INTERNATIONAL TOUR OF PERMAFROST AFFECTED SOILS

The Yukon and Northwest Territories of Canada

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ERRATA

Figure 8 (page 17). Figure 8C is upside down.

Table 3 (page 33). The depth of the Ofz horizon should be 35 to 59 cm.

Table 13 (page 63). C/N ratios should read Ck 40, Ckgj 35, Ckgjz 39.

Table 21 (page 73). In order for the data to refer to the correct horizons, the order of the horizons in the three parts of this table should be changed from Of, Om, Bmgjy, *Bgy, Ahy1, Ahy2*, Ohyz to Of, Om, Bmgjy, *Ahy1, Ahy2, Bgy*, Ohyz.
% >2 mm should be: Bmgjy 4%, Ahy1 3%, Ahy2 2%, Bgy 6% and Ohyz 2%.

Table 29 (page 92). The correct data for the physical analysis are as follows:

Physical Analysis											
Horizon	Fibre Content (%)		%	Part. Size Dist. (% <2 mm)				Bulk Den.	Moisture (%)		Texture
	Unrub.	Rub.	>2 mm	Sand	Silt	Clay	F-Clay	(g/cc)	1/3 atm	15 atm	
F	50	15	-					0.42	53.7	36.7	
Of	90	60	-							100.0	
Ohy	40	10	-					0.53	198.5	40.4	
Bmy			3	7.5	56.1	36.4	17.9	1.37	27.2	14.7	SiCL
Bmgjy			4	9.9	54.5	37.6	18.7	1.56	27.5	15.2	SiCL
Bgy			5	8.1	54.8	37.1	17.4	1.75	21.3	14.7	SiCL
Ohyz	25	10	-					0.39	113.1	51.3	
BCgz			6	9.8	48.5	41.7	20.8	1.79	22.8	20.9	SiC
Cz			11	9.3	47.0	43.7	16.2			14.1	SiC

Table 35 (page 110). % >2 mm should read: Bmk1 15%, Bmk2 20% and Bmk3 20%.
1/3 atm moisture % for the Bmk1 horizon should be 17.3.
Textures are: Bmk1 gL, Bmk2 L and Bmk3 vgL.

Page 120 Cy1 Horizon. The third sentence should read: *The loose distribution suggests considerable disturbance from surface ice crystal formation, successive freezing cycles, and surface wetting and drying.*

Table 40 (page 122). The pH for the F horizon is 4.9 (H_2O), 4.3 ($CaCl_2$).
The correct 1/3 and 15 atm moisture data are as follows:

Chemical and Physical Analysis		
Horizon	Moisture (%)	
	1/3 atm	15 atm
F	18.3	5.0
Cy1	12.8	2.9
BCy	9.3	2.8
Bmy	14.5	5.8
Cy2	12.9	4.4
Cy3	–	–

Plate 9 (page 159). The descriptions for Plates 9B and 9I should begin *In the...* and not *Iin the....*

Table 59 (page 173). Soil Classification: Can. should be Gleysolic Turbic Cryosol
U.S. should be Histic Pergelic Cryaquept.
Horizon designators should be changed from Cz1 to Czy1, from Ahbz to Ahbzy and from Cz2 to Czy2.
The total exchangeable cations (me/100g) should be: Om 34.2, Czy1 5.5, Ahbzy 7.7, and Czy2 6.7.

Appendix 3 (page 190). The definition for Fragmoidic should read: *Relatively densely packed, accommodated units, are not discrete but appear to be fused (united) at contact points, without coatings on or bridges between units. Similar prefixes as for granic can be used.*

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There's a land where the mountains are nameless,
  And the rivers all run God knows where;
There are lives that are erring and aimless,
  And deaths that just hang by a hair;
There are hardships that nobody reckons;
  There are valleys unpeopled and still;
There's a land – oh, it beckons and beckons,
  And I want to go back – and I will.

Robert Service

from The Spell of the Yukon

ACKNOWLEDGMENTS

A great number of people have assisted in a variety of ways in organizing the Canadian portion of this tour and preparing this guidebook. The Centre for Land and Biological Resources Research (CLBRR) of Agriculture Canada, the United States Department of Agriculture–Soil Conservation Service (USDA–SCS), the Inuvik Research Centre, and the Yukon Territorial Government contributed personnel, time, and financial and logistical support.

Researchers from a number of disciplines outside of soil science have contributed information or sections, and thus greatly enriched and broadened the scope of this guidebook. These people include S.R. Morison, Chief Geologist, Northern Affairs Program, Indian and Northern Affairs Canada, Whitehorse, Yukon, who reviewed the section on physiography and geology; C.R. Burn of the Geography Department, Carleton University, Ottawa, Ontario, who contributed the section on permafrost; A. Duk-Rodkin of the Geological Survey of Canada, Calgary, Alberta, who contributed part of the section on physiography and geology and the site description for Site 5; O.L. Hughes, formerly of the Geological Survey of Canada, Calgary, Alberta, who contributed part of the section on physiography and geology; L. Jackson of the Geological Survey of Canada, Vancouver, B.C., who contributed part of the section on physiography and geology, and; C. Kennedy of the Department of Renewable Resources, Yukon Territorial Government, Whitehorse, Yukon, who contributed information on vegetation for various sites.

Analytical services were provided by the CLBRR Laboratory in Ottawa and the USDA–SCS–NSSC Soil Survey Laboratory in Lincoln, Nebraska, U.S.A. Thin sections for micromorphology were prepared by Ray Guertin, CLBRR (Ottawa).

In addition to these people and agencies, several others have provided valuable assistance. Mike and Jenny Heydorf generously gave permission for the establishment of two sites on their farm in the Dawson City area of the Yukon. Logistical arrangements for the entire tour were made by Charlotte Mougeot. Gary White of the Inuvik Research Centre, Northwest Territorial Government, provided facilities and support during the preparation of the tour. Hugo Veldhuis, CLBRR (Winnipeg, Manitoba) and Dave Kroetsch, CLBRR (Ottawa) helped in the preparation of soil pits and in the cleaning up of the sites after the tour. Finally, special thanks are due to Marlene Tarnocai for her volunteer work in editing, inputting and organizing the guidebook manuscript.

PREFACE

The primary objective of this guidebook is to demonstrate the pedogenesis of permafrost-affected soils, and the related geomorphic and biological phenomena existing in the northern interior of the Yukon and the Mackenzie Delta regions of northwestern Canada.

The Top of the World and Dempster highways make it possible to undertake an integrated transect through this area, from the Yukon – Alaska border (latitude 64°N, longitude140°W) to the Inuvik area (latitude 68°N, longitude 133°W). The route crosses the northern Boreal, Subarctic and Arctic–Alpine ecological zones, where sites include both mineral and organic soils.

Pedological investigation in northern Canada goes back several decades, beginning with Leahy who, in 1943, carried out the first soil studies and soil survey north of 60°N latitude. This was followed by Tedrow and his associates, who worked in Arctic areas of Canada. Pedological work accelerated markedly during the early 1970's because of large-scale studies carried out in connection with energy development in the north. In conjunction with these projects, systematic soil surveys were conducted on large portions of both the western and eastern Arctic and Boreal regions. As a result, the amount of pedological information available increased rapidly and new concepts and approaches were developed, especially in relation to soil classification, soil genesis and soil mapping. These new approaches to Arctic soils were first introduced to the international soil science community in 1978, when a soil tour was held in this area in conjunction with the 11th Congress of the International Society of Soil Science (ISSS). This was followed by other international tours in 1983 and 1987 in which soil science played an important role. Information for a number of the sites presented in this guidebook has been drawn from these tours.

We are very pleased to conduct this tour and present this material to this distinguished international group of soil scientists. In this way, we can illustrate our approaches to the study and classification of permafrost-affected soils and share the beauty of our northern environment.

The authors.

ITINERARY FOR CANADIAN PORTION OF TOUR*

July 19 Opening and technical sessions: tour briefing and banquet in the evening.

– overnight Inuvik

July 20	Site 1:	km 4	Peat plateau	**detailed – monitored**
	Site 2:	km 36	Earth hummock	**detailed – monitored**
	Site 3		Delta alluvium	**detailed**

– overnight Inuvik

July 21	Site 4		Mackenzie River	point of interest
	Site 5:	km 30	Glacial limit	general
	Site 6:	km 14	James Creek *aufeis*	point of interest
	Site 7:	km 5	Solifluction	general
	Site 8:	km 0	Continental divide	point of interest
	Site 9:	km 425	Pediment site	**detailed**
	Site 10:	km 403	Arctic Circle	point of interest
	Site 11:	km 400.5	Mudboil site	**detailed**

– overnight Eagle Plain

July 22	Site 12:	km 366	Eagle Plain site	**detailed – monitored**
	Site 13:	km 322	Fire overview	point of interest
	Site 14:	km 259	Peel River view	point of interest
	Site 15:	km 174	Sulphur springs	general
	Site 16:	km 160–180	Tors	point of interest
	Site 17:	km 155	Calcareous soil	**detailed**
	Site 18:	km 115.5	Pingo	general

– overnight Dawson City

July 23	Site 19:	km 96.5	Ice-wedge polygons	general
	Site 20:	km 84	Frost mounds	general
	Site 21:	km 80	Glacial limit	point of interest
	Site 22:	km 77	Nonsorted circles	**detailed**
	Site 23:	km 74	Tombstone Mountain	point of interest

– overnight Dawson City

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* Tour route and site locations are shown in Figure 1. Sites 1–23 are located along the Dempster Highway (Sites 1 and 2 are measured from the junction of the Inuvik Airport road and the Dempster Highway; Sites 5–8 are measured from the N.W.T./Yukon border; Sites 9–23 are measured from the junction of the Dempster and Klondike highways), Site 24 is located near Dawson City, Sites 25–28 are located along the Klondike Highway, and Sites 29–32 are located along the Top of the World Highway (measured from Dawson City).

July 24	Site 24	Midnight Dome	point of interest
	Site 25	Heydorf farm	**detailed – monitored**
	Site 26	Placer mining	general

– overnight Dawson City

July 25	[MORNING FREE]		
	Site 27	Pleistocene paleosol	**detailed**
	Site 28	Aspect site	**detailed**

– overnight Dawson City

July 26	Site 29: km 4	Sunnydale view	point of interest
	Site 30: km 53	Tors	point of interest
	Site 31: km 102	Solifluction	point of interest
	Site 32: km 107	Sorted nets	**detailed**

– cross into Alaska in PM

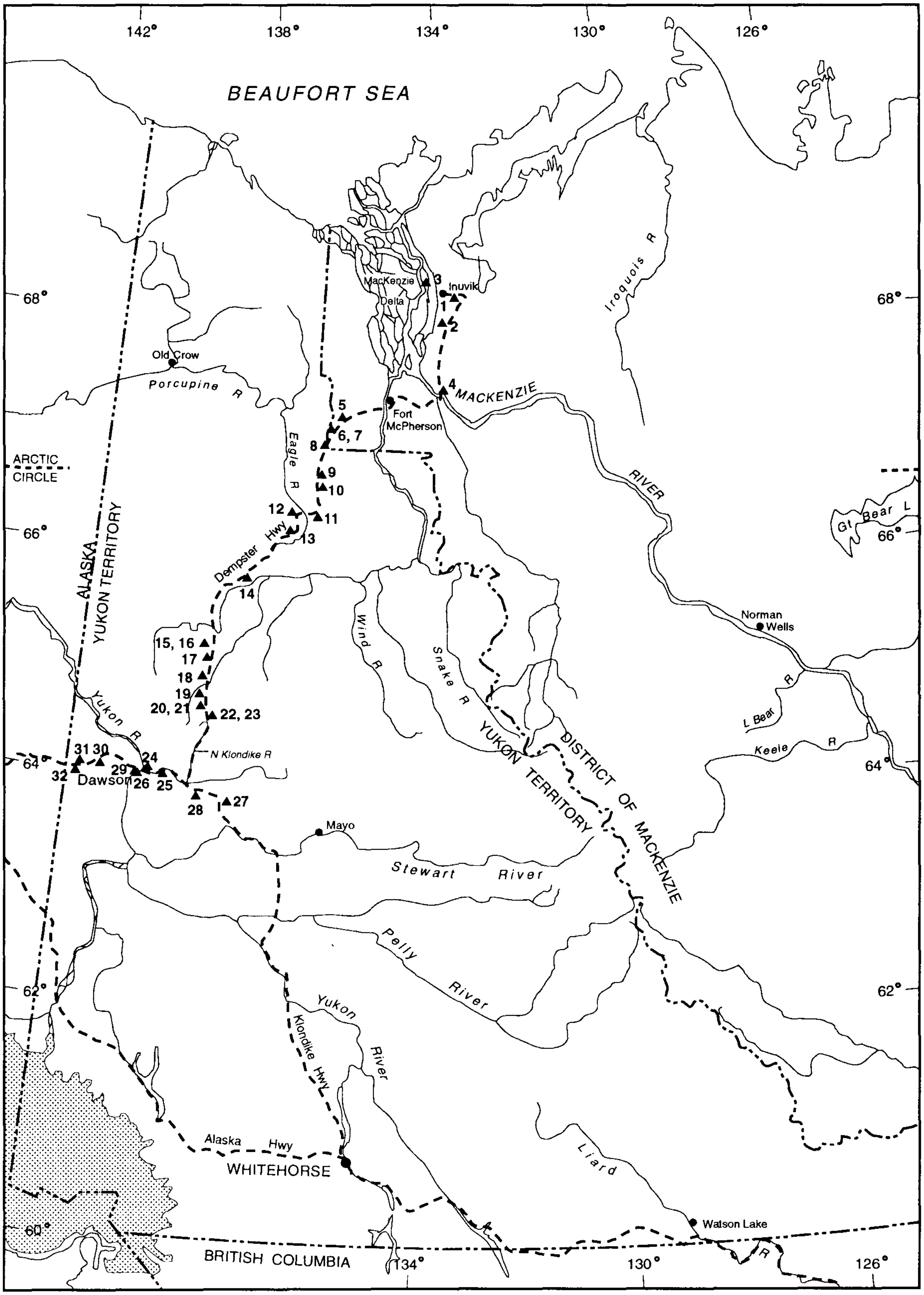

Figure 1. Map of tour route and site locations .

GENERAL DESCRIPTION OF THE AREA

PHYSIOGRAPHY AND GEOLOGY

O.L. Hughes,[1] A. Duk-Rodkin[2] and L. Jackson[3]

The physiography and geology of Canada consists, at the macroscale, of a core of Precambrian crystalline rocks partially overlain by younger sedimentary and volcanic rocks. The latter form many regions and subregions, the two most obvious being the Interior Plains, which are underlain by generally flat sedimentary rocks, and the Canadian Cordillera, an area of discontinuous fold mountains and plateaus. This guidebook includes parts of these regions as well as the Mackenzie Delta portion of the Arctic Coastal Plain.

The Interior Plains are underlain by flat Paleozoic, Mesozoic, and Tertiary sedimentary strata. The terrain consists of a series of lowlands, hills, and plateaus that rise gradually southward from the Arctic coast, reaching elevations of 1,000 m in central Alberta.

The Cordillera can be divided into three systems (Figure 2): an eastern system, composed almost entirely of folded sedimentary strata (Richardson Mountains, Porcupine Plateau, and Mackenzie Mountains); an interior system, composed of folded sedimentary, metamorphic, and volcanic strata, together with some flat volcanic rocks (British Mountains, Ogilvie Mountains, Yukon Plateau, and Selwyn Mountains) and; a western system, possessing plutonic and volcanic rocks and containing Canada's highest mountains, the St. Elias Range, culminating in Mt. Logan (6,050 m). Several east – west trending belts of relatively low terrain (the Yukon and Porcupine plateaus) separate the major mountain ranges.

The Arctic Coastal Plain is represented on the mainland of northwestern Canada by the Mackenzie Delta and the Yukon Coastal Plain (Figure 2). The former includes both the Holocene and Pleistocene deltas. The Mackenzie Delta (Holocene) is remarkable for its intricate pattern of channels and lakes, whereas the older Pleistocene delta is noted for its numerous pingos, many of which form outstanding features of the landscape. West of the Mackenzie Delta is the Yukon Coastal Plain, a gently sloping erosional surface cut in bedrock and mantled with a veneer of surficial sediments. The plain is characterized by lakes, lagoons, deltas, and alluvial fans formed by streams flowing from the nearby Richardson and British Mountains.

QUATERNARY GEOLOGY

A diverse Quaternary history characterizes the area of northwestern Canada treated in this guidebook. Parts of the area were glaciated by the northern Cordilleran Ice Sheet; other parts supported extensive montane glacial systems or were glaciated by the Laurentide Ice Sheet. Finally, large areas were never glaciated and, instead, display a wide range of Quaternary deposits and periglacial landforms.

Northern Yukon Territory and Mackenzie Delta

For convenience of description, the Yukon and adjacent parts of the western portion of the District of Mackenzie, Northwest Territories can be divided into six regions (Figures 2 and 3):

1. An area of southern and central Yukon, comprising the western slopes of the Selwyn Mountains, all of the Yukon Plateau, except for an elongate belt adjacent to the Alaska border, plus the Coast Mountains. This large area was subject to repeated advances of the Cordilleran Ice Sheet.
2. An area comprising the northeastern slope of the St. Elias Mountains, the adjacent Shakwak Trench, and a small part of the Yukon Plateau northeast of the Shakwak Trench. This area was subject to repeated advances of montane glaciers originating in the St. Elias Mountains.
3. The Wernecke Mountains and southern Ogilvie Ranges. These mountains were repeatedly affected by advances of montane glaciers that were independent of Cordilleran ice, although outlet glaciers of the latter may have spilled northward across the lowest passes in the Wernecke Mountains.
4. The Mackenzie Mountains. Virtually all of the major valleys of the Mackenzie Mountains were occupied repeatedly by glaciers that flowed eastward and northward, locally extending as piedmont glaciers beyond the mountain front.
5. The Interior Plains and adjoining areas to the west, including the lower slopes of the Mackenzie Mountains, Peel Plateau, Bonnet Plume Basin, the lower slopes of the Richardson Mountains, and the Yukon Coastal Plain. These areas lie within the maximum limit of Laurentide glaciation and, depending on location, were glaciated one or more times.

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[1] Formerly of the Terrain Sciences Division, Geological Survey of Canada.
[2] Terrain Sciences Division, Geological Survey of Canada, Calgary, Alberta.
[3] Terrain Sciences Division, Geological Survey of Canada, Vancouver, B.C.

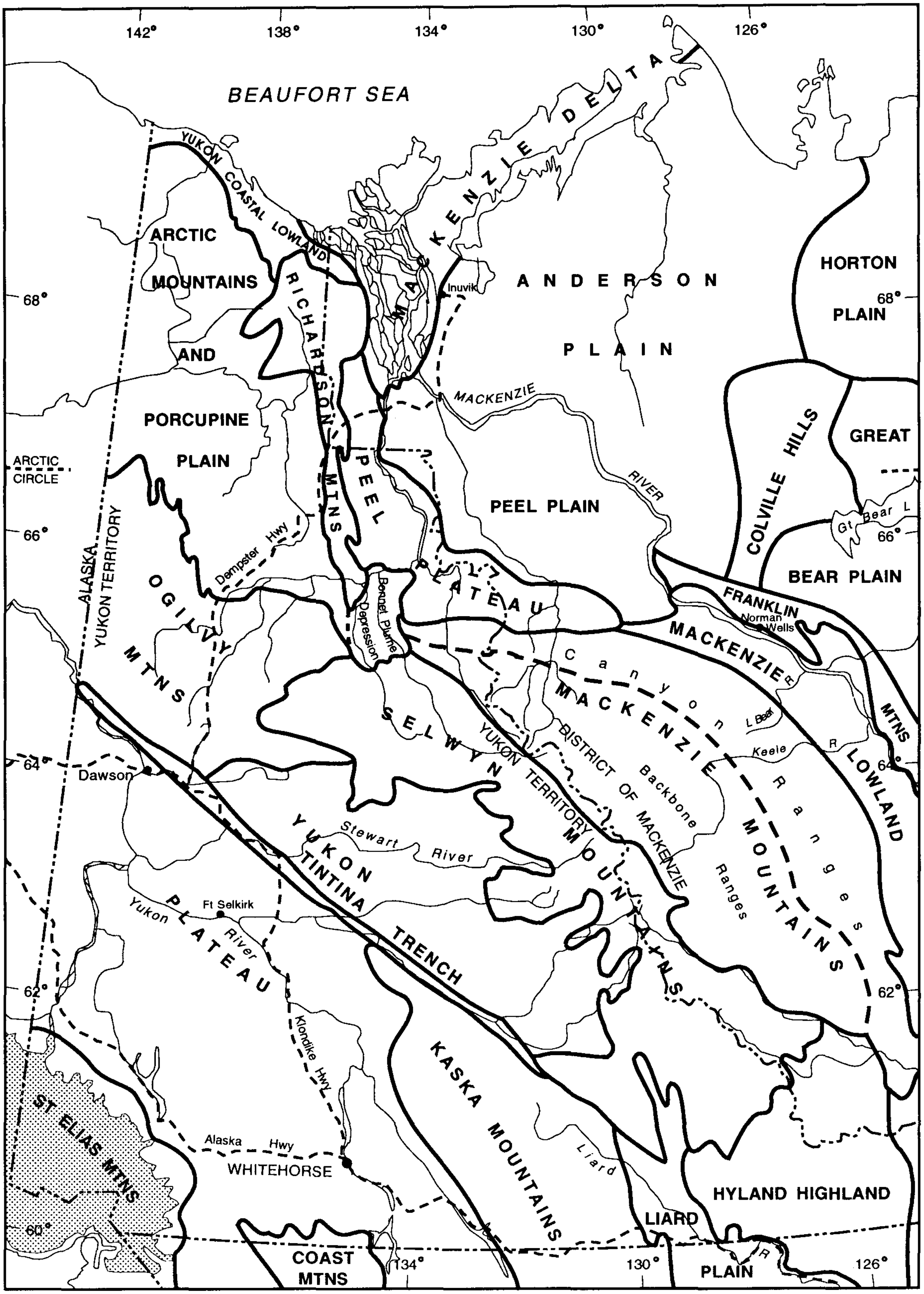

Figure 2. Physiography of the Yukon and adjacent Northwest Territories (after Bostock 1948, 1961 and 1970).

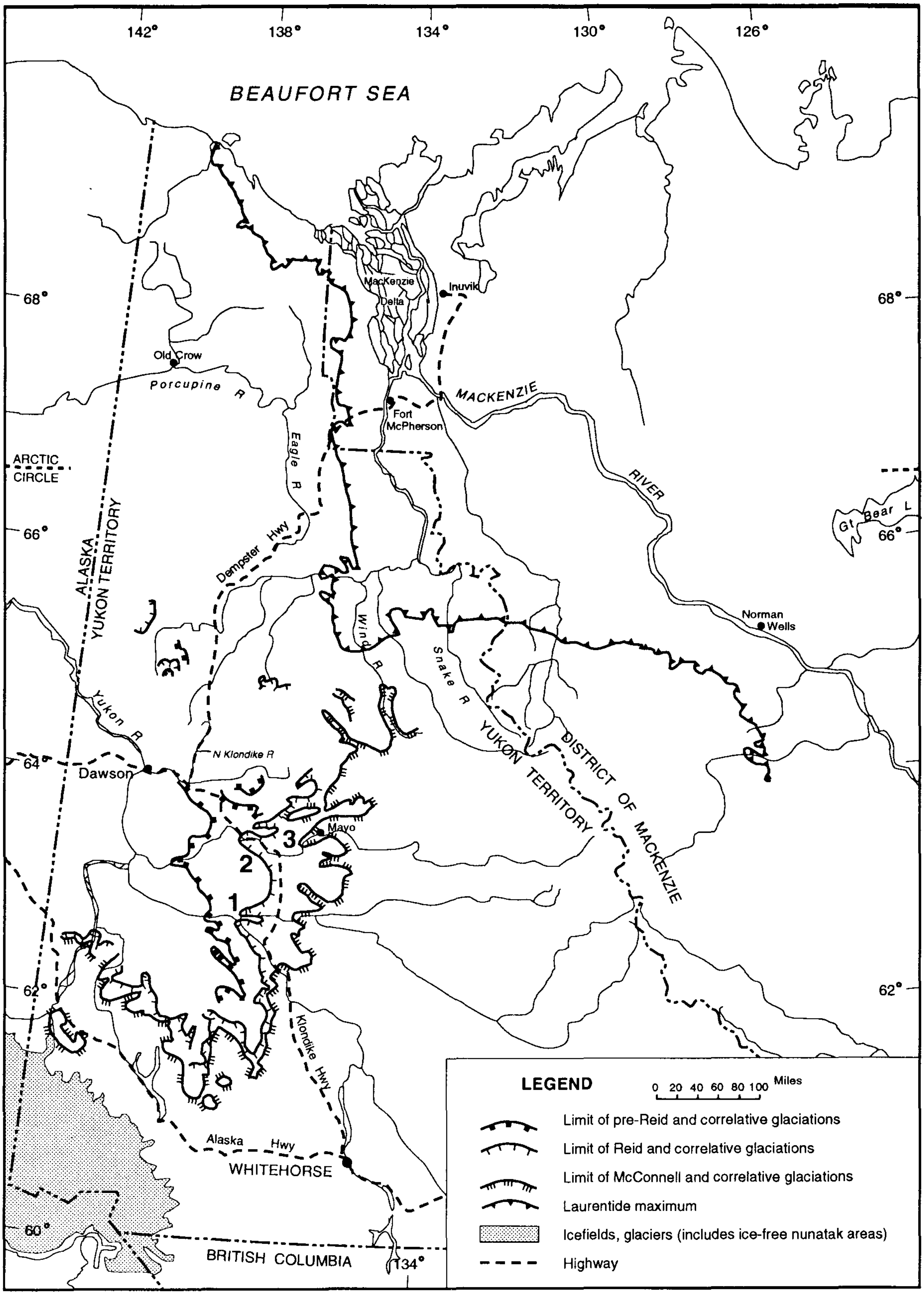

Figure 3. Map showing the glacial limits in northwestern Canada.

6. The unglaciated western and northern Yukon, comprising part of the Yukon Plateau, the northern Ogilvie Mountains, the Porcupine Plain and Plateau region, the Richardson Mountains, and the Arctic Ranges. This region is the eastern extremity of Beringia, a vast, generally unglaciated region extending westward through Alaska, that is the largest unglaciated area in Canada.

The field-trip route begins in the glaciated Mackenzie Delta region, then crosses the mainly unglaciated Richardson Mountains. We then follow the Dempster Highway southward through the unglaciated Porcupine Plain and Plateau region. The route crosses the montane-glaciated southern Ogilvie Mountains and then follows the Tintina Trench, on which the Cordilleran Ice Sheet left a variety of glacial sediments. The final Canadian tour sites, in the Dawson City area and the Klondike Plateau, were unglaciated during the Pleistocene.

Cordilleran Ice Sheet

Bostock (1966) inferred four advances of the Cordilleran Ice Sheet: Nansen (oldest), Klaza, Reid, and McConnell (youngest), with each successive advance being less extensive than the previous advance. Few glacial features remain from the Nansen and Klaza advances, and detailed ground studies are required outside the area mapped by Bostock to define precisely the limits of those advances. Ice-marginal features marking the limits of the Reid advance are moderately well preserved and those of the McConnell advance are very well preserved, permitting airphoto interpretation of their limits across much of the central Yukon (Figure 3; Hughes *et al.* 1969). Deposits of these glaciations are further distinguished by conspicuous differences in soil development (Tarnocai *et al.* 1985, Smith *et al.* 1986, Foscolos *et al.* 1977). (See Soils section)

During successive advances of the Cordilleran Ice Sheet, ice moved generally westward and northwestward. The topography of the deeply dissected Yukon Plateau controlled local patterns of ice movement to produce highly irregular ice margins. Near the limits of successive glaciations, numerous peaks and plateaus were isolated as nunataks.

Montane glaciers of the southern Ogilvie Ranges. At least three glaciations, termed simply 'old', 'intermediate', and 'last' (Vernon and Hughes, 1966), have been distinguished in the southern Ogilvie Ranges. During one or possibly more old glaciations, montane glaciers extended northward and southward from the axis of the ranges. Montane glaciers had a similar pattern during the intermediate glaciation, but fell short of the early advance. The last glaciation was very restricted, with glaciers for the most part occupying tributary valleys and only locally extending into and along major north- or south-draining valleys.

In the Tintina Trench east of Dawson, the Flat Creek beds (McConnell 1905) consist of lacustrine sediments, outwash gravel, and till 200 m or more thick. In addition, outwash gravel, the Klondike River gravels, or Klondike gravels of McConnell (1907) lie on bedrock terraces along the lower reaches of the Klondike River. The origin of these gravels is controversial, but they are thought to be either the product of one or more old advances of montane glaciers in the southern Ogilvie Ranges, which extended to and across the trench, or the product of the Cordilleran Ice Sheet, which extended into the trench from the east..

Deposition of drift was followed by incision of the Klondike River and the lower reaches of tributaries, such as the North Klondike River, to near present levels, some 200 m below the surface of the early drift. Consequently, moraines and other terminal features of the next (intermediate) advance, which in the North Klondike Valley reached the east margin of the Tintina Trench, are inset below the surface of the old drift. There, ice of the intermediate glaciation appears to have reached its maximum extent, then retreated upvalley. In the north-draining Blackstone Valley, two moraines of intermediate age (Ricker 1968) suggest a halt or a readvance following retreat from the maximum position.

In terms of the degree of preservation of the geomorphology of the surfaces, drift of the intermediate and last glaciations corresponds closely to Reid and McConnell drift of the Cordilleran Ice Sheet. Drift of the old glaciation(s) (Flat Creek beds) resembles pre-Reid drift of the Cordilleran Ice Sheet with respect to a lack of readily discernible glacial features and the development of Brunisolic soils with thick Bt horizons.

Correlation and chronology. The name "Selkirk volcanics" was given by Bostock (1936) to a complex of basaltic lava flows, pillow basalts, pillow breccias and altered tuffs that locally contain exotic pebbles. They occur principally in the vicinity of Fort Selkirk, at the confluence of the Yukon and Pelly rivers (Figure 3, Location 1). These basaltic volcanics, which were partly erupted beneath glacial ice during the last of the pre-Reid glaciations, are interstratified with glacial and nonglacial sediments (Owen 1959a and b; Jackson *et al.* 1990). They, and their interstratified sediments, document the late Tertiary/early Pleistocene glacial record and provide correlation and chronological information on the Cordilleran glaciation of the central Yukon.

Glacial deposits from the older pre-Reid glaciation are exposed between the upper and lower basalts, along with interglacial or interstadial sediments, at two sites along the Yukon River in the area of Fort Selkirk (Figure 2). The lower basalts, which are magnetically reversed, have been radiometrically (K–Ar) dated at 1.60±0.08 Ma (Westgate 1989). The older pre-Reid till and outwash is succeeded by 3–4 m of fine sands and silts, informally referred to as the Fort Selkirk interglacial sediments, which are in turn capped by the upper basalts. The sands and silts, which are interstratified at several localities with the Fort Selkirk Tephra (Naeser *et al.* 1982), a fine silicic tephra ranging up to 20 cm in thickness in the area, represent an undefined period of ice-free conditions between the older and younger pre-Reid glaciations in the Fort Selkirk area. The age of the older pre-Reid till and outwash is constrained by the age of the underlying lower basalt and by the fission track and K–Ar ages of 1.01±0.17 Ma to 1.54±0.27 Ma (Westgate 1989) most recently reported for the overlying Fort Selkirk Tephra. The ages determined for this tephra are close to the range of ages determined for the overlying basalts, which form impressive pallisades along the Yukon River from Pelly Ranch to approximately 12 km downstream from Fort Selkirk, and agree with the known reversed polarity of the paleofield during this part of the Matuyama Chron (Mankinen and Dalrymple 1979, Shackleton *et al.* 1990). They are also younger than the ca 1.6 Ma age reported for the lower basalts. Thus, through these stratigraphic relationships, radiometric ages date the younger pre-Reid glaciation at between 1.0 and 1.47 Ma (Naeser *et al.* 1982; Westgate 1989).

There are no dates directly relevant to the beginning of the Reid advance. Organic silt on the valley floor of Hunker Creek, a tributary of the Klondike River upstream from Bonanza Creek, has been radiocarbon dated to greater than 53,900 years B.P. (GSC-527, GSC VIII). Because of poor counting characteristics, the fission-track age of Dawson tephra from within the organic silt could be stated only as probably younger than 120,000 years B.P. (Naeser *et al.* 1982). These ages are minima for the incision of the Klondike drainage system, that preceded the intermediate glaciation of the southern Ogilvie Ranges. Incision may been much earlier.

The Cordilleran Ice Sheet began retreating from the Reid limit (Figure 3, Location 2) more than 42,900 years ago (GSC-524, GSC VIII). This age was obtained from wood in the Stewart tephra, near the base of organic silt lying above Reid drift (Hughes *et al.* 1969). Wood from beneath till of McConnell age (Figure 3, Location 3), dated to greater than 46,580 years old, is probably also of post-Reid age (Hughes *et al.* 1969).

Laurentide Glaciation

The Laurentide Ice Sheet reached its late Wisconsinan, and all-time, maximum in northwestern Canada as early as ca 30 ka B.P. Two radiocarbon ages of 36,900±900 years B.P. (GSC-2422) and 34,200±120 years B.P. (TO-124; Schweger and Matthews 1992) from sub-till sediments, document the late Wisconsinan age of this advance (Hughes *et al.* 1981, Duk-Rodkin and Hughes 1991). The Laurentide Ice Sheet margin reached up to 1500 m in elevation in the area of Keele River, blocking east-flowing drainage along hundreds of kilometres of mountain front. Diverted drainage cut channels, hundreds of metres deep, through the Canyon Ranges of the Mackenzie Mountains. These waters emptied into a large proglacial lake along the ice sheet margin in the Bonnet Plume Depression. An annual flow of water 2.5 times that of the present-day Mackenzie River spilled northward from this lake via Eagle River. This diversion, along with blockage of McDougall Pass by the Laurentide Ice Sheet, inundated the Bell, Bluefish and Old Crow basins, creating lakes many thousands of square kilometres in extent. Radiocarbon ages of 32,400±770 years B.P. (GSC-952) and 31,400±660 years B.P. (GSC-2739) provide maximum dates for ponding. Radiocarbon dates on gravel sequences along the Porcupine River in Alaska (Thorson and Dixon 1983) indicate that waters were spilling into this river system shortly after 31 ka B.P. Late Pleistocene megafauna roamed around these lakes (Morlan 1986) and perhaps by 25–15 ka B.P. so did their human predators (Cinq-Mars 1979).

The late Wisconsinan climax of the Laurentide Ice Sheet along the Mackenzie and Richardson mountains, ca 30 ka B.P., means that the "ice-free corridor" closed 12 ka earlier north of 60°N than it did farther south. It remained blocked until well into deglaciation, a period of up to 19 ka, as will be explained subsequently. The Mackenzie Mountains themselves, however, remained unglaciated until the formation of the Cordilleran Ice Sheet and the Richardson Mountains were never glaciated.

Following its late Wisconsinan maximum, the Laurentide Ice Sheet had two significant readvances. The older (Katherine Creek Phase) was synchronous with the maximum of the Cordilleran Ice Sheet, which is known to have climaxed after 24 ka B.P. in the Yukon. The younger (Tutsieta Lake Phase), dated at ca 13 ka B.P. (Hughes 1987), was the last advance before the "ice-free corridor" opened east of the Richardson and Mackenzie mountains.

In the Mackenzie Mountains, an icecap along the continental divide (the Yukon/N.W.T. boundary), and smaller satellite icecaps on isolated high peaks and small mountain ranges to the east, expanded after 24 ka B.P. Valley glaciers extended partly, or completely, across the northern and central Mackenzie Mountains, where they locally coalesced with the Laurentide Ice Sheet, which was stagnating in places at the close of the Katherine Creek Phase. This blocked the southward movement of game animals and people through the Mackenzie Mountains (Duk-Rodkin and Hughes 1991, 1992).

A succession of ice marginal channels formed as the Laurentide Ice Sheet retreated eastward from the Richardson and Mackenzie mountains. Following the Katherine Creek Phase, drainage along the Mackenzie Mountains was no longer diverted into the Old Crow, Bluefish and Bell basins, but followed the retreating margin of the Laurentide Ice Sheet into the Arctic Ocean. Radiocarbon ages associated with ice marginal lakes and re-establishment of formerly dammed river channel systems document the opening of the "ice-free corridor" (Duk-Rodkin and Hughes 1991). These dates indicate that the Peel River (Tutsieta Lake Phase) was re-established ca 13 ka, the Arctic Red River and Glacial Lake Travaillant ca 12 ka, and the Ramparts River and Glacial Lake Ontaratue and the Mountain River and Glacial Lake Mackenzie between ca 11.5 and 11.2 ka B.P. The Laurentide Ice Sheet retreated completely from the Mackenzie Mountains and the "ice-free corridor" opened along the western limit of the Interior Plains by the time of the Kelly Lake Phase of the Laurentide Ice Sheet, which is dated at between ca 9.6 ka B.P. and 11.5 ka B.P. (Hughes 1987). This opened the "ice-free corridor" in the Interior Plains along the eastern slopes of the Mackenzie Mountains.

CLIMATE

The climate of northwestern Canada is continental, with long, very cold winters and short, cool to warm, summers. To the north, the summers become cooler and shorter, but the winter temperature does not change significantly. The warm summers of the Yukon interior and the Mackenzie Valley offer a marked contrast to comparable latitudes eastward in Canada. Most of the area is forested and falls within the humid microthermal (Dfc) of the Koppen System, with a tundra climate (ET) occurring beyond the Arctic tree line, in the interior and along the Beaufort Sea coastal area.

THE MACKENZIE BASIN

The Mackenzie Basin has a continental climate characterized by a wide range of temperatures from summer to winter. The long winters are intensely cold; the summers are relatively warm (Figure 4; Table 1). The Inuvik area has a continental climate, but does not have the temperature extremes exhibited further inland (cf. Fort Good Hope). Although the three summer months have mean temperatures near or above 10°C, the total heat accumulation is low and frost can occur in all months (Burns 1973). The extreme maximum and minimum temperatures recorded at Inuvik are 31°C and -57°C, respectively. Precipitation in Inuvik is 260 mm (174 cm snow) and it is slightly higher in the middle part of the Mackenzie Basin (Figure 4; Table 2).

Tuktoyaktuk, on the coast, has a more maritime climate, with slightly warmer winter temperatures and a much cooler summer. Although it lies 80 km beyond the tree line, the mean July temperature is about 10°C. The temperature extremes recorded at Tuktoyaktuk are 28°C and -50°C. Along the Arctic coast, precipitation is quite low (Tables 1 and 2; Figure 4), but fog is very common during the summer.

NORTHERN YUKON

In the northern part of the Yukon mean annual temperatures range from -5° to -10°C (Figure 4; Table 1). July is the warmest month with mean monthly temperatures ranging from 14° to 16°C in the valley floors. January is the Yukon's coldest month, except along the Arctic coast, where February is the coldest. The mean monthly temperatures in January are -28° to -32°C. Official extreme temperatures range from 36.1°C at Mayo on June 14, 1969 to -62.3°C at Snag on February 3, 1947.

The mean annual precipitation in the northern Yukon ranges from 200 to 300 mm, of which almost half is snow (Figure 4; Table 2). The mountainous nature of the terrain greatly affects the amount of precipitation. Low precipitation areas lie in the rain shadow of the Coast – St. Elias, Selwyn and Ogilvie mountains, and along the Arctic coast. The heaviest precipitation occurs along the windward sides, the southern and western slopes, of these same mountains. Winds are generally light, except over the southwestern Yukon and near the Arctic coast, where some high winds can occur.

Table 1. Mean monthly, maximum and minimum temperatures at selected climate stations in northwestern Canada (Atmospheric Environment Service 1982).

Station	Temp. Parameter	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dawson City	Mean (°C)	-28.6	-23.0	-14.1	-1.8	-7.8	13.9	15.5	12.7	6.4	-3.2	-16.5	-25.3	-4.7
	Max. (°C)	-24.9	-17.9	-7.1	5.2	14.7	21.0	22.2	19.0	11.7	0.2	-13.3	-21.8	0.7
	Min. (°C)	-32.7	-27.6	-21.1	-8.8	0.9	6.7	8.8	6.3	1.2	-6.8	-19.8	-28.9	-10.1
Mayo	Mean (°C)	-26.7	-19.6	-11.3	-0.8	7.7	13.3	14.7	12.1	6.4	-2.1	-15.7	-23.3	-3.8
	Max. (°C)	-21.5	-13.4	-3.9	5.7	14.4	20.6	21.9	16.8	12.3	2.3	-11.3	-18.3	2.3
	Min. (°C)	-31.9	-25.8	-18.9	-7.4	0.9	6.1	7.6	5.1	0.6	-6.4	-20.2	-28.3	-9.9
Old Crow	Mean (°C)	-31.7	-30.0	-23.3	-11.7	-1.1	10.6	14.4	8.9	2.2	-8.3	-21.7	-30.6	-10.0
	Max. (°C)	-27.8	-25.6	-17.8	-5.6	3.9	17.2	21.1	15.0	6.7	-3.9	-17.8	-26.7	-5.0
	Min. (°C)	-36.1	-34.4	-28.3	-18.3	-6.7	3.3	8.3	3.3	-2.8	-12.8	-26.1	-33.9	-15.6
Fort Good Hope	Mean (°C)	-31.0	-28.8	-20.5	-9.4	3.8	13.2	15.9	12.7	5.1	-5.4	-20.2	-27.3	-7.7
	Max. (°C)	-26.9	-24.3	-14.4	-2.6	9.8	19.6	22.3	18.9	10.2	-1.6	-16.4	-23.2	-2.4
	Min. (°C)	-34.9	-33.1	-26.6	-16.2	-2.2	6.7	9.6	6.4	0.0	-9.2	-24.1	-31.3	-12.9
Fort McPherson	Mean (°C)	-30.5	-28.5	-22.7	-11.5	1.1	11.4	14.9	11.5	3.7	-7.7	-21.0	-26.8	-8.8
	Max. (°C)	-26.2	-23.9	-16.7	-5.0	6.3	16.9	20.2	16.3	7.5	-4.5	-17.1	-22.8	-4.1
	Min. (°C)	-34.7	-33.0	-28.6	-17.9	-4.3	5.9	9.5	6.6	-0.2	-10.9	-24.8	-30.8	-13.6
Inuvik	Mean (°C)	-29.0	-29.2	-23.6	-14.4	-0.8	9.7	13.2	10.2	2.7	-7.2	-20.4	-26.8	-9.6
	Max. (°C)	-24.1	-23.9	-17.7	-7.9	3.9	16.0	19.2	15.5	6.8	-3.8	-16.5	-22.1	-4.6
	Min. (°C)	-34.5	-35.0	-30.0	-21.2	-5.7	3.7	7.4	5.0	-1.3	-10.7	-24.7	-32.1	-14.9
Tuktoyaktuk	Mean (°C)	-27.2	-29.2	-24.9	-16.9	-4.6	-4.7	10.3	8.7	2.3	-6.9	-19.3	-25.2	-10.7
	Max. (°C)	-23.6	-25.6	-21.5	-12.7	-1.1	9.1	14.9	12.2	4.6	-4.5	-16.2	-21.8	-7.2
	Min. (°C)	-30.8	-32.7	-28.2	-21.1	-8.2	0.2	5.8	5.2	0.0	-9.4	-22.4	-28.5	-14.2

Table 2. The precipitation and snowfall at selected climate stations in northwestern Canada (Atmospheric Environment Service 1982).

