R	Bedrock	Cretaceous sand- [illegible]	[illegible]	Mainly prominent [illegible]	Generally freely [illegible]	0	No records of segregated ice, but [illegible]	0	Variable	-	0	[illegible]	Excess 7, Imp. to [illegible]	bare	bare	2	Carbonate rocks of Paleozoic age [illegible]
								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

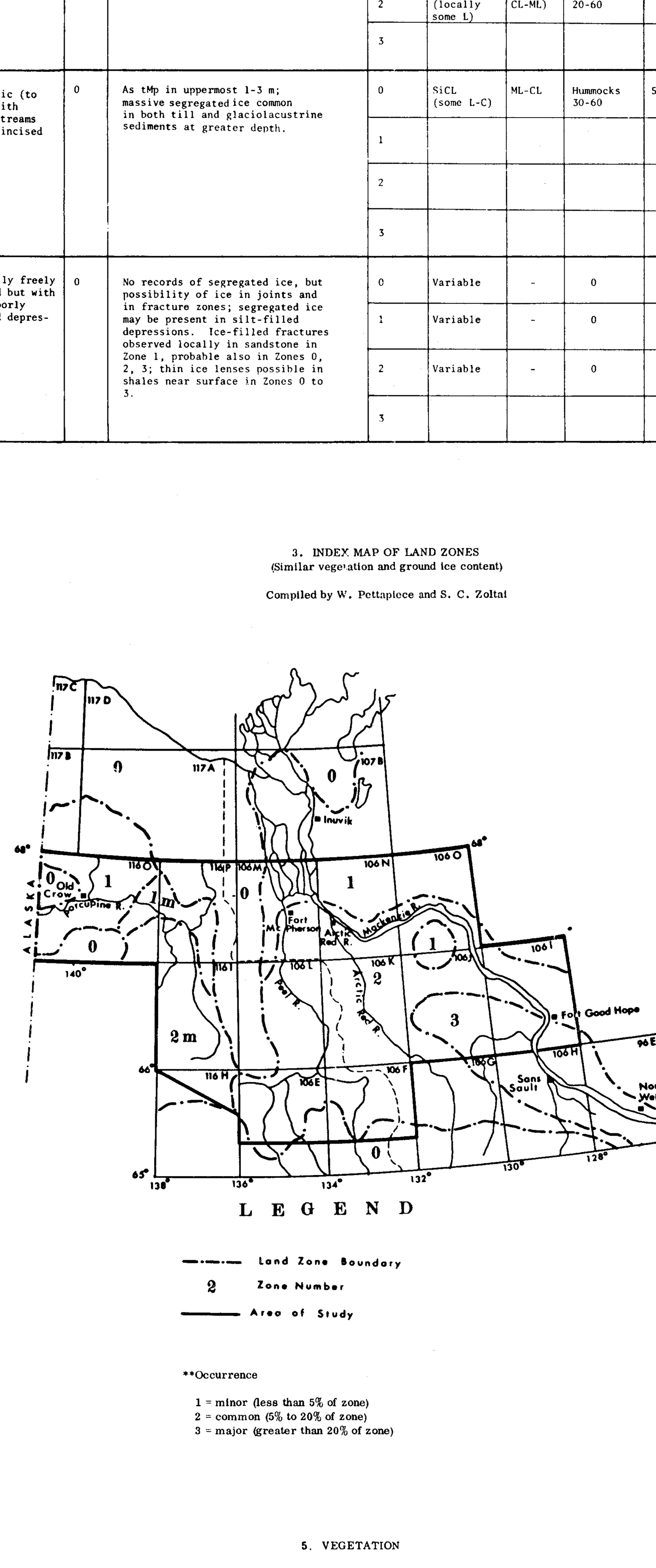
1. MAP UNIT DESIGNATION

[illegible]



2. INDEX MAP OF LAND ZONES

Compiled by W. Pettapiece and S. C. Zoltai



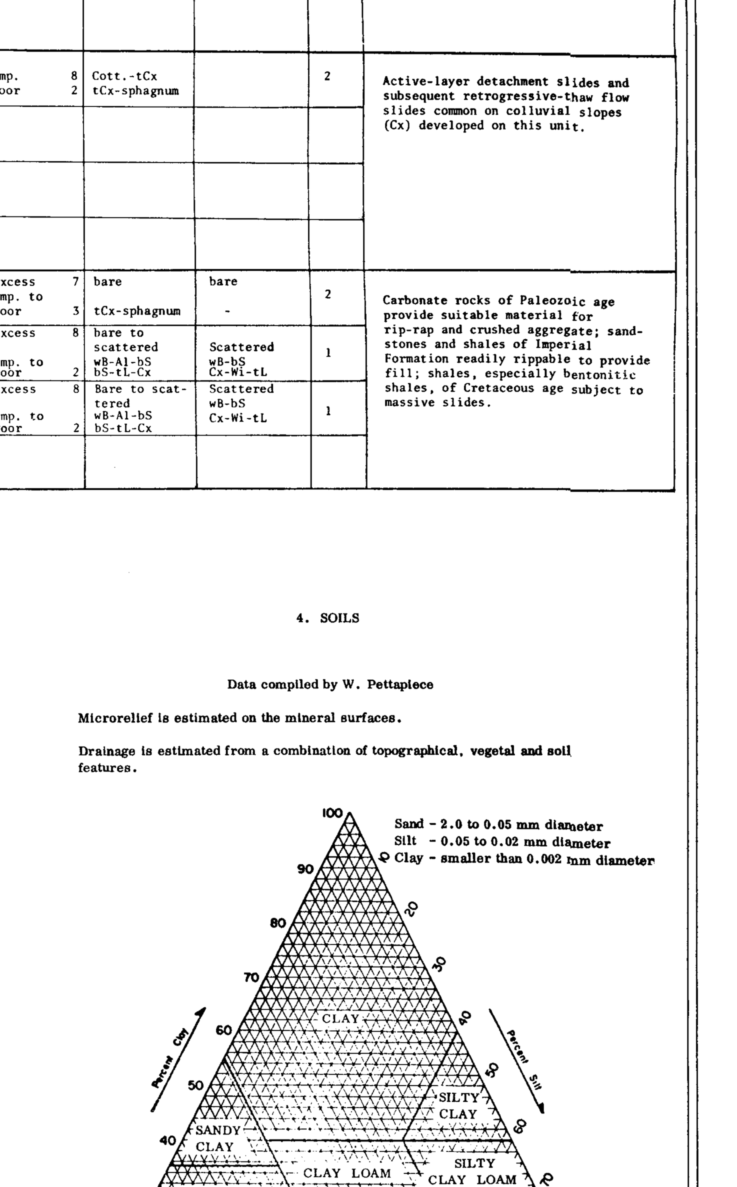
MAP SYMBOLS

[illegible]

4. SOILS

Data compiled by W. Pettapiece

[illegible]



U.S.D.A. TEXTURAL CLASSIFICATION

[illegible]

UNIFIED CLASSIFICATION

5. VEGETATION

Data compiled by S. C. Zoltai

[illegible]