Station	Precip. Parameter	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dawson City	Total (mm)	19	16	13	9	22	37	53	51	28	27	26	27	328
	Snow (cm)	19	16	13	7	2	–	–	tr	2	20	26	27	132
Mayo	Total (mm)	22	15	10	8	19	32	44	42	29	25	25	23	294
	Snow (cm)	22	15	10	7	2	–	–	–	2	18	25	23	123
Old Crow	Total (mm)	8	5	8	10	13	25	33	38	20	20	13	10	203
	Snow (cm)	8	5	8	10	5	tr	tr	tr	3	20	13	10	81
Fort Good Hope	Total (mm)	16	11	11	11	14	33	41	48	32	26	22	19	284
	Snow (cm)	16	11	11	9	7	tr	–	tr	6	23	22	19	124
Fort McPherson	Total (mm)	22	21	24	22	15	23	27	39	28	50	40	30	344
	Snow (cm)	22	21	24	22	14	tr	0	tr	11	49	40	30	234
Inuvik	Total (mm)	20	10	17	14	18	13	34	46	21	34	15	19	260
	Snow (cm)	22	12	18	15	14	2	tr	4	11	35	19	22	174
Tuktoyaktuk	Total (mm)	5	5	4	5	7	13	22	29	14	13	5	8	130
	Snow (cm)	5	5	4	5	4	3	tr	tr	4	12	5	8	56

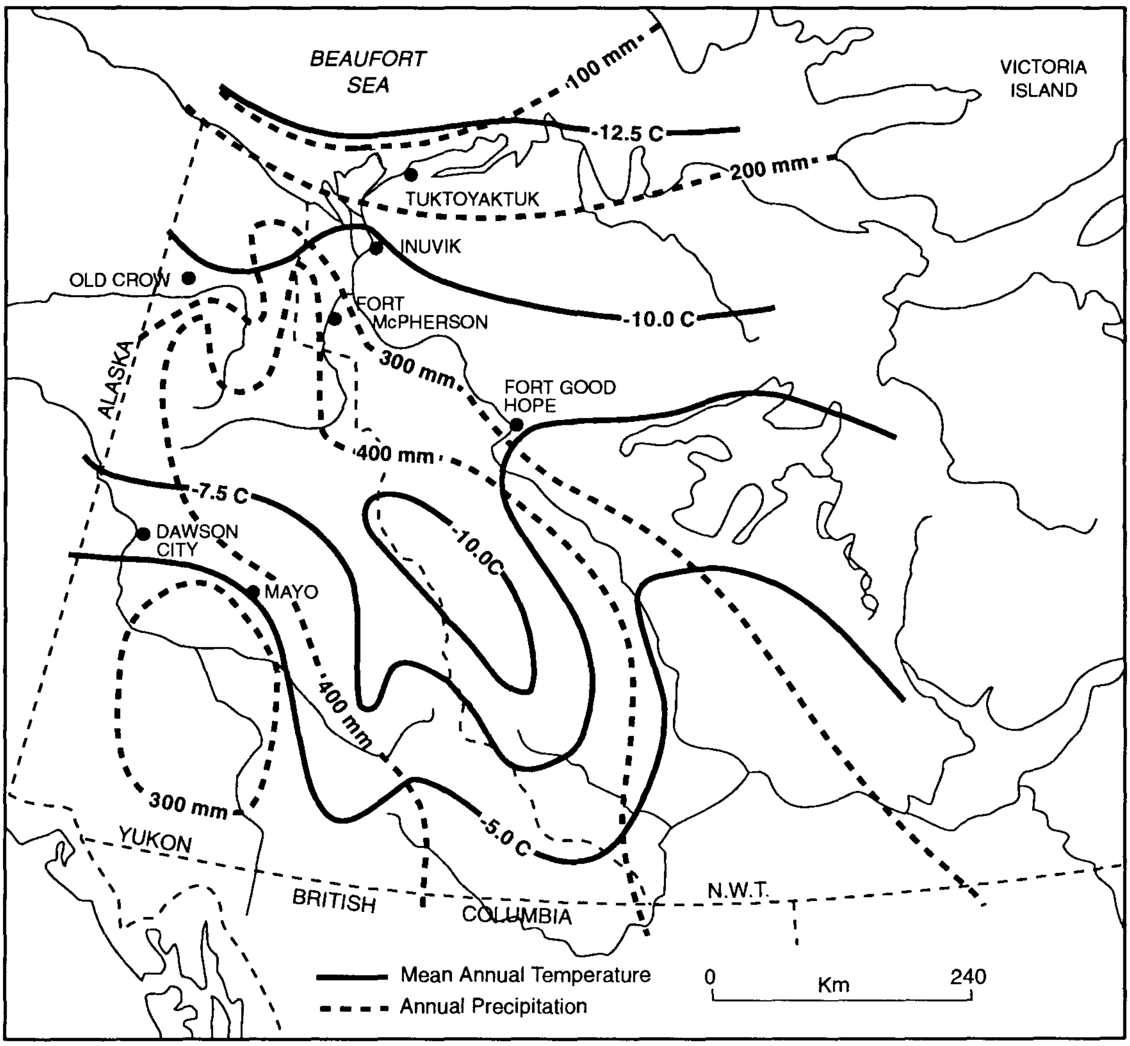

Figure 4. Distribution of mean annual air temperatures and precipitation in northwestern Canada (Burns 1973).

SOILS

All soils of northern Canada are characterized by a cold soil climate and, in most cases, by the presence of permafrost. Cryosols dominate northern Canada and are associated with Brunisols and Organic soils in the southern part of the area. Some Luvisols occur in the upper Mackenzie River – Liard River area and in the southern Yukon Territory. These soils are classified according to The Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987). The correlation of this classification with the U.S. Taxonomy and the F.A.O. soil classification is found in Appendix 1.

DISTRIBUTION IN THE PERMAFROST REGIONS OF CANADA

The distribution of soils in the permafrost regions of Canada is summarized by Tarnocai (1978) and Tarnocai and Smith (1992). This section is an excerpt from this work.

Cryosols are mainly associated with peat deposits (Organic Cryosols) in the southern part of the Discontinuous Permafrost Zone (Widespread and Scattered Permafrost Zones, Figure 9). Organic soils (Mesisols), which are very common in this area, are found mainly on fen peatlands. The mineral soils are dominantly Brunisols, with Eutric Brunisols in the west and Dystric Brunisols in the Canadian Shield area to the east.

In the rest of the Discontinuous Permafrost Zone, Cryosols are the common soils on both mineral and organic materials. On medium- and fine-textured materials, permafrost is near the surface and the soils are affected by cryoturbation (Turbic Cryosols). On coarse-textured materials (sand and gravels), Eutric and Dystric Brunisols still occur.

The Continuous Permafrost Zone (Figure 9) is dominated by Cryosols. Minor amounts of Brunisols may occur in coarse-textured materials in the extreme south, but elsewhere only Cryosols are found. Turbic Cryosols are the dominant soils in fine-textured and loamy materials, where they are associated with strong cryoturbation and various types of patterned ground. Static Cryosols occur mainly in coarse-textured materials, whereas Organic Cryosols are associated with peatlands.

DISTRIBUTION IN NORTHWESTERN CANADA

The distribution of soils in northwestern Canada is shown in Figure 5.

The lower Mackenzie River valley and the Pleistocene coastlands are dominated by Turbic Cryosols. The topography of these areas is irregular in the Arctic Red River and Inuvik areas, gradually becoming flatter northeastward to the coast. Coarse-textured deposits, especially along the Arctic coast, are associated with Static Cryosols. In the forested region south of Inuvik, however, such deposits are rare and are associated mainly with Brunisols.

Soils in the Mackenzie Delta are Static Cryosols and Regosols, all of which have developed on recent alluvium. Specific soil types are related to elevation above the distributary channels. The sequence of soils, permafrost, and vegetation from the river channel to the higher portion of the delta follows a regular pattern. Low areas adjacent to the river channels are unfrozen, and are associated with Gleysols and with vegetation belonging to the Equisetum Association. This area is succeeded by a slightly higher and better drained area that is associated with Regosols and with vegetation belonging to the Salix–Equisetum Association. Both areas are subject to annual spring flooding. Above the main flood plain, soils are perennially frozen Regosolic Static Cryosols associated with vegetation belonging to the Alnus–Salix and Picea Associations. The latter occurs only south of the Arctic tree line.

Organic soils developed on peat materials are common in the Mackenzie Valley (Zoltai and Tarnocai 1975). The term "organic soils" refers to all soils that include more than 40 cm of peat; they may be classified in either the Organic Cryosol Great Group (as Organic Cryosols) or the Organic Order (as Organic soils), depending on the presence or absence of perennially frozen conditions within 1 m of the surface. South of the Arctic tree line, in the lower Mackenzie River valley, Organic Cryosols are associated with peat plateaus and a palsa type of peatland. These features develop mainly from moderately-decomposed woody peat or woody peat underlain by sedge peat. North of the Arctic tree line, Organic Cryosols occur only in association with lowland polygons, both the high- and low-centered types, and are composed mainly of sedge peat with some sphagnum peat (Tarnocai and Zoltai 1988).

The Eagle Plain is dominated by Cryosols, with Turbic Cryosols being the most common. Most of the Turbic Cryosols are associated with earth hummocks.

The Ogilvie and Richardson mountains are dominated by Cryosols. Some Brunisols are found on well-drained, coarse-textured materials. On calcareous colluvium, especially on south-facing slopes of the Ogilvie Moun-

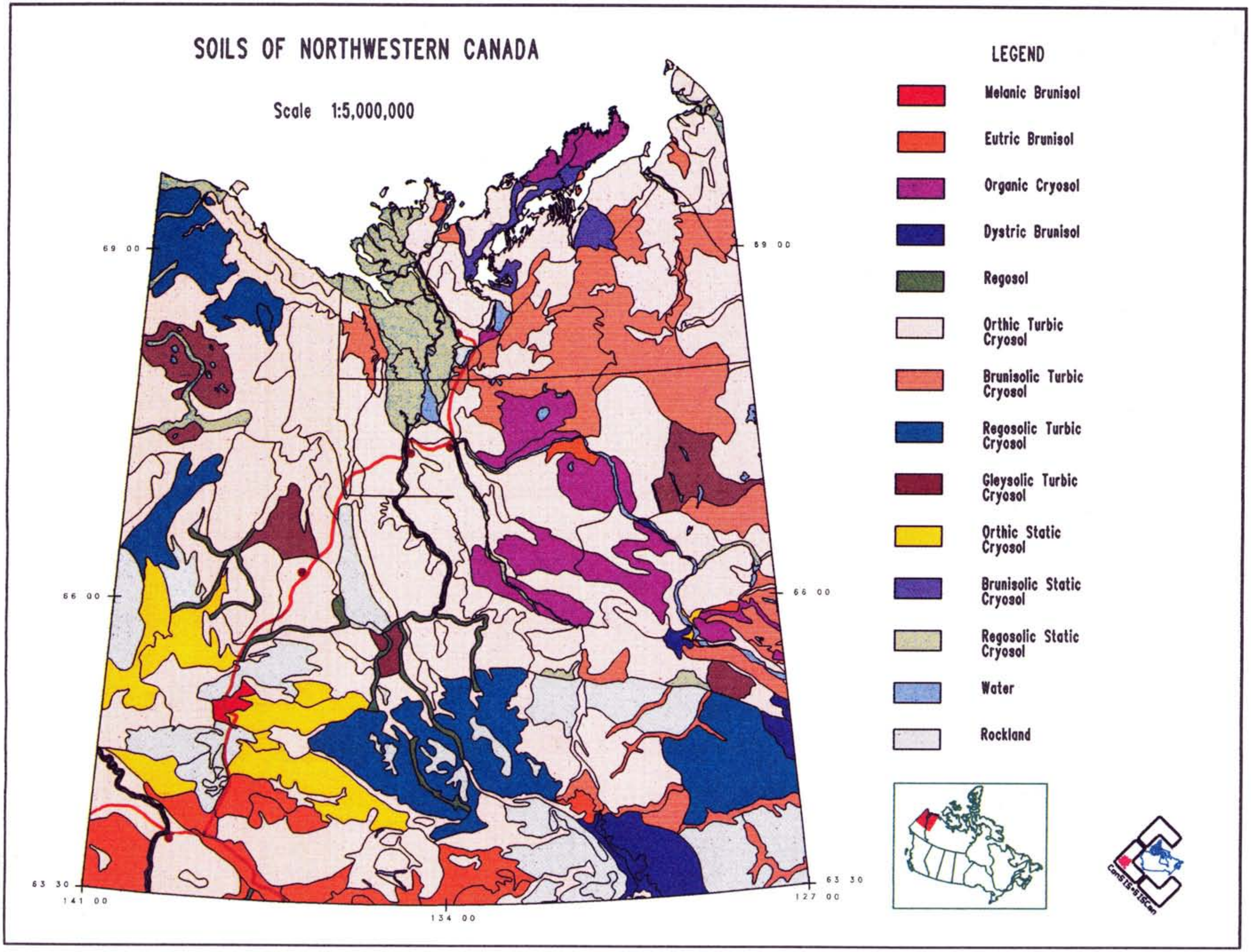

Figure 5. Distribution of soils in northwestern Canada.

tains, Regosols are found in association with minor amounts of Brunisols. Various patterned-ground types are common in these areas.

The Yukon Plateau (Figure 2, Dawson City area) is dominated by Brunisols and Cryosols. Because much of this area was not glaciated, the more stable upland surfaces often have soils with deeply weathered, well-developed Bt horizons. Most of these paleo Luvisols are capped with postglacial loess on which Brunisolic soils have developed (Tarnocai 1987a, b and c, 1990; Tarnocai *et al.* 1985; Tarnocai and Schweger 1991). Because of the strongly dissected nature of the plateau, there are marked microclimatic variations, depending on aspect. Steep, north-facing slopes support an open black spruce forest and have Cryosolic soils, often with a significant thickness of surface peat. On the other hand, Brunisolic soils have developed on south-facing slopes and these areas are most commonly associated with aspen or mixed aspen and white spruce forest.

Areas above the tree line are dominated by Cryosols and bedrock. Some of the soils are associated with well-developed patterned ground, but these features do not appear to be active at this time and are probably relict features from a cooler past. Thick organic accumulations (peat deposits) are extremely rare in the unglaciated Yukon Plateau because of the well-developed drainage systems. They occur only on some of the younger flood plains, usually in association with alluvial silts. The associated soils are commonly Mesisols on fens and Organic Cryosols on peat plateaus.

SOIL PROPERTIES

Patterned Ground Morphology: Microrelief of mineral terrain is dominated by earth hummocks (Figure 6A), which cover about 80% of the landscape south of the Arctic tree line and approximately 95% north of it (Zoltai and Tarnocai 1974). Most of the soils in the forested region are associated with various thicknesses of surface peat; in the Arctic region, surface peat is found mainly in the interhummock depressions. Mineral horizons are rich in organic material, which occurs either dispersed or as smears and intrusions. Organic-rich subsurface mineral horizons or subsurface peaty layers commonly occur near the permafrost table. Some of these soils have a granular B horizon, and most show evidence of gleying, even on better drained sites. All of these sites have a high ice content in the perennially frozen layer (Figure 6B). The high- and low-centered ice wedge polygons are usually associated with organic deposits. Well-developed ice wedges are common in these types of patterned ground (Figure 6C).

Soil Texture and Rate of Decomposition: Most of the soils in the Yukon are loam in texture with various amounts of coarse fragments. Soils with glacial parent material are generally gravelly sandy loam. Soils in the Mackenzie Valley are dominantly silt loam, silty clay and clay. Soils associated with the Mackenzie Delta are silt loam and loam in texture. Organic soils are associated with moderately-decomposed woody moss and sedge peat and undecomposed fibric sphagnum peat.

Moisture and Ice Content: Texture is one of the main factors controlling moisture and ice content. Fine-textured Cryosols generally have higher moisture and ice content than coarse-textured soils. The relationship between texture and ice and moisture content, on a volume basis, is shown in Figure 7. Coarse-textured soils (for example, DC 6, Figure 7) show a relatively small increase in moisture content (30%) with depth; thus the moisture and ice-content curve is nearly vertical. Medium- and fine-textured soils, on the other hand, have a slightly greater surface moisture content than do coarse-textured soils. In medium- and fine-textured soils, moisture content increases close to the permafrost table and increases rapidly below the permafrost table. In these soils the difference between the moisture content of the active layer and the ice content of the near-surface permafrost can be as much as 80%. Pure ice layers are common in fine-textured Cryosols, especially in near-surface permafrost. Although coarse-textured soils have relatively low ice contents, they are often associated with ice-wedge polygons.

Organic Cryosols associated with palsas and peat plateaus have ice contents between 60 and 90% on a volume basis (Tarnocai 1972, 1973; Zoltai and Tarnocai 1971, 1975). Ice occurs mainly in the form of ice crystals, ice layers and ice lenses. Organic Cryosols associated with polygonal peat plateaus and lowland polygons may also contain large amounts of wedge ice. The ice content of these soils ranges from 60 to 100%.

Soil Temperatures: According to the Soil Climate of Canada map (Clayton *et al.* 1977), the mean annual soil temperature at the 50 cm depth in the Subarctic region ranges between -7°C and 2°C, whereas in the Arctic region it is lower than -7°C. Most Subarctic soils are associated with permafrost, and all soils in the Arctic are perennially frozen.

The Soil Climate of Canada map uses temperature at a depth of 50 cm for characterization of the soil thermal regime. At the 50 cm depth, Cryosols on the uplands of the Inuvik area have a mean annual soil temperature (MAST) of -3.4° to -1.4°C and a mean summer soil temperature (MSST) of -0.5° to 2.7°C. Cryosols associated with the Mackenzie River Delta are slightly

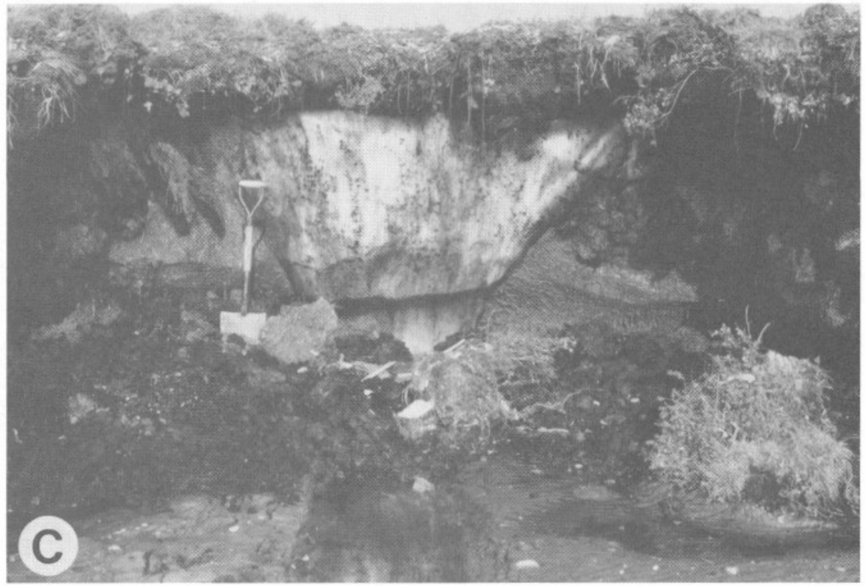

Figure 6. Turbic Cryosols associated with earth hummocks (A and B), and Organic Cryosols associated with high-centre polygons (C). High ice content is characteristic of both of these soils. Ice is present in the form of ice lenses and pure ice layers (B, lower part of soil profile), and ice wedges (C).

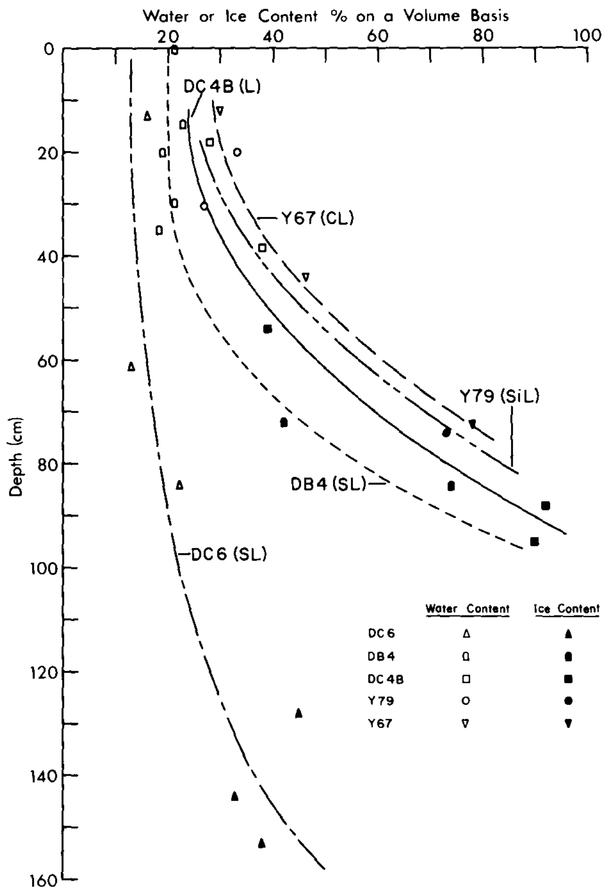

Figure 7. Moisture and ice content of some soils in the Canadian north. Locations and corresponding textures are as follows: DC 6 – sandy loam (70°10' N, 94°37' W); DB 4 – sandy loam (75°40' N, 97°41' W); DC 4B – loam (68°38' N, 92°52' W); Y79 – silt loam (69°35' N, 131°48' W); Y67 – clay loam (68°44' N, 134°03' W).

colder than the adjacent upland soils. Cryosols in the Eagle Plain area have a MAST of -2.8°C and a MSST of 0.6°C. Cryosols in the Dawson City area are generally somewhat warmer, with soils under undisturbed vegetation having a MAST of -1.4°C and a MSST of -0.6°C and soils in cleared areas having a MAST of 0.6°C and a MSST of 4.2°C. For more details, see descriptions of Sites 1, 2, 12 and 25.

For Cryosols, especially those in the Inuvik area, topographic position, vegetation cover, and thickness of the surface organic layer affect the soil temperature. Soil moisture affects not only the rate of thawing and freezing, but also the depth of the active layer. Soil texture and materials have much less effect on temperatures of these soils.

Micromorphology: For the soils presented on this tour, the emphasis of the micromorphological description will be directed towards the morphological features that are the result of the influence of cryogenic processes. Van Vliet-Lanoe (1985) noted that distinctive soil structure developed directly in response to the number of freezing and thawing cycles, the percent slope, and the water content. Brewer and Pawluk (1975) and Pawluk and Brewer (1975) presented micromorphological terminology for characterizing the microstructure of permafrost and alpine soils. Fox and Protz (1981), Fox (1983), and Smith *et al.* (1991) showed that distinct patterns of morphology result from cryogenic processes active in Turbic Cryosols (permafrost soils). The micromorphology of paleosols occurring in the central Yukon, and the interpretation of their micromorphological properties as relates to past environments, is given in Tarnocai (1987c) and Tarnocai and Smith (1989).

Two of the microstructures associated with freezing and thawing are illustrated in Figure 8, A and B. Microscale particle sorting resulting from the presence of freezing fronts can lead to sorting of the mineral material into circular or elliptical patterns, as shown in Figure 8A, and vertical alignment of the coarser mineral grains, as shown in Figure 8B, frequently with accumulations of fine material on the grain surfaces, often a result of infillings from ice lens melting. Cryostatic pressures from two freezing fronts, one penetrating downward from the surface, the other rising upward from the permafrost table, can cause displacement of materials. In addition, desiccation cracks can form as a result of the removal of water for ice lens formation. These cracks can subsequently be infilled by soil material breaking off from the adjacent soil, or by material that is transported from surface mineral and organic horizons into the crack during thaw periods. This material is incorporated into the lower mineral horizons. Later ice lens formation produces planar voids that delineate secondary structural units such as the platy structure as shown in Figure 8C. Ice lens formation from freezing cycles where there is little movement downslope can result in the platy structure (Van Vliet-Lanoe 1985) shown in Figure 8D. Platy structure is frequently observed in horizons at or near the permafrost table where considerable ice lens formation has occurred.

Cryoturbation: Most northern Canadian soils are subject to cryoturbation. This process makes soil surfaces unstable when soil materials are mixed internally and soil horizons are disrupted and displaced. Cryoturbation is associated with Turbic Cryosols and with those Brunisols and Gleysols in the Boreal forest or above tree line in mountainous areas.

Studies by Zoltai and Tarnocai (1974) indicate that cryoturbation has been active in Arctic areas since deglaciation, but it was probably initially absent from the Subarctic forest region. When climatic conditions became cooler about 4,500 years ago, cryoturbation became widespread throughout northern Canada. Dendrochronological data from the Mackenzie Valley (Zoltai 1975) have shown that, during the last 200 years, there have been alternating active and dormant periods of cryoturbation. It was concluded that there was a dormant period between 1967 and 1975, when Zoltai published the data,.

PERMAFROST

C.R. Burn[1]

Permafrost is "ground (soil or rock) that remains at or below 0°C for at least two years" (Associate Committee on Geotechnical Research 1988). Permafrost terrain comprises a seasonally-thawed active layer underlain by perennially-frozen ground. The upper surface of permafrost is the permafrost "table". Major permafrost features and processes viewed during the tour are described in this section.

DISTRIBUTION

The distribution of permafrost is broadly controlled by climate: in northern portions of the region, permafrost is continuous within the landscape (Figure 9), and only

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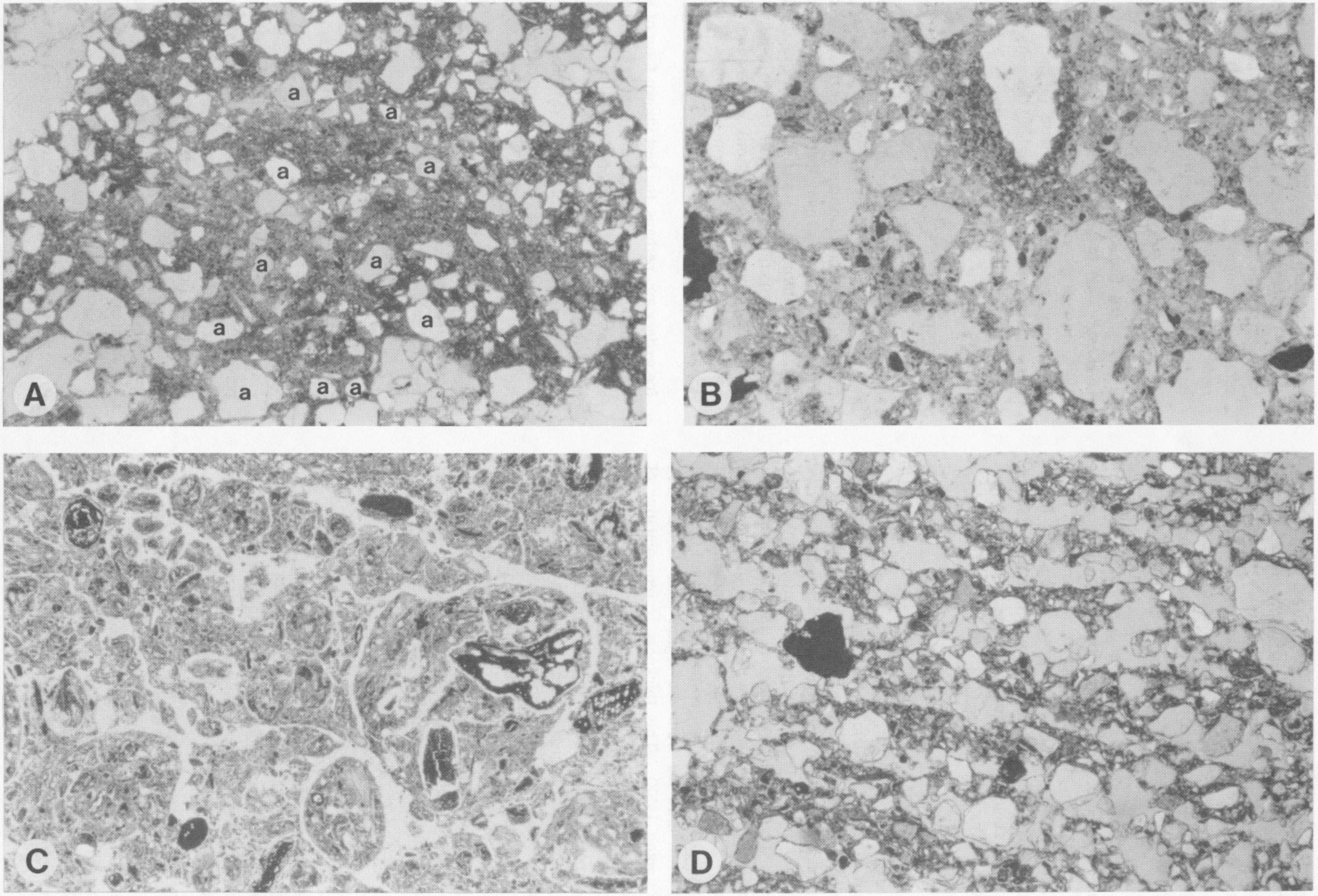


Figure 8. Micromorphology of Cryosolic soils. (A) Ombiculic fabric: a circular or ellipsoidal arrangement of skeleton grains (identified as 'a' on photo); (B) suscitic fabric: vertically aligned skeleton grains with accumulation of finer materials at the base; (C) conglomeric fabric: skeleton grains and organic fragments are enclosed by a dense groundmass of fine material; (D) banded fabric: skeleton grains are sorted in a nearly horizontal direction.

absent under major rivers and lakes. In the central Yukon, however, permafrost is thinner and discontinuous, and the presence of perennially-frozen ground depends on microclimatic factors, particularly aspect and wetness, which reduce ground surface temperature (Smith and Riseborough 1983). Ground temperatures in the Mackenzie Delta are controlled largely by the distribution of surface water.

A significant portion of the region is mountainous terrain, where cool summers contribute to the development of permafrost. In the valleys of the central Yukon, where summers are warm, the persistence of frozen ground is due to extremely low winter temperatures, brought about by topographic enhancement of atmospheric inversions.

THICKNESS

East of the Mackenzie Delta, near Inuvik, permafrost extends to a depth of 300 m. Within the delta, however, permafrost is highly variable in thickness and may be only 90 m thick because of the substantial influence on regional ground temperatures of the numerous water bodies that do not freeze to the bottom throughout the year. The thickness of 300 m represents the extent of equilibrium permafrost that has grown since the retreat of Laurentide Ice from the region after 13,000 B.P. (Rampton 1988). This thickness is representative of most of the delta area and the Richardson Mountains. Permafrost thins southward; near Dawson the maximum thicknesses are about 60 m (McConnell 1905). The thickness of discontinuous permafrost in valleys of the central Yukon is influenced by heat convection in groundwater. These valleys are filled with hundreds of metres of Plio-Pleistocene unconsolidated deposits, allowing significant groundwater circulation, in comparison with the competent bedrock east, south and west of the Mackenzie Delta.

ACTIVE LAYER

Near Inuvik, seasonal thaw depths are usually less than one metre. Minimum thaw depths (0.3–0.4 m) are associated with peatlands (Site 1). Active layers in the central Yukon are also usually less than one metre thick, although thaw depths less than 0.4 m are uncommon.

The portion of the permafrost immediately below the active layer is characteristically ice-rich (Figure 10) because of incorporation of water into the permafrost by temperature-induced suction in summer and fall (Mackay 1983, Cheng 1983, Burn and Michel 1988), and injection during freeze-back (J.R. Mackay 1989, personal communication). If active-layer depth increases following surface disturbance, such as forest fire (Site 13) or land clearance, thaw of this ice-rich layer leads to subsidence (Mackay 1977). Landslides are common on slopes following fire or after late summer rains because of thawing of the near-surface permafrost layer (Harry and MacInnes 1988).

Towards the end of the early Holocene warm period in northwestern Canada (10,000–8,000 B.P.), the active layer was about twice as thick as it is today (Mackay 1978, Burn *et al.* 1986). A well-recognized thaw unconformity, representing the base of the paleoactive layer, has been identified throughout the region.

GROUND ICE

Permafrost derives its geotechnical significance from frost heave generated by growth of ice during soil freezing, and from subsidence during thawing of ice-rich soil. Ground ice may form as a result of burial of surface ice, intrusion of water into permafrost, either by trickling down cracks or being driven by hydraulic pressures, and incorporation (suction) of water into freezing soil, leading to ice segregation (Williams and Smith 1989).

Ice wedges are, perhaps, the best known form of ground ice. Although these features are found throughout the excursion area, and are common in terrain elevated above the Mackenzie Delta near Inuvik, they appear to crack regularly only farther north (Mackay 1992). In the central Yukon, ice wedges that crack occasionally have been documented (Burn 1990). Ice-wedge casts (outlines of former ice wedges that have melted and filled with soil material) are among the few diagnostic indicators of permafrost conditions, and have been used to assist reconstruction of Quaternary environments in the Yukon (Tarnocai 1990). In the Klondike District there are large ice wedges that formed during the late Wisconsinan period, when the area experienced periglacial conditions, but these features do not *seem* to be active today.

Pingos are another ground-ice feature diagnostic of permafrost. Open-system, or hydraulic, pingos are widespread in portions of the central Yukon, where groundwater flow downslope is through unconsolidated deposits below, or between, thin discontinuous permafrost (Hughes 1969). There is no published, systematic investigation of the growth of open-system pingos, so details of their evolution are unknown.

In the active sedimentary environment of the Mackenzie

Delta, ice formed in the fall by upfreezing at the base of the active layer may be incorporated into the permafrost following addition of material at the ground surface (Mackay 1983; Figure 10). Ice incorporated in permafrost by aggradation of the surface is also found in the mountains, where solifluction and other mass movements lead to deposition downslope, raising the permafrost table.

PERMAFROST AND CLIMATE CHANGE

Permafrost is a geologic manifestation of climate and, as such, will respond to climate change. The cryostratigraphic record indicates that active-layer depths doubled during the early Holocene; deepening of the active layer is also foreseen under a warmer climatic regime (Smith 1988). The extent of deepening depends on both the response of the various microclimates to atmospheric warming and the ground ice conditions in specific terrain units. However, the spatial resolution of current general circulation models permits only a smoothed representation of the topography of the region; often the St. Elias Mountains cannot be resolved. As a result, the current regional climate is not well reproduced (Ruddiman and Kutzbach 1989), and the reliability of scenarios for future changes is unclear.

VEGETATION

The vegetation of northern Canada strongly reflects latitudinal and altitudinal temperature gradients. Northern Canada is dominated by four broad vegetation zones (Figure 11). The Arctic Zone occurs north of the Arctic tree line while the Alpine Tundra Zone occurs at high elevations, above timberline. The Subarctic Forest Zone occurs south of the Arctic tree line and generally supports an open coniferous forest. The Boreal Forest Zone, in the southern areas of northwestern Canada, is covered by closed-canopy coniferous and mixed coniferous forests. Within these four broad zones, local differences occur because of variations in soil, moisture, aspect, elevation and fire history. A brief description of the vegetation in the major physiographic regions covered by this tour is given here.

The uplands around Inuvik support Subarctic forests of open, stunted stands of black spruce (*Picea mariana*) with some willow (*Salix* spp.); lichen (*Cladonia* spp.) and moss provide the ground cover. Tamarack (*Larix laricina*) reaches its northern limit at the Inuvik airport, and the most northerly trembling aspen (*Populus tremuloides*) occur on the rocky upland at Campbell Lake (Figure 12B). On the uplands northward from Inuvik, the Subarctic forests gradually become restricted to small clumps of white or black spruce (*Picea glauca* or *P. mariana*) growing in sheltered locations in an increasingly dominant tundra setting. When black spruce grow on severely cryoturbated soils, they are usually tilted (Figure 12A) by frost heaving of the ground. After fires (especially on south- and west-facing slopes), white birch (*Betula papyrifera* ssp. *humilis*) forms the pioneer vegetation, although, when forest fires kill the trees in the vicinity of the Arctic tree line, it may be several hundred years before they are re-established. As a result, it is common to find these fire-induced shrubby tundras in this area. Eventually, however, both white and black spruce invade the shrubby birch stands.

In the Tuktoyaktuk area, the Arctic tundra consists of low shrub – cotton grass – moss – lichen assemblages on the better drained sites. Poorly-drained areas are characterized by sedges, mosses, and cotton grass.

Vegetation in the Mackenzie River delta can be divided into three zones that grade from south to north without distinct boundaries: southern forest, central forest – shrub, and northern tundra.

Southern Forest Zone: This zone is dominated by white spruce (*Picea glauca*), which often forms closed-crown stands. Because wildfires are absent, trees attain great longevity, with individuals reaching 500 years and more. During such a time period, a considerable thickness of alluvium is deposited on the delta, and the rising ground surface is followed by a corresponding rise in the permafrost table. In adjusting to the rising permafrost, long-lived species such as white spruce send out adventitious roots from the buried stem section into the new alluvium. Such spruce stems with their ladder-like horizontal root extensions are exposed by erosion along many cut banks.

Balsam poplar (*Populus balsamifera*) is the only other significant tree species in the delta. Its best growth occurs on coarse (therefore comparatively drier and warmer) point bar deposits, where it forms pure stands, or stands succeeding to white spruce.

Willow (*Salix* spp.) and alder (*Alnus crispa*) are the dominant shrubs throughout the delta, and form an understory in most spruce stands. The ground flora consists principally of low ericoid shrubs such as *Arctostaphylos rubra*, perennial herbs such as *Pyrola grandiflora*, and a variable cover of mosses.

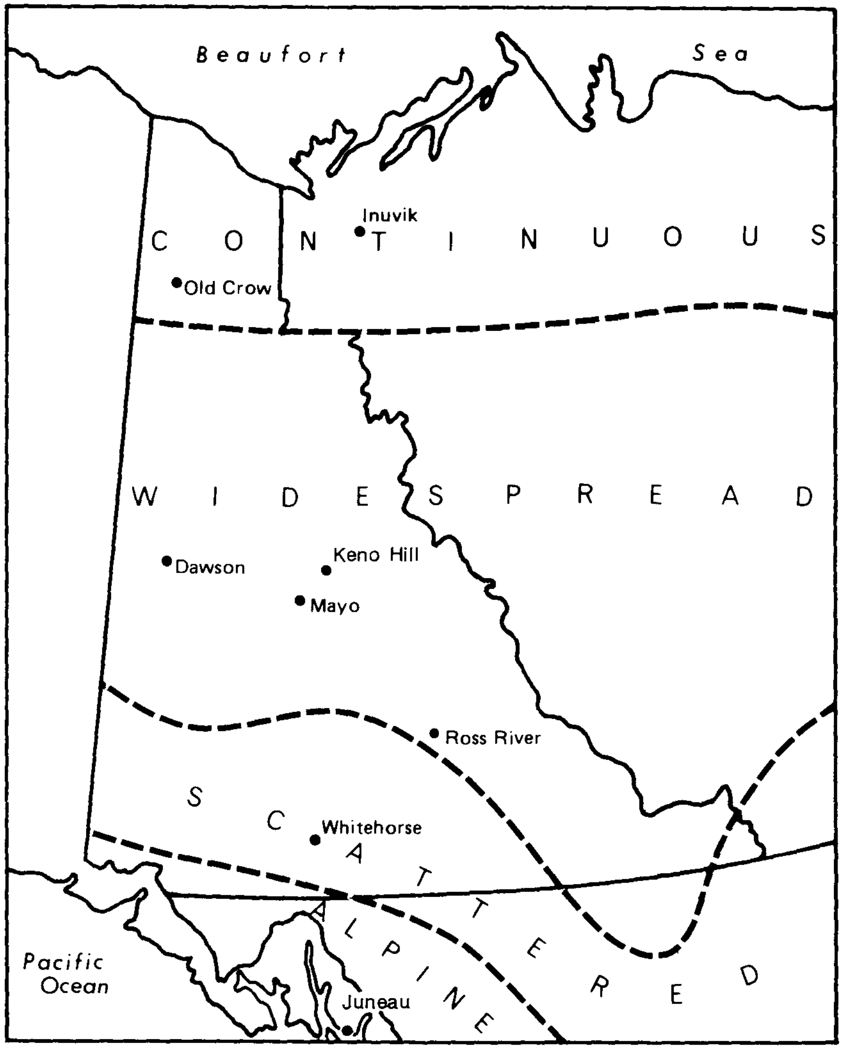


Figure 9. Permafrost regions of the Yukon and adjacent Northwest Territories (after Brown 1978).

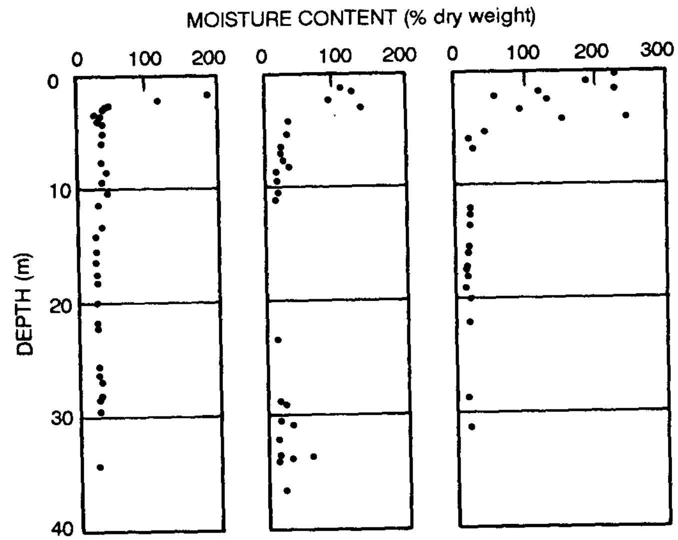


Figure 10. Moisture content profiles for three boreholes in the Mackenzie Delta near Inuvik (Williams 1968: Figs 2, 4, 5).

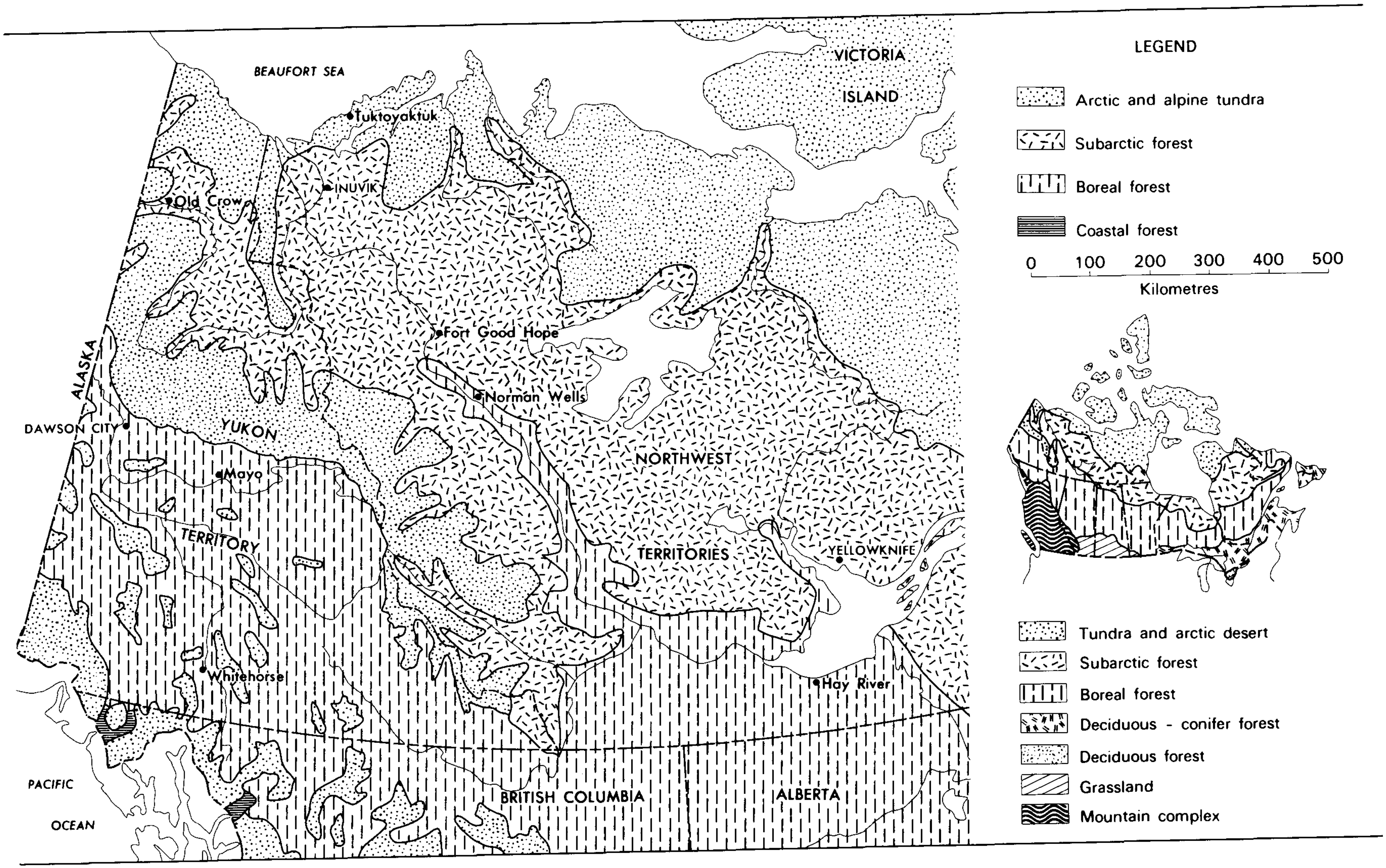


Figure 11. Distribution of vegetation in northwestern Canada (Pettapiece *et al.* 1978).

Many lakes occupy the interlevee depressions, and those that are connected to distributaries annually receive flood water and sediment. Shallow shorelines that receive alluvium are dominated by equisetum (*Equisetum fluviatile*). Where less sediment is deposited, sedges (especially *Carex aquatilis*) and semi-grasses (especially *Arctophila fulva*) dominate. Steeper shorelines are normally bordered by willow and alder communities.

Lakes that are not connected to distributaries receive little sediment and thus are not turbid, enabling a greater penetration of sunlight. These lakes contain substantial populations of submerged and emergent aquatic vegetation, including the genera *Potamogeton*, *Myriophyllum*, *Hippuris*, and *Menyanthes*, and thus support a large concentration of staging and nesting waterfowl.

Central Forest – Shrub Zone: This zone is botanically similar to the southern delta, but the levees are lower and thus more subject to flooding and sedimentation. Channel shifting is more active, and the accelerated erosion along one bank is balanced by sediment deposition along the other, which annually creates new sites for the initiation of primary plant succession. The most dynamic succession begins along the slipoff slopes of shifting channels, where the Equisetum Association functions as the pioneer community.

Northern Tundra Zone: This zone lies north of the Arctic tree line. Large depressed areas are dominated by wet meadows of sedges (especially *Carex aquatilis*), grasses (*Arctophila fulva*, *Dupontia fisherii*) or rushes (*Juncus arcticus*). Better-drained locations support low growths of willow (especially *Salix richardsonii* and *S. glauca*) and some alder interspersed with *Equisetum* spp. and *Carex* spp.

As a result of sediment deposition and channel shifting, distinct vegetation associations, representing stages of succession, develop along the Mackenzie Delta channels (Figure 12, C and D). In the Southern Forest and Central Forest – Shrub Zones of the delta, five vegetation associations can be recognized. These associations represent successional stages from the highly dynamic shorelines to the high part of the delta. A brief description of these five associations is as follows:

Equisetum Association: This association is dominated by *Equisetum fluviatile*, the most important pioneer species in the delta. It is shade intolerant and withstands flooding and high rates of sedimentation and thus is adapted to the exposed lower slipoff slopes, where it forms nearly pure communities.

Salix–Equisetum Association: This association succeeds the pioneer community. The dominant, and often sole, shrub is the feltleaf, or Alaska, willow (*Salix alaxensis*), which is especially capable of placing adventitious roots, an adaptation necessary for colonizing sites that alluviate rapidly. The herb layer is also dominated by one plant, *Equisetum arvense*, another species capable of withstanding extended flooding and sedimentation.

Salix–Alnus Association: This association is normally the third sere in this sequence, and becomes established just above average flood level (this is visible by the thick band of driftwood that is usually lodged at the foot of this association). Reduced flooding and sedimentation enables a proliferation of shrub growth, with several species of willow (*Salix arbusculoides*, *S. glauca*, and *S. barclayi*) and alder becoming established.

***Populus balsamifera* Association**: This association is found on higher levees and is dominated by *Populus balsamifera*.

Picea Association: This association represents the delta's climax stage and normally succeeds the Salix–Alnus Association within one century. Spruce stands invariably occupy the uppermost levee surfaces, which rarely experience flooding and sedimentation. The botanical make-up is similar to that described for the southern delta.

All five of these vegetation associations occur in the Southern Forest Zone, although not necessarily in the same location. They also form a much narrower band along the channels because of the nature of the high banks, which restrict the regular flooding. The sequence of these five associations is best seen in the Central Forest – Shrub Zone since the flood plain is more dynamic here.

The vegetation sequences in the Northern Tundra Zone of the Mackenzie Delta are somewhat different from those found in the southern part (south of the Arctic tree line) (Tarnocai and Zoltai 1988). In this part of the delta the Equisetum Association occurs adjacent to the shoreline. This association generally forms a wide band along the channels because of the low-lying nature of their shorelines. Immediately above this association, a Salix community occurs in association with various amounts of sedge and *Equisetum* species. The large, low-lying areas on the islands and alluvial flats are covered by sedge – grass vegetation, interspersed with

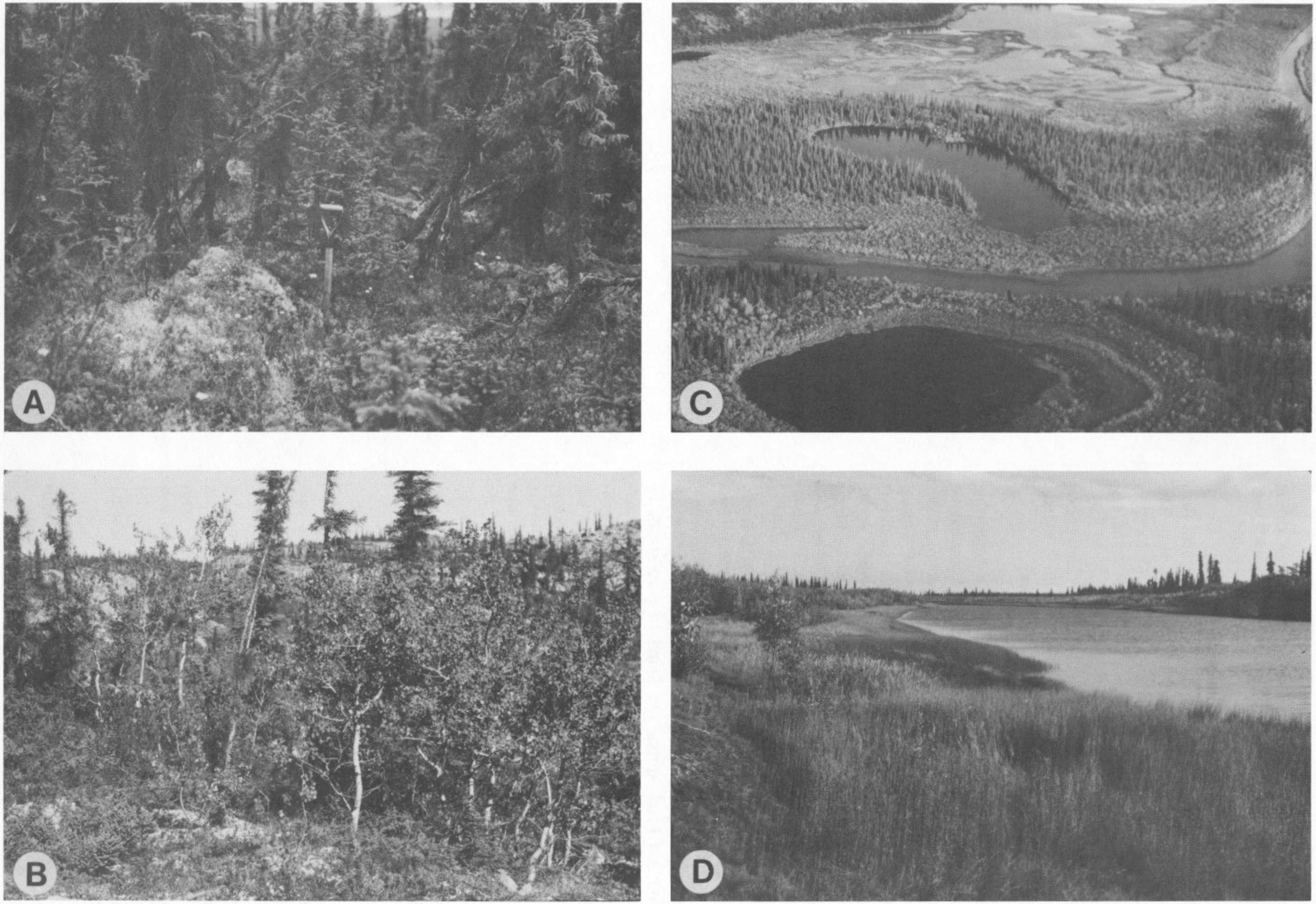


Figure 12. Typical vegetation assemblages of the Mackenzie Delta region. (A) Tilted black spruce on hummocky terrain; (B) northern limit of trembling aspen on the rocky upland at Campbell Lake; (C) sequence of vegetation communities on the Mackenzie Delta; (D) Equisetum Association occurring adjacent to the channel, followed by the Salix–Equisetum Association and then by the Picea Association (white spruce forest) on the highest part of the delta.

clumps of alder and low willows.

The most common vegetation in the Eagle Plain area is a Subarctic forest (taiga). This spruce – tussock forest covers large areas of poorly- to imperfectly-drained silty soils. The tree cover consists of stunted black spruce with some tamarack. Although the trees are small (less than 4 m tall), they may be over 200 years old. The sparse shrub layer consists mainly of willow (*Salix* spp.) and shrub birch (*Betula glandulosa*), with some ericaceous shrubs. Tussocks, composed mainly of sedge (*Carex bigelowii*), occur on low earth hummocks. White spruce commonly occurs on well-drained sites in association with white birch and black spruce.

In the Ogilvie Mountains, the valleys below timberline are covered with an open Subarctic spruce forest having a dense shrub layer. Large areas of the mountain slopes above timberline are covered with moss – lichen vegetation, or are devoid of vegetation. Alpine tundra is common at elevations above 1,000 m in the Ogilvie Mountains. This tundra is composed of shrub birch, willow (*Salix reticulata*), cotton grass (*Eriophorum vaginatum*) and Dryas (*Dryas integrifolia*).

The Yukon Plateau, especially in the area of Dawson City, is covered by Boreal forest, but the northern character of the forest is reflected by the absence of common Boreal species such as tamarack and pine (*Pinus* spp.). White and black spruce are found in pure stands or mixed with trembling aspen, balsam poplar (*P. balsamifera*) and white birch. South-facing slopes are generally covered with aspen and/or white spruce. On north-facing slopes, which are associated with permafrost, black spruce is the dominant tree. The perennially frozen peatlands (peat plateaus and palsas) in this area are also dominated by black spruce, whereas fens are dominated by sedges (*Carex* spp.). On mineral soils, disturbance and fire create a situation that initially favours the growth of hardwoods. As these trees mature, however, spruce invades until it forms a significant portion of the forest.

At higher elevations in the Yukon Plateau, poplar and white birch are absent. These subalpine sites are covered by open stands of white and black spruce with a dense shrub growth of shrub birch (*Betula glandulosa*). Subalpine forests may vary from nearly closed-canopy spruce stands at lower elevations on south-facing slopes to a scattering of dwarfed, wind-sculptured trees (*krummholtz*) at higher elevations. Fires are common in areas of shrub birch, and it may take a long time for conifers to become re-established (Rowe and Scotter 1973).

On the Yukon Plateau and in the Ogilvie and Richardson mountains, the dominant vegetation above tree line is low shrubs, consisting of dwarf birch (*Betula nana*), Labrador-tea (*Ledum palustre* ssp. *decumbens*) and other ericaceous (heath) shrubs, along with lichens (*Cetraria* spp. and *Cladonia* spp.), mosses (*Polytrichum* spp.) and some herbs. In rocky areas, the cover is much reduced, being confined mainly to sheltered spots. Crustose lichens grow on boulders and rock outcrops, but the species depends on the type of rock.

AGRICULTURE

OVERVIEW

The Northwest Territories has possibly 1.75 million ha of arable land, while reconnaissance soil surveys indicate that the total arable area of the Yukon may be in excess of 400,000 ha, although much of it is currently inaccessible by road (Rostad *et al.* 1977). All of this land is south of the Continuous Permafrost Zone. Agriculture in these territories is unique within the Canadian perspective by its very existence in such northern regions. It is an attempt at import substitution, and aims at supplementing, where possible, imported foods from southern Canada and abroad with agricultural products produced locally.

As a result of the short frost-free period and cool temperatures during the growing season, climate is the greatest limiting factor to agriculture. Any site above 820 m in elevation is considered to be non-arable because of climate restrictions. In the Whitehorse area, where the majority of farming occurs, annual precipitation of less than 265 mm creates semi-arid conditions, further limiting agricultural potential. Few farms have yet developed sophisticated irrigation systems to overcome this limitation.

Soils in their natural state are low in fertility and organic matter, and are characterized by cold soil temperature regimes. Well-managed operations have overcome these limitations by including plowdown crops in rotations, using row covers for vegetable production, and carefully planning seeding and harvesting dates. In general, soils are neutral to slightly acid in the central Yukon and alkaline in the southwest Yukon, where localized inclusions of saline soils exist.

YUKON

Along the tour route in the Yukon, agricultural development can be observed in the Klondike and Yukon river valleys, in the vicinity of Dawson City. These areas represent the northernmost field-scale agricultural developments in Canada. No agriculture is practiced north of 64°20'N in the Yukon. Typical ventures include forage production (principally grass hay) and market gardening. There are also some greenhouses that produce a spring crop of bedding plants, followed by summer vegetables. The majority of the Yukon's agriculture, however, is found in the Whitehorse area, approximately 300 km south of Dawson City. In this region, there is both elk and reindeer farming and specialty crop production in addition to the activities taking place near Dawson City.

Agriculture in the Yukon dates back to the time of the Klondike gold rush in the 1890's, when the territory produced food for a population approximately equal to that of today (about 30,000). Transportation at that time was neither rapid nor reliable, therefore, crops and livestock were a necessity. With the advent of efficient transportation systems, however, the need for locally produced goods diminished, and local agriculture died. About 15 years ago, however, an agricultural revival began and today there are over 100 farms, run mostly on a part-time basis, operating in the territory. The estimated total area of cultivation is 3500 ha, with an equal amount in improved pasture. Recent surveys put agricultural production at $2.5 million annually, with another $25–30 million invested in land, machinery and buildings (Agriculture Branch 1993).

The primary limitation to agriculture is climate. The Yukon holds the continental record low temperature of -62.8°C, yet the extreme maximum summer temperature of 36.1°C, which occurred at Mayo, rivals temperatures occurring in the south. The summer temperatures in the Dawson region are suitable for maturing oats and barley. Greenhouse production is very successful under the long daylight conditions of this latitude. Frosts can occur at any time of year, and are most frequent in depressional landscape positions. Most of the soils used for agriculture in the central Yukon were underlain by permafrost prior to cultivation. Once soils are cleared of native vegetation, they warm dramatically, and the permafrost table drops below the plant rooting zone (see Site 25).

The principal grass hay grown is bromegrass (*Bromus inermis* var. *carleton*). Average yields of 2,000–3,000 kg/ha are being produced in nonfertilized trials conducted around the territory, with up to 6,000 kg/ha being produced with the addition of fertilizer. Protein content is 8–12%. Hay sells for up to $8.00/60 lb. bale, giving the producer a reasonable return. This product is consumed by the 2,500 horses and 500 head of cattle and farmed game (mainly elk) found in the territory (Agriculture Branch 1993). Currently, there is little silage production and no forage dehydration. Despite the small size of the market, a great deal of hay is brought up the highway from southern provinces and consumed by local stock. Some of this imported product is alfalfa and timothy, which is sold to a sector of the population demanding this higher protein feed.

Small acreages of oats and barley are produced in the Yukon. Green feed is popular and is produced in most areas where the crop is unable to mature. The most common varieties sown are Grizzly and Cascade oats, with Otal and Datal being the most popular barley varieties. There is very little commercial production of wheat.

The last few years have seen an increase in interest in horticulture. Throughout the Yukon there are approximately 40 ha of mixed vegetable production, with an additional 6130 m^2 in greenhouse production. Although much of this is produced for home consumption, most areas have a Farmer's Market or other established outlets to absorb the excess. Bedding plants and hydroponic operations make up the balance of this sector, producing numerous varieties of plants for the home gardener and supplying fresh lettuce and bean sprouts to local markets.

The livestock sector consists of cattle, sheep, goats, chickens, hogs and a few more unusual species such as musk oxen. The game-farming industry numbers 300 elk and 70 reindeer, held primarily as breeding stock. Their velvet is harvested annually and sold to the Korean market.

In addition to cultivated agriculture, many hectares of Yukon wilderness are used by big game outfitters to range horses. These horses are used to pack supplies into and out of hunting and guiding camps during the summer and fall seasons. Grazing agreements are established between the government and individual outfitters. Range managers ensure that a grazing management plan is established with each agreement holder, and that sustainable grazing practices are followed so that no environmental degradation occurs because of overgrazing. There are numerous guiding outfits along the route of the tour in the Ogilvie Mountains along the southern portion of the Dempster Highway.

Since 1984, both industry and government have been conducting studies in the Yukon to determine the best varieties and cultural methods for the agricultural sector. The Yukon Agriculture Branch, together with Agriculture Canada, have test plot sites that enable both farmers and interested members of the public to observe forages, cereals and horticultural varieties. The Agriculture Branch has a soil and feed data base developed from the past five years of testing. These data provide valuable information on soil nutrient content and protein levels of Yukon-grown feed.

The Yukon Agricultural Association (YAA) is a group of Yukon agri-business people who represent the voice of the industry before government and work to raise the profile of Yukon agriculture. The association has produced a videotape of territory-wide agricultural activities that we intend to show you during our stay in Dawson City.

NORTHWEST TERRITORIES

Agriculture in the Northwest Territories developed around church missions and fur trade forts. The early missions in such places as Fort Smith, Fort Simpson, and Fort Providence had farms attached, where they raised vegetables and some livestock. In the 1930's the missionaries cooperated with the Experimental Farms Service to give the first plant adaptation and agricultural production figures. Reports indicate that production of everything, including potatoes, tomatoes, cabbage, cereal grains, and milk, varied from very good to poor depending upon the available moisture. Some of the constraints mentioned were biting flies, grasshoppers, crows, starlings, and prolonged periods of drought. As transportation by road and air improved, the need for locally-produced food diminished, so livestock raising has almost ceased and gardens have been reduced in size.

Large areas of land along the Slave, Mackenzie and Liard rivers are suitable for farming. There are also areas of grazing land. However, the prevalence of flies and the very long winter feed period has discouraged commercial livestock production. At present there are small holdings growing readily saleable garden produce close to population centres, but there are no major farming operations in the Northwest Territories. For example, there is a greenhouse operation in Norman Wells producing bedding plants, vegetables and flowers for the markets in Norman Wells and Inuvik.

Game ranching using bison, musk oxen and caribou may have a place in the use of our northern lands. So far, the reindeer herds in the Inuvik – Tuktoyaktuk area have achieved some success.

FOREST RESOURCES

About 60% of northwest Canada, north of 60°N latitude and west of about 120°W longitude, contains forest species of which white spruce (*Picea glauca*), black spruce (*P. mariana*), lodgepole pine (*Pinus contorta*), jack pine (*P. banksiana*), tamarack (*Larix laricina*), alpine fir (*Abies lasiocarpa*), trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), and white birch (*Betula papyrifera*) are primary constituents. Approximately 75% of the forested land consists of scrub possessing virtually no commercial value. Much of the remaining forest land, about 15% of the total, possessing potentially commercial forests consists of immature stands resulting from fire. This leaves about 4 x 10^6 ha of merchantable stands.

Initial forest harvesting occurred in association with land settlement and mining. Most early dwellings, including forts and commercial establishments, were made of logs, and heating was provided entirely by cordwood. Perhaps the most dramatic logging incident occurred around Dawson City, Yukon Territory during the gold rush near the turn of the century. About 12 sawmills were in operation during this period to meet the demands of the boom town and of the mining industry (Berton 1958) in addition to numerous permits issued for cordwood for fuel, especially for operating steamboats (Merrill 1961) along the major rivers of the central Yukon.

A few logging operations are still active in the central and southeastern region of the Yukon, where the primary species utilized are white spruce and pine. Most logging is done on accessible alluvial plains supporting white spruce, and to a lesser extent on higher terraces supporting lodgepole pine. Sufficient saw logs can be obtained to meet some local demands, as they exist today, for rough construction purposes and for mining timbers, but transportation costs limit export from remote areas. However, the rapid increase in demand for kiln-dried and finishing-grade lumber because of the growth of Yukon communities has been satisfied by importing processed material. No facilities for producing or processing pulpwood have been developed, although pulpwood production may be feasible in some areas.

Forest production is limited by shortness of growing season, moisture deficits during the growing season, generally cool temperatures, and amount of solar radiation (Gairns 1968; Hirvonen 1968, 1975; Peaker 1968). The highest productivity occurs on well-drained alluvial terraces along the Liard and Mackenzie rivers (Figure 2). Volumes average about 250 m^3/ha with mean annual increments (MAI) of approximately 3.5 m^3/ha. Prime sites, however, may attain volumes of over 800 m^3/ha and have MAI's over 5 m^3/ha. The productivity declines on higher alluvial terraces and on upland sites. Upland sites have average volumes of about 110 m^3/ha and MAI's around 2 m^3/ha. A further general decline occurs with increasing latitude and increasing relative elevation. For example, in the vicinity of Dawson City, the volume on alluvial sites amounts to about 125 m^3/ha with MAI's of about 2 m^3/ha, while on upland sites the volume is about 70 m^3/ha and MAI's are less than 1 m^3/ha.

Another factor influencing the allowable annual cut to maintain a sustained yield is the rotation period. A rotation of about 160 years is required to obtain suitable sawtimber on alluvial sites. Since sawlogs are seldom attained on upland sites, in part because of the frequency of fires, the rotation of pine can be shortened to about 120 years to produce poles, cordwood and pulpwood.

Most of the forest that we travel through on this tour in the Northwest Territories and the Yukon has little or no commercial timber value. With the exception of the major fluvial landforms of the Mackenzie, Peel, Ogilvie and Klondike rivers, the forest is composed of black spruce and tamarack, and has no commercial value. Most of the logs produced on the alluvial flats and on the Mackenzie Delta have spiral grains and so are not suitable for lumber. The logs, mainly white spruce, from these areas are used as pilings for structures built on the permafrost.

This Subarctic forest is important for wildlife habitat purposes and as a source of firewood for local residents. There is an important relationship between forest fires and these forest ecosystems in regions of discontinuous permafrost. These stands are subject to repeated wildfires because of the often short, warm, and sometimes dry summers. These fires remove the accumulated forest floor materials, which insulate the soil from summer warming. The result is rapid subsidence of the permafrost table and a change in the thermal characteristics of the soil. During the tour we will see many examples of the thermal effects resulting from disturbance of the surface cover of these soils.

MINING AND EXPLORATION

OVERVIEW

Mining and exploration have been major catalysts in the opening of the north and continue to be of economic importance. Numerous examples may be cited of the influence of mining on the settlement and development of the north. The famous Klondike gold rush led to the establishment of Dawson City and Whitehorse, and transportation networks to serve them. Prospectors traveling to the Klondike explored vast areas of the north and located mineral deposits of future significance. The first railway into the Northwest Territories was completed in 1964 to facilitate exploitation of the large lead–zinc deposit at Pine Point and to accelerate the exploration and development of adjacent territory.

Despite the vast potential of this region, however, problems of isolation and adverse climate have restricted development of mineral resources to very large or high grade deposits, materials that are needed and used locally, or minerals whose scarcity elsewhere makes them profitable to extract under these adverse conditions.

YUKON

Mining and exploration, along with tourism, are the foundations of the Yukon economy. Historically, mining and exploration have been a major part of the Yukon's life and economic well-being. Exploration expenditures in 1992 totaled about $10 million, down $6 million from the previous year (INAC 1993). There were about 60 individual exploration projects in 1990 and 1991. While still a significant expenditure, the 1992 amount is far below that of 1988, the peak year of mineral exploration, when close to $50 million was spent in the Yukon. The peak in 1988 represented the end of a government cost-sharing program, a time of active gold exploration. A number of today's advanced programs are focused on targets discovered during these earlier years of substantial expenditure.

In 1992 there were only two operating hardrock mines in the Yukon, both operated by Curraugh Resources. The mine at Faro in the central Yukon is both an open pit and underground operation, producing approximately 100,000 kg of lead and 140,000 kg of zinc (INAC 1993). The mine near Watson Lake in the southeast Yukon also produces lead and zinc concentrate, in about the same quantity as Faro. Exact revenue figures for these mines is not available, but these operations have a major impact on all sectors of the Yukon economy, including transportation, service industries and community economic health. There are also smaller gem-grade mines in the Yukon. The King Arctic jade mine in the southeast region and the Marlin rhodonite mine in the central Yukon are two of the most active.

Placer mining is also an important form of mining in the Yukon today, and has been since before the Klondike gold strike of 1896. The total production of placer gold in 1992 is estimated at just under 100,000 troy ounces, with a value of approximately $45 million (INAC 1993). The production figure represents a decline of 10% from 1991, and the third consecutive year of production decline. The figures for 1992 represent a decline in production of 60% since the peak year of modern production in 1989, when almost 166,000 ounces of placer gold were mined in the territory (Placer Mining Section 1991). The drop can be attributed to depletion of reserves in traditional placer mining districts, low gold prices and the difficulty of raising capital funding (INAC 1993). During the First World War, vast amounts of gold were extracted by dredges and large-scale hydraulic mining. Almost 220,000 ounces of gold were produced in 1917. Most placer mining takes place in the Klondike and Mayo regions of the central Yukon, with lesser activity in the Carmacks and Burwash districts farther south and west. We will visit an operating placer mine during our stay in Dawson City (Site 26), about midway through the tour.

NORTHWEST TERRITORIES

There are a number of proven oil and gas fields in the Mackenzie Valley. The field at Norman Wells has been operational since World War II. It was upgraded in the early 1980s and a 850-km pipeline, the first in Canada on permafrost, was built in the mid-1980's to carry the oil from Norman Wells to the northern Alberta pipeline system. Considerable oil has been found in the Beaufort Sea and some has also been found in the Mackenzie Delta. In addition, significant amounts of natural gas have been found in the Mackenzie Delta area and in the Arctic islands. Neither the oil fields in the Beaufort Sea and Mackenzie Delta nor the gas fields are currently in production.

As a point of interest, it should be mentioned that Canada's most northerly mine is located on Little Cornwallis Island. The main product of this mine, which is located on sedimentary rock, is copper.

The huge area of the Precambrian Shield is very rich in minerals (primarily copper, zinc and gold). The Canada Tungsten Corporation mine in this region of the Northwest Territories is Canada's only tungsten mine, and at one time supplied roughly 15% of the requirements of the western world. The Eldorado mine at Port Radium, N.W.T. is now exhausted, but in its time produced both silver and, during World War II, the uranium used in the world's first atomic bombs. Recently, gem-grade macro diamonds have been found in this area, creating a great deal of excitement in prospecting circles.

There's gold, and it's haunting and haunting,
It's luring me on as of old;
Yet its isn't the gold that I'm wanting
So much as just finding the gold.
It's the great, big, broad land 'way up yonder,
It's the forest where the silence has lease;
It's the beauty that thrills me with wonder,
It's the stillness that fills me with peace.

Robert Service

from The Spell of the Yukon

DESCRIPTION OF SOIL STOPS AND POINTS OF INTEREST

SITE 1, KM 4: PERMAFROST SOIL DEVELOPED ON ORGANIC TERRAIN

Organic soils are of major importance in the Mackenzie Valley. The following summary will provide information concerning the distribution and characteristics of these soils.

ORGANIC SOILS IN THE MACKENZIE VALLEY

Organic soils developed on peat materials are one of the major soil types in the Boreal and Subarctic regions (including the Mackenzie Valley) and are also common in the Low Arctic region of Canada (Zoltai *et al.* 1988, Tarnocai and Zoltai 1988). The term "organic soils" refers to all soils that have more than 40 cm (depth) of peat. They may be classified in either the Organic Order or the Organic Cryosol Great Group (Agriculture Canada Expert Committee on Soil Survey 1987), depending on the absence or presence of perennially frozen conditions within 1 m of the surface.

The unfrozen organic soils belonging to the Organic Order occur primarily in the Boreal and lower Subarctic regions (southern and central Mackenzie Valley) and are mainly Mesisols associated with a fen type of peatland (Zoltai and Tarnocai 1975; Zoltai *et al.* 1988, Tarnocai and Zoltai 1988). These soils have developed mainly from sedge and moss materials that are moderately decomposed and medium to slightly acid in reaction. They are very poorly drained and are saturated with water to the surface for most of the year.

Soils belonging to the Organic Cryosol Great Group are perennially frozen and are the most common organic soils in the Mackenzie Valley, particularly in the northern part. All Organic Cryosols are associated with high ice content peat materials. This ice occurs as ice crystals, ice lenses, and various sizes of ice wedges, with the ice content generally ranging from 60 to 95% on a volume basis. The chemical composition of the frozen peat (permafrost layer) may differ from that of unfrozen peat (active layer) in the same soil. In general, the unfrozen peat has lower pH and exchangeable calcium and higher exchangeable hydrogen than similar peat material from the frozen layer. The larger amount of calcium in the frozen layer results from, among other factors, water migration along the thermal gradient, as has been explained by Tarnocai (1972, 1973).

In the southern part of the Mackenzie Valley, Organic Cryosols are associated with peat plateau and palsa types of peatlands and have developed mainly from moderately decomposed woody moss peat or woody moss peat underlain by sedge peat (Mesic Organic Cryosols) and from undecomposed sphagnum peat (Fibric Organic Cryosols) (Zoltai and Tarnocai 1975, Zoltai *et al.* 1988). The chemical properties of these soils depend mainly on the peat materials from which they have developed. In general, soils developed from woody moss peat materials are strongly to medium acid, while those developed from sphagnum peat materials are very strongly to extremely acid.

In the central and northern part of the Mackenzie Valley, as far north as the Arctic tree line, Organic Cryosols also occur in polygonal peat plateaus (Tarnocai and Zoltai 1988). North of the Arctic tree line, Organic Cryosols are found only in association with lowland polygons, both the high- and low-centered forms. Soils associated with polygonal peat plateaus and lowland polygons are composed mainly of sedge peat with some sphagnum peat. They are generally moderately decomposed and are strongly to medium acid.

MESIC ORGANIC CRYOSOL (POLYGONAL PEAT PLATEAU)

This site is located on a polygonal peat plateau. The soil at this site developed on sedge and sphagnum peat and is classified as a Mesic Organic Cryosol (Table 3 and Figure 13). The vegetation on the peatland consists mainly of lichens, mosses, and ericaceous shrubs (Table 5), with some stunted black spruce, shrub birch and alder near the edge of the peatland. The central part of the peatland, where Site 1 is located, is virtually treeless except for some occasional stunted black spruce and alder.

This soil has developed dominantly from moderately decomposed sedge peat ranging in rubbed fibre content from 20 to 80%. A thin sphagnum peat layer is present in the profile, but it is found only adjacent to the polygonal trench. The somewhat moister environment in the polygonal trench provides favourable conditions for sphagnum peat development.

The sedge peat material in this soil has a pH (H_2O) between 4.5 and 5.6 (Table 4). Its exchangeable calcium and magnesium levels are relatively high, which is characteristic of sedge peat deposited in a minerotrophic environment. Greater than 70% of the organic material is insoluble humin, with fulvic acids dominating the soluble fraction.

A cross section of the site (Figure 13) makes it possible to reconstruct the history (genesis) of this soil. As with other organic soils associated with polygonal peat plateaus, no basal mixing of organic and mineral soil is suggested, indicating that the peat was deposited in a permafrost-free environment (Zoltai and Tarnocai 1975). In fact, the peat layers are often contorted near the ice wedges showing that the ice wedges developed after the peat was deposited. The botanical composition of the peat also indicates the permafrost-free deposition. Thus, both the internal structure and the botanical composition suggest that these organic soils first developed in a permafrost-free environment (Typic Mesisol) and later, as the climate deteriorated, became frozen and elevated into peat plateaus with subsequent ice wedge formation and the development of the Mesic Organic Cryosol occurring here.

Micromorphology

The Om horizon (Table 6) has distinct fabric zones composed of similar organic materials, giving a clustered appearance to the morphology of the soil materials. The sphagnum moss tissues appear to have been intruded into the fragmented organic materials because of the preferred orientation of the tissues (Pl.1:A). The Ofz horizon is dominated by close packing of sphagnum moss and leaf tissues that are intact and show little to only moderate decomposition of the cell structure (Pl.1:C). Fungal hyphae are distributed throughout the moss tissues and are probably responsible for the chemical breakdown of the moss tissues. The Omz1 horizon is characterized primarily by the fragmentation of the organic materials (Pl.1:E). In one fabric zone there are amorphous fungal masses associated with woody tissues (Pl.1:F). These masses are either remnants from the decomposition of wood materials prior to the horizon being frozen, or fungal growth along a crack leading into this horizon and exposing the woody tissues.

Cryogenic processes have affected the soil morphology of the Om and Ofz horizons to a greater extent than in the Omz1 horizon (Table 6). Cryogenic processes have influenced the soil fabric by inclusions of material (Pl.1:A), compression of more humified material, and movement and twisting of the more fibrous materials (Pl.1:C, E), and have contributed to the fragmentation of the organic particles. A perhaps greater influence on the fragmentation of the organic particles is faunal activity. Evidence is especially prominent in the Om and Omz1 horizons. Abundant fecal material of varying sizes and shapes is a dominant soil constituent in the Om horizon (Pl.1:B), suggesting both the presence of a wide soil fauna diversity and that this horizon is not permanently frozen, but thaws during summer periods to support faunal activity. In the Ofz horizon, faunal activity is associated with the humified root materials that are located in distinct zones between fairly undisturbed sphagnum moss zones (Pl.1:D). These distinct fabric zones suggest the possibility of cracks along the root material that soil fauna can enter from the upper horizon (Pl.1:C). In the Omz1 horizon, the soil fauna aggregates show advanced decomposition and breaking apart, and are not as distinct in appearance as those in the Om horizon. The condition of the fecal material indicates that this horizon is permanently frozen throughout the year and that no new activity is possible.

Soil Temperature and Moisture

Soil temperatures have been monitored at this site since 1978. At that time, thermistors were installed at depths of 2.5, 5, 10, 20, 50 and 100 cm and readings were taken manually, approximately once a month. Using this data, the soil temperature parameters were calculated using the best-fitting line generated by a computer program. The mean annual soil temperatures (MAST) from 1978 to 1981 are presented in Table 7 (Tarnocai 1984).

During 1989 the instrumentation on the site was upgraded with the installation of a data logger that automatically records soil and air temperatures every 3 hours. Since then, the soil temperatures have been taken at depths of 2.5, 5, 10, 20, 50, 100 and 150 cm. The mean monthly and maximum and minimum soil and air temperatures have been plotted and are shown in Figure 14. The mean annual, and the absolute minimum and maximum soil temperatures for 1990 and 1991, along with the mean summer soil temperatures (MSST), are given in Table 7.

Soil temperature data from the 20 cm and 50 cm depths are used to characterize the soil temperature regimes of Cryosolic soils. Based on the data presented in Table 7, this soil has a MAST of -1.5° to -2.5°C at the 20 cm depth and -1.4° to -2.9°C at the 50 cm depth. The MSST values (Table 7) clearly indicate that the upper 20 cm of this soil thaws during the summer, since the MSST at this depth is approximately 3°C, while the soil is perennially frozen at the 50 cm depth, having a MSST of approximately -0.5°C.

In 1992 the moisture content of the peat at the 0–15 cm depth was 30% on July 14 and 23.4% on September 14.

Snow Depth, Active Layer Depth and Subsidence

Snow depth, especially the occurrence of a large amount of snow in early winter, greatly affects freeze-back (cooling) of the soil. In the Boreal region, snow has a fluffy nature and thus provides a good insulating layer for the soil surface. The snow depth at this site (Figure

15) was monitored during the winter of 1978-79 (October 12, 1978 to June 12, 1979) and was found to increase rapidly to a depth of approximately 30 cm during the first month of monitoring, thereafter varying between 15 and 30 cm. The snow had completely melted by the early part of June at this site. The variation of snow depth was due to snow drifting (this site is treeless and thus exposed), periodic snowfalls and recrystallization.

The depth of the active layer has been measured each September for the past six years and has been found to vary only slightly, remaining at a depth of approximately 50 cm (Figure 15). The development of the active layer at this site was monitored between May and October of 1979 (Figure 15). It was found that the active layer developed rapidly between late May and mid-July, reaching a maximum depth in September and October.

No subsidence has occurred at this site in the three years between 1990 and 1992 that systematic surface subsidence measurements have been taken.

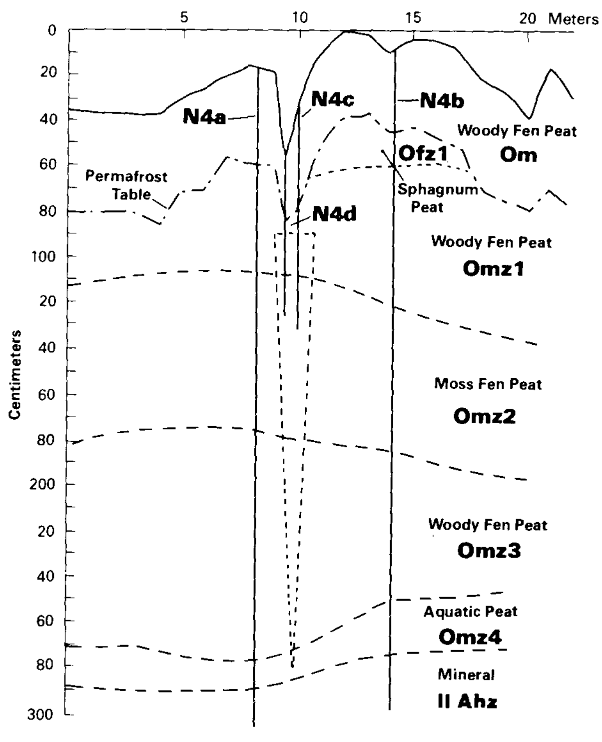


Figure 13. Cross section of the Mesic Organic Cryosol associated with a polygonal peat plateau at Site 1 (N4a – N4d mark the positions of the auger holes).

Table 3. Site and pedon descriptions for Site 1.

Location: 68°18'57" N Lat., 133°25'51" W Long.
Landform: Polygonal peat plateau
Drainage: Poor to imperfect in the rooting zone
Soil Temperature (50 cm depth; 1991): MAST -2.3°C, MSST -0.5°C
Parent Material: Mesic sedge peat
Patterned Ground: Large polygonal pattern; approximate diameter – 10 m, up to 50 cm relief along trenches

Elevation: 100 m (a.s.l.)
Slope: Level
Vegetation: Tundra of dwarf shrubs, lichens and mosses
Soil Classification: Can. – Mesic Organic Cryosol
U.S.A. – Pergelic Cryohemist
F.A.O. – Gelic Histosol

Horizon		Depth (cm)	Description
Canada	U.S.		
Om	Oe	0 – 35	Black (2.5YR 2.5 m); moderately decomposed, woody sedge peat; composed dominantly of sedges, birch and brown mosses; loose, friable; very strongly acid; smooth boundary.
Ofz	Oif	35 – 39	Dark brown (7.5 YR 4/4 m); frozen, undecomposed, sphagnum peat; composed dominantly of sphagnum mosses, minor amounts of birch branches; segregated ice crystals; very strongly acid.
Omz1	Oef1	59 – 110	Dark reddish brown (5YR 3/3 m); frozen, moderately decomposed, woody moss sedge peat; composed dominantly of sedges, brown mosses and woody remains; segregated ice crystals; strongly acid.
Omz2	Oef2	110 – 175	Dark reddish brown (5YR 2.5/2 m); frozen, moderately decomposed, moss sedge peat; composed dominantly of brown mosses and sedges; segregated ice crystals; medium acid.
Omz3	Oef3	175 – 240	Black (10YR 2/1 m); frozen, woody sedge peat; composed dominantly of sedges, woody remains and mosses; segregated ice crystals; very strongly acid.
Omz4	Oef4	240 – 265	Black (10YR 2/1 m); frozen, aquatic peat; charcoal particles; segregated ice crystals and ice lenses; very strongly acid.
IIAhz	Af	265 – 300	Frozen silt loam; segregated ice crystals and ice lenses; extremely acid.

Table 4. Analytical data for the Mesic Organic Cryosol at Site 1.

Chemical Analysis															
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)									
						Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)		K	Ca	Mg	Al	Total	Total	Ca	Mg	Na	K
Om	4.8	4.2	47.1	1.90	25	0.2	67.0	12.3	0.3	79.8	176.8	74.2	13.8	0.2	0.1
Ofz	4.9	4.7	36.0	1.10	33										
Omz1	5.3	5.0	45.3	2.52	18	0.7	55.8	10.2	0	67.4	128.3	63.4	12.3	0.1	0.6
Omz2	5.6	5.3	42.9	1.98	22	0.5	69.5	12.3	0	82.3	150.4	83.1	13.8	0.4	0.5
Omz3	4.9	4.9	41.4	2.43	17	0.3	78.3	11.4	0.3	90.3	134.2	78.8	12.6	1.4	0.3
Omz4	4.5	4.5	25.3	1.85	14						85.7	60.2	9.5	1.8	0.3
IIAhz	4.1	4.1	18.8	1.50	13	0.3	56.8	6.9	0.7	64.6	64.2	43.4	8.3	0.3	0.3

Table 4. Analytical data for the Mesic Organic Cryosol at Site 1 (cont.)

Chemical and Physical Analysis												
Horizon	Available Nutrients (ppm)				Organic Matter					Fibre Content (%)		% Ash
					Extracted		Cha/Cfa	FA	HA	Unrubbed	Rubbed	
	N	P-Bray	K	S	%C	%N		E4/E6	E4/E6			
Om	1	0	9	1	14	28	0.27	7.0	6.2	80	20	6.7
Ofz										90	80	7.5
Omz1										80	32	13.1
Omz2					26	14	0.30	6.9	4.6	70	34	8.9
Omz3										70	20	14.3
Omz4												49.0
IIAhz												

Table 5. Vegetation description for Site 1.

Vegetation

a) Central part

Tall shrubs 5%
80 *Betula glandulosa*
10 *Salix* sp.
10 *Alnus crispa* ssp. *crispa*

Low shrubs 20%
75 *Ledum palustre* ssp. *groenlandicum*
25 *Vaccinium uliginosum*

Dwarf shrubs 20%
75 *Vaccinium vitis-idaea*
5 *Andromeda polifolia*

Herbs 1%
100 *Tofieldia pusilla*

Grasses 10%
100 *Arctagrostis latifolia*

Mosses – Lichens 95%
50 *Cladina rangiferina*
45 *Cetraria nivalis*
5 *Cladina alpestris*

b) In polygon trough

Low shrubs 15%
60 *Vaccinium uliginosum*
40 *Chamaedaphne calyculata*

Dwarf shrubs 5%
100 *Rubus chamaemorus*

Grasses 50%
100 *Eriophorum* sp.

Mosses – Lichens 70%
70 *Sphagnum fuscum*
30 *Hylocomium splendens*

Table 6. Micromorphological Features for Site 1: Peat Plateau.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Om (Oe)	**Overall:** Moderately decomposed organic particles, aggregates, charcoal fragments and sphagnum moss stem tissues are clustered in distinct zones. (Pl.1:A) **Related DP:** Phytogranic/humi-phytogranic/ phytogranoidic. Plasmic: Not applicable as no clay fraction present. **Microstructure:** Crumb structure with close packing of individual organic particles; clusters. b-fabric: No clay present. c/f RDP: Enaulic with monic in sphagnum moss inclusions.	**Void Pattern:** Simple and compound packing voids; interconnected, extremely porous matrix. **Basic Components:** Mineral: Very minor occurrence of angular quartz (10–70 μm) randomly distributed throughout; suggestive of dust input. Organic: The organic materials tend to be distributed in clusters of similar components. Aggregates composed of fragmented, moderately decomposed plant tissues (size ranges highly variable), which are the result of soil faunal activity, are the dominant feature of the soil fabric. Sphagnum moss stem tissues are common in distinct zones; tissues show weak to moderate decomposition, but distinct cell structure is clearly maintained. Fungal hyphae are associated commonly with aggregates and occasionally with root tissues; frequent fungal sclerotia (50–280 μm) are commonly broken apart. Black humified (charcoal) particles of plant tissues are frequent and tend to be clustered; probably affected by fungal hyphae and/or fire (Pl.1:A). Root sections 0.4–2.2 mm are common, and occasionally the centre portion is removed by faunal activity. Occasional leaves of sedge show moderate to strong decomposition. Interference colours shown only in sphagnum moss particles and root sections. **Pedofeatures:** Faunal: Abundant fecal material of various size ranges indicating variety of faunal diversity; most abundant 50–70 μm rounded aggregates consist of fragmented plant tissues; occasional rectangular units 280–400 μm. (Pl.1:B)	Clusters of organic materials of similar composition; for instance, 1. Sphagnum moss fragments appear intruded into the fragmented plant tissues; clusters with the stem tissues are oriented (direction varies as some clusters are horizontal, at 40° to horizontal). (Pl.1:A) 2. Concentrations of the black humified fragments included into granular material. Fecal activity is abundant and suggests relatively stable conditions and periods where material remains unfrozen.
Ofz (Oif)	**Overall:** Close packing of sphagnum moss stem and leaf tissues with common inclusions of well decomposed plant material in association with fecal material. (Pl.1:C) **Related DP:** Dominantly phytogranic; in the inclusions humigranic. Plasmic: Not applicable as no clay fraction present. **Microstructure:** Single grain distribution of organic particles. b-fabric: No clay fraction. c/f RDP: Monic.	**Void Pattern:** Porosity is associated mainly with the interior structural cells of sphagnum moss fragments as well as the simple packing voids between the fragments. Extremely porous soil fabric. **Basic Components:** Mineral: None Organic: Primarily sphagnum moss stem and leaf tissues; cell structures show little to moderate decomposition, common fungal hyphae distributed throughout the moss tissues. Distinct fabric zones where moss tissues show a preferred orientation. Frequent root and rare sedge leaf tissues occur in distinct zones between the moss fragments; have moderate to strong decomposition; and show alignment and twisting in association with the moss fragments. Moderate to strong interference colours in sphagnum tissues. **Pedofeatures:** Faunal: Occasional fecal material in association with humified root tissues (0.7–200 μm); rare faunal body remnants. (Pl.1:D)	Orientation of sphagnum moss tissues is very pronounced in distinct zones. Humified root tissues appear to be incorporated into sphagnum moss tissues; show diagonal trend (30–65° from horizontal); appearance suggests being compressed in distinct zones between the sphagnum moss. Roots may have originally penetrated cracks within sphagnum moss; when humified with age subjected to compression from freezing processes. (Pl.1:C)

Table 6. Micromorphological Features for Site 1: Peat Plateau (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Omz1 (Oefl)	**Overall:** Extremely porous soil matrix of moderately to strongly decomposed fragmented organic material; dominance of root tissues (woody); frequent leaf tissues; and common amorphous aggregates of faunal origin. (Pl.1:E) **Related DP:** Phytogranic. Plasmic: No clay fraction. **Microstructure:** Single grain distribution of organic particles; close packing. b-fabric: No clay fraction. c/f RDP: Enaulic.	**Void Pattern:** Simple packing voids between organic fragments. **Basic Components:** Mineral: Extremely minor; random distribution; dominantly silt-size (10–50 μm); probable origin wind-blown. Organic: Moderate to strongly decomposed plant tissues; dominantly woody root material, with occasional leaf tissues still distinguishable; most fragments origin unknown because of fragmentation and/or state of advanced decomposition. Occasional fragments show moderate to strong interference colours. Rare fungal material as mycorrhizal remnants; rare fungal sclerotia. Distinct zone in upper part of sample dominated by amorphous masses (0.8–2.2 mm) composed of fungal hyphae, very rare diatoms, rare incorporated woody tissues; located between organic fragments and associated with woody fragments. (Pl.1:F) **Pedofeatures:** Faunal: Occasional to common evidence of fecal material but tend to show advanced decomposition (dominantly 100–280 μm aggregates of amorphous and fragmented tissues; occasional rectangular aggregates 0.5–1.0 mm of very finely fragmented tissues in close association with fungal amorphous masses).	Distribution of root fragments may have been affected by freezing pressures as there tends to be changes in orientation in distinct fabric zones; but, evidence is weak to conclusively differentiate from actual parent material deposition that is often typical of random distribution of woody peat materials. (Pl.1:E)

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine related distribution after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 1

List of Plates for Site 1: Peat Plateau.

Plate 1: A

Moderately decomposed organic particles with inclusion of sphagnum moss fragments. Organic fragments tend to be clustered together. Phytogranic/phytogranoidic fabric in the Om horizon. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 1: B

Faunal material in the Om horizon represents a variety of faunal diversity, most abundant are 50–70 μm with occasional rectangular units 280–400 μm. Frame length 1.0 mm. (PPL).

Plate 1: C

Closely packed sphagnum moss stem and leaf tissues with well decomposed root material along probable desiccation crack observed in the Ofz horizon. Sphagnum moss fragments show orientation into distinct zones. Frame length 4.0 mm. (PPL).

Plate 1: D

Little to moderate decomposition of sphagnum moss fragments in the Ofz horizon. The rounded structure in the centre is the faunal body remnant of an Oribatid mite [Oribatida: Limnozetidae: *Limnozetes* sp.], a common species in Subarctic peat environments. Frame length 1.0 mm. (PPL).

Plate 1: E

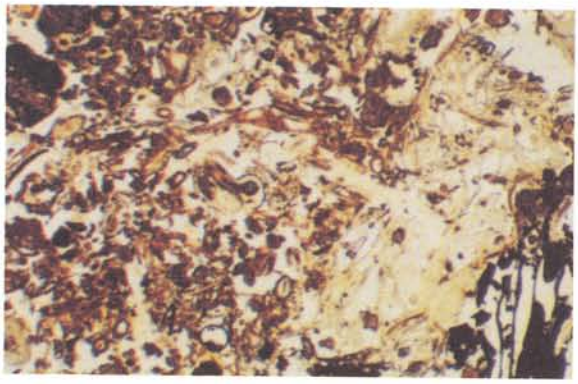
Porous soil matrix of moderately to strongly decomposed organic fragments observed in the Omz1 horizon; phytogranic soil arrangement. Some reorganization of plant structures may have occurred as a result of cryogenic processes, but it is difficult to differentiate from actual parent material deposition. Frame length 4.0 mm. (PPL).

Plate 1: F

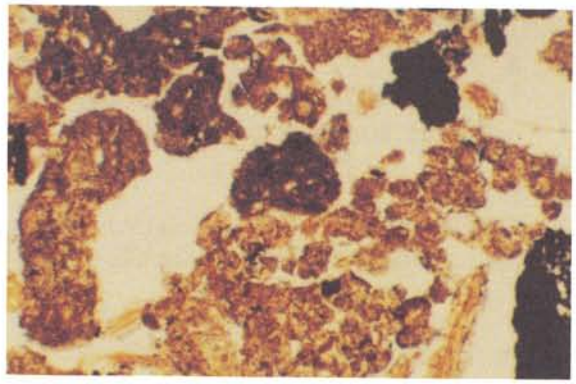
Amorphous masses (left side) composed of fungal hyphae, very rare diatoms, and rare incorporated woody tissues are in association with woody fragments and located between organic fragments in a distinct zone in the Omz1 horizon. Frame length 1.0 mm. (PPL).

PLATE 1

Site 1: Peat Plateau

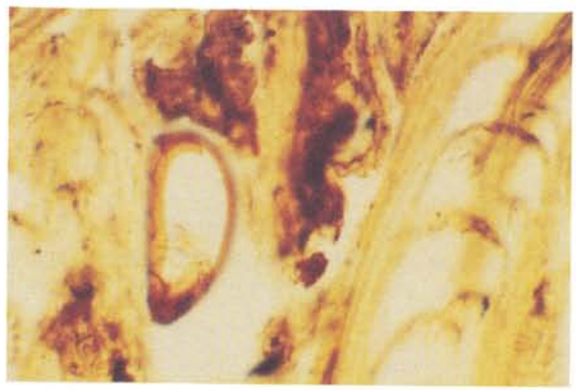


A

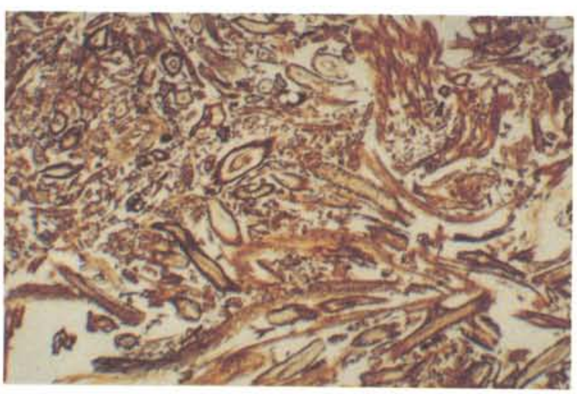


B

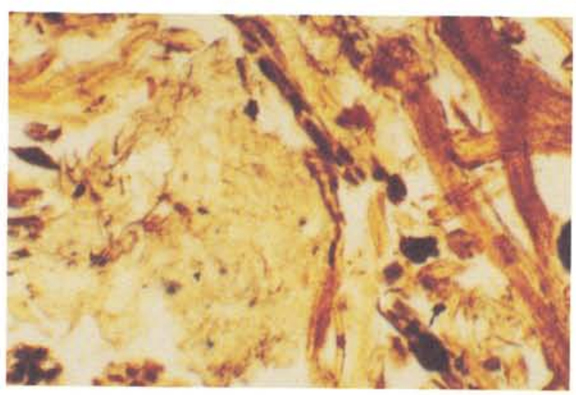
C



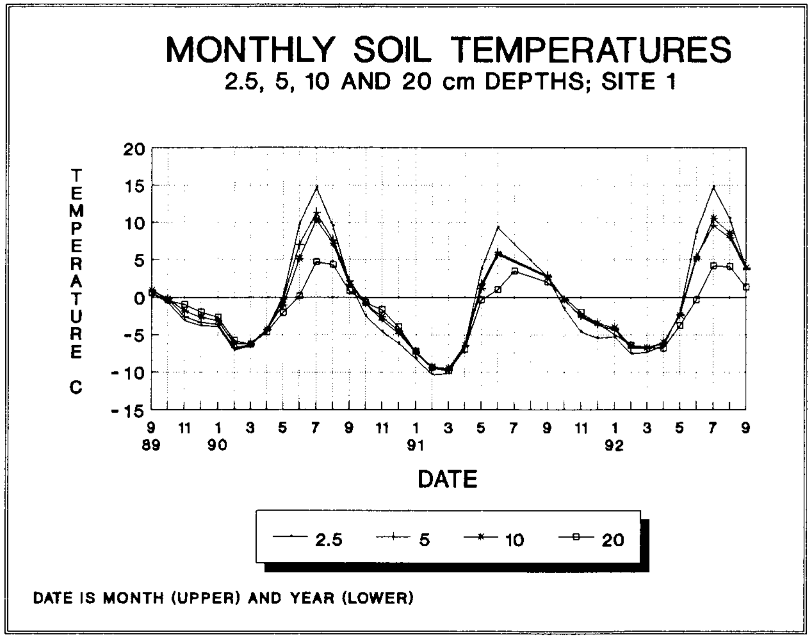
D

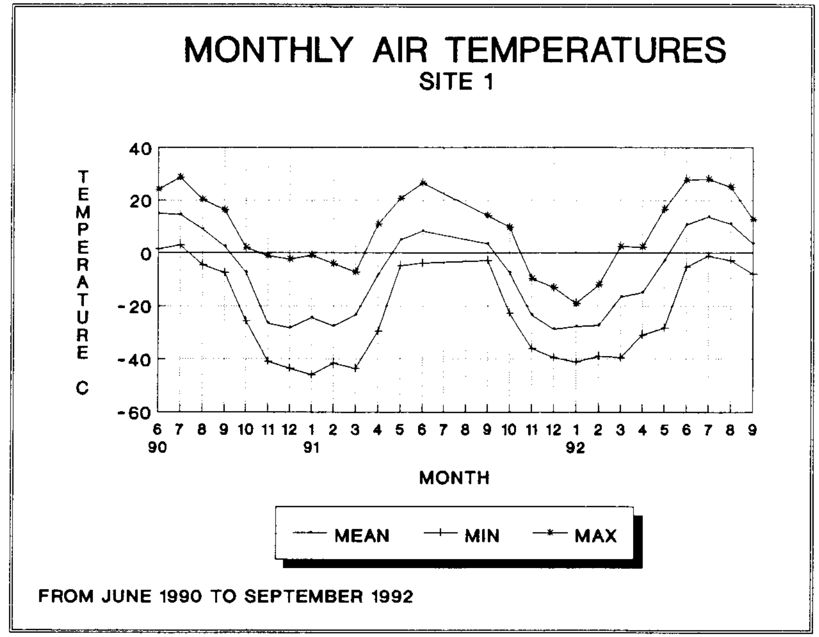


E



F





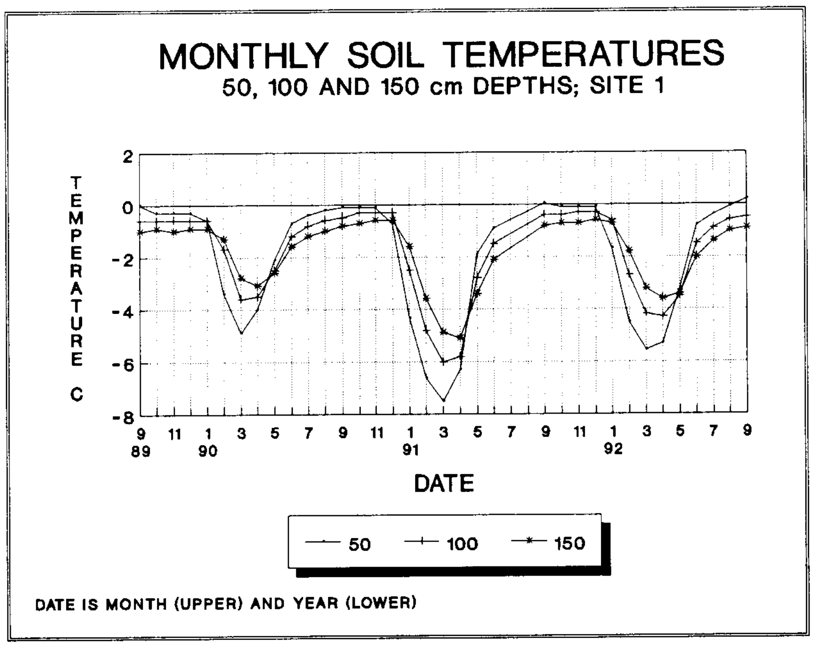
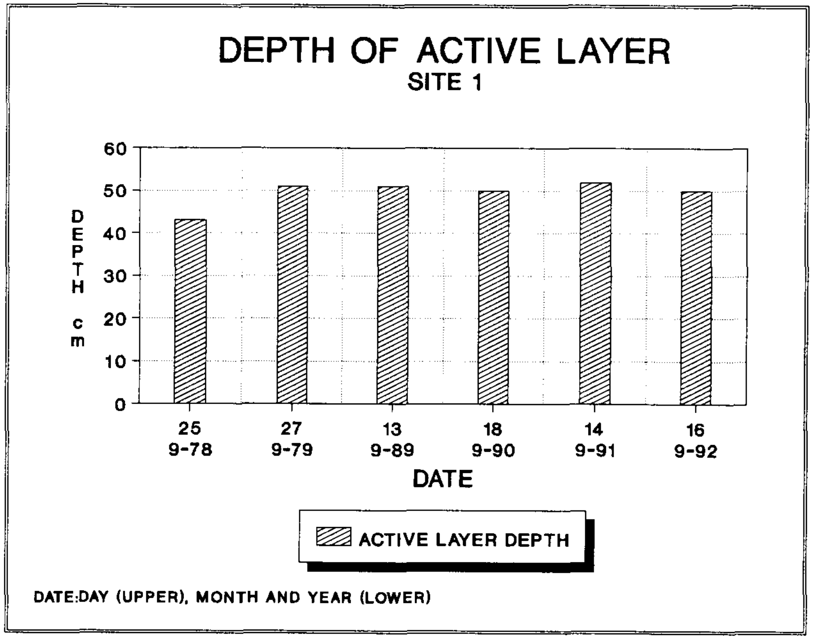
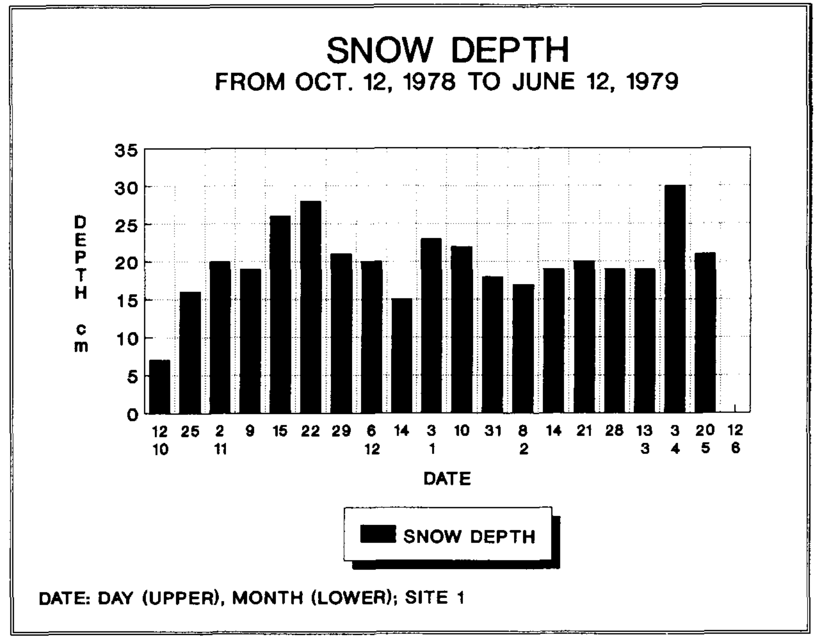


Figure 14. Monthly soil and air temperatures at Site 1 between June 1990 and September 1992.





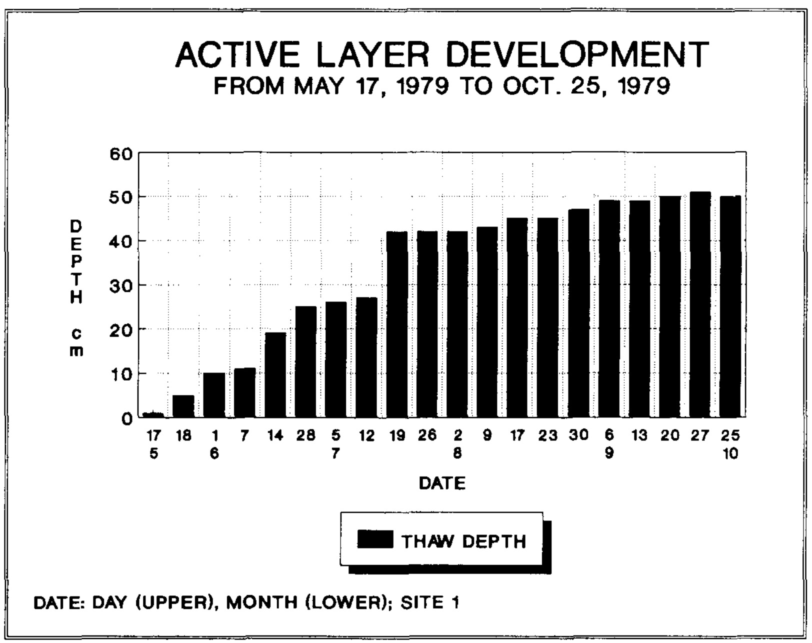


Figure 15. Depth of the active layer, measured in six years, and active layer development and snow depth during 1978 and 1979 at Site 1.

Table 7. Mean annual (MAST), minimum, maximum and mean summer* (MSST) soil temperatures in 1978-81 (Tarnocai 1984), 1990 and 1991 at Site 1.

Depth	MAST (°C)			MIN (°C)			MAX (°C)			MSST (°C)	
(cm)	1978-81	1990	1991	1978-81	1990	1991	1978-81	1990	1991	1990	1991
2.5	-1.1	0.1	-0.5	-17.5	-9.2	-11.8	17.5	29.1	28.9	11.3	11.5
5	-0.4	-0.2	-0.9	-16.5	-8.7	-10.8	15.4	17.4	15.3	8.6	7.8
10	-1.5	-0.4	-0.8	-15.9	-8.0	-10.6	15.0	15.6	17.9	7.6	8.2
20	-2.5	-1.5	-2.5	-15.0	-7.5	-10.6	7.6	6.8	7.7	3.0	3.1
50	-2.9	-1.4	-2.3	-10.7	-5.1	-7.8	0.2	0.0	0.2	-0.4	-0.5
100	-2.7	-1.3	-2.2	-8.4	-3.8	-6.3	-0.3	-0.3	-0.3	-0.9	-1.0
150		-1.4	-2.1		-3.2	-5.3		-0.6	-0.6	-1.2	-1.5
Air		–	-8.5		-43.5	-46.0		28.7	27.9	12.9	10.9

* Summer refers to June, July and August

SITE 2, KM 36: PERMAFROST SOIL DEVELOPED ON EARTH HUMMOCKS

Earth hummocks, which belong to the category of non-sorted circles or nets in the classification of patterned ground by Washburn (1973 and 1980), are widely distributed in the western Arctic, and are the dominant type of patterned ground in the Mackenzie Valley area. At this site, soils associated with earth hummocks will be examined.

Earth hummocks have developed on fine- to medium-textured (clay to silt loam) materials. On level ground they are nearly circular, but on slopes they tend to be elongated. Their diameters vary from 1 to 2 m and their average height is 50 cm, ranging from 20 to 60 cm. Some extremely large hummocks, with diameters of 2 to 3 m and heights of up to 80 cm, are found in a few areas of the Mackenzie Valley (Tarnocai and Zoltai 1978).

Within the hummock, the irregular permafrost table separates the active layer from the permafrost. It is characteristic that the permafrost table is a mirror image of the surface, being deepest under the top of the hummock and shallowest under the interhummock depression. The depth of the active layer (measured at the top of the hummock) is usually 1 m or more in the southern portion of the Mackenzie Valley, 60 cm in the northern part and the North Slope of the Yukon, and 40 cm in the High Arctic islands. Forest fires in the Subarctic can result in an approximately twofold increase in the depth of the active layer.

Earth hummocks are formed as a result of cryogenic processes that are only periodically active. This activity coincides mainly with higher than normal summer temperatures and rainfall, which combine to produce a deeper active layer with a higher moisture content and, thus, a greater amount of frost heaving (Tarnocai and Zoltai 1978). There was relatively little activity during the 1960's and 1970's as reflected in minimal cryostatic pressure development (Mackay and MacKay 1976) and minimal ground movement as registered by the ring structure of trees growing on these hummocks (Zoltai 1975).

In forested regions, soils associated with hummocks are generally characterized by a continuous peaty surface layer, while in Arctic regions the peat layer is discontinuous and occurs mainly in the interhummock depressions. The granular surface mineral horizon (Smith and Fox in press) is thickest at the top of the hummock and tapers in thickness down the side of the hummock. It is only present where well- to moderately well-drained conditions exist. The underlying horizons are discontinuous or disrupted, with intrusions of organic materials being present. An organic-rich or peaty subsurface horizon is common near the permafrost table. High-ice-content horizons near the surface of the permafrost table or pure ice layers are almost always present in soils that have not been recently affected by forest fire or other disturbance.

No clay movement was found in the B horizon of hummocks in the central and northern part of the Mackenzie Valley. Some soils, however, show minor textural variation within different portions of the hummock. Soil from the interhummock trough often contains slightly higher amounts of sand and silt, while that from the central portion of the hummock has slightly more clay (Tarnocai and Zoltai 1978).

The moisture content (on a volume basis) of the active layer varies greatly. In general, the surface soil at the top of the hummock is driest and the moisture content increases both with depth (to 40% or higher) and laterally to the interhummock depression (to approximately 70%). The material below the permafrost table contains large amounts of ice in the form of vein ice or ice lenses, with various thicknesses of pure ice occurring commonly.

ORTHIC TURBIC CRYOSOL, PEATY PHASE

This site is situated on a gently undulating morainal plain composed of moderately fine-textured till. The soil is classified as an Orthic Turbic Cryosol, peaty phase (Table 8; Figure 16). This soil is typical of those Turbic Cryosols situated in the vast Subarctic area of the Mackenzie Valley that have been unaffected by forest fires for a long period of time. The oldest tree found was 232 years old (Pettapiece *et al.* 1978). A continuous peaty surface layer, a shallow active layer, strongly cryoturbated soil horizons and high ice content in the near-surface permafrost are common features of these Subarctic soils. In addition, intrusions of organic matter are common, especially in the BCy horizons, and a discontinuous subsurface Omyz horizon occurs near the permafrost table. Radiocarbon dating of material from the Omyz horizon yielded a date of 4690±100 years B.P. (BGS 320). This is an older date than most for organic matter from earth hummocks in the Canadian North (Zoltai *et al.* 1978), but it could mark the beginning of earth hummock development in the area.

The analytical data for this pedon are presented in Table 9. The soil is silty loam in texture and there is negligible textural difference between the mineral horizons. Some coarse rock fragments are found close to the interhummock depressions. Some preferred orientation of long axes may be noted.

The soil is moderately acid to neutral and contains moderate amounts of exchangeable calcium and magnesium. The perennially frozen material may, however, be mildly alkaline and weakly calcareous. The pyrophosphate-extractable iron and aluminum, on the other hand, are high, especially in those horizons (Bm and BCy) that are associated with higher organic matter content. The total organic carbon is high in all horizons. Most of the organic carbon is mixed in the mineral horizons as a result of cryoturbation, often as an accumulation near the permafrost table, forming a subsurface organic horizon (Ahy). The organic fraction indicates that fulvic acid is the major soluble component, although over 50% of the total organic carbon was found to be insoluble, residual, humin material. Qualitative clay mineral analysis indicates the presence of all major species of phyllosilicates but, as a general statement, mica, smectite and vermiculite tend to dominate (Table 9).

The surface peaty organic horizons are moderately moist. The Bm horizon has the lowest moisture content and the moisture increases with increasing depth. The Cyz horizon contains up to 99% ice, mainly in the form of ice lenses and vein ice. The BCy horizon is again typical of those affected by cryoturbation. This horizon has the highest bulk density (1.68 g/cm^3 at this site) with very little void space and irregular distribution of organic materials (Table 9).

The vegetation at the site is a mature black spruce – lichen forest characteristic of the northern Subarctic in this area (Table 10). The trees lean in all directions, indicating ground movement during the life of the tree. In addition, the vegetation distribution varies as a result of the microrelief (earth hummocks).

Micromorphology

The micromorphology of the horizons sampled at Site 2 is described in Table 11 and shown in Plate 2.

Oh Horizon. Abundant faunal activity in the Oh horizon has led to considerable granular material and fragmented plant tissues. Abundant moss root tissues continue into the Oh horizon from the upper Of horizon. There is weak to moderate expression of sorting of large organic fragments into clusters and zones of similar sizes, with the finer granular material in the intervening pore space. This is reflected in an ortho-phytogranic soil fabric morphology with humigranoidic-humigranic granular material. (Pl.2:A, B)

Bm Horizon. This horizon represents a transition between the Oh and the Bmy horizons. Considerable amorphous organic material has moved into the Bm horizon and been incorporated into the mineral material. Cryogenic processes, especially freeze–thaw cycles, have led to alignment of lithofragments, packing of clay particles on the surfaces of the silt-size grains, and flocculation of amorphous organic material with the fine silt-size mineral material during very wet conditions to form fine, irregular, smooth-sided aggregations. Faunal activity is a remnant from the Oh horizon and can be observed in the interiors of root fragments and, rarely, intermixed with the mineral material. (Pl.2:C, D)

Bmy Horizon (upper). Although only weakly expressed in the Bm horizon, the effects of cryogenic processes are very pronounced in the upper Bmy horizon. The Bmy (upper) horizon was sampled at about the mid-portion of the horizon, but away from the distinct Ahy horizon material that has inclusions into the Bmy. There is considerable movement of mineral material, as evidenced both by very strong sorting of the grains into circular patterns and by alignment of the lithofragments. In the mineral horizons, alignment of the soil particles is near vertical, ranging from 70° to 90° from the horizontal and, diagonally, ranging from 30° to 50° from the horizontal. Differences between the horizons occur with respect to the number of grains observed in a particular alignment. These differences can be attributed to the intensity and number of freezing cycles, as well as the direction of the freezing front. (Pl.2:E, F)

Bmy Horizon (lower). The Bmy (lower) horizon was sampled in the vicinity of the permafrost table, below the Ahy horizon. The soil fabric is dense with occasional planar voids (Pl.2:G). The distinguishing characteristic of this horizon is the silt-size accumulations (20–300 μm) on the grain surfaces of the lithofragments and organic particles. Successive layering, as well as variations in thickness around the lithofragments, was often observed (Pl.2:H). From these features, it can be inferred that considerable movement has taken place by the rotation of the grains in conjunction with intervening periods of relative stability to account for the maintainence of the accumulations.

Ahy Horizon. The Ahy horizon that was sampled is located adjacent to the upper part of the Bmy horizon and below the Oh horizon. This horizon (Pl.2:I, J) shows considerable sorting of the silt-size and coarser quartz grains into circular patterns. The influence of the freezing front is shown in the sorting of the grains by size with depth. Accumulations of silt-size material on the lithofragments are less pronounced than in the Bmy (lower) horizon, likely indicating fewer periods of stability. Desiccation cracks are common, with rare occurrences of included material. Considerable amounts of organic tissue have been included from the overlying Oh horizon (Pl.2:K). In addition, extremely fine cell structure material and well decomposed fragments form part of the groundmass.

BCy Horizon. The morphology of the BCy horizon has fabric zones very similar to those of the Ahy horizon. Organic fragments have been included into the mineral material along desiccation cracks (Pl.2:L). Freezing cycles can be inferred from the alignment of lithofragments, the silt-size accumulations, and clay particle packing on grain surfaces. The clay particle alignment around silt-size grains is observed as lattisepic fabric.

Soil Temperature and Moisture

Soil temperatures have been monitored at this site since 1978. At that time, thermistors were installed at depths of 2.5, 5, 10, 20, 50 and 100 cm and readings were taken manually, approximately once a month. Using this data, the soil temperature parameters were calculated using the best-fitting line generated by a computer program. The mean annual soil temperatures (MAST) from 1978 to 1981 are presented in Table 12 (Tarnocai 1984).

A data logger that automatically records soil and air temperatures every 3 hours was installed in 1989. Since then, soil temperatures have been taken at depths of 2.5, 5, 10, 20, 50, 100 and 150 cm. The mean monthly and maximum and minimum soil and air temperatures have been plotted and are shown in Figure 17. The mean annual, the absolute minimum and maximum, and the mean summer (MSST) soil temperatures for 1991 and 1992 are given in Table 12.

Soil temperature data from the 20 cm and 50 cm depths are used to characterize the soil temperature regimes of Cryosolic soils. Based on the data presented in Table 12, this soil has a MAST of -3.4°C at the 20 cm depth and -3.7°C at the 50 cm depth in 1991-92. The MSST values (Table 12) clearly indicate a fluctuating permafrost table. The upper 20 cm of this soil thaws during the summer, having MSST values of 5.2° (1991) and 2.7°C (1992), while at the 50 cm depth the MSST values were 2.7°C (1991) and -0.1°C (1992). It should be noted that the MSST value at 100 cm was still above 0°C in 1991, but it was -1.4°C in 1992. This fluctuation of the permafrost table was due to the warm years that occurred between 1988 and 1990.

At the 0–15, 15–30 and 30–50 cm depths (Figure 18), the moisture content was found to vary between 40 and 84% during the four occasions on which it was measured during the summers of 1991 and 1992.

Snow Depth, Active Layer Depth and Subsidence

Snow depth, especially the occurrence of a large amount of snow in early winter, greatly affects freeze-back (cooling) of the soil. In this region, snow has a fluffy nature and thus provides a good insulating layer for the soil surface. The snow depth at this site (Figure 19) was monitored during the winter of 1978-79 (October 5, 1978 to June 12, 1979) and was found to increase rapidly during October, thereafter gradually increasing throughout the winter, reaching a maximum depth of approximately 55 cm during the later part of the winter. The snow had completely melted by the early part of June at this site. Because of the protected nature of this site, no snow drifts formed during the winter.

The depth of the active layer has been measured each September for the past six years and has been found to vary greatly, having the highest value in 1991 (105 cm) and the lowest value in 1978 (69 cm) (Figure 19).

Systematic surface subsidence measurements have been taken at this site since 1990. No subsidence occurred in 1990, but 2 cm subsidence was measured in 1991 and 4 cm in 1992.

Table 8. Site and pedon descriptions for Site 2.

Location: 68°06'39" N Lat., 133° 28'29" W Long.
Landform: Undulating morainal plain
Drainage: Internal – moderately well to poor; external – imperfect to poor
Soil Temperature (50 cm depth; 1991-92): MAST -3.7°C, MSST 1.3°C
Parent Material: Fine silty till
Patterned Ground: Earth hummocks; average diameter – 135 cm, average height – 45 cm

Elevation: 30 m (a.s.l.)
Slope: 3% to the southwest; site is mid-slope
Vegetation: Subarctic forest
Soil Classification: Can. – Orthic Turbic Cryosol, peaty phase
U.S.A. – Pergelic Ruptic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Depth or thickness (cm)	Description
Can.	U.S.		
Of	Oi	6 – 3	Very dusty red (2.5YR 2.5/2 m); undecomposed feathermoss peat; loose to matted; abundant, medium to large, horizontal roots; extremely acid; clear, wavy boundary; found mainly in interhummock depression; 0 to 20 cm thick.
Oh	Oa	3 – 0	Black (5YR 2.5/1 m); moderately well decomposed, feathermoss peat; matted; plentiful, medium to fine, random roots, few, medium horizontal roots; slightly acid; clear, wavy boundary; 2 to 10 cm thick.
Bm	Bw1	0 – 10	Dark brown (10YR 4/3 m); silt loam; strong, fine to medium, granular; sticky and plastic; friable; plentiful, fine random roots, few, medium horizontal roots; very strongly acid; clear, wavy boundary; found on apex of hummock; 0 to 10 cm thick.
Bmy	Bw2	10 – 35	Very dark grayish brown (10YR 3/2 m); silt loam; moderate, fine to medium, granular; sticky and plastic; friable; few, fine random roots; slightly acid; gradual, wavy boundary; discontinuous, 0 to 30 cm thick.
BCy	BC	35 – 65	Dark brown (10YR 4/3 m) to very dark gray (10YR 3/3 to 3/1 m); silty clay; strongly cryoturbated with intrusions of organic matter; structureless, massive; sticky and plastic; firm; very few, fine vertical roots; stones up to 10 cm in diameter in interhummock depression; neutral; abrupt, wavy boundary; discontinuous, 0 to 3 cm thick.
Ahyz	Af	up to 5	Black (2.5Y 2.5/0m); frozen, organic-rich mineral; neutral; ice lenses up to 5 mm thick; 0 to 5 cm thick.
Cyz	Cf	65 – 110+	Dark grayish brown (2.5Y 4/2m); frozen silty clay; 65% segregated ice crystals and ice lenses up to 10 mm thick; intrusions of organic matter; structureless, massive; mildly alkaline.
Ahy	A	up to 5	Black (2.5Y 2.5/0m); silty clay; organic-rich mineral; neutral; 0 to 5 cm thick.
Omyz	Oef	4 – 8	Black (10YR 2/1m); frozen, moderately decomposed moss peat; segregated ice crystals; slightly acid; 4 to 8 cm thick.

Table 9. Analytical data for the Orthic Turbic Cryosol at Site 2.

Chemical Analysis																
Horizon	pH		Org. C	$CaCO_3$ Equiv.	Total N	C/N	Exchangeable Cations (me/100g)									
							Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)	(%)		K	Ca	Mg	Al	Total	Total	Ca	Mg	Na	K
Of	4.4	4.1	43.0		1.98	22	2.2	41.6	10.9	0.1	54.8	163.8	56.4	12.8	0.1	1.2
Oh	6.1	5.7	35.9		2.06	17	0.7	92.3	20.0	0	112.9	178.8	120.1	23.9	0.2	0.6
Bm	5.0	4.6	3.0		0.20	15	0.4	12.8	4.9	2.4	20.4	35.4	13.3	5.9	0.1	0.2
Bmy	6.2	6.1	1.8		0.14	13	0.3	15.3	5.3	0	20.9	26.9	16.8	6.7	0.1	0.2
BCy	6.9	6.5	2.7		0.19	14	0.5	20.8	5.2	0	26.4	32.8	23.9	6.7	0.1	0.2
Ahyz	–	6.8	9.5		0.52	18						66.4	61.6	10.5	0.1	0.2
Cyz	7.5	7.1	1.5	3.3	0.09	17	0.4	11.6	2.0	0	14.0					

Sesquioxides (%)							
Horizon	Dithionite			Oxalate		Pyrophos.	
	Fe	Al	Mn	Fe	Al	Fe	Al
Of							
Oh							
Bm	2.17	0.18	0.04	0.71	0.11	0.36	0.10
Bmy	1.79	0.07	0.03	0.57	0.07	0.17	0.02
Bcy	1.78	0.07	0.04	0.74	0.12	0.20	0.02
Ahyz							
Cyz	1.64	0.05	0.03	0.39	0.02	0.05	0.02

Mineralogy and Chemical Analysis																	
Horizon	Available Nutrients (ppm)				Organic Matter					Clay Mineralogy (<2µ)*							
					Extracted		Cha /Cfa	FA	HA								
	N	P-Bray	K	S	%C	%N		E4/E6	E4/E6	Mica	Chlor.	Kaol.	Smect.	Verm.	Quartz	Felds.
Of	1	3	72	3												
Oh	8	2	32	3	30	37	0.15	5.7	5.4							
Bm	0	0	57	2	48	69	0.30	7.3	4.3	tr	tr	tr	2	2	1	
Bmy	1	0	85	1						tr	tr	tr	1	1	1	
BCy	1	0	92	4						2	tr	tr	tr	1	1	
Ahyz																
Cyz										2	tr	tr	–	1	2	tr

* Amount estimated from x-ray diffractograms: tr = trace, 1 = 2-20%, 2 = 20-40%.

Table 9. Analytical data for the Orthic Turbic Cryosol at Site 2 (cont.)

Physical Analysis												
Horizon	**Fibre Content (%)**		**%**	**%**	**Part. Size Dist. (% <2 mm)**				**Bulk Den.**	**Moisture (%)**		**Texture**
	Unrub.	**Rub.**	**Ash**	**>2 mm**	**Sand**	**Silt**	**Clay**	**F-Clay**	**(g/cc)**	**1/3 atm**	**15 atm**	
Of	90	50	5.6									
Oh	65	5	29.1						0.29			
Bm				5	20	52	28	12	1.12	30	15	SiL-SiCL
Bmy				5	16	58	26	12	1.53			SiL
BCy				4	19	53	28	13	1.68			SiL-SiCL
Ahyz				21								
Cyz				14	20	55	25	9				SiL

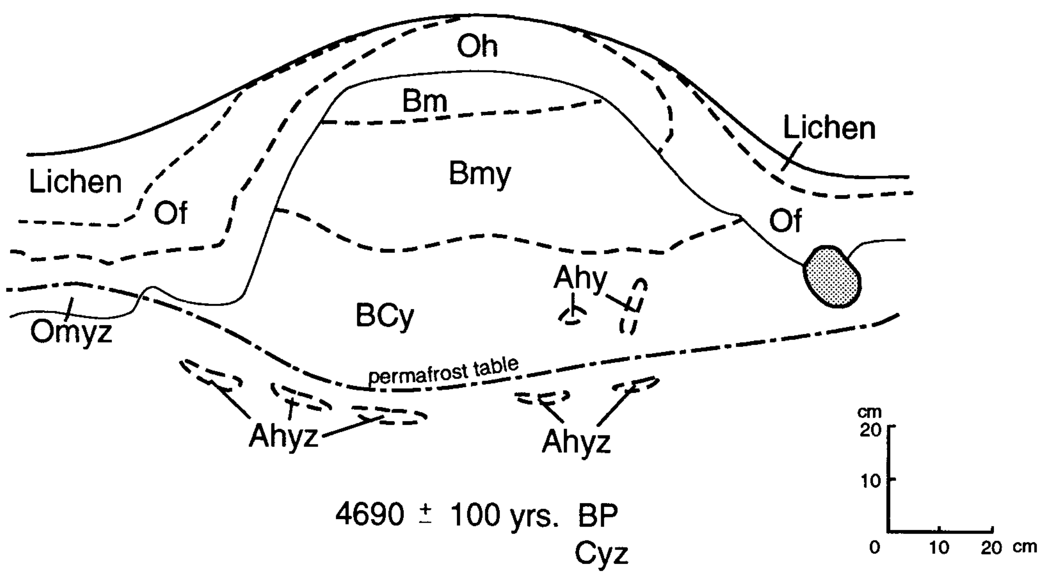


Figure 16. Cross section of the Orthic Turbic Cryosol associated with earth hummocks at Site 2.

Table 10. Vegetation description for Site 2.

Tree ages, *Picea mariana* –	232 yr
	129 yr
	108 yr
	59 yr
	50 yr

Vegetation

A) On hummock tops

Trees 5%
100 *Picea mariana*

Tall shrubs 20%
80 *Alnus crispa* ssp. *crispa*
20 *Salix alaxensis*

Low shrubs 35%
60 *Vaccinium uliginosum*
30 *Ledum palustre* ssp. *groenlandicum*
10 *Ledum palustre* ssp. *decumbens*

Dwarf shrubs 35%
55 *Vaccinium vitis-idaea*
40 *Arctostaphylos rubra*
5 *Empetrum nigrum*

Herbs 1%
100 *Saussurea angustifolia*

Grasses 1%
100 *Arctagrostis latifolia*

Mosses – Lichens 90%
45 *Cladina mitis*
30 *Cladina alpestris*
10 *Cladina rangiferina*
5 *Cladonia amaurocrea*
5 *Cetraria nivalis*

B) In interhummock troughs

Trees 20%
100 *Picea mariana*

Tall shrubs 30%
75 *Salix alaxensis*
25 *Alnus crispa* ssp. *crispa*

Low shrubs 40%
40 *Ledum palustre* ssp. *groenlandicum*
35 *Vaccinium uliginosum*
25 *Ledum palustre* ssp. *decumbens*

Dwarf shrubs 45%
50 *Vaccinium vitis-idaea*
25 *Empetrum nigrum*
25 *Arctostaphylos rubra*

Herbs 1%
100 *Equisetum scirpoides*

Grasses 5%
80 *Arctagrostis latifolia*
20 *Carex lugens*

Mosses – Lichens 80%
25 *Dicranum fuscescens*
25 *Hypnum crista-castrensis*
20 *Cladina mitis*
20 *Dicranum acutifolium*
10 *Ptilidium ciliare*

Table 11. Micromorphological Features for Site 2: Earth Hummock.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Oh (Oa)	**Overall:** Closely packed fine to very fine organic fragments and aggregates distributed between abundant moss roots, occasional wood fragments and well-humified conifer needles. (Pl.2:A) **Related DP:** Ortho-phytogranic with intervening pore space humigranoidic-humigranic; weak orbiculic fabric. Plasmic: No clay present. **Microstructure:** Single grain structure of organic particles with closely packed fine granular units occupying the pore space. b-fabric: No clay present. c/f RDP: Enaulic.	**Void Pattern:** Simple and compound packing voids between organic fragments and granular units. Extremely porous soil fabric. **Basic Components:** Mineral: Occasional single grain angular quartz (<10–140 μm); randomly distributed throughout soil fabric; probable dust input. Organic: Abundant fragments of moss root tissues (size range varies considerably, mainly 0.4–6.0 mm) are randomly oriented and tend to occur in clusters. Occasional wood fragments (1–2.5 cm) are moderately decomposed with the interiors often affected by faunal activity. Distinct region of extremely humified (black, charcoal-like) fragments of leaf tissues; dominantly coniferous (0.4–2.4 mm). Fine granular material and fragmented plant tissues (50–200 μm, mainly 50–100 μm) occupy the pore spaces between the large fragments. Rare mycorrhizal mantle on woody root tissue; occasional fungal hyphae associated with granular material. **Pedofeatures:** Faunal: Faunal activity is considerable. The fine granular units are dominantly fauna derived. Destruction of the interior tissues of wood by fauna; fecal material 30–100 μm, concentric and composed of fragmented tissues. (Pl.2:B)	Sorting of large organic fragments into clusters with homogeneous central portions of granular units as well as zones of similar size ranges of fragmented material; weak to moderate expression.
Bm (Bw1)	**Overall:** Fine granular material, often aggregated, occupies the pore space between commonly occurring plant fragments and occasional mineral grains and lithofragments. (Pl.2:C) **Related DP:** Mullgranoidic porphyroskelic//ortho-humi-phyto-mullgranic//mullgranoidic. Plasmic: In granular units: weakly skel-insepic/insepic. **Microstructure:** Spongy structure with portions showing crumb structure. b-fabric: In aggregations: stipple-speckled. c/f RDP: Enaulic. In aggregations: porphyric.	**Void Pattern:** Extremely porous matrix; simple and compound packing voids. **Basic Components:** Mineral: Occasional lithofragments (0.12–1.5 cm) of shale, granitic, and metamorphic origin. Angular quartz (<10–300 μm mainly <10–50 μm) distributed randomly within the aggregates and occasionally as single grains in the soil matrix. Organic: Dominant proportion of the soil fabric of the granular material consists of extremely fine amorphous organic particles from the Oh horizon that give the dark brown colour to the matrix. Very frequent moss root tissues (0.6–1.6 mm length) are randomly distributed throughout. Root sections (0.8–3.6 mm width) occur commonly; show moderate to strong decomposition with frequent well-humified outer cortex layer. Well-humified (black) wood fragments (mainly 20–250 μm, few 500–700 μm) become incorporated as part of constituents of aggregates; larger fragments are distributed as single grains in soil matrix. Occasional fungal hyphae associated with aggregates and rarely with moss root fragments. **Pedofeatures:** Textural: In peds, extremely thin (<5 μm) clay particles and/or clay material occur discontinuously on mineral grains surfaces. Faunal: Rare to occasional fecal material from Oh horizon, mainly 50–250 μm. Interior of wood fragments occasionally completely removed by fauna; (size range 30–80 μm; 100–250 μm)	Alignment of very large rectangular-shaped lithofragments to near vertical (75–80°) and at diagonal 45°. (Pl.2:D) Packing of clay particles on silt-sized grains indicates influence of freeze–thaw cycles; very weakly expressed. Organic material and mineral fraction are mixed together, probably by a flocculation process, since irregular aggregates with smoothed surfaces have formed.

Table 11. Micromorphological Features for Site 2: Earth Hummock (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmy (Bw2) upper	**Overall:** Dense soil matrix with strongly sorted mineral grains into circular patterns; occasional vertical alignment of lithofragments. (Pl.2:E) **Related DP:** Suscitic-orbiculic porphyroskelic. Plasmic: Insepic//skel-insepic **Microstructure:** Massive. b-fabric: Grano-stipple-speckled. c/f RDP: Porphyric.	**Void Pattern:** Dense soil morphology with few vughs (0.8–1.2 mm wide) that are associated with root material. Extremely fine planar voids (4–10 µm wide) occur occasionally in soil material and around mineral grains. **Basic Components:** Mineral: Mineral grains show considerable sorting and alignment. (Pl.2:F) Dominantly angular to subangular quartz; mainly two size ranges (i.e., fine sand 100–250 µm and silt 10–50 µm). Frequent subrounded lithofragments; varied origin, but mainly shales, siltstones, sandstones, igneous; often aligned vertically. Abundant clay particles (weathered mica) throughout groundmass. Organic: Rare to occasional strongly decomposed plant tissues occur in groundmass. Rare root tissues are moderately to strongly decomposed. Abundant, extremely fine, reddish-brown cell tissue structures are disseminated throughout the groundmass. **Pedofeatures:** Nodules: Occasional; 150–400 µm, rounded, rarely concentric. In some cases the nodules are very weathered shale fragments. Textural: Frequent, discontinuous packing of clay particles and material around mineral grains; thickness varies <4–40 µm.	Very strong sorting of mineral grains into circular patterns throughout soil matrix. (Pl.2:F) Moderately expressed alignment of lithofragments at near vertical (70–90° from horizontal) and diagonal orientations (40–50° from horizontal). Packing of clay particles on surfaces of mineral grains. Thin cracks around grains may indicate zones of weakness from ice crystal formation.
Bmy (Bw2) lower	**Overall:** Dense soil fabric with weakly to moderately sorted silt-size grains; commonly aligned lithofragments; and fabric zones with abundant organic material. (Pl.2:G) **Related DP:** Orbiculic-suscitic porphyroskelic with minor weak granoidic-porphyroskelic in zones with increased proportion of organic material. Plasmic: Insepic//skel-insepic. **Microstructure:** Massive b-fabric: Grano-stipple-speckled c/f RDP: Porphyric.	**Void Pattern:** Vertical oriented planar voids (10–200 µm wide) pass occasionally to commonly through the soil material and occasionally in association with the outer surfaces of lithofragments. These planar voids are rarely to occasionally intersected either at right angles (Pl.2:G) or diagonally with channels (150–300 µm wide) or with thin planar voids (<10–50 µm). **Basic Components:** Mineral: Subrounded to rounded lithofragments (weathered shales, sandstone, siltstone, carbonates, igneous) of varying size (0.5–7 mm) tend to be aligned in the soil matrix and frequently have coatings. Silt-size grains are dominantly subangular quartz; weakly to moderately sorted in circular patterns. Organic: Fabric zone of included organic particles; extremely abundant particulate material; moderately to strongly decomposed root tissues and wood fragments; humified particles (black, charcoal-like). Extremely fine, strongly decomposed, reddish-brown organic material derived from plant cell structures occurs throughout the groundmass. (Pl.2:G, H) **Pedofeatures:** Textural: Very fine silt-size accumulations vary in thickness (20–300 µm) around the lithofragments and on coarse organic particles; often successive accumulations can be differentiated due to a change in texture or composition of constituents. Clay particle and material alignment (<10–20 µm) on grain surfaces of silt-size grains is common. Nodules: Ferruginous, rounded, 100–500 µm; may also be derived from very weathered shale.	Alignment of the lithofragments; dominantly near vertical (70–90° from horizontal); occasionally diagonal (32–54° from horizontal). Accumulations of silt size material of varying thicknesses around the surfaces of the lithofragments and on organic fragments suggest considerable rotation with periods of stability. (Pl.2:H) Alignment of clay particles on outer grain surfaces of silt-size particles occurs throughout the soil matrix. Sorting of the silt-size grains into circular patterns. Inclusion of organic particles; show alignment around lithofragments; granular structure expressed within this zone of abundant organic material probable result of ice lens formation. Pore pattern of planar voids around the lithofragments and through the soil matrix often intersected at diagonal or right angles suggests ice lens formation. (Pl.2:G)

Table 11. Micromorphological Features for Site 2: Earth Hummock (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ahy (A)	**Overall:** Dense soil fabric with abundant organic material and moderate to strong sorting and alignment of mineral grains. (Pl.2:I) **Related DP:** Suscitic-orbiculic porphyroskelic; with depth, minor occurrence of fabric zones with weak expression of granoidic-porphyroskelic. (Pl.2:K) Plasmic: Skelsepic; most plasma masked by amorphous organic material. **Microstructure:** Massive. b-fabric: Granostriated. c/f RDP: Porphyric.	**Void Pattern:** Sub-vertical planar voids (mainly 20–150 µm) are common; occasionally follow discontinuously the outer surfaces of coarse-sized mineral grains. Very rare irregular vughs (200 µm wide) connected to planar voids at end point. Rare channel with root material present. **Basic Components:** Mineral: Lithofragments are frequent; mainly sandstone, siltstone with minor shale and igneous. In groundmass, dominantly subangular to angular quartz of silt-size with subrounded to subangular quartz fine-medium sand size (mainly 150–300 µm). Mineral material is moderately to strongly sorted. (Pl.2:J) Organic: Abundant well-decomposed (reddish brown) and humified (black) fragments (50–450 µm) occur throughout soil (dominantly unrecognizable as to origin). Extremely fine particles (cell structures and broken fragments <50 µm) occur in the groundmass. Very rare conifer needle and root material (moderately to strongly decomposed). **Pedofeatures:** Textural: Packing of clay particles on mineral grain surfaces; thin (<10 µm), discontinuous; more pronounced on coarse-size grains. On grain surfaces of lithofragments, accumulations of very fine silt-size material (40–100 µm); occasionally portions of the coating may be amorphous organic material; rare occurrences of successive accumulations, i.e., oriented clay particles with silt-size material. Nodules: Occasional, rounded, 100–300 µm; in some cases may be weathered shale fragments.	Strong sorting of silt-size material into distinct patterns with coarser grains forming outer boundaries of the circular patterns. (Pl.2:J) Sorting by size with depth; lithofragments become coarser grained (from mainly 0.8–2.8 mm to 0.5 to >1.0 cm). Alignment of lithofragments; frequently diagonally (36–48° from horizontal) and occasionally to commonly near vertical (78–90° from horizontal). (Pl.2:I) Frequent surface accumulations of silt-size material on lithofragments; not as pronounced as in lower Bmy; suggests fewer periods of stability. Clay particle alignment and packing on mineral grain surfaces; very discontinuous and weakly to moderately expressed. Cracks; rare occurrence of included particles. Planar pores around coarse-size mineral material suggest preferential segregation of ice lens formation.
BCy (BC)	**Overall:** Dense soil fabric with inclusions of zones of strongly decomposed and humified organic fragments. (Pl.2:L) **Related DP:** Suscitic-porphyroskelic/ porphyroskelic with fabric zones of ortho-phyto-humigranic. Plasmic: Skelsepic-insepic; rare occurrences of weakly expressed lattisepic. **Microstructure:** Massive with zones of single particles of organic fragments. b-fabric: Granostriated and stipple-speckled with weakly expressed reticulate striated. c/f RDP: Porphyric with zones of monic.	**Void Pattern:** Simple packing pores occur in fabric zones with organic fragments. Occasional to rare subvertical planar voids and rare irregular vughs occur in dominantly mineral zones. **Basic Components:** Mineral: Few lithofragments 0.8–2.8 mm; randomly distributed with rare occurrence of vertical alignment of largest fragments. Groundmass consists of dominantly silt-size subangular quartz with occasional fine sand-size grains. Clay particles (weathered mica) are distributed throughout the mineral soil zones. Nodules of weathered shale (<500 µm) occur occasionally. Organic: Inclusions of strongly decomposed plant tissues, strongly fragmented; often associated with desiccation cracks. (Pl.2:L) Extremely fine fragments and cell structures distributed throughout groundmass. **Pedofeatures:** Textural: Surface accumulations on grain surfaces of lithofragments; consist of dense packing of silt-size groundmass material and/or preferred horizontal alignment of clay particles; discontinuous (<10–100 µm). Clay particles in groundmass often aligned on silt-size grains; very thin (4–10 µm); very discontinuous.	Inclusions of organic fragments associated with cracks suggest that individual particles moved into mineral material along open pore by ice. (Pl.2:L) Surface accumulations on coarse-size mineral material; clay particle alignment on grain surfaces. Lattisepic fabric, although weakly expressed, indicates orientation of the clay particles in response to drying cycles from freeze-thaw periods. Alignment of lithofragments; commonly diagonally (30–50° from horizontal) and near vertical (78–90° from horizontal).

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine related distribution after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 2

List of Plates for Site 2: Earth Hummock.

Plate 2: A

Closely packed fine organic material between abundant fragments of woody tissues and well-humified conifer needles characterize the Oh horizon. There is a weak tendency for clustering of the coarse organic fragments. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 2: B

Fine granular units produced as a result of faunal activity during the break-up of the organic fragments. Note the abundance of well-humified (charcoal) fragments. The soil fabric of the Oh horizon is ortho-phytogranic with intervening pore space humigranoidic-humigranic. Frame length 4.0 mm. (PPL).

Plate 2: C

Fine granular material in the Bm horizon is often aggregated, forming a mullgranoidic fabric component. Frame length 4.0 mm. (PPL).

Plate 2: D

Close-up view of aggregated granular material in the Bm horizon. Note diagonal alignment of quartz lithofragment. Frame length 1.0 mm. (PPL).

Plate 2: E

Dense soil fabric in the upper Bmy horizon, with particle sorting of coarse mineral grains into clusters and circular arrangements. Frame length 8.5 mm. (PPL).

Plate 2: F

Close-up view of strong particle sorting in the upper Bmy horizon. In this field of view, the mineral grains tend to be linear aligned, suggesting presence of a freezing front. Frame length 4.0 mm. (PPL).

Plate 2: G

Planar voids with occasional intersections at right angles and alignment of lithofragments to near vertical are observed in the dense soil fabric of the lower Bmy horizon. Frame length 8.5 mm. (PPL).

Plate 2: H

In the lower Bmy horizon, thick accumulation of silt-size material mixed with fine organic material was observed on the upper surface of the organic fragment; accumulations vary from 20 to 300 μm and may show successive accumulations. Frame length 4.0 mm. (PPL).

Plate 2: I

Dense soil fabric in Ahy horizon with strong evidence of the effect of cryogenesis on the coarse fraction shown by particle sorting and vertical alignment of the lithofragments. Frame length 4.0 mm. (PPL).

Plate 2: J

Close-up view of particle sorting in the Ahy horizon; coarse quartz grains are aligned in circular pattern producing an orbiculic-porphyroskelic fabric arrangement. Frame length 4.0 mm. (PPL).

Plate 2: K

Fabric zone with considerable organic matter content, which was included into the Ahy horizon as a result of cryogenic pressures and movement downslope. Frame length 1.0 mm. (PPL).

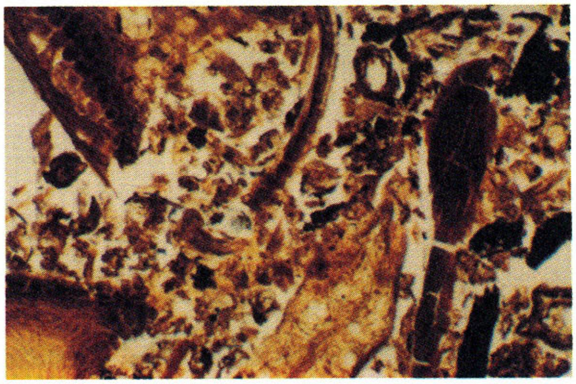
Plate 2: L

Strongly decomposed and humified organic fragments are included into the dense mineral material of the BCy horizon. Frame length 4.0 mm. (PPL).

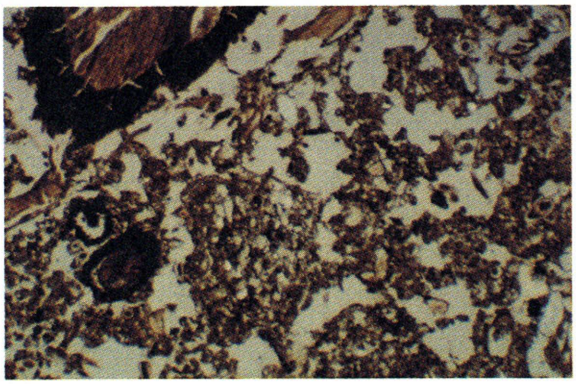
PLATE 2

Site 2: Earth Hummock

A



B



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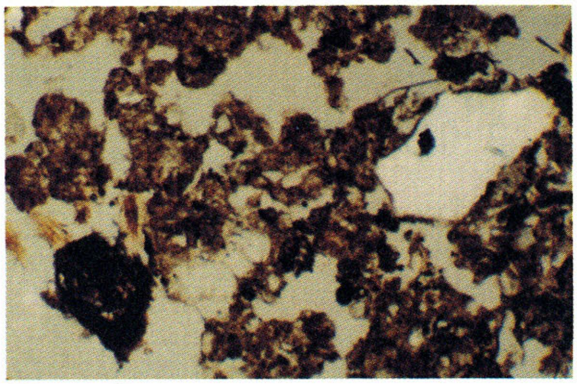

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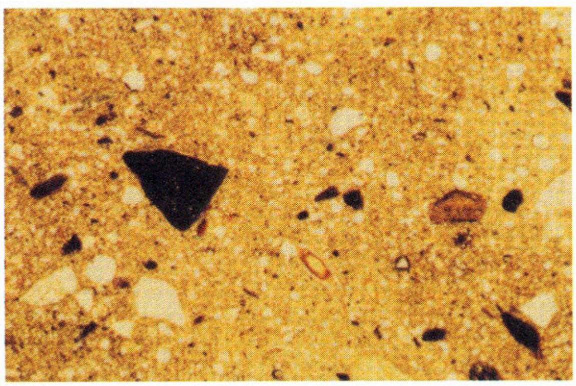

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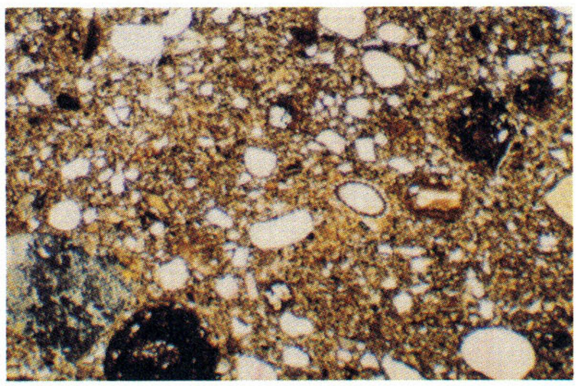
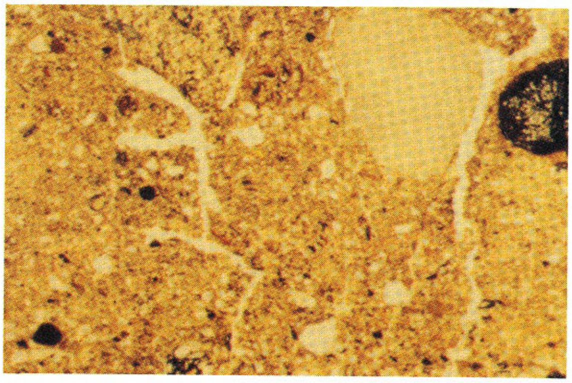


F

PLATE 2 (cont.)

Site 2: Earth Hummock



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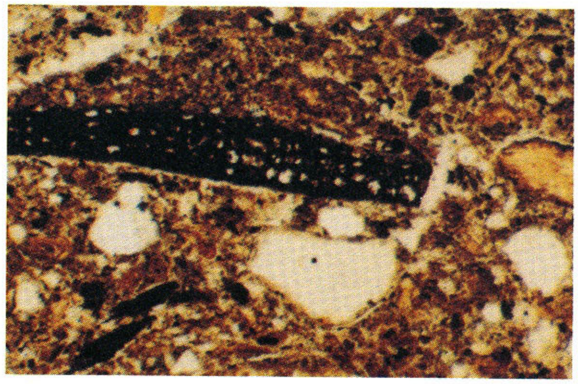
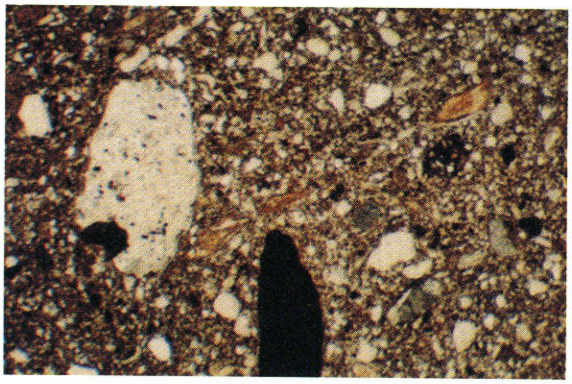
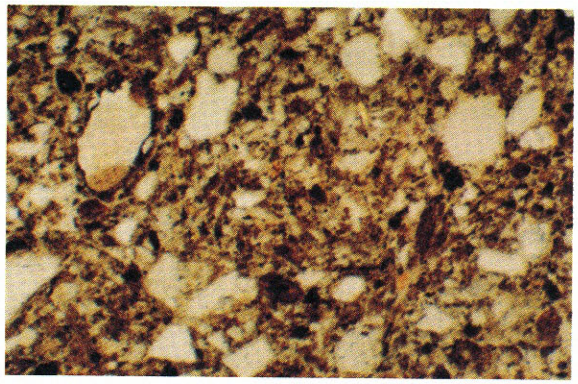


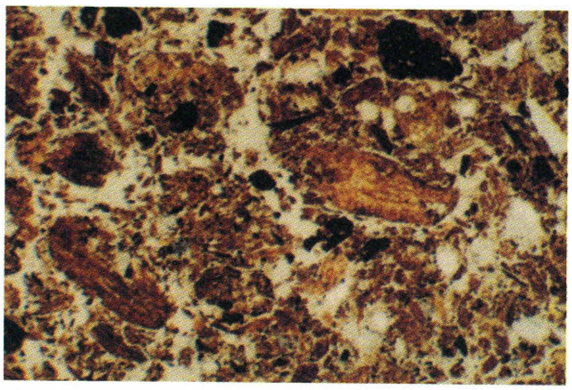
H



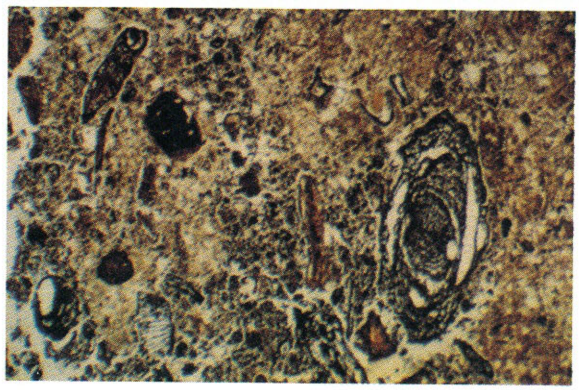
I



J



K

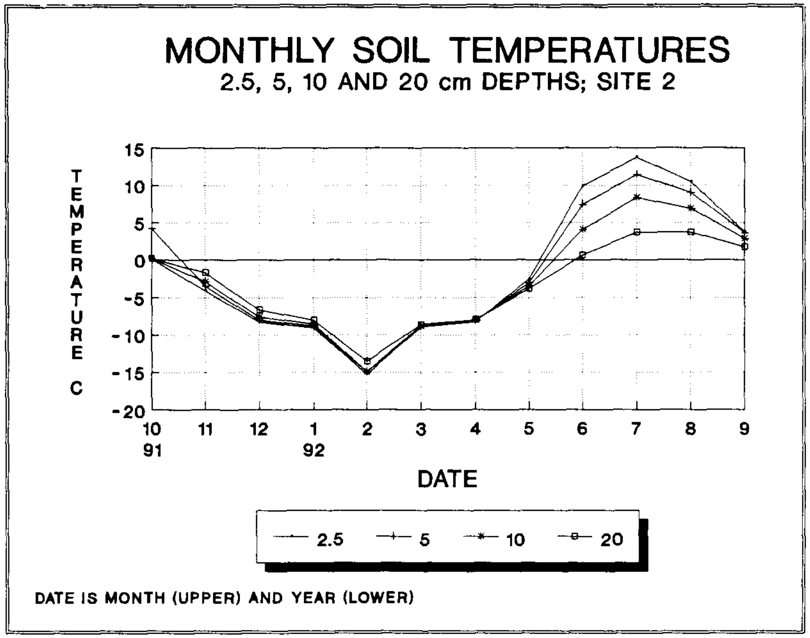


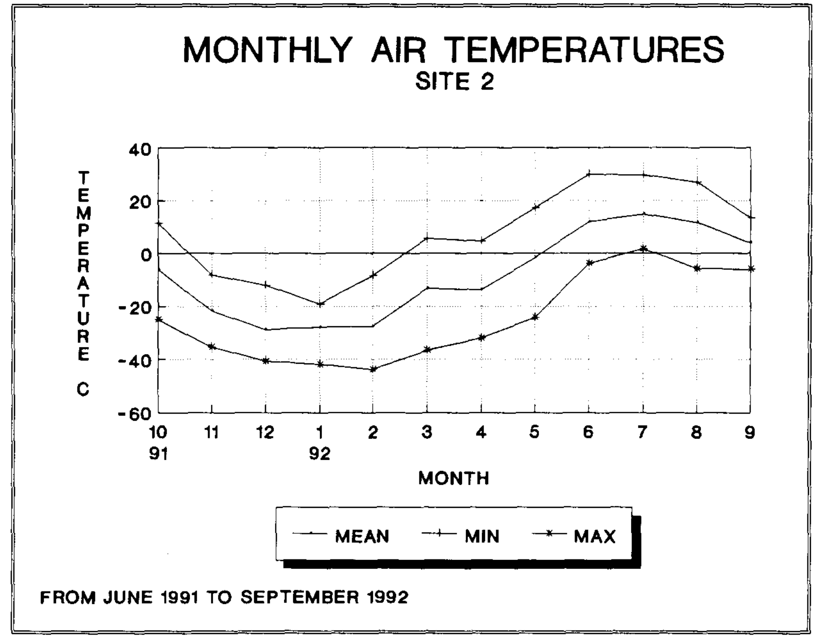
L

Table 12. Mean annual (MAST), minimum, maximum and mean summer* (MSST) soil temperatures in 1978-81 (Tarnocai 1984) and October 1991 – September 1992 at Site 2.

Depth	MAST (°C)		MIN (°C)		MAX (°C)		MSST (°C)	
(cm)	1978-81	1991-92	1978-81	1991-92	1978-81	1991-92	1991	1992
2.5	-0.8	-1.6	-13.9	-17.5	16.9	27.2	10.0	11.3
5	-0.4	-1.6	-13.8	-17.0	13.6	20.8	9.1	9.3
10	-1.1	-2.7	-13.5	-16.6	9.7	13.9	7.3	6.4
20	-2.3	-3.4	-12.7	-14.8	6.8	6.1	5.2	2.7
50	-2.8	-3.7	-11.2	-12.5	2.4	1.1	2.7	-0.1
100	-3.0	-3.6	-9.4	-9.1	0.4	-0.5	0.6	-1.4
150		-3.5		-7.0		-0.8	-0.4	-2.1
Air		-8.2		-41.8		30.0	12.4	12.8

* Summer refers to June, July and August





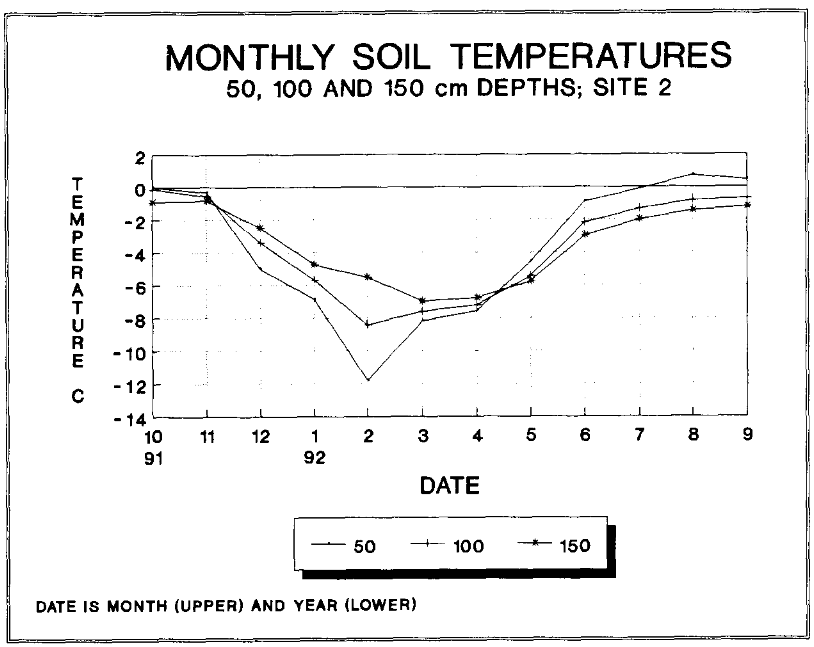


Figure 17. Monthly soil and air temperatures at Site 2 between October 1991 and September 1992.

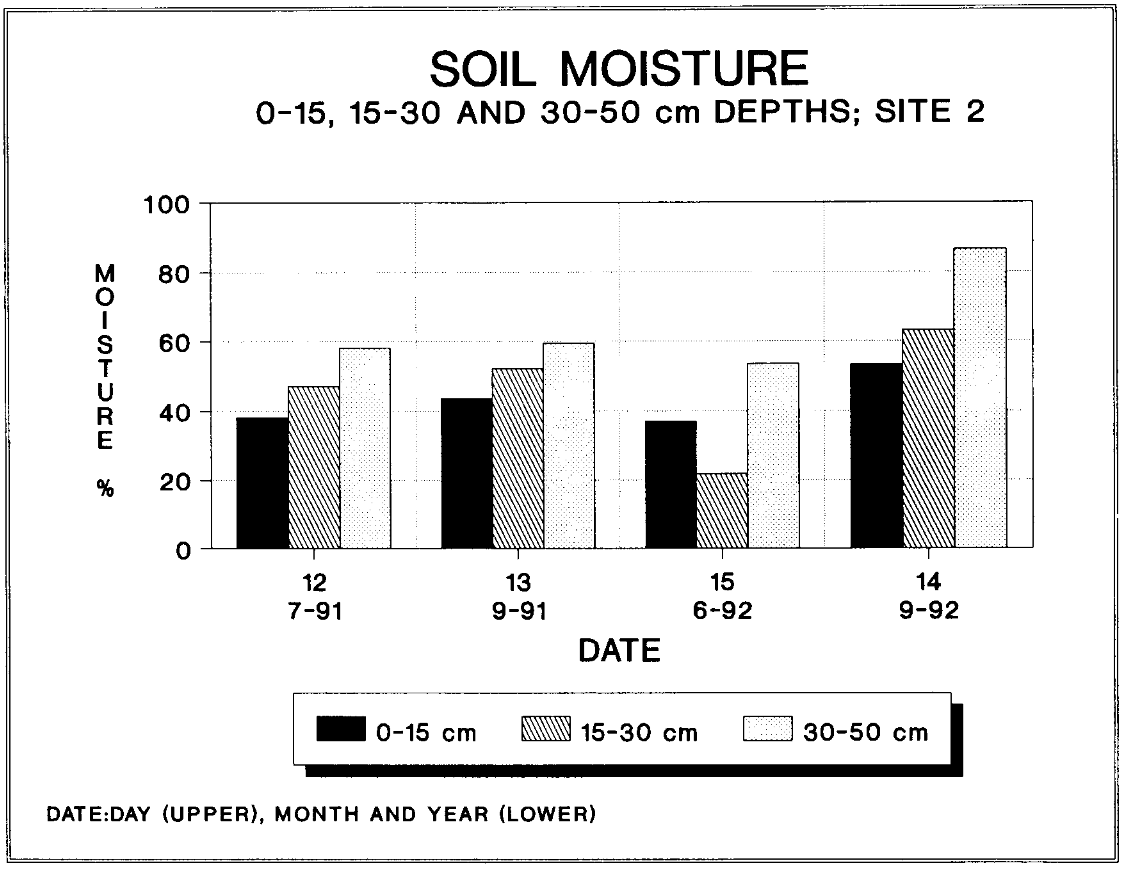
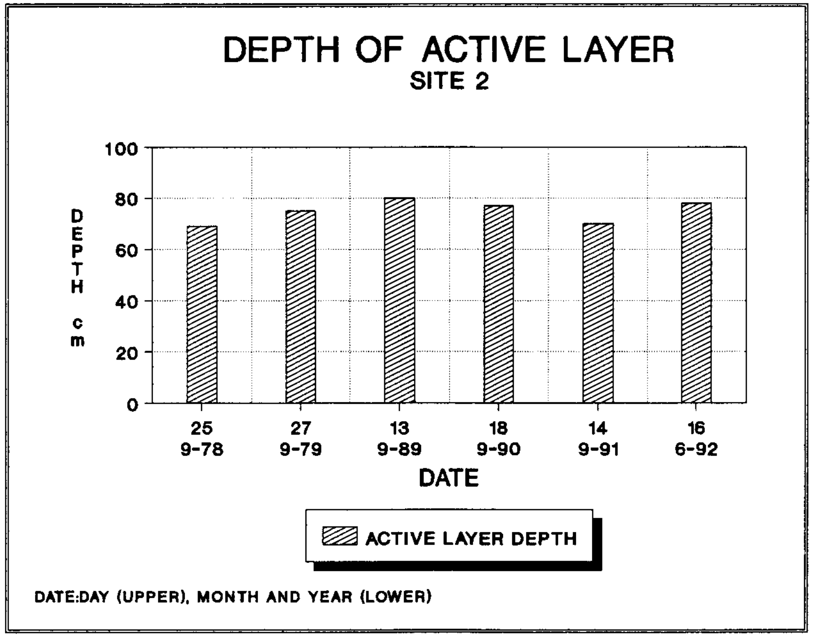
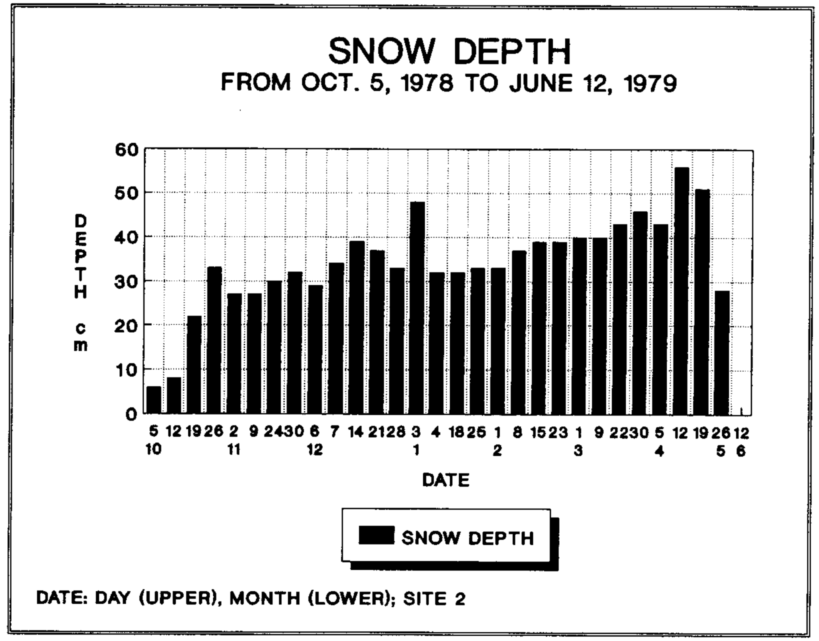


Figure 18. Summer soil moisture (%) at the 0–15, 15–30 and 30–50 cm depths at Site 2.





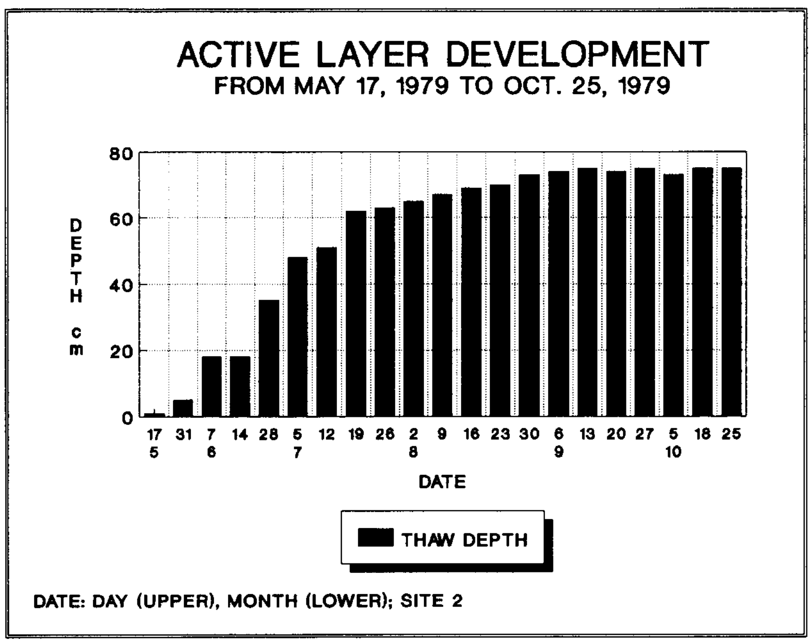


Figure 19. Depth of the active layer, measured in six years, and active layer development and snow depth during 1978 and 1979 at Site 2.

SITE 3: SOIL AND PERMAFROST DEVELOPMENT ON RECENT ALLUVIUM

ECOLOGY OF THE MACKENZIE DELTA

The 13,000 km^2 Mackenzie Delta was formed by the postglacial deposition of sediments in a large estuary between the Richardson Mountains to the west and the Caribou Hills to the east (Figure 20). Most of the alluvium forming the delta is transported by the spring snowmelt flood, that peaks in early June. The annual flood is also largely responsible for the ameliorated summer climate of the delta (mean July temperature 13.5°C). During May, water under hydrostatic pressure initiated by snowmelt to the south begins to break through the delta's ice deck to flood the snow-covered surfaces of distributaries and lakes, and their shorelines. As breakup progresses, rising water lifts and breaks this ice and flushes it seaward, leaving open water in its place. At this time, water surfaces on the delta absorb up to five times more solar radiation than that absorbed by the snow cover. Since some 50% of the delta is covered by lakes and channels, the rapid alteration in surface albedo adds significantly to the delta's heat budget.

The principal landforms of the delta that influence the distribution of vegetation are levees and interlevee basins. Levees reach a height of 9 m (above summer low water levels) in the southern part of the delta, but drop to 3 to 6 m north of Inuvik and to 1 to 3 m in the northern portion. Interlevee basins are correspondingly shallower with increasing distance downstream.

Because of the dynamic nature of the delta, the river channels are constantly shifting. This shifting causes a continuous build-up of alluvial materials in some areas, while other areas may be eroding. In addition, the delta is being regularly built up by the annual deposition of the large amounts of sediments carried by the river. These sediments are deposited when the river spreads out and slows as it moves through the delta. Such annual deposition gradually raises the elevation of the delta and leads to a gradient where successional stages of vegetation occur and soils exhibit a sequence of development. This provides an opportunity to study the soil development in various ecological zones. The youngest soils, immediately adjacent to the river channels, are poorly drained, strongly reduced, mottled, structureless, and lack organic surface horizons. In addition, they still receive a significant annual deposition of alluvium. Soils at a slightly higher elevation, at the margins of the annual flood level, show increased soil development, with a surface organic horizon, platy soil structure and a permafrost table within the 1 m control section. As a result of the alder vegetation associated with these soils, the nitrogen content of the organic horizon is high, providing an essential nutrient for biological productivity. Finally, soils at the highest elevations have well developed organic surface horizons, the shallowest active layers, and a platy structure in the unfrozen mineral horizons.

MACKENZIE DELTA ECOSYSTEMS, BOMBARDIER CHANNEL

The vegetation, soil, and permafrost development and relationships along a 95 m transect (Figure 21) are demonstrated at this site. Four major ecosystems occur on this transect, each having distinct vegetation, soil, drainage and permafrost components. A brief description of the four ecosystems, named according to their vegetation associations and beginning at the water's edge, is as follows:

a. **Equisetum Ecosystem**. This ecosystem covers a 14-m-wide strip along the Bombardier Channel. The highest part is about 2 m above the water level. The soil developed on this most recently developed material is a poorly drained Rego Gleysol with silt loam texture. The soil is strongly reduced, grayish, with prominent mottles throughout the soil profile. No permafrost occurs within a depth of 4 m.

   The vegetation consists of 90% *Equisetum fluviatile*. Minor species are a moss (*Leptobryum pyriforme*) that gives a greenish appearance to the soil surface, *Salix alaxensis*, *Potentilla egedii* and some *Carex* spp.

b. **Salix–Equisetum Ecosystem**. This ecosystem occurs above the Equisetum Ecosystem and covers a strip about 17 m wide, 2 to 4 m above the water level. The soil in this ecosystem is an imperfectly-drained, gleyed Cumulic Regosol with silt loam texture. No surface organic horizon is associated with this soil. There is still active deposition of alluvium on this ecosystem, in some years as much as two to three centimetres. The lower part of the solum is reduced with some faint and distinct mottles. Permafrost occurs at a depth of 110 cm. The frozen layer has a low ice content and contains only small ice crystals.

   The shrub layer consists mainly of *Salix alaxensis*, which grows to a height of 3 to 4 m and covers about 80% of the area. The herb layer is dominated by *Equisetum arvense*, which covers about 40% of the area.

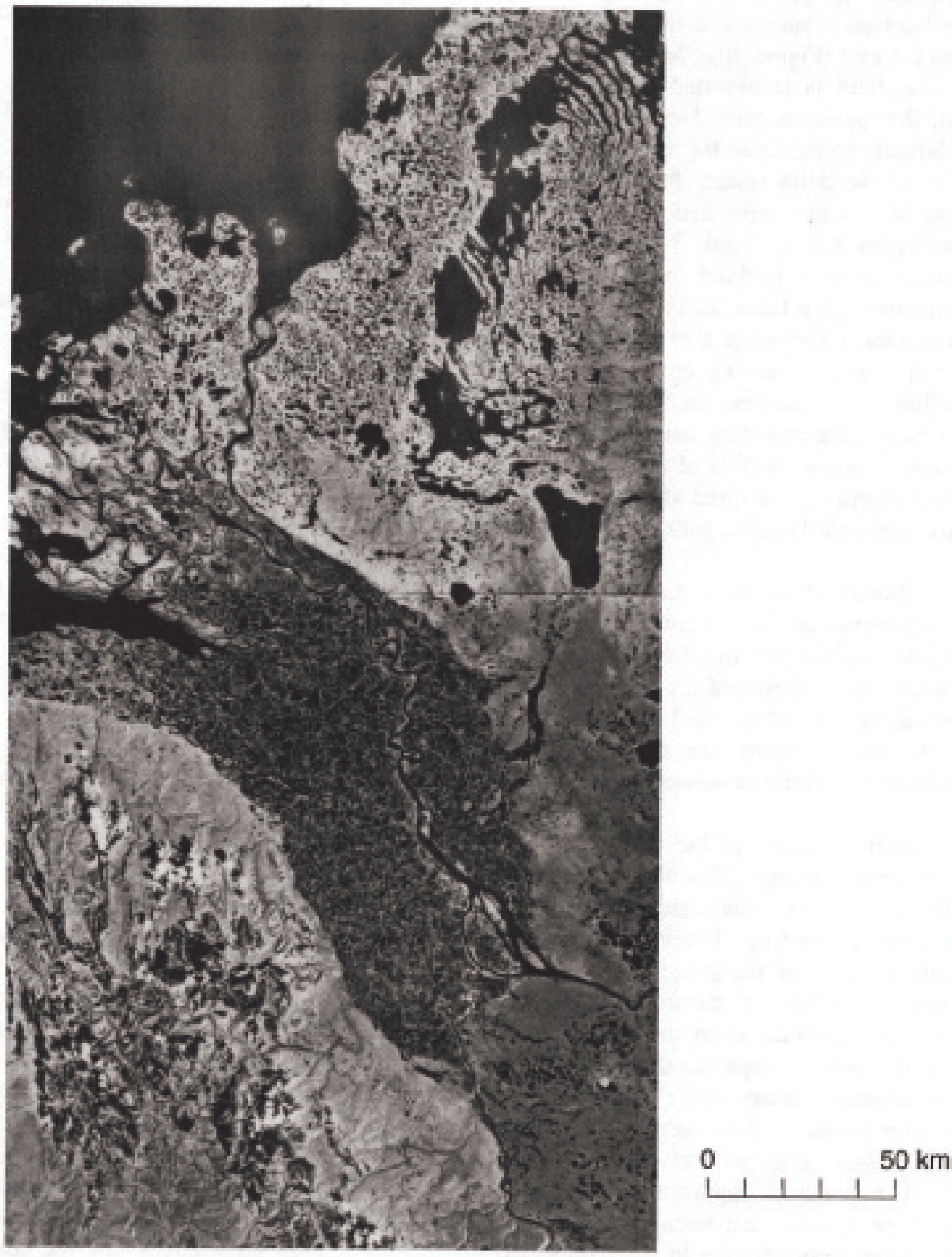


Figure 20. An uncontrolled satellite photomosaic of the Mackenzie Delta taken in 1973.

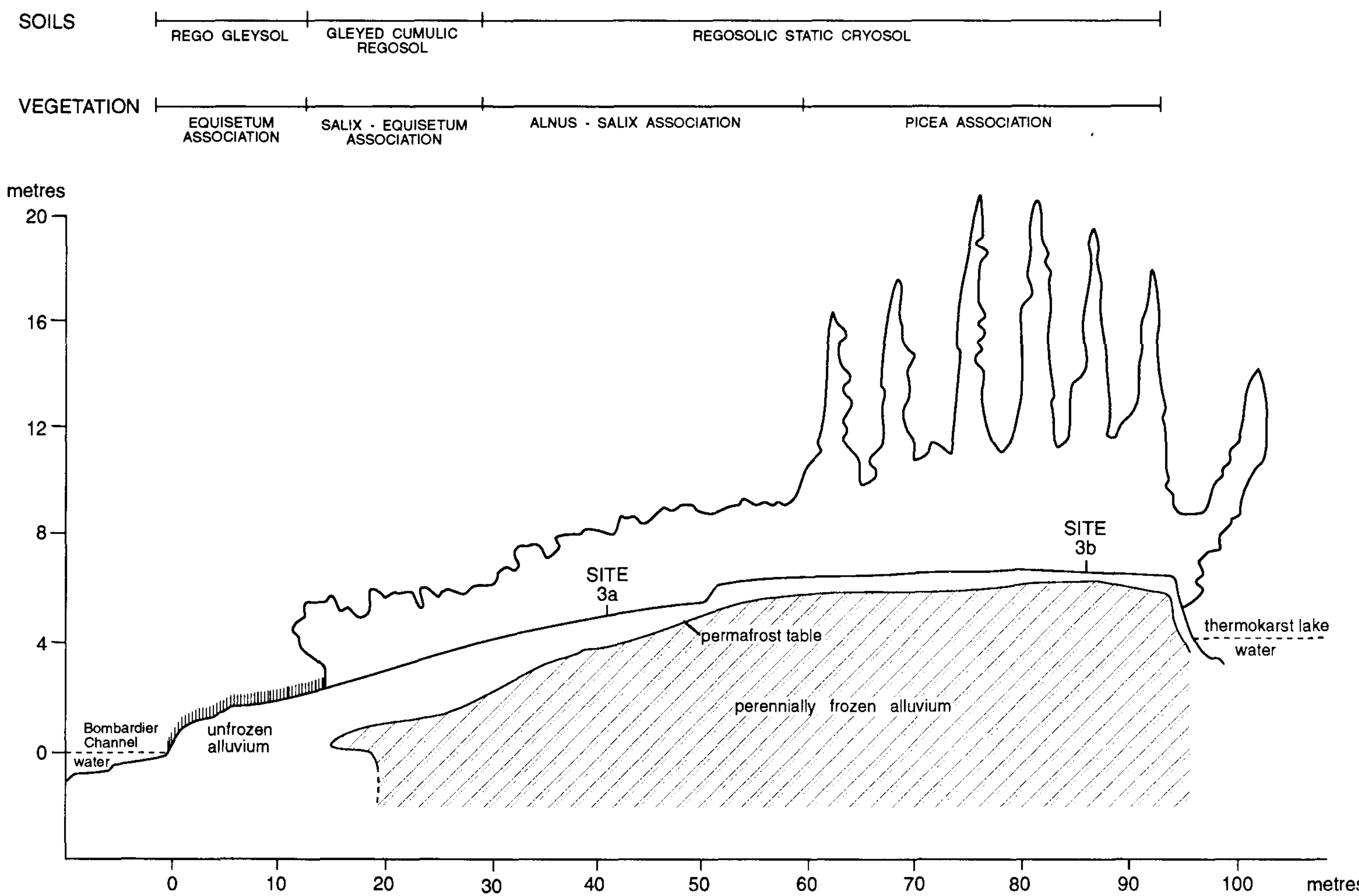


Figure 21. Cross section showing vegetation, soil and permafrost conditions for an ecosystem sequence at the Bombardier Channel in the Mackenzie River delta.

c. **Alnus–Salix Ecosystem**. This ecosystem occurs above the Salix–Equisetum Ecosystem and covers a band about 30 m wide, 4 to 6 m above the water level. The Alnus-Salix Ecosystem lies just above the average flood level, which is marked by a thick band of driftwood that is usually lodged at the foot of this ecosystem. The soil at this site (Site 3a, Figure 21) is a well-drained Regosolic Static Cryosol with silt loam texture. It has a well-developed litter layer (L and F horizons). The active layer of the soil has a platy structure, probably resulting from the development of vein ice (Table 13). The soil is mildly alkaline, and there is no change in pH throughout the soil profile. The organic carbon content of all mineral horizons is relatively high, and the nitrogen content of the L and F horizons is 4% (Table 14). This high level of nitrogen results from the nitrogen-fixing capacity of the alder. Permafrost occurs at a depth of 70 cm, and has a low ice content, with segregated ice crystals. The MAST of this soil at the 50 cm depth is -3.5°C and the MSST is 0.1°C (Table 19).

The dominant species of the ecosystem are alder (*Alnus crispa*) and willows (*Salix arbusculoides*, *S. glauca* and *S. alaxensis*). These shrub species range in height from 0.5 to 3.5 m. The low shrub and herb layers consist of *Arctostaphylos rubra* and *A. alpina*, *Hedysarum alpinum*, *Pyrola grandiflora*, *Picea glauca* seedlings, and mosses (Table 15).

d. **Picea Ecosystem**. This ecosystem occupies the highest areas of the delta and represents the climax stage on the delta south of the Arctic tree line. It is situated just above the Alnus–Salix Ecosystem, 6 to 6.3 m above the water level of the Bombardier Channel, and drops about 4 m down to the level of a thermokarst lake. The soil at this site (Site 3b, Figure 21) is a well-drained Regosolic Static Cryosol with silt loam texture. A well-developed litter layer (L and F horizons) is 10 cm thick (Table 16). The active layer part of the mineral horizon has a platy structure, probably as a result of vein ice formation during the winter months. This soil is mildly alkaline and has a relatively high organic carbon content in all mineral horizons (Table 17). Permafrost, which is associated with ice crystals and has a low ice content, occurs at a depth of 35 cm depth.

The MAST of this soil at the 50 cm depth is -3.2°C and the MSST is -0.6°C (Table 19). Although the MSST of the rooting zone (0 to 30 cm) at this site was the lowest of the mineral soils monitored in the Inuvik area, its forest productivity is probably the highest, suggesting that forest growth is controlled to a greater extent by the nutrient status of the soil than by soil temperature. The higher nutritive and pH values result from periodic inundation (approximately every decade) by the Mackenzie River. A similar phenomenon was found on disturbed sites in Alaska by Chapin and Shaver (1981).

The vegetation is dominated by an open stand of white spruce (*Picea glauca*), the trees of which are distinctly spire shaped. The white spruce trees are 10 to 12 m tall with trunk diameters up to 25 cm. Associated tall shrubs are *Alnus crispa*, *Salix glauca* and *S. arbusculoides*. The low shrub and herb layers consist of *Arctostaphylos rubra*, *A. alpina*, *Hedysarum alpinum* and *Pyrola grandiflora*. There is also a well-developed moss layer (Table 18).

White spruce occurs only in the highest areas of the delta. Even though it is able to grow adventitious roots into newly-deposited sediments, it can only do this after reaching a certain age. For this reason, white spruce is not encountered in areas that are flooded on a more regular basis.

Table 13. Site and pedon descriptions for Site 3a.

Location: 68°25' N Lat., 133° 52' W Long.
Landform: Fluvial terrace
Drainage: Well drained
Soil Temperature (50 cm depth; 1978-81): MAST -3.5°C, MSST 0.1°C
Parent Material: Alluvium

Elevation: 8 m (a.s.l.)
Slope: Level
Vegetation: Alnus–Salix Ecosystem
Patterned Ground: None
Soil Classification: Can. – Regosolic Static Cryosol
U.S.A. – Pergelic Cryorthents
F.A.O. – Gelic Regosol

Horizon		Depth	Description
Canada	U.S.	(cm)	
L–F	Oi and Oa	2 – 0	Black (2.5YR 2.5/0 m); litter of twigs, alder and willow leaves; abundant, fine to medium, horizontal roots; moderately alkaline; abrupt, smooth boundary.
Ck	C	0 – 11	Dark gray (5Y 4/1 m); silt loam; very weak, fine to medium, platy; slightly sticky, friable, slightly hard; plentiful, medium to coarse, horizontal roots; moderately alkaline; clear, smooth boundary.
Ckgj	Cg	11 – 71	Dark gray (5Y 4/1 m); loam; very weak, fine to medium, platy; slightly sticky, friable, slightly hard; few, fine to medium roots; fine, faint mottles; moderately alkaline; abrupt, smooth boundary.
Ckgjz	Cgf	71 – 110	Dark gray (5Y 4/1 m); frozen silt loam; structureless, massive; slightly sticky, friable, slightly hard; fine, faint mottles; segregated ice crystals; low ice content; mildly alkaline.

Table 14. Analytical data for the Regosolic Static Cryosol at Site 3a.

Chemical Analysis and Physical Analysis									
Horizon	pH		Org. C	Total N	C/N	Part. Size Dist. (% <2 mm)			Texture
	H_2O	$CaCl_2$	(%)	(%)		Sand	Silt	Clay	
L–F	7.9	7.6	18.2	4.0	4.6	–	–	–	
Ck	7.9	7.5	4.0	0.1	4.0	2.4	79.5	17.1	SiL
Ckgj	7.9	7.5	3.5	0.1	3.5	5.1	79.5	15.4	
Ckgjz	7.8	7.5	3.9	0.1	3.9	7.6	73.2	19.2	SiL

Table 15. Vegetation description for Site 3a.

Vegetation		
Tall shrubs 80%	**Low shrubs 10%**	**Mosses – Lichens 2%**
50 *Salix arbusculoides*	60 *Arctostaphylos rubra*	40 *Tomenthypnum nitens*
50 *Alnus crispa*	40 *Picea glauca*	40 *Bryum* sp.
		20 *Hylocomium splendens*

Table 16. Site and pedon descriptions for Site 3b.

Location: 68° 25' N Lat., 133° 52' W Long.
Landform: Fluvial terrace
Drainage: Well drained
Soil Temperature (50 cm depth; 1978-81): MAST -3.2°C, MSST -0.6°C
Parent Material: Alluvium
Patterned Ground: None

Elevation: 10 m (a.s.l.)
Slope: Level
Vegetation: Picea Ecosystem
Soil Classification: Can. – Regosolic Static Cryosol
U.S.A. – Pergelic Cryorthents
F.A.O. – Gelic Regosol

Horizon		Depth	Description
Canada	U.S.	(cm)	
L–H	Oi and Oa	10 – 0	Dark reddish brown (2.5YR 2.5/2 m); litter of twigs, spruce needles, alder and willow leaves; abundant, fine to medium, horizontal roots; slightly acid; abrupt, smooth boundary.
Ckgj	Cg	0 – 35	Dark gray (10YR 4/1 m); silt loam; weak, fine to medium, platy; slightly sticky, friable, slightly hard; very few, medium roots; fine, faint mottles; mildly alkaline; abrupt, smooth boundary.
Ckgjz	Cgf	35 – 105	Dark gray (5Y 4/1 m); frozen silt loam; structureless, massive; slightly sticky, friable, slightly hard; fine, faint mottles; segregated ice crystals; low ice content; mildly alkaline.

Table 17. Analytical data for the Regosolic Static Cryosol at Site 3b.

Chemical and Physical Analysis											
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)*			Part. Size Dist. (% <2 mm)		
	H_2O	$CaCl_2$	(%)	(%)		K	Ca	Mg	Sand	Silt	Clay
L–H	6.6	6.1	31.9	1.3	24.5	2.8	40.8	14.3	–	–	–
Ckgj	7.7	7.4	3.5	0.1	35.0	–	–	–	8.8	76.5	14.7
Ckgjz	7.6	7.5	3.4	0.1	34.0	–	–	–	16.1	65.9	18.0

* neutral salt extraction

Table 18. Vegetation description for Site 3b.

Vegetation

Trees 60%
100 *Picea glauca* (8-12 m high, 8-16 cm DBH)

Tall shrubs 30%
50 *Salix* spp.
50 *Alnus crispa*

Dwarf shrubs 2%
100 *Arctostaphylos rubra*

Herbs 5%
100 *Pyrola grandiflora*

Mosses - Lichens 10%
50 *Hylocomium splendens*
50 *Drepanocladus* sp.

Table 19. Mean annual (MAST), minimum, maximum and mean summer* (MSST) soil temperatures in 1978-81 at Sites 3a and 3b.

Depth	MAST (°C)		MIN (°C)		MAX (°C)		MSST (°C)	
(cm)	Site 3a	Site 3b	Site 3a	Site 3b	Site 3a	Site 3b	Site 3a	Site 3b
2.5	-2.2	-1.7	-16.3	-14.2	13.6	12.0	-5.9	-6.3
5	-2.1	-2.4	-16.1	-13.8	11.8	10.1	5.2	5.1
10	-2.5	-3.2	-15.6	-11.1	9.1	4.1	3.9	1.1
20	-3.1		-15.3		7.0		2.4	
50	-3.5	-3.2	-13.3	-10.0	2.9	-0.2	0.1	-0.6
100	-3.3	-3.1	-11.1	-8.6	-0.3	-0.4	-1.4	-1.2

* Summer refers to June, July and August

SITE 4: MACKENZIE RIVER

The Mackenzie River is one of the great river systems of the world. It is the twelfth largest in drainage area and eleventh largest in mean annual discharge. It is the largest north-flowing river in North America. The catchment includes three major lakes and two significant fresh-water deltas.

The Mackenzie River catchment is the largest in Canada, draining an area of about 1.8 x 10^6 km^2. From its most distant point at the head of the Finlay River in British Columbia, the river is over 4,200 km long; the mean discharge at its mouth is estimated at between 10,500 and 11,000 m^3/s. The three largest lakes in the basin, Great Bear Lake, Great Slave Lake and Lake Athabasca, are all in the east, along the boundary between the Interior Plains and the Canadian Shield. The Mackenzie River proper begins in Great Slave Lake and flows over 1,600 km northwest to the Beaufort Sea. The largest tributaries, the Peace, Liard and Athabasca rivers, flow generally northeastward from headwaters in the Cordillera.

SITE 5, KM 30: RICHARDSON MOUNTAINS AND GLACIAL LIMIT

(Alejandra Duk-Rodkin)

The Richardson Mountains form an impressive north – south barrier between the lowlands of the Arctic coast and Mackenzie River delta and the intermontane plateau of the northern interior of the Yukon. They rise to elevations in excess of 1700 m. At this latitude (67°N), the timberline is about 500 m. The Richardson Mountains are part of the continental divide of northwestern Canada. The landscape of the mountains and foothills has been shaped by fluvial processes and pedimentation along the western slopes and by glacial activity (Laurentide Ice Sheet) along the eastern slopes.

The eastern slopes, where this site is located, are dominated by morainic and lacustrine surfaces. During the Late Wisconsinan period, the Laurentide Ice Sheet reached its maximum extent, covering pediment areas along the eastern flanks of the Richardson Mountains. Meltwater crossed the divide into unglaciated terrain at several points, the most important being McDougall Pass, approximately 70 km northwest of this site. During advance and retreat, the ice sheet impounded water between the ice and the slope, leaving rolling morainic slopes dotted with small lakes that account for the unstable surface that exists today.

At this site the Dempster Highway crosses the former maximum position of the Laurentide Ice Sheet at an elevation of about 600 m. The area below the glacial limit is dominated by morainal (till) and lacustrine deposits. The till deposits are found on flat to gently sloping surfaces and are generally 1 to 3 m thick. The silt and clay textured lacustrine deposits occur on flat or gently sloping surfaces and are up to 2 m thick. These lacustrine sediments are often overlain by a veneer of organic deposits.

SITE 6, KM 14: *AUFEIS*, OR ICING, ON JAMES CREEK

The *aufeis*, or icing, is a mass of surface ice formed during the winter by successive freezing sheets of water that seep from the ground, from rivers, or from springs. The icing on James Creek at this location develops annually and, during some cooler summers, lasts through the month of July.

Icing develops during some winters in a number of locations along the Dempster Highway. This icing blocks the culverts, fills the upslope drainage ditch and covers the roadway, creating a hazard for winter traffic.

SITE 7, KM 5: SOLIFLUCTION SITE

The solifluction process is a slow flowing of water-saturated earth materials from higher to lower ground. In a permafrost environment, the frost table provides a water barrier, thereby producing a saturated soil layer that can then slide downslope on the frost table. The melting snow, or thawing frozen ground, provides the moisture and, when the moisture value approximates or exceeds the Atterberg liquid limit (i.e., the value at which soils have little or no shear strength), the material moves downslope (Washburn 1967).

Although the process of solifluction is affected by the gradient of the slope, it is strongly influenced by grain size (Washburn 1967). The high porosity and permeability of gravel and coarse sand provide good drainage and do not favour saturated flow. On the other hand, fine-textured materials have slow drainage and a low Atterberg limit and, consequently, less moisture is required to cause them to flow. Diamictic materials (a mixture of coarse, rubbly and fine materials) are especially prone to flow.

The front of a solifluction lobe situated at the mid-slope position on this site was excavated in July 1992 and no frost was found to a depth of 150 cm. The well-developed vegetation mat and the B horizon below this mat suggest that this lobe is relatively stable. The lobe is composed of stony loam to silt textured material in the lower part, overlain by very stony diamictic materials in the middle, overlain, in turn, by stone-free, fine, granular, loamy material (Figure 22). The entire lobe is covered with a thin organic mat that is well vegetated with arctic willows, ericaceous shrubs, mosses and Dryas.

SITE 8, KM 0: CONTINENTAL DIVIDE, NWT/YUKON BORDER

At this point, the Dempster Highway crosses the hydrologic divide at the crest of the Richardson Mountains. Waters flowing to the west ultimately flow into the Pacific Ocean through the Porcupine River, which is a tributary of the Yukon River. The waters flowing to the east are part of the Arctic drainage, flowing into the Peel River, which is a tributary of the Mackenzie River.

The highway pass (named Wright Pass after the highway engineer who initially surveyed the route location through here) is at an elevation of 859 m a.s.l. and crosses the northernmost extension of the Rocky Mountain chain in North America. These mountains are composed of the same Paleozoic and Mesozoic complex of marine sedimentary rocks as are found farther south, in the Rocky Mountains of northeastern British Columbia.

This pass tends to funnel winds that are generated by pressure differences between air masses lying over the Beaufort – Mackenzie Delta region and those over the northern Cordilleran interior. The highway often has to be closed in the winter because of drifting snow, poor visibility and extreme wind chill factors. Prior to the opening of the highway in 1979, there were few travellers in this region other than native hunters from Fort McPherson or Old Crow. Even today there are no permanent settlements in the region of the Richardson Mountains or their associated foothills.

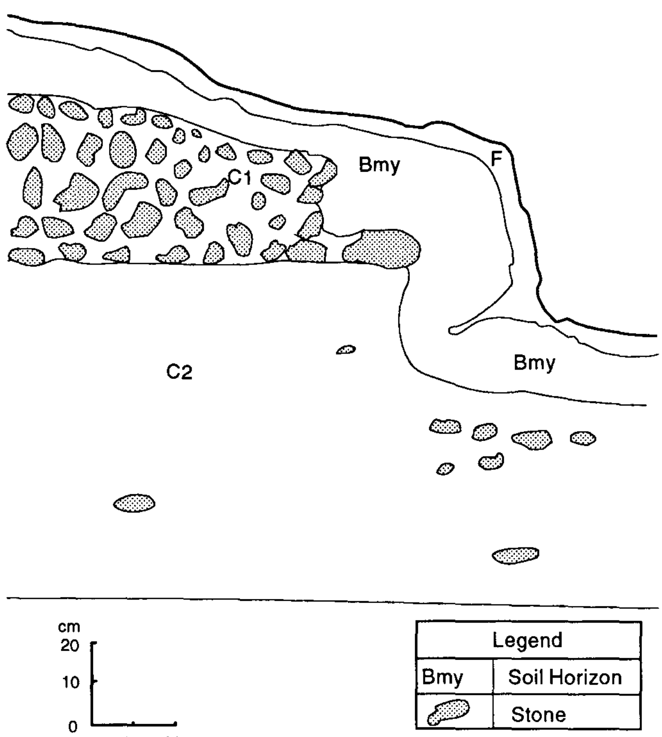


Figure 22. Cross section of a solifluction lobe at Site 7.

SITE 9, KM 425: PEDIMENTS AND FOOTHILLS, RICHARDSON TRANSECT

At this site, the landforms and soils associated with the Richardson Mountains and surrounding landscapes will be discussed. The soils of the unglaciated portions of the Richardson Mountains are controlled by the underlying geologic materials. The geomorphic origin of the pediment slopes in the northern Yukon is unclear, but is thought to date back to pre-glacial Tertiary times and to be attributable to the same processes that lead to pediment formation in warm, arid environments (French and Harry 1992). Where the stratigraphy of the pediments has been exposed elsewhere in the region, generally a veneer of cobbles and gravels overlie truncated bedrock materials. These in turn are overlain by fine-textured sediments such as are found here. The fine sediments can be partially attributed to eolian deposition and partially to fine detritus derived from slope wash of the shales and siltstones of the Rock River Formation. The fine sediments are mixed by cryoturbation within the active layer, and distinct depositional strata are not discernible. Most geomorphologists feel that the processes that led to the formation of pediments in the unglaciated northern Yukon are not active under present climatic conditions (French and Harry 1992; Rampton 1982).

Figure 23 shows the general landscape condition of the region. The soils associated with the slopes of the Richardson Mountains are formed in colluvium derived from the black shales of the Rock River Formation (Norris 1984). The soil (Pedon 9c) that is common on the front slopes of the Richardson Mountains is notable for its high organic carbon content, moder humus forms and interesting suite of soil fauna (Smith *et al.* 1990, Tynen *et al.* 1991).

The soil conditions to the west of the highway are quite different. Here, the landscape is controlled by the erosion surfaces of the sandstone and siltstones of the Imperial Formation, which underlies much of the Eagle Plain region. These rocks have been physically weathered (frost shattered) and, on stable surfaces, can also be strongly chemically weathered. The upland soils are not underlain by near-surface permafrost. Pedon 9b is representative of this ecosystem. The soils of the upland surfaces are strongly acidic and can contain appreciable citrate- and oxalate-extractable iron and aluminum (Smith *et al.* 1990).

Data from three sites (Pedons 9b, 9c and 9d, Figure 23) that represent the array of soil – topographic conditions occurring in this section of the northern Yukon are presented in a poster display on-site. The group will view the Gleysolic Turbic Cryosol developed on the pediment slope (Figure 23, Pedon 9a; Figure 24). The site and pedon descriptions are given in Table 20. The analytical data for this soil are given in Table 21. The soil on this pediment slope is strongly acidic, and contains abundant organic carbon throughout the profile, both in the active layer and in the underlying permafrost. Cryoturbation and reducing conditions prevail within the soil environment. The vegetated surface is characterized by tussock tundra (Table 22) that produces a micro-hummocky relief and makes foot travel over any distance very difficult. Beneath the tundra vegetation, which is dominated by *Eriophorum vaginatum*, the permafrost table undulates in a mirror image of the hummocky surface. The active layer is usually less than 50 cm thick.

The soils contain considerable quantities of iron oxides in horizons with abundant organic matter. Most of the iron appears to be complexed with organic matter, as shown by high proportions of pyrophosphate-extractable iron (Table 21). The clay mineralogy is dominated by mica and kaolinite in all horizons analyzed. Because of strong mixing within the active layer, it is difficult to see any weathering trends between horizons. The phyllosilicate suite reflects inherited mineralogy derived from the parent geological materials at the site.

Micromorphology

Bmgjy Horizon. This horizon was sampled close to the surface, adjacent to a tussock. The soil fabric (Table 23) is massive with common cracks and occasional root channels that contribute to formation of the subangular blocky structure observed at the time of sampling. Periodic wetting fronts (freeze–thaw cycles) have occurred as indicated by successive rims of iron oxide staining of the soil material. (Pl.3:A, B)

Bgy Horizon. The morphology of this horizon (Table 23) is characterized by a dense soil fabric with prominent mottling associated with cracks and remnant root channels. Periodic freezing fronts can be inferred from the successive lines of iron oxide concentrations. The water is oxygenated to result in iron oxide staining. The cracks have rare occurrences of loose, as well as extremely fine, silt-size material, suggesting material enters the crack either by breaking off from the sides of the voids or by being transported by water flow through the pores. The cracks suggest that thermal contraction of the soil material may have taken place. Freeze–thaw cycles contribute to the alignment of the clay particles. (Pl.3:C, D)

Ahyl Horizon. In this horizon, the alignment of the mineral material is very pronounced and suggests that freezing cycles are more frequent (Table 23). This observation is supported in that the Ahy1 horizon is positioned along the seasonal permafrost line. The Ahy1 horizon is characterized by fabric zones with concentrations of organic fragments and amorphous organic material. There is a granular morphology to the organic material, indicating transport from the upper Of and Om horizons. There are rare occurrences of faunal material in root fragments, but the faunal activity is not of recent origin. Some of the granular amorphous organic material is also suspected to have been faunal in origin. Frequent horizontal cracks are observed intersecting at right angles with the vertical crack. This crack contains loose granular material, suggesting a mechanism for movement of materials within the horizon. Cryogenic processes, together with periodic freezing fronts, have resulted in cracks, progressive intensity of clay particle alignment with depth, as well as prominent mottling, with successive rims around pores and lines in the soil fabric. (Pl.3:E, F)

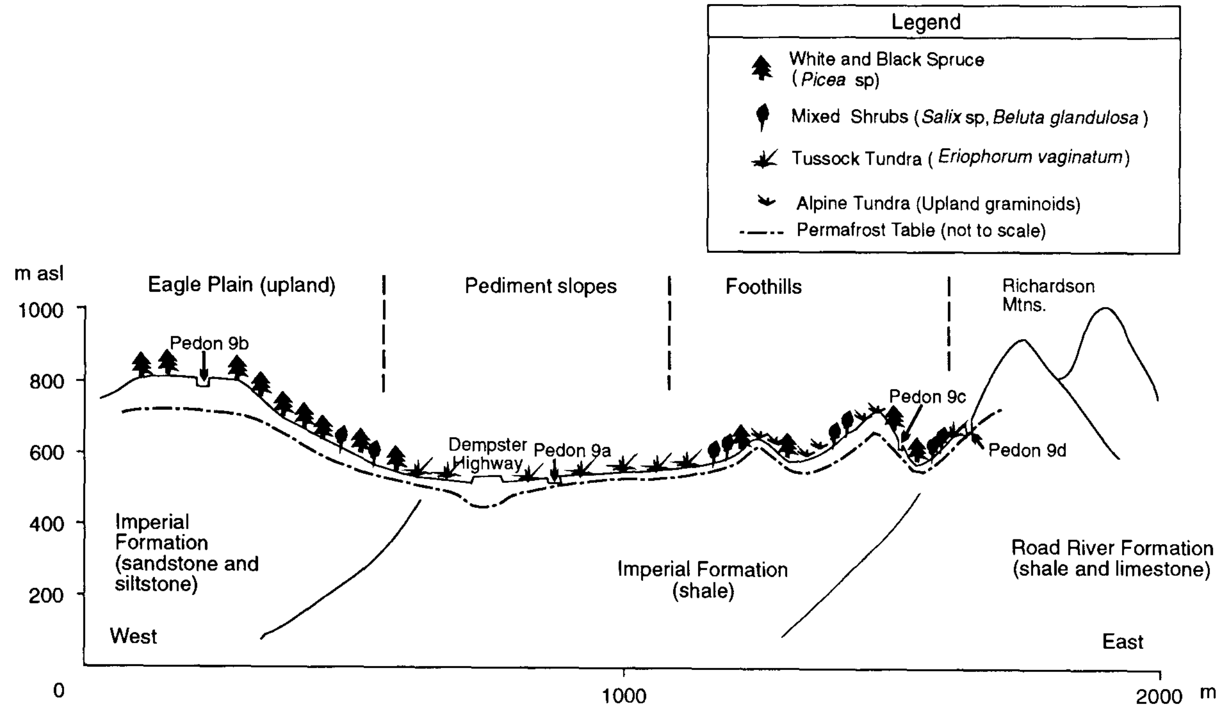


Figure 23. Schematic cross section of the Richardson Mountains, foothills and adjacent Eagle Plain uplands at Site 9.

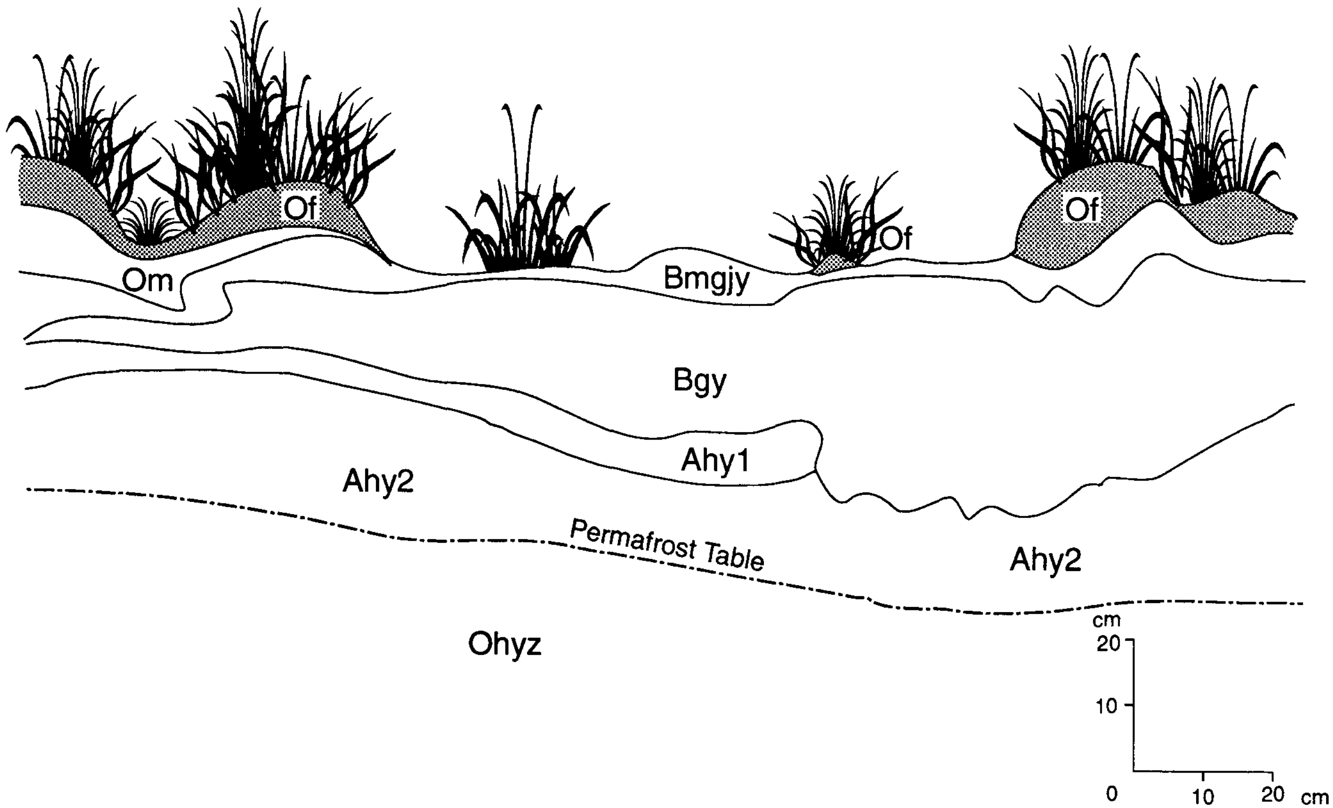


Figure 24. Cross section of pedon 9a, a Gleysolic Turbic Cryosol formed in fine-textured colluvium at Site 9.

Table 20. Site and pedon descriptions for Site 9.

Pedon no: EP - 2 , S91-FN-260-004
Location: 66°42'59" N Lat., 136° 21'11" W Long.
Landform: Pediment slope
Drainage: Poor
Parent Material: Clayey colluvium
Patterned Ground: None

Elevation: 760 m (a.s.l.)
Slope: 3%
Aspect: Southwest
Vegetation: Eriophorum tundra
Soil Classification: Can. – Gleysolic Turbic Cryosol
U.S.A. – Pergelic Ruptic Histic Cryaquept
F.A.O. – Gelic Gleysol

Horizon		Thickness	Description
Can.	U.S.	(cm)	
Of	Oi	0 – 20	Dark reddish brown (5YR 3/3); undecomposed sphagnum peat; 95% unrubbed fibre, 85% rubbed fibre; common, medium roots, and many, very fine and fine roots; clear, broken boundary. [91P5978]
Om	Oe	0 – 5	Very dark grayish brown (10YR 3/2); moderately decomposed peat; 25% rubbed, 65% unrubbed fibre; few, medium roots, and many, very fine and fine roots; clear, broken boundary. [91P5979]
Bmgjy	Bw	3 – 9	Very dark gray (5Y 3/1), dark gray (5Y 4/1); silty clay loam; common, fine and medium, prominent, yellowish brown (10YR 5/8) redoximorphic concentrations; moderate, medium, subangular blocky structure; firm, moderately sticky, moderately plastic; few, medium roots, and common, very fine and fine roots; 5% 20 to 75 mm rock fragments; gradual, wavy boundary. [91P5980]
Bgy	Bg	3 – 27	Dark gray (5Y 4/1); silty clay loam; many, fine and medium, prominent, yellowish brown (10YR 5/8) redoximorphic concentrations; massive; firm, slightly sticky, moderately plastic; few, very fine and fine roots, and few, medium roots; 2% 20 to 75 mm rock fragments; clear, wavy boundary. [91P5981]
Ahy1	BCg	0 – 7	20% very dark gray (5Y 3/1), 30% brown (7.5YR 4/4), 50% olive gray (5Y 4/2); silty clay loam; massive; firm, slightly sticky, slightly plastic; few, very fine and fine roots; cryoturbated; 3% 20 to 75 mm rock fragments; clear, broken boundary. [91P5982]
Ahy2	Oa/Cg	15 – 20	55% yellowish red (5YR 5/6), 45% brown (7.5YR 4/4); silty clay loam; 40% unrubbed, 12% rubbed fibre; few, very fine and fine roots; cryoturbated; frozen when sampled with 3 to 4 mm ice lenses, horizon has living roots throughout; dark grayish brown (10YR 4/2) matrix with olive gray (5Y 4/2) redoximorphic depletions and strong brown (7.5YR 4/6) concentrations; 3% 20 to 75 mm shale fragments; clear, wavy boundary. [91P5983]
Ohyz	Cgf / Oaf	40 – 45	95% dark grayish brown (10YR 4/2), 5% yellowish red (5YR 4/6); well decomposed peat; few, fine, prominent olive gray (5Y 4/2) redoximorphic depletions and brown (7.5YR 4/4) concentrations; 3% 20 to 75 mm shale fragments. [91P5984]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 21. Analytical data for the Gleysolic Turbic Cryosol at Site 9.

Chemical Analysis

Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)									
						Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total	Total	Ca	Mg	Na	K
Of	3.8	3.8	43.2	0.47	92	7.2	4.2	1.7	2.8	15.9	19.5	12.9	5.3	0.5	0.8
Om	4.7	4.4	25.0	1.01	25	7.8	2.4	0.4	3.5	14.1	12.4	9.3	2.9	0.2	0.0
Bmgjy	4.5	4.2	5.4	0.27	20	2.3	0.6	0.1	4.0	7.0	2.9	2.1	0.7	0.1	tr
Bgy	4.8	4.4	15.5	0.70	22	4.0	1.1	0.3	4.5	9.9	2.5	1.8	0.5	0.1	0.1
Ahy1	4.5	4.3	8.2	0.41	20	1.8	0.5	0.2	4.2	6.7	2.8	2.0	0.7	0.1	tr
Ahy2	4.5	3.8	5.1	0.25	20	1.7	0.6	0.2	3.3	5.8	5.5	4.3	0.9	0.1	0.2
Ohyz	4.7	4.1	20.7	0.93	22	6.7	1.5	0.7	3.3	12.2	10.3	7.9	1.7	0.2	0.5

Chemical and Physical Analysis

Hor-izon	Sesquioxides (%)						Fiber Cont. (%)		%	Part. Size Dist. (% <2 mm)			Bulk Den.	Moisture (%)		Tex-ture
	Dithionite		Oxalate		Pyrophos.											
	Fe	Al	Fe	Al	Fe	Al	Un-rub.	Rub.	>2 mm	Sand	Silt	Clay	(g/cc)	1/3 atm	15 atm	
Of	0.33	0.11	0.22	0.14	0.16	0.04	95	85							104.4	
Om	2.59	0.26	2.68	0.24	2.55	0.29	65	25							55.6	
Bmgjy	1.07	0.11	1.22	0.15	1.18	0.17			5	10.4	56.0	33.7	1.45	26.7	14.3	SiCL
Bgy	2.93	0.40	2.87	0.36	2.72	0.49			2	11.6	55.9	32.5	1.47	28.0	13.0	SiCL
Ahy1	2.77	0.17	2.06	0.28	2.06	0.32			3	11.2	58.3	30.5	1.30	41.2	21.7	SiCL
Ahy2	0.98	0.12	0.95	0.18	0.65	0.17			3	11.3	57.3	31.4	0.94	64.9	24.4	SiCL
Ohyz	1.42	0.39	1.50	0.48	1.60	0.45			3	5.1	70.3	24.6			65.4	

Clay Mineralogy (<2μ)

Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size*)					
	Al_2O_3	Fe_2O_3	K_2O	Kaolinite	Verm.	Mica	Quartz	Chlorite	Interstrat. Montmor.-Chlorite
Of									
Om									
Bmgjy	19.0	5.1	2.4	2	2	3	1		1
Bgy	21.0	4.9	2.7	2	2	3		1	1
Ahy1	17.0	8.3	2.1	1		2	1		
Ahy2									
Ohyz									

* Relative peak size: 3 = medium, 2 = small, 1 = very small

Table 22. Vegetation description for Site 9.

Vegetation			
SHRUBS (% cover)			
Low Shrubs		**Dwarf Shrubs**	
5.0	*Betula glandulosa*	1.0	*Arctostaphylos rubra*
15.0	*Ledum decumbens*	10.0	*Empetrum nigrum*
1.0	*Salix pulchra*	1.0	*Oxycoccus microcarpus*
10.0	*Vaccinium uliginosum*	10.0	*Vaccinium vitis-idœa*
HERBS (% cover)			
1.0	*Rubus chamœmorus*		
GRASSES (% cover)			
1.0	*Carex physocarpa*	0.5	*Juncus* sp.
35.0	*Eriophorum vaginatum*		
MOSSES – LICHENS (% cover)			
Mosses		**Lichens**	
1.0	*Bryophyte* spp.	0.5	*Cetraria cucullata*
5.0	*Hypnum* sp.	0.5	*Cladina stellaris*
10.0	*Sphagnum* sp.		
NON-VEGETATION (% cover)			
5.0	Bare	–	Slash
25.0	Litter	–	Water
–	Rock		

Table 23. Micromorphological Features for Site 9: Pediment Site.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmgjy (Bw)	**Overall:** Massive soil fabric with occasional lithofragments and frequent well decomposed organic fragments. (Pl.3:A) **Related DP:** Porphyroskelic. Plasmic: Insepic with minor zones showing weak lattisepic. (Pl.3:B) **Microstructure:** Crack structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled with minor reticulate-striated.	**Void Pattern:** Common planar voids (10–150 µm wide) occur both in the massive soil fabric and rarely around lithofragments; very irregular surfaces, fully to partially accommodated; rare infillings of loose material in cracks. Occasional root channels; smoothed surfaces. **Basic Components:** Mineral: Silt-size material (mainly <10–30 µm), angular quartz and clay particles (weathered mica) predominate in the groundmass. Occasional lithofragments of shale, siltstone, igneous (mainly 0.4–1.8 mm, rare 7 mm); commonly weathered edges. Iron-oxide mottles. Organic: Abundant, strongly decomposed to amorphous plant fragments (mainly <10–150 µm) are randomly distributed in the soil matrix. Remnants of root tissues occur occasionally in the matrix; extremely thin remnants were rarely observed in root channels. **Pedofeatures:** Mottles: Weakly to strongly impregnated in soil fabric; successive outer rims.	Successive outer rims on mottles indicate changes in wetting front, possibly from variations in freeze–thaw front. Orientation of clay particles forming weak lattisepic fabric suggests differential freezing pressures. Lithofragments and long plant tissues show alignment occasionally sub-vertical 10–25°. (Pl.3:A) Cracks, especially with observations of included soil material particles; severed organic fragments, and very irregular pore surfaces. Cracks would support ice lens formation and contribute to close packing of soil material to produce dense morphology.
Bgy (Bg)	**Overall:** Dense soil fabric with prominent mottles commonly associated with root channels and cracks. (Pl.3:C) **Related DP:** Porphyroskelic. Plasmic: Insepic with gradations to zones of mosepic and lattisepic. (Pl.3:D) **Microstructure:** Crack structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled with gradations to mosaic-speckled and reticulate-striated.	**Void Pattern:** Cracks oriented frequently horizontally (100–500 µm wide) and occasionally diagonally (20–80 µm); very irregular surfaces, fully to partially accommodated. Root channels (0.8–1.2 mm wide) occur occasionally; commonly associated with mottles; very smooth regular surface. Rare irregular to rounded vughs (200–800 µm). **Basic Components:** Mineral: Dominantly silt-size (<30 µm) occasional to rare very fine sand-size angular quartz in groundmass; occasional aligned lithofragments of shale, siltstone, igneous (0.8–2.4 mm); often weathered edges. Organic: Extremely fine, strongly decomposed fragments of plant tissues (mainly <50 µm) occur throughout the groundmass. Very thin root tissue remnants along root channel walls. **Pedofeatures:** Mottles: Prominent, weakly to strongly impregnated in soil fabric; successive rims around channels and as lines in soil fabric. Coatings: Very rare sesquioxide clay coating in base of root channel. Very thin discontinuous coating of silt-size material covering root remnants in channel. Iron oxide staining/hypo- and quasi-coatings occur commonly where voids are associated with mottling. Infillings: Rare occurrences in cracks of loose extremely fine silt-size soil material; very discontinuous distribution.	Mottling with series of successive rims indicating different water table levels from sequence of fluctuations in permafrost table and freezing fronts. Water was oxygenated to result in iron-oxide mottles. Mottles primarily associated with old root channels. These channels now conduits for water. (Pl.3:C) Cracks with rare occurrences of loose material. Cracks suggest that areas of soil material have contracted due to freezing processes. Soil matrix material is very dense and compact; one can infer that high bulk densities will result. Cracks would be susceptible to ice lens formation to produce close packing of the soil material. Occasional alignment of lithofragments. Clay particle alignment in the groundmass; probable result of freeze–thaw processes. (Pl.3:D)

Table 23. Micromorphological Features for Site 9: Pediment Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ahy1 (BCg)	**Overall:** Granular units and well decomposed organic fragments set in silt-size groundmass that grades with depth to massive soil fabric; common cracks; iron oxide mottles and staining. (Pl.3:E) **Related DP:** Granoidic-porphyroskelic//-conglomero-porphyroskelic//-porphyroskelic. Plasmic: Latti-skel-mosepic. **Microstructure:** Crack structure. c/f RDP: Porphyric. b-fabric: Mosaic-speckled with common granostriated and occasional reticulate-speckled.	**Void Pattern:** Cracks (planar voids), with irregular surfaces, fully to partially accommodated; dominantly horizontal (mainly 20–300 µm wide, rarely to 600 µm) (Pl.3:F); intersection at near right angles of vertical crack (20–300 µm wide), partially accommodated. Occasional loose soil material observed in vertical crack. Rare irregular vughs 80–200 µm wide. **Basic Components:** Mineral: Silt-size angular quartz (<10–30 µm) and clay particles (weathered mica) that are often strongly aligned dominate the groundmass. Lithofragments of mainly shale, siltstone, igneous (0.4–1.4 mm, rarely 5 mm) show occasional vertical alignment; edges of siltstone, shales are often weathered; rounded siltstone and shale fragments (30–120 µm) are frequent in groundmass. Organic: In the fabric zones with weak granular structure, abundant well decomposed organic fragments (mainly 100–400 µm, occasionally 1–3 mm) and amorphous organic material are concentrated. With depth, in the massive soil fabric zone the organic fragments (<10–200 µm, rarely 0.5–1.6 mm) are randomly distributed. **Pedofeatures:** Mottles: Stainings, weakly to strongly impregnated in distinct zones; often with distinct lines or rims; commonly when in association with cracks intensity of iron oxide concentration increases to dark brownish-black from reddish-brown. (Pl.3:E) Nodules: Distinct, rounded, irregular, ferruginous (60–300 µm, rarely 900 µm); appear to be transported similar to lithofragments in parent material; commonly suggest successive rims of mottles or very weathered shale fragments. Infillings: In vertical crack, soil material loosened from walls. Faunal: Very rare occurrence of faunal material in centre of root fragment; amorphous organic granular material may have had faunal origin; probably transported into soil.	Cracks meeting at right angles to vertical crack indicates shrinking of the soil material, possibly as a result of thermal contraction and/or drying processes. These cracks would also be susceptible to ice lens formation. (Pl.3:F) Strong alignment of clay particles in distinct zones and in lattisepic arrangement suggests successive freeze–thaw cycles. Transport of organic fragments into concentrated zones. No evidence for active faunal activity, but remnants of fragments have included fecal material, and amorphous organic granular material may have had a faunal origin, suggesting this material was transported. Mottling with successive lines suggests varying freezing fronts that were stable for extended time periods to facilitate staining of materials. (Pl.3:E)

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine related distribution after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 3

List of Plates for Site 9: Pediment Site.

Plate 3: A

Massive soil fabric in the Bmgjy horizon with vertical planar voids, and incorporated lithofragments and organic fragments. Frame length 8.5 mm. Plane polarized light (PPL).

Plate 3: B

Porphyroskelic (insepic) fabric of the Bmgjy horizon. Note alignment of well-humified organic fragments and clustering of silt-size grains. Frame length 1.0 mm. Crossed polarized light (XPL).

Plate 3: C

Dense soil fabric of the Bgy horizon has prominent mottling around former root channels. Note successive staining rims of mottles. Frame length 8.5 mm. (PPL).

Plate 3: D

Porphyroskelic (insepic with gradations to mosepic and lattisepic) fabric characterizes the Bgy horizon. Frame length 1.0 mm. (XPL).

Plate 3: E

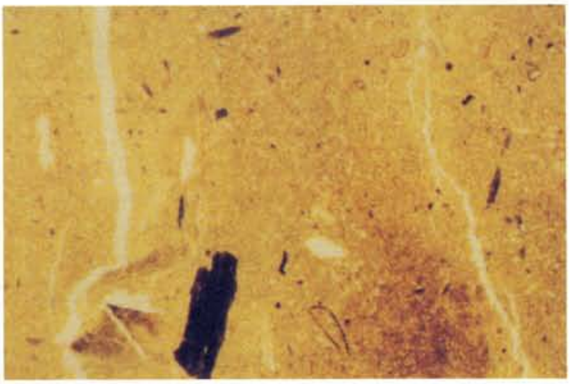
Prominent mottle around crack and vugh (possible former root channel) in the Ahy1 horizon, showing successive rims. Frame length 8.5 mm. (PPL).

Plate 3: F

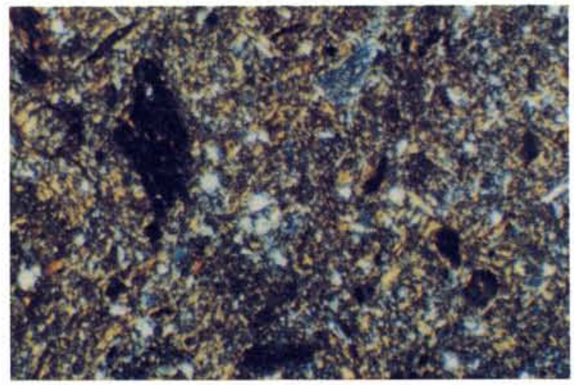
Crack with material loosened from soil material along pore walls in the Ahy1 horizon. Note well-decomposed organic fragments and fine organic material in the groundmass. Frame length 1.0 mm. (PPL).

PLATE 3

Site 9: Pediment Site



A



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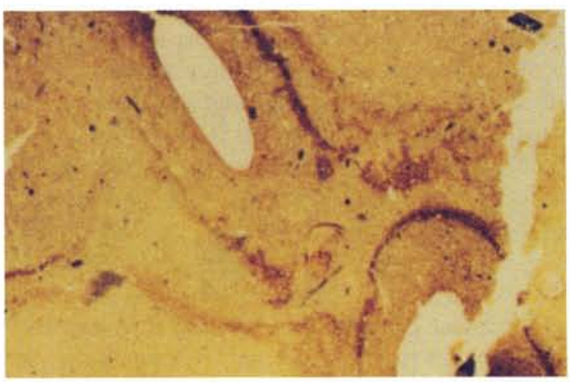

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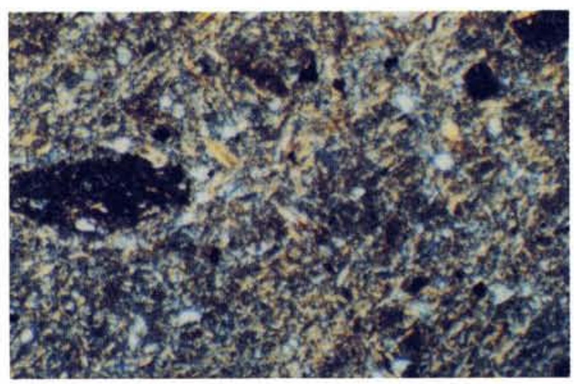
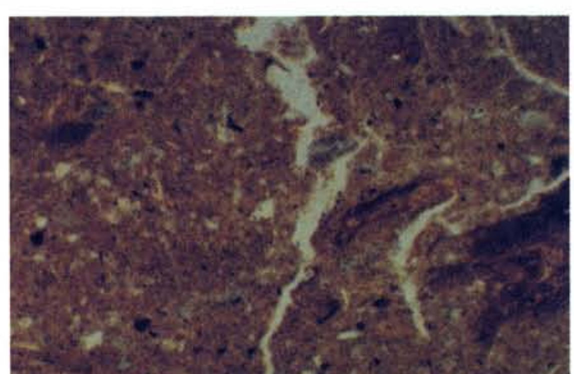


D

E



F

SITE 10, KM 403: ARCTIC CIRCLE

At this point, the highway passes south of the Arctic Circle (66°32' North latitude). A rest stop and display have been built by the Yukon Highways Department. The bus will stop and allow participants to view and photograph the landscape at this point.

SITE 11, KM 400.5: NONSORTED CIRCLES (MUDBOILS)

ORIGIN OF MUDBOILS

At this site we will view a well-developed patterned ground feature and associated soil formed largely through the weathering of underlying shale and siltstone parent materials. These nonsorted circles are common along the better-drained portions of the Eagle Plain ridge tops, and are associated with fine-grained materials. When the circles are interconnected, they are referred to as nonsorted nets. A good example of this periglacial phenomenon can be seen to the east of the highway at this point. These features, termed "mudboils," form as the result of intense cryoturbation within the soil materials. Soil movement is so dynamic that plant cover is not established on the circle centres, but rather is concentrated in the intercircle areas.

Mudboils (Zoltai and Tarnocai 1981) are a form of Washburn's (1973) nonsorted patterned ground. They are characterized by a level, or slightly domed, surface in a circular or irregular patch that may or may not be surrounded by a ring of peat, soil or stones (Zoltai and Tarnocai 1981). More specifically, these features are referred to as raised centre mudboils and are associated with better-drained portions of the landscape.

They are believed to form when liquefied soil material is extruded to the surface as a viscous mass (Shilts 1978). Shilts found that the upward movement of mud varied between 9 and 54 cm, generally away from the central point of the circle. The mechanism for liquefaction is not fully understood, but is thought to be attributable to slight changes, either in moisture content or in internal or external stress, in soils that have a low liquid limit, low plasticity index, and natural moisture content near the liquid limit (Veillette 1980). Mackay (1980) studied the origin of hummocks (the higher relief form of nonsorted circle) in the Inuvik area and attributed the movement of material within the patterned ground features to differential volume changes associated with freezing and thawing of soil water. Heave, contraction and resultant upward flow of material into the centre of the circle could all be explained by his equilibrium model. The process of mudboil formation involves greater liquifaction, but the driving forces may be the same.

ORTHIC TURBIC CRYOSOL ASSOCIATED WITH STRONGLY CRYOTURBATED MATERIALS

The lack of vegetation (insulating) cover produces very cold soil temperatures in winter and relatively warm temperatures in summer. As a result, the active layer in this soil is greater than one metre thick. When the pedon was sampled in September 1991, the permafrost table was not encountered to a depth of 130 cm. All horizons were strongly cryoturbated, with evidence of movement of materials upward towards the centre of the mudboil (Figure 25). The site and pedon descriptions for the mudboil site are presented in the Table 24.

The soil is strongly acidic throughout the profile (Table 25). Exchangeable cations are dominated by Al and H. The surface horizons within the trough portion of the pedon (Ahy1 and Ahy2) are high in organic matter, while values in the other horizons are lower. Like most Turbic Cryosols, considerable (>1%) organic carbon is found in subsurface horizons. The soil is derived from shale and eolian parent materials, and is very fine textured. The silty clay texture and high moisture-holding capacity (Table 25) of this soil facilitate the formation of mudboil features, which are related to the freezing and thawing of soil water. Seepage water was also observed in the Bgfy horizon at the time of sampling..

The site is sparsely vegetated, with vegetation growing only around the perimeter of individual mudboils. A listing of the species occurring adjacent to the mudboils is given in Table 26. The vegetation is subalpine in character, with *krummholtz* black spruce and larch mixed into a scrub-dominated community.

Micromorphology

The parent material at this site is composed of residual material of rounded to subangular lithofragments of dominantly shale and siltstone. The micromorphology (Table 27; Plate 4) of the groundmass obtains a ped-like structure from the close packing of the well weathered fragments. Under polarized light, the orientation of the clay material and the fabric differences distinguish the boundaries of the "peds" (Pl.4:I, L). Freeze–thaw processes have enhanced the orientation of the clay particles resulting in stress cutans and lattisepic fabric arrangements.

Oriented clay zones (stress cutans) are most prominant in the Bmy1 horizon, from which one can infer that the effect of freeze-thaw cycles is most extensive in the surface horizon (Pl.4:B, C). In the lower horizons, the dominant process is ice lens formation, causing an extensive void pattern and the physical break-up of the residual material into aggregations. Planar voids are observed frequently in the Bmy2 and Cy horizons and commonly in the Bmy3 horizon (Pl.4:D, G, J). Ice lens formation in these pores has contributed to the formation of aggregates (conglomeric, matrifragmic fabrics) and their breakup into smaller units (granular structure; matrigranic).

Differential freezing fronts may have contributed to the sorting of the lithofragments by frequency of occurrence and size. Lithofragments are most abundant and have the widest size range in the Cy horizon, followed by the Bmy3 horizon. In the Bmy2 horizon, lithofragments are fewer in frequency and size range (50–600 μm) compared to the lower part of the Cy horizon, where they range from 0.1 to 4.5 mm. In the upper part of the Bmy1 horizon, the frequency of lithofragments is less than in the Cy horizon, and about the same as the Bmy2 horizon, but the size range is larger than in the Bmy2 horizon, ranging from 0.5 to 3.2 mm.

The soil fabric of the Bmy2 horizon is the most compact of the horizons examined, having thin planar voids and irregular vughs. Considerable ice lens formation must have occurred in the Cy and Bmy3 horizons to produce the very fragmented soil morphology. In the Bmy1 horizon, a very wet environment with considerable movement of materials is suggested by the very smoothed, very rounded, outer surfaces of the granular units. The frequent fusing of the units at contact points, with strong orientation of the clay particles forming stress cutans, suggests associated pressures from freezing. (Pl.4:B, C). The formation of granular units in strongly cryoturbated materials has been described by Smith *et al.* (1990) and Smith and Fox (in press).

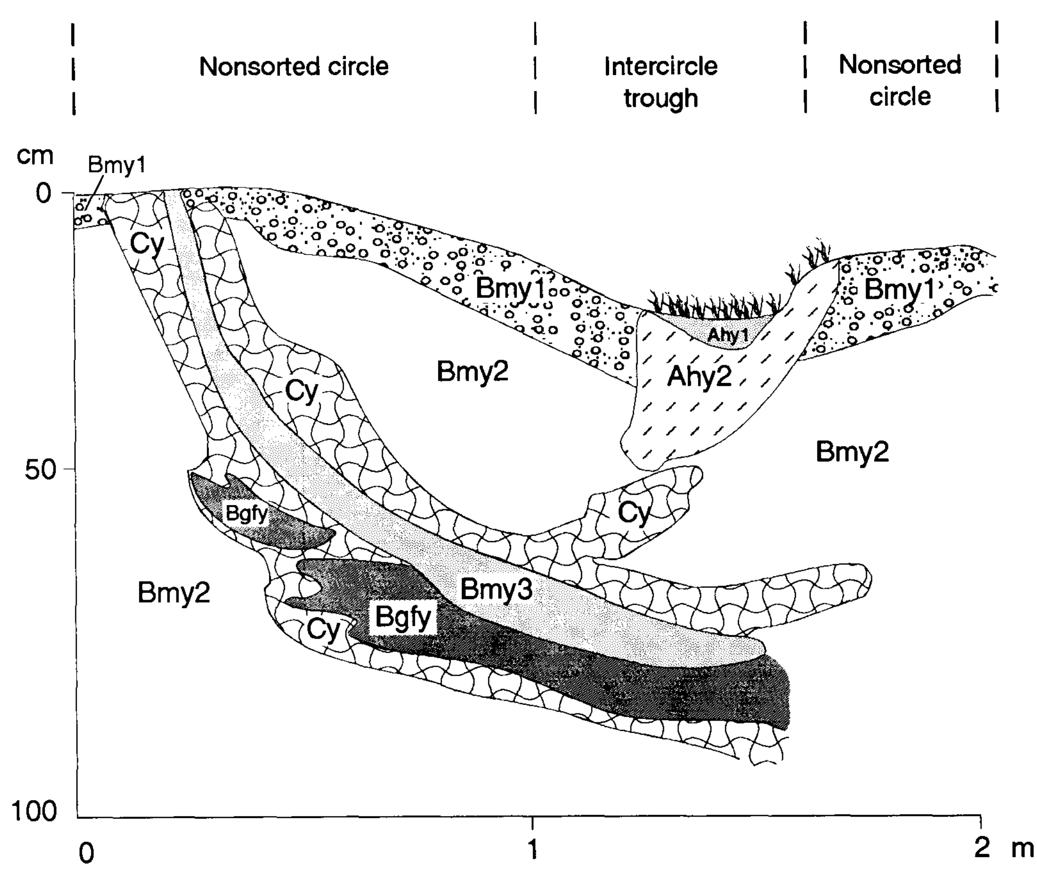


Figure 25. Cross section of the Orthic Turbic Cryosol associated with nonsorted circles (mudboils) at Site 11.

Table 24. Site and pedon descriptions for Site 11.

Pedon no.: EP – 3
Location: 66°32'27" N Lat., 136° 22'28" W Long.
Landform: Ridge crest
Parent Material: Mixed eolian and shale saprolite
Patterned Ground: Nonsorted circles (mudboils)

Elevation: 640 m (a.s.l.)
Slope: 2%
Drainage: Imperfect
Vegetation: Subarctic forest
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Thickness	Description
Can.	U.S.	(cm)	
Ahy1	A1	0 – 10	Dark grayish brown (10YR 4/2 m); silty clay; moderate to strong, fine to medium, granular; slightly sticky, friable, slightly plastic; abundant, fine to medium, random roots; highly porous; gradual, broken boundary.
Ahy2	A2	0 – 30	Brown (10YR 5/3 m); clay; moderate to strong, fine, subangular blocky, breaking to moderate, fine to medium, granular; slightly sticky, friable, plastic; few, fine to medium, random roots; moderately porous; gradual, broken boundary.
Bmy1	Bw1	0 – 15	Yellowish brown (10YR 5/6 m); silty clay; weak, medium, subangular blocky, breaking to moderate to strong, fine to medium, granular; sticky, friable, plastic; few, fine, random roots; highly porous; gradual, broken boundary.
Bmy2	Bw2	0 – 30	Olive brown (2.5Y 4/4 m); silty clay; yellowish brown (10YR 5/6 m) mottles; weak to moderate, fine to medium, subangular blocky; sticky, firm, plastic; few, fine, vertical roots; moderately porous; clear, broken boundary.
Bmy3	Bw3	5 – 15	Dark brown (7.5YR 3/4 m); silty clay; weak to moderate, fine, subangular blocky; sticky, firm, very plastic; few, fine, vertical roots; moderately porous; clear, broken boundary.
Bgfy	Bg	0 – 20	Dark grayish brown (2.5Y 4/2 m); silty clay; many, medium to coarse (7.5YR 4/6 m) mottles; weak, fine, subangular blocky; sticky, firm, very plastic; very few, fine roots; moderately porous; clear, broken boundary.
Cy	C	0 – 25	Dark grayish brown (2.5Y 4/3 m); silty clay; moderate to strong, fine to medium, subangular blocky; moderately porous.

Table 25. Analytical data for the Orthic Turbic Cryosol at Site 11.

Chemical Analysis														
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)*					Sesquioxides (%)			
											Oxalate		Pyrophos.	
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total	Fe	Al	Fe	Al
Ahy1	4.1	3.4	9.2	0.38	24	3.0	1.6	0.9	6.4	11.9	0.26	0.20	0.24	0.21
Ahy2	4.0	3.5	4.2	0.24	18	0.7	0.3	0.4	11.2	12.6	0.40	0.27	0.37	0.22
Bmy1	4.0	3.5	1.7	0.16	11	0.6	0.2	0.3	11.8	12.9	0.40	0.24	0.33	0.22
Bmy2	4.0	3.5	2.0	0.17	12	0.5	0.2	0.4	12.0	13.1	0.39	0.23	0.29	0.21
Bmy3	3.8	3.3	1.0	0.13	8	0.3	0.2	0.3	13.2	14.0	0.40	0.19	0.12	0.18
Bgfy	3.8	3.2	0.8	0.12	7	0.4	0.2	0.4	12.8	13.8	0.46	0.18	0.10	0.18
Cy	3.9	3.3	1.0	0.13	8	0.3	0.2	0.4	12.4	13.3	0.25	0.18	0.19	0.19

* Neutral salt extraction

Table 25. Analytical data for the Orthic Turbic Cryosol at Site 11 (cont.)

Physical Analysis							
Horizon	%	Part. Size Dist. (% <2 mm)			Moisture (%)		Texture
	>2 mm	Sand	Silt	Clay	1/3 atm	15 atm	
Ahy1	1						SiC
Ahy2	1	8.6	34.4	57.0	39.3	14.8	C
Bmy1	3	4.6	44.1	51.3	33.2	15.6	SiC
Bmy2	2	5.5	43.0	51.5	33.2	14.6	SiC
Bmy3	2	3.8	45.1	51.2	27.7	14.5	SiC
Bgfy	2	4.4	43.7	51.9	27.7	13.4	SiC
Cy	4	3.5	47.0	49.6	27.0	15.3	SiC

Table 26. Vegetation description* for Site 11.

Vegetation

SHRUBS (% cover)

Tall Shrubs
- 1.0 *Betula occidentalis*
- 0.5 *Larix laricina*
- 1.0 *Picea mariana*

Low Shrubs
- 10.0 *Betula glandulosa*
- 10.0 *Ledum palustre* ssp. *decumbens*
- 0.5 *Rosa acicularis*
- 10.0 *Salix* sp.
- 10.0 *Vaccinium uliginosum*

Medium Shrubs
- 5.0 *Betula glandulosa*
- 1.0 *Salix* sp.

Dwarf Shrubs
- 10.0 *Arctostaphylos rubra*
- 15.0 *Empetrum nigrum*
- 0.5 *Pedicularis* sp.
- 1.0 *Vaccinium vitis-idœa*

HERBS (% cover)

- 0.5 *Petasites frigidus*
- 0.5 *Polygonum alaskanum*

GRASSES (% cover)

- 1.0 *Carex physocarpa*
- 0.5 *Gramineæ* sp.
- 0.5 *Hierochloe alpina*

MOSSES – LICHENS (% cover)

Mosses
- 1.0 *Bryophyte* sp. 1
- 1.0 *Bryophyte* sp. 2
- 1.0 *Bryophyte* sp. 3

Lichens
- 0.5 *Cetraria cucullata*
- 0.5 *Cetraria nivalis*
- 0.5 *Cladina mitis*

NON-VEGETATION (% cover)

- 20.0 Bare
- 5.0 Litter
- 35.0 Rock
- – Slash
- – Water

* The plant community adjacent to the area of bare soil is described.

Table 27. Micromorphological Features for Site 11: Nonsorted Circles (mudboils).

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmy1 (Bw1)	**Overall:** Dense soil fabric with weak to moderate granular structure; numerous irregular vughs and strongly oriented clay particles delineate ped boundaries (stress cutans). (Pl.4:A to C) **Related DP:** Meta-matrigranoidic-porphyroskelic with rare occurrence of matrigranoidic. Plasmic: Dominantly bimasepic//masepic; occasional vomasepic and skel-masepic. **Microstructure:** Vughy structure with moderately developed pedality. c/f fabric: Porphyric. b-fabric: Parallel with reticulate striated; occasional poro- and grano-striated.	**Void Pattern:** Abundant vughs; various sizes (50 µm–2.8 mm length); smoothed rounded surfaces identify weak granular structure; occasional compound packing voids. **Basic Components:** Mineral: Very fine-grained soil matrix with lithofragments of mainly shales, siltstones that are incorporated into peds; vary from occasional to common with depth; mainly 0.5–3.2 mm, rarely 1.2 cm. Groundmass composed of silt-size angular quartz (<10–40 µm) and dominant oriented clay material. Organic: Root tissues occur occasionally to commonly in vughs, tissues are moderately to strongly decomposed. Rare well-humified (black) fragments (0.2–1.1 mm) of plant tissues (woody, leaf, stem) are incorporated into soil material, similar to lithofragments. In groundmass, strongly decomposed and well-humified plant tissue fragments (<10–100 µm) are frequent. **Pedofeatures:** Fabric: Oriented clay material occurs in soil matrix as zones commonly delineating boundaries of pedal units; stress cutans from compression of units; may form zones of weakness. Rare to occasionally, stress cutans surround both lithofragments and well-humified organic fragments, strongly to moderately oriented clay material. Faunal: Rare occurrence of fecal material in centre portion of root.	Very smooth, rounded appearance of pedal units with extremely fine materials adjacent to pore suggests very wet conditions of freeze–thaw cycles. Numerous freezing cycles have enhanced the strong alignment of clay particles in the groundmass. In a wet state, the pedal structure would be subjected to compaction from pressures from ice formation resulting in the irregular shaped pore pattern and oriented clay zones between peds at points of contact, forming stress cutans. (Pl.4:A to C) Lithofragments increase in frequency with depth, indicating sorting by size has occurred; commonly aligned diagonally and near vertical. (Pl.4:A) Occasional incorporation of plant tissues and lithofragments in pedal structures, with surfaces having a distinct coating of oriented clay material.
Bmy2 (Bw2)	**Overall:** Dense fine-grained soil fabric with common to frequent lithofragments; numerous planar voids; moderately to strongly oriented clay material in the groundmass (stress cutans). (Pl.4:D to F) **Related DP:** Matrifragmic// matrifragmoidic porphyroskelic// porphyroskelic. Plasmic: skel-lattisepic//mosepic. **Microstructure:** Weak to moderate platy structure grading to crack structure. c/f RDP: Porphyric (125X) b-fabric: Mosaic-speckled with grano- and reticulate striated.	**Void Pattern:** Frequent planar voids (mainly <10–50 µm wide); partially to fully accommodated. (Pl.4:D) Root channel (600 µm) occurs rarely. Irregular (rarely triangular shaped, often prolate or rounded) vughs (250–500 µm) are frequently connected to planar voids; rarely to occasionally contain root tissues. **Basic Components:** Mineral: Fine-grained soil matrix with lithofragments (50–600 µm) of mainly shale, siltstone, sandstone, occasional igneous. Groundmass consists of oriented clay material/particles and angular quartz grains (<10–50 µm). (Pl.4:E, F) Organic: In groundmass, frequent strongly decomposed plant tissues and well-humified fragments (<10–200 µm). Rare to occasional well-humified fragments (black) of leaf conifer tissues, amorphous woody materials occur in the soil material as lithofragments with coating of oriented clay; often evidence of breaking apart. Root tissues (mainly 100–200 µm) in vughs are weak to moderately decomposed. **Pedofeatures:** Fabric: Clay material organized in reticulate pattern in soil matrix; weak expression of pedal structure that is inherited from parent material. (Pl.4:F) Occasionally to rarely, concentrations (<10–50 µm wide) of clay particles are moderately to strongly oriented on surfaces of both lithofragments and well-humified organic fragments. (Pl.4:E) Packing of clay material along grain surfaces; discontinuous.	Clay material in the groundmass is often oriented in zones at right angles. The orientation of the clay material commonly delineates a weak granular structure that is inherited from the parent material (See description for Cy horizon) and probably enhanced by freeze–thaw processes (stress cutans). (Pl.4:F) Planar voids probably the result of cracks due to contraction of fine-grained, clayey soil material; sites for ice lens formation. Irregular vughs connecting to planar voids characteristic of ice lens formation. (Pl.4:D) Clay material oriented in groundmass is aligned on lithofragments and well-humified fragments as a result of freeze–thaw processes forming stress cutans. Well-humified organic fragments mixed into groundmass. Occasionally near vertical alignment of lithofragments, commonly oriented diagonally (20–45° from horizontal). (Pl.4:E)

Table 27. Micromorphological Features for Site 11: Nonsorted Circles (mudboils) (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Cy (C)	**Overall:** Complex morphology consisting of numerous aggregates composed of dense soil fabric with abundant lithofragments and oriented clay concentrations (stress cutans) defining a weak pedal structure; extremely porous. (Pl.4:G) **Related DP:** Dominantly ortho-conglomeric with minor ortho-matrigranic/matrigranoidic and matrifragmic. Plasmic: Mosepic with zones of weak lattisepic and occasional skelsepic. **Microstructure:** Complex structure: zones of platy, subangular blocky, and granular structure. c/f RDP: Porphyric. b-fabric: Mosaic-speckled with zones of weak reticulate striated and occasional granostriated.	**Void Pattern:** Very frequent planar voids and compound packing voids separate the aggregates (size ranges extremely variable). Within the aggregates, voids are commonly observed along, or adjacent to, the boundaries of weathered lithofragments (probable cracks and/or voids from cryogenic effects). (Pl.4:G to I) **Basic Components:** Mineral: Subrounded to subangular lithofragments occur very frequently; dominantly shale, and siltstone; poorly sorted with respect to size range, vary 0.1–4.5 mm, frequently 0.1–1.0 mm; appear to be highly susceptible to movement. (Pl.4:G, H) In the groundmass, weak pedal structure results from very weathered shale and very fine siltstone fragments; clay particles and concentrations delineate pedal boundaries. (Pl.4:I) Rare occurrences of weathered iron oxide rims on shale lithofragments. Organic: No plant tissues observed. Extremely fine well-humified particles frequent in groundmass; source is probably weathered organic-rich shales. **Pedofeatures:** Fabric: Clay concentrations derived from weathered lithofragments; produce a weak granular structure within aggregates; zones of weakness for pore formation and eventual separation and break-up. Fine-grained material (10–80 μm) firmly packed on siltstones; moderate to strong orientation of clay particles, stress cutans. (Pl.4:I)	Most dominant aspect of effect of freezing processes is the soil material arrangement with breakup of the parent material. Ice lens formation has produced numerous planar voids, resulting in abundant aggregates (very variable size ranges). (Pl.4:G) Lithofragments, part of the residual parent material, are moved about in the soil matrix. There is a concentration of lithofragments in this horizon compared to the upper part of the Bmy2 (Bw2). Larger lithofragments (>800 μm) occasionally occur as single grains; probably broken free from aggregates. Concentrations of fine-grained matrix material most frequently observed on grain surfaces of siltstone fragments; weak to strong orientation of clay particles (stress cutans). (Pl.4:H, I) Within aggregate, ped-like structure delineated by clay concentrations, zones for ice lens/crystal formation, stress cutans formed from freeze–thaw cycles.
Bmy3 (Bw3)	**Overall:** Subangular blocky to occasional platy structure with aggregates composed of fine-grained material with frequent included lithofragments. (Pl.4:J) **Related DP:** Dominantly ortho-conglomeric with ortho-matrigranic // matrifragmic. Plasmic: Mosepic with minor lattisepic. **Microstructure:** Complex structure: Granular with zones of platy structure. c/f RDP: Porphyric. b-fabric: Mosaic-speckled with minor occurrences of reticulate striated.	**Void Pattern:** Frequent compound packing voids and commonly planar voids separate aggregates; variable size ranges. Within aggregates, planar voids (10–30 μm wide) are occasional to common. (Pl.4:J, K) **Basic Components:** Mineral: Frequent lithofragments of dominantly shale with common occurrences of siltstone (0.2–1.4 mm); incorporated into aggregates. Clay particle (weathered mica) alignment in groundmass observed as lattisepic fabric. Organic: Very rare occurrence of root tissue (100 μm wide) in aggregate. Well-humified, amorphous, extremely fine fragments occur commonly in the groundmass (origin may also be from weathered organic-rich shales). **Pedofeatures:** Coatings: Iron-oxide-rich weathering rim observed occasionally on reddish-brown shale fragments. Fabric: Concentrations of clay particles/material defining "ped-like" structure inherited from residual parent material; weathering shale, siltstone, mudstone becoming part of groundmass. Packing of fine-grained material on siltstone fragments (<10–60 μm); strongly oriented clay particles, stress cutans.	Lithofragments are less abundant and have smaller size range than in Cy horizon. Very fragmented morphology with granular and blocky structure suggests intense ice lens formation and possibly numerous freezing cycles. Conglomeric fabric with included lithofragments in the aggregates suggests movement and ice lens formation. (Pl.4:J) Clay particle alignment into lattisepic fabric as a result of freeze–thaw cycles. Within the aggregates, ped-like structure provides zones for ice lens/crystal formation. Also suggests zones of weakness along which aggregates will break-up. "Ped-like" structure a result of stresses set up by freeze–thaw cycles. (Pl.4:K, L)

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 4

List of Plates for Site 11: Nonsorted Circles (Mudboils).

Plate 4: A
Dense soil fabric with weak granular structure in the Bmy1 horizon. Note rounded, smooth surfaces of granular units and irregular, triangular-shaped vughs. Frame length 8.5 mm. Plane polarized light (PPL).

Plate 4: B
Close-up view of rounded granular structure in the Bmy1 horizon. Note the compression at point of contact of the individual units. Frame length 1.0 mm. (PPL).

Plate 4: C
Same as Pl.4:B, but crossed polarized light. Note the orientation of clay particles (stress cutan) at point of contact (vosepic fabric) as well as in the interior of the aggregate (masepic fabric). Frame length 1.0 mm. Crossed polarized light (XPL).

Plate 4: D
Dense fine-grained soil fabric in the Bmy2 horizon, with common to frequent lithofragments and numerous planar voids. Frame length 8.5 mm. (PPL).

Plate 4: E
Close-up view of dense soil fabric in the Bmy2 horizon, showing orientation of lithofragments and planar voids. Frame length 2.7 mm. (PPL).

Plate 4: F
Orientation of clay particles in the Bmy2 horizon, showing weak expression of pedal structure with reticulate fabric arrangement (lattisepic). Frame length 1.0 mm. (XPL).

Plate 4: G
Complex morphology characterizes the Cy horizon, with numerous aggregates composed of dense soil fabric with abundant lithofragments; dominantly ortho-conglomeric fabric with ortho-matrigranic // matri-fragmic. Frame length 8.5 mm. (PPL).

Plate 4: H
Close-up view of dense soil fabric of an aggregate from the Cy horizon. Note the near vertical alignment of lithofragments and planar voids. Frame length 1.0 mm. (PPL).

Plate 4: I
Same as Pl.4:H, but crossed polarized light. Clay particle alignment around siltstone grain as a result of stress from freeze–thaw cycles. Frame length 1.0 mm. (XPL).

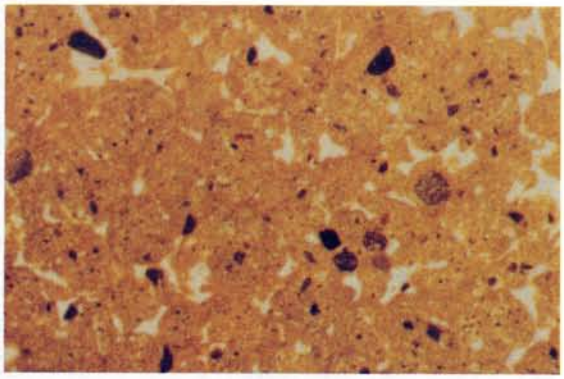
Plate 4: J
Subangular blocky to platy structure in the Bmy3 horizon. The aggregates consist of fine materials with frequent included lithofragments. Frame length 8.5 mm. (PPL).

Plate 4: K
Close-up view of aggregate in the Bmy3 horizon, showing dense soil fabric. Frame length 1.0 mm. (PPL).

Plate 4: L
Same as Pl.4:K, but crossed polarized light. Note concentrations of clay particles/materials defining "ped-like" structure probably inherited from the residual parent material. Frame length 1.0 mm. (XPL)

PLATE 4

Site 11: Mudboil Site



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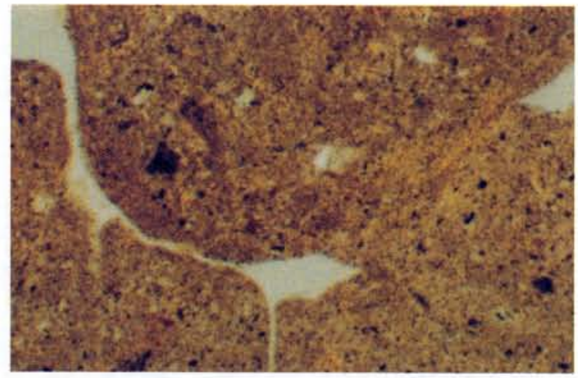

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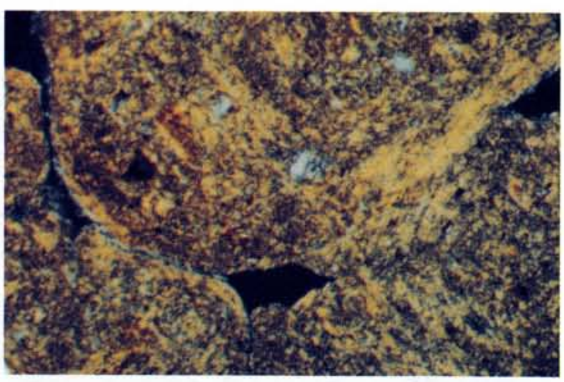

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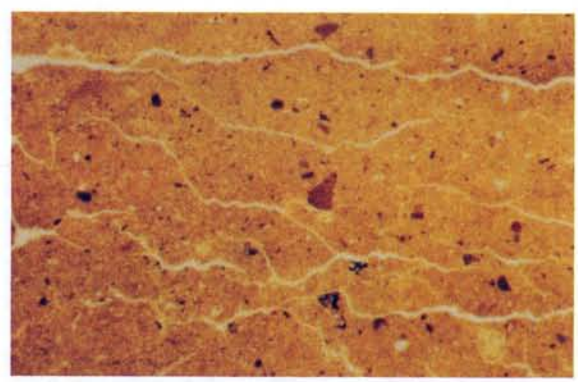

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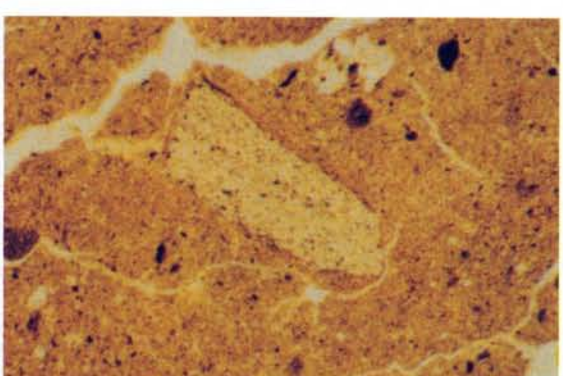

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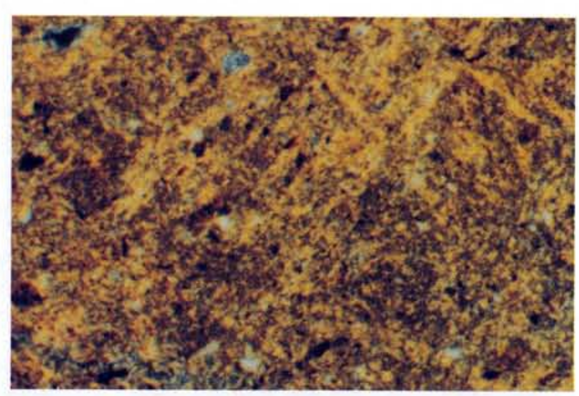

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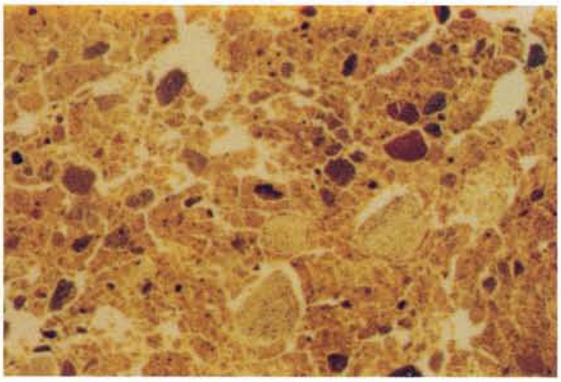
PLATE 4 (cont.)

Site 11: Mudboil Site



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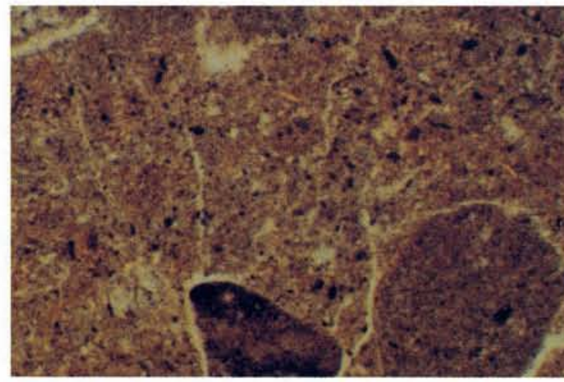

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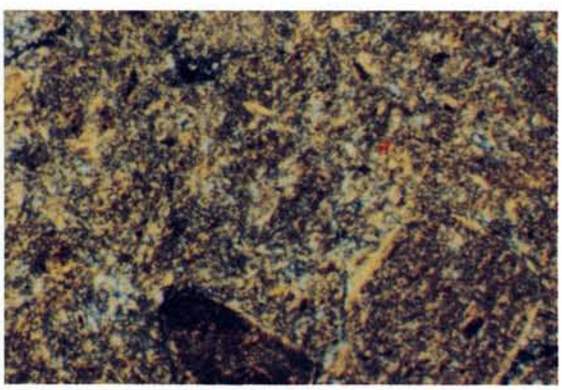

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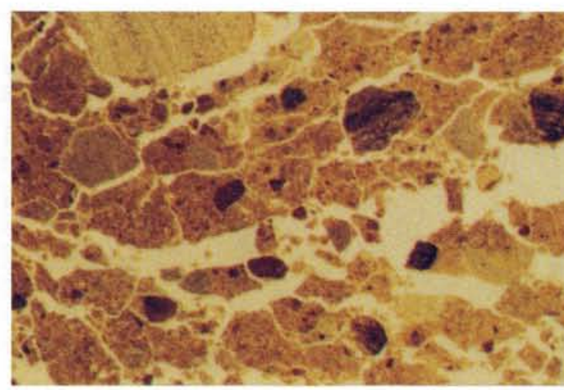

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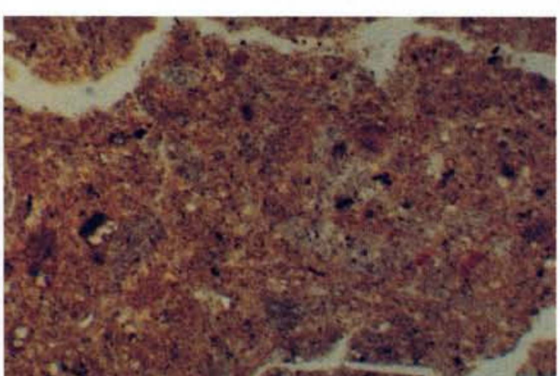

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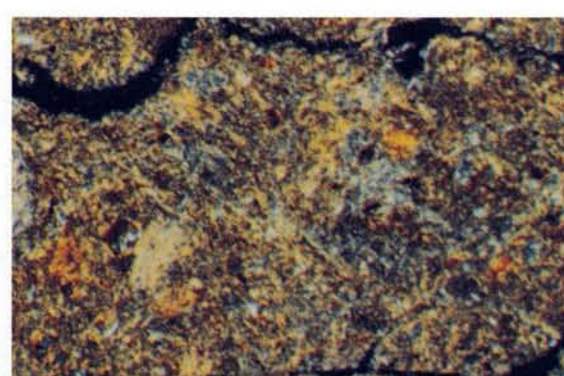


L

SITE 12, KM 366: EAGLE PLAIN MONITORING SITE, DEMPSTER HIGHWAY

This site is typical of the Subarctic Cordilleran Ecoclimatic Province in the northern Yukon. Morphologically, the site is similar to the forested upland sites in the Inuvik region, but it is nearly 600 m a.s.l. and is subject to a slightly warmer climate, particularly in the winter. Summer temperatures are slightly warmer in the Inuvik region. Soil temperatures have been monitored intermittently at this site since 1985. Prior to 1991, the site was monitored by manual readings; for the last two years, data have been recorded at 3-hour intervals by a data logger. The site and pedon descriptions for Site 12 are given in Table 28.

The pedon covers an earth hummock that is approximately 95 cm in diameter (Figure 26). The soil is strongly acidic, with pH increasing slightly with depth (Table 29). The depth to permafrost is approximately 45 cm in the interhummock depression and 95 cm under the apex of the hummock. There is a prominent accumulation of organic matter immediately above the permafrost table as a result of cryoturbation associated with the earth hummock. There is a high organic carbon content in all horizons, including the Cz horizon. Soil chemistry (C:N) and micromorphological observations indicate that most of the subsoil organic matter is composed of peat or charcoal detritus incorporated from rather well-humified substances. Total exchangeable cations are low and, in many horizons, dominated by aluminum. Iron oxides are abundant within the B horizons of the soil, and appear to be composed of a range of crystalline and non-crystalline forms.

The principal component of the parent material at this site is marine shale. The soils are fine textured, and contain up to 20% fine clay and few coarse fragments (Table 29). The soils have high moisture-holding capacity. The horizons in the centre of the hummock tend to be compressed, and to have slightly higher bulk densities than surrounding mineral horizons.

The clay mineralogy (Table 29) is dominated by mica, kaolinite and vermiculite in all horizons. There are lesser amounts of montmorillinite–mica and montmorillinite–chlorite interstratified minerals in the lower horizons. There is not a striking change in the clay mineralogy through the profile. We assume that the mixing that takes place and the current climate do not facilitate strong mineralogical gradients within the soil of this region and that the phyllosilicate minerals present are inherited from the underlying parent materials.

A list of the vegetation occurring at this site is given in Table 30. The only trees on this site are black spruce (*Picea mariana*). The plant community is a mosiac of hydrophilic species (*Equisetum arvense*, *Eriophorum vaginatum* and *Sphagnum* sp.) in the interhummock depressions and upland forest floor species such as *Vaccinium uliginosum*, *Empetrum nigrum* and *Pleurozium schreberi*. This is a mature forest community, and has not been affected by fire for at least 100 years. The largest trees are at least 85 years old.

Soil Temperature and Moisture

Mean soil (for seven depths) and air temperatures, based on one year's data, are given in Table 31. The site has a continental climate with pronounced seasonal variations. The minimum winter air temperature is -36.7°C and the summer maximum is 31.0°C. Temperature flucuations are strongly dampened within the soil profile. The mean annual soil temperature at the 50 cm depth is -2.8°C and the mean annual temperatures at all depths are less than 1°C. The soil remains permanently frozen at all depths below 100 cm. Manual measurements of active layer depth indicate that the permafrost table lies at a maximum of approximately 75 cm below the surface on the hummock centres.

During the winter months, soil temperatures are nearly the same throughout the surface 20 cm of the soil, and reach a minimum of approximately -10°C during February (Figure 27). Soil temperatures at depths of 50 to 150 cm show less annual variation and much less warming during the summer months than do the soils above this depth.

Periodic measurements of soil moisture indicate that, during the summer months, the surface organic materials are very dry (Figure 28). This condition enhances the thermal insulating capacity of the forest floor and also leaves it highly susceptible to burning by wild fire. Moisture levels remain high at depths >15 cm throughout the growing season. Moisture values tend to increase through the summer at greater depths in the active layer, as water is liberated from underlying ice lenses and vein ice.

Micromorphology

The micromorpholgy of the soil at this site is given in Table 32 and discussed below. Refer also to Plate 5.

Ohy Horizon. This horizon was sampled at the boundary with the permafrost table at the time of sampling. Because of this position in the pedon, the soil materials have been influenced by cryogenic processes as follows:

1. Cracks have formed as a result of water removal during freezing; down-turning at sides of cracks suggests ice wedge formation. (Pl.5:B)
2. Iron oxide staining is prominent and developed as a consequence of water being perched due to the impermeable barrier of permafrost below. (Pl.5:B)
3. Close packing of the organic material aggregations forms a massive-appearing fabric as a result of compaction from removal of water towards the permafrost table as well as probable cryostatic pressures. (Pl.5:A)
4. Inclusions of sphagnum moss from the upper part of the Of horizon indicate pressures due to freezing fronts causing movement of materials (Pl.5:A); and
5. Incorporation of fragments of roots into massive material with weak sorting into distinct zones.

Bmy Horizon. This horizon shows a gradation in size of the structural units, increasing from the upper to lower portion and ranging from 0.15 to 12 mm (Pl.5:C, D). The soil morphology in the upper part of the Bmy horizon has been influenced more intensely by freeze–thaw processes than the soil morphology in the lower part. In the upper portion there is a definite weak granular structure with close packing of peds. These peds tend to be rounded and, in massive-appearing fabric, weak boundary delineations are observed, suggesting close packing of the material under saturated conditions has occurred during freeze–thaw cycles; the rounding of the peds suggests that rotation of the units has probably taken place. The lower part of the Bmy horizon is characterized by weak blocky structure (matrifragmic-porphyroskelic fabrics). From the planar voids one can infer that this structure has resulted primarily from ice lens formation in the dense soil fabric. Freeze–thaw cycles are more prominent in the upper part of the Bmy horizon. Freezing fronts have produced sorting of both the silt and very fine sand-size material and have resulted in lattisepic fabric. In addition, mica particles packed along grain surfaces are frequent to common in the upper portion of the Bmy horizon. Oriented clay was observed in former root channels, indicating that these pores are now conduits for water. Iron oxide staining along pores between the structural units suggests that a perched water table occurs periodically above the permafrost table.

Bmgjy Horizon. This horizon shows moderate evidence of cryoturbation, with alignment of mineral fragments diagonally and near vertical, sorting of mineral grains (mainly silt to medium sand size, 20–300 μm) into circular patterns and clusters, and the alignment of clay particles along grain surfaces and in the groundmass around coarser fragments, suggesting movement of materials takes place during thaw and freeze-up periods; pressures created in saturated soil material would lead to the movement of particles (Pl.5:G). Movement of particles within the horizon is also suggested by the frequent occurrence of well-humified (charcoal) particles and fragments of organic material, probably derived from adjacent Of and Ohy horizons. The soil fabric is massive, suggesting compression due to freezing pressures in conjunction with the removal of water towards the permafrost table creating a desiccated, dense and compacted morphology. Numerous nodules were also observed, often in clusters, aligned and rounded. Their probable source is mottled regions, such as those observed in the Bgy horizon, when mottled regions are broken apart and moved by cryogenic processes. Water flow is indicated by infillings of fine materials associated with old root channels. (Pl.5:H)

Bgy Horizon. This horizon is similar to the Bmgjy horizon, with a dense soil fabric from which water is removed for ice lens formation in the adjacent permafrost zone, producing a compact material (Pl.5:I). Unlike the Bmgjy horizon, there are distinct mottled zones around the planar voids and root channels. In the Bmgjy horizon, numerous nodules represent probable fragmented mottled zones or the movement of the nodules from the Bgy into the Bmgjy horizon by cryoturbic processes. Lattisepic (or reticulate striated fabric) arrangements indicate movement and alignment of material; this fabric often results from drying cycles (Pl.5:J). The intensity of this fabric is greater in the mottled zones than in the groundmass. As the mottled zones tend to be associated mainly with the planar voids and root channels, one could infer that these zones would possibly be subjected to frequent wetting and drying cycles, resulting in more prominent alignment. Abundant organic material is present in this horizon, suggesting incorporation from adjacent Of and Ohy horizons.

BCgz Horizon. This sample was taken in an area with considerable inclusion of organic material into dominantly silty-clay material. A distinctive layering has resulted from ice lens formation, producing secondary structural units of layered to weak platy structure (Pl.5:K). Sorting of fine sand size quartz and lithofragments into clusters or horizontally aligned zones was observed; a result of movement away from freezing fronts due to ice lens formation. The plant tissues and aggregations are generally embedded in the mineral material, with zones of inclusions of single plant particles. The morphology of the organic material is very similar to that observed in the Ohy horizon and, thus, one can conclude that this latter horizon is the source for the organic material. Under saturated conditions and with the influence of cryogenic pressures under downward slope movement, the organic material was either forced in or was slowly moved over the mineral horizon at the permafrost table and the tissues were incorporated into the groundmass. The pronounced unistrial alignment of the mineral material in occasional layers, as well as the prominent horizontal alignment of the organic particles, suggests considerable pressure, probably under saturated conditions. Another possibility for the movement of the organic materials from the Of and Ohy horizons may be that a portion of the organic horizon remains saturated when the freezing front advances both from the permafrost table and from the surface. The organic material between these two freezing fronts is squeezed into the planar cracks existing in the mineral material or intruded into the saturated mineral material.

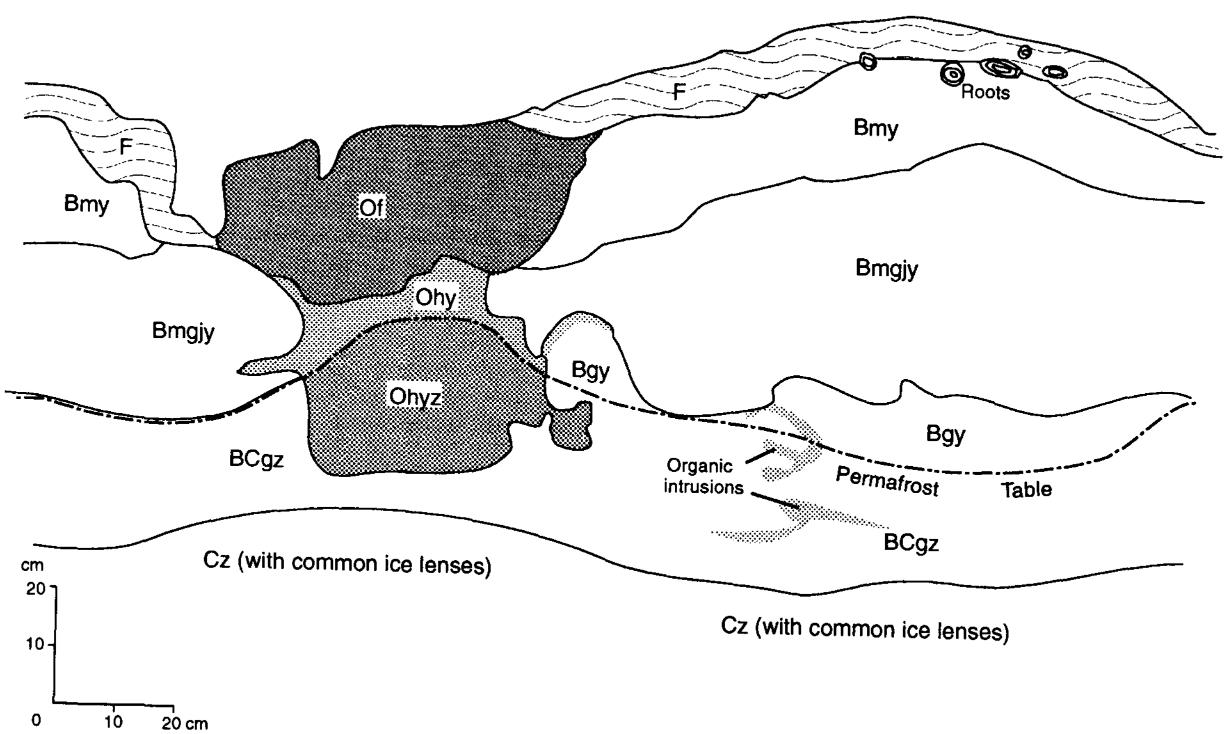


Figure 26. Cross section of the Orthic Turbic Cryosol formed in association with an earth hummock under Subarctic forest at Site 12.

Table 28. Site and pedon descriptions for Site 12.

Pedon no.: EP –1, S91-FN-260-003
Location: 66°23'20" N Lat., 136° 41'44" W Long.
Landform: Shale and sandstone ridge
Drainage: Imperfect to poor
Soil Temperature (50 cm depth; 1991-92): MAST -2.8°C, MSST 0.6°C
Parent Material: Mixed loess and colluvial veneer
Patterned Ground: Earth hummock

Elevation: 594 m (a.s.l.)
Slope: 4%, northwest aspect
Vegetation: Subarctic forest
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Ruptic Histic Cryaqupt
F.A.O. – Gelic Cambisol

Horizon		Thickness	Description
Can.	U.S.	(cm)	
F	Oe	0 – 8	Very dark brown (10YR 2/2); forest litter; 50% unrubbed, 15% rubbed fibre; few, medium roots, and many, very fine and fine roots; clear, broken boundary. [91P5969]
Of	Oi	0 – 27	Dark red (2.5YR 3/6), dark reddish brown (5YR 3/3); undecomposed peat; 90% unrubbed, 60% rubbed fibre; common, medium roots, and many, very fine and fine roots; clear, broken boundary. [91P5970]
Ohy	Oa	0 – 15	Dark brown (7.5YR 3/2); well decomposed peat; 40% unrubbed, 10% rubbed fibre; few, fine roots; cryoturbated; clear, broken boundary. [91P5971]
Bmy	Bw	0 – 20	Very dark grayish brown (10YR 3/2), dark grayish brown (2.5Y 4/2); clay; few, fine, prominent, strong brown (7.5YR 4/6) redoximorphic concentrations; strong, coarse, granular structure; firm, slightly sticky, slightly plastic; few, medium and coarse roots, and common, very fine and fine roots; cryoturbated; 1% pebbles; gradual, broken boundary. [91P5972]
Bmgjy	Bg1	0 – 30	Very dark grayish brown (2.5Y 3/2), dark gray (5Y 4/1); clay; common, medium, prominent, strong brown (7.5YR 4/6) redoximorphic concentrations; strong, fine and medium, granular structure; firm, slightly sticky, moderately plastic; few, very fine and fine roots; cryoturbated; gley 10%; horizon appears compressed; 1% pebbles; gradual, broken boundary. [91P5973]
Bgy	Bg2	0 – 12	Very dark grayish brown (2.5Y 3/2), dark gray (5Y 4/1); clay; common, medium, prominent, strong brown (7.5YR 5/6) redoximorphic concentrations; weak, coarse, granular structure; firm, moderately sticky, moderately plastic; few, fine roots; gley 10%, some organic staining; cryoturbated; gradual, broken boundary. [91P5974]
Ohyz	Oaf	0 – 25	Dark reddish brown (5YR 3/3), dark brown (7.5YR 3/4); well decomposed peat; few, fine roots; clear, broken boundary. [91P5975]
BCgz	Cgf	5 – 20	Dark gray (5Y 4/1), 40% very dark grayish brown (2.5Y 3/2); silty clay; many, coarse, prominent, strong brown (7.5YR 4/6) redoximorphic concentrations; massive; firm, moderately sticky, moderately plastic; few, fine roots; gley 20%; gradual, wavy boundary. [91P5976]
Cz	Cf	–	Dark gray (5Y 4/1); silty clay; many, fine, prominent, strong brown (7.5YR 4/6) redoximorphic concentrations; very firm, moderately sticky, moderately plastic. [91P5977]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 29. Analytical data for the Orthic Turbic Cryosol at Site 12.

Chemical Analysis															
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)									
						Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total	Total	Ca	Mg	Na	K
F	4.3	3.7	24.6	0.75	33	3.6	4.5	1.9	5.6	15.6	6.7	2.6	3.0	0.2	0.9
Of	3.5	3.4	44.7	0.86	52	5.7	4.4	2.4	1.6	14.1	17.5	9.6	5.3	0.5	2.1
Ohy	4.3	4.0	20.3	0.74	27	5.7	2.3	0.4	0.4	8.8	10.7	7.1	3.0	0.2	0.4
Bmy	4.6	4.2	4.2	0.18	23	2.3	1.1	0.3	0.2	3.9	3.6	2.3	1.1	0.1	0.1
Bmgjy	4.7	4.5	3.0	0.15	20	3.7	1.6	0.2	5.4	10.9	5.3	3.6	1.6	0.1	tr
Bgy	4.6	4.3	3.4	0.16	21	5.0	2.2	0.2	7.6	15.0	8.9	6.2	2.5	0.1	0.1
Ohyz	4.5	4.2	23.5	0.80	30	9.0	3.3	0.3	7.5	20.1	13.1	9.3	3.3	0.2	0.3
BCgz	4.7	4.1	8.1								10.9	7.9	2.8	0.1	0.1
Cz	5.4	4.7	1.8								12.7	8.1	4.4	0.1	0.1

Sesquioxides (%)						
Horizon	Dithionite		Oxalate		Pyrophosphate	
	Fe	Al	Fe	Al	Fe	Al
F	1.55	0.22	0.68	0.22	0.56	0.26
Of	0.21	0.11	0.19	0.07	0.06	0.05
Ohy	2.29	0.35	1.94	0.43	2.26	0.46
Bmy	1.98	0.18	1.45	0.24	0.93	0.29
Bmgjy	2.21	0.15	1.47	0.21	1.04	0.27
Bgy	2.54	0.13	1.52	0.18	0.84	0.24
Ohyz	2.38	0.39	1.79	0.36	2.48	0.49
BCgz						
Cz						

Table 29. Analytical data for the Orthic Turbic Cryosol at Site 12 (cont.)

Physical Analysis											
Horizon	Fibre Content (%)		%	Part. Size Dist. (% <2 mm)				Bulk Den.	Moisture (%)		Texture
	Unrub.	Rub.	>2 mm	Sand	Silt	Clay	F-Clay	(g/cc)	1/3 atm	15 atm	
F	50	15						0.42	53.7	36.7	
Of	90	60								100.0	
Ohy	40	10						0.59	161.1	40.4	
Bmy			2	9.8	58.0	36.4	17.9	1.37	27.2	14.7	C
Bmgjy			2	9.9	55.5	37.6	18.7	1.56	27.5	15.2	C
Bgy			2	10.5	53.7	37.1	17.4	1.75	21.3	14.7	C
Ohyz	25	10	2					0.39	113.1	51.3	
BCgz			2	9.8	48.5	41.7	20.8	1.79	22.8	20.9	SiC
Cz			2	9.3	47.0	43.7	16.2			14.1	SiC

Clay Mineralogy (<2μ)									
Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size*)					
	Al_2O_3	Fe_2O_3	K_2O	Kaolinite	Vermi-culite	Mica	Interstrat. Montmor.-Mica	Chlorite	Interstrat. Montmor.-Chlorite
F									
Of									
Ohy									
Bmy	21.0	7.4	3.1	3	3	3	2	1	
Bmgjy									
Bgy	22.0	6.0	6.0	3	2	3	2		1
Ohyz									
BCgz									
Cz	25.0	6.0	3.9	3	2	4	2		1

* Relative peak size: 4 = large, 3 = medium, 2 = small, 1 = very small

Table 30. Vegetation description for Site 12.

Vegetation

TREES (% cover)

Tall Trees		Low Trees	
1.0	*Picea mariana*	15.0	*Picea mariana*

SHRUBS (% cover)

Tall Shrubs		Low Shrubs	
10.0	*Picea mariana*	1.0	*Betula glandulosa*
1.0	*Salix planifolia*	15.0	*Ledum palustre* ssp. *decumbens*
		1.0	*Picea mariana*
		1.0	*Spiræa beauverdiana*
		1.0	*Vaccinium uliginosum*

Medium Shrubs		Dwarf Shrubs	
1.0	*Betula glandulosa*	1.0	*Empetrum nigrum*
15.0	*Picea mariana*	1.0	*Oxycoccus microcarpus*
1.0	*Salix planifolia*	20.0	*Vaccinium vitis-idæa*

HERBS (% cover)

25.0	*Equisetum sylvaticum*	1.0	*Petasites frigidus*
1.0	*Lycopodium clavatum*	10.0	*Rubus chamæmorus*

GRASSES (% cover)

10.0	*Eriophorum vaginatum*

MOSSES – LICHENS (% cover)

Mosses		Lichens	
20.0	*Bryophyte* sp.	1.0	*Cetraria cucullata*
10.0	*Hylocomium splendens*	1.0	*Cetraria islandica.*
5.0	*Pleurozium schreberi*	1.0	*Cladina mitis*
20.0	*Sphagnum* sp.	1.0	*Cladonia* spp.
		25.0	*Cladina rangiferina*
		10.0	*Cladina stellaris*
		0.5	*Nephroma* sp.
		5.0	*Peltigera* sp.

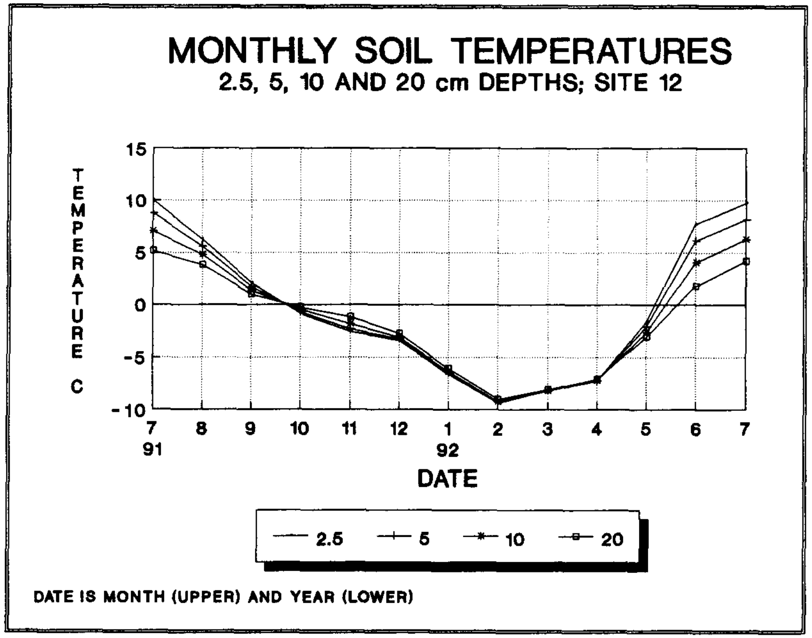
NON-VEGETATION (% cover)

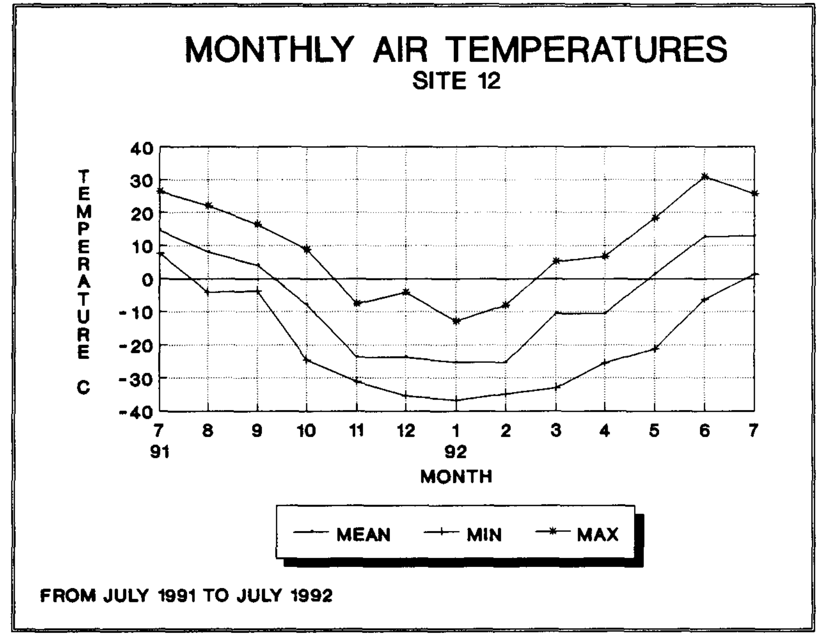
1.0	Bare	–	Slash
25.0	Litter	–	Water
–	Rock		

Table 31. Mean annual (MAST), minimum and maximum soil temperatures between July 1991 and June 1992 and mean summer* (MSST) soil temperature in 1992 at Site 12.

Depth (cm)	MAST (°C) 1991-92	MIN (°C) 1991-92	MAX (°C) 1991-92	MSST (°C) 1992
2.5	-1.1	-10.5	23.1	7.9
5	-1.4	-10.4	17.3	6.6
10	-1.8	-10.3	10.9	5.0
20	-2.1	-10.0	6.8	3.3
50	-2.8	-9.0	3.1	0.6
100	-2.8	-7.5	-0.3	-1.0
150	-2.8	-6.5	-0.8	-1.7
Air	-7.2	-36.7	31.0	11.2

* Summer refers to June, July and August





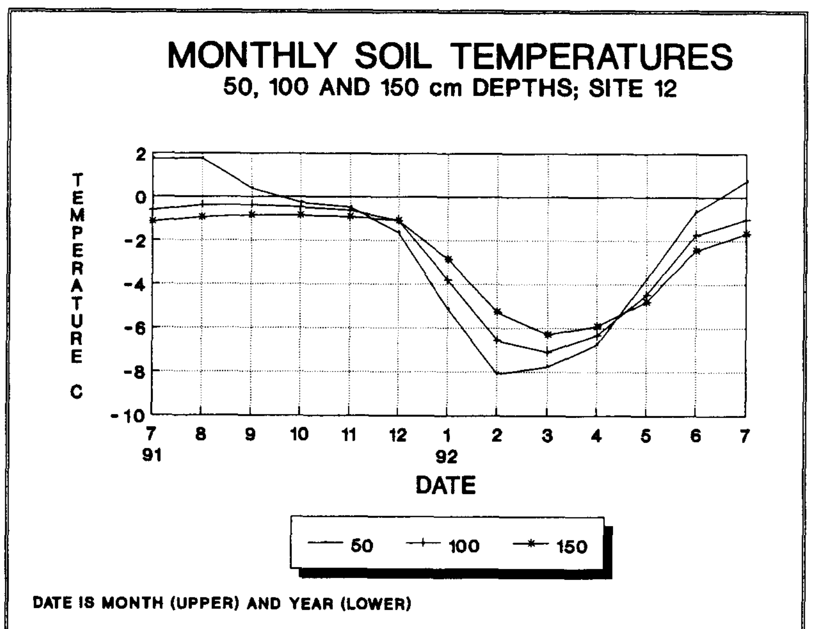


Figure 27. Monthly soil and air temperatures at Site 12 between July 1991 and September 1992.

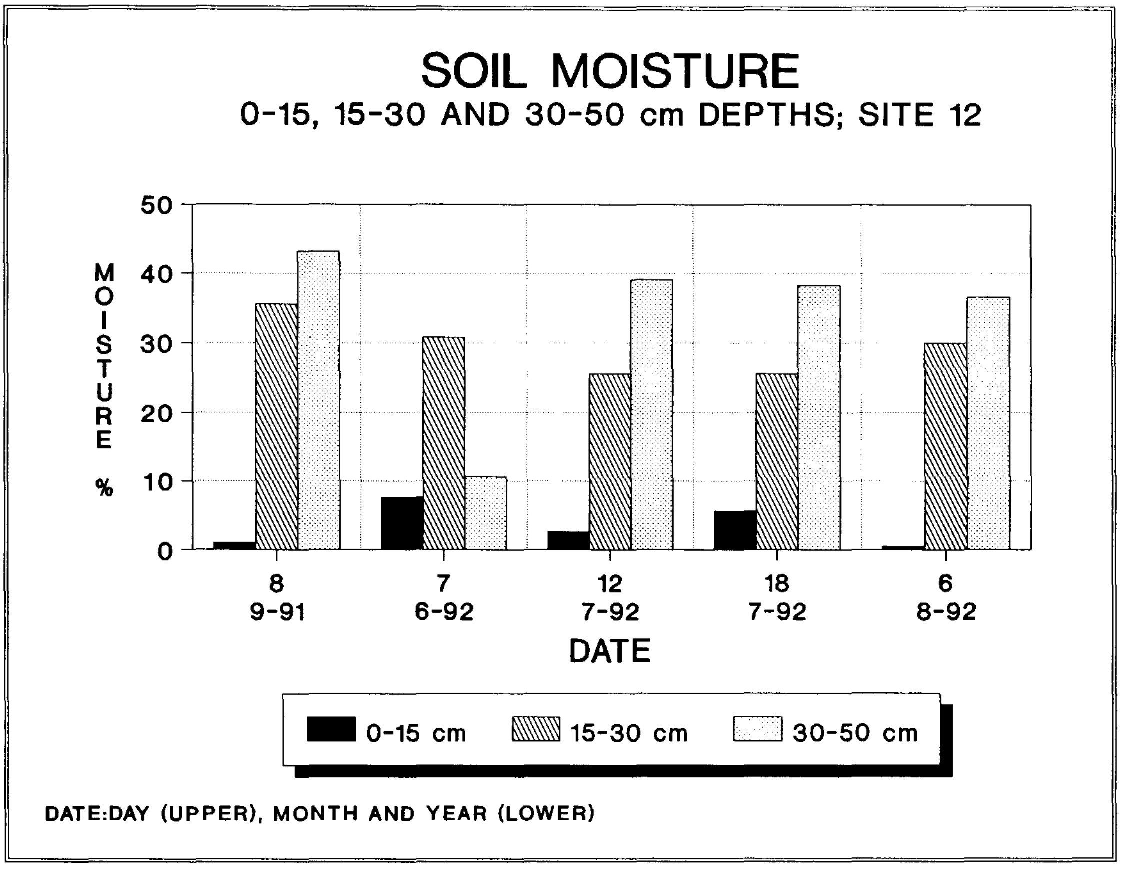


Figure 28. Summer soil moisture (%) at the 0–15, 15–30 and 30–50 cm depths at Site 12.

Table 32. Micromorphological Features for Site 12: Eagle Plain Site.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ohy (Oa)	**Overall:** The morphology consists mainly of closely packed aggregations of amorphous organic material along with root structures in a weak granular structure; occasional zones of sphagnum moss fragments; moderate cryoturbation. (Pl.5:A) **Related DP:** Primary structure of phytogranic/humi-phytogranic-mullgranoidic-porphyroskelic. Secondary structure weak mullconglomeric/mullconglomeric-porphyroskelic. Plasmic: In zones with mineral material intermixed with organic: mo-insepic. **Microstructure:** Complex: Primary structure of densely packed crumb structure; secondary structure of weak granular and platy structure. c/f RDP: Monic. b-fabric: Mosaic-stipple-speckled.	**Void Pattern:** Complex packing voids (mainly 30–250 μm) occur frequently between aggregations of organic material; irregular vughs (400–800 μm) are common; occasional to common planar voids 30–150 μm wide; and rare former root channels, 1 mm diameter occur in the closely packed zones, evidence of movement of amorphous mineral material with very thin discontinuous coating. Zones of inclusions of moss fragments characterized by simple packing voids. Vertical crack (500–800 μm wide) interconnected to large (width varies 1–6 mm) diagonally aligned planar crack. **Basic Components:** Mineral: Mineral material in varying amounts occurs in the organic aggregations; dominantly quartz <40 μm with occasional grains of fine sand-size. Infilling in crack consists of fine silt-size mineral material and amorphous organic material. Organic: Amorphous (unrecognizable) organic material and fragmented plant tissues dominate as aggregations; closely packed to form weak granular and blocky structure with interior of units having massive-appearing fabric; weak sorting of organic fragments into distinct zones. Inclusions of sphagnum moss fragments show weak to moderate decomposition of cell structures. Root sections occur commonly to frequently, are strongly to extremely decomposed and frequently have mycorrhizal layers. Fungal hyphae are common, and associated with closely packed aggregations. **Pedofeatures:** Infilling: Dense, incomplete infilling of crack with amorphous organic and silt-size mineral material; medium brownish-grey; distinctly different from adjacent soil matrix. Mottles: Distinct, irregular band of iron oxide (possible organic component) staining. (Pl.5:B)	Cracks with infillings of fine amorphous material; result of shrinkage due to water removal by ice formation or surface drying; slight down-turning of material along crack as well as removal of material from sides into crack. (Pl.5:B) Inclusions of sphagnum moss fragments from upper horizons into densely packed aggregations suggests differential pressures from freezing fronts. (Pl.5:A) Distinct line of iron oxide staining indicates poor drainage as a result of perched water table from permafrost. (Pl.5:B)

Table 32. Micromorphological Features for Site 12: Eagle Plain Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmy (Bw)	**Overall:** Massive-appearing structural units increase in size with depth; close packing of granular units in upper Bmy horizon results in massive-appearing structure; moderate effect of cryogenic processes on soil fabric. **Related DP:** Occasional orbiculic fabric occurs randomly throughout; with depth, gradation of fabric zones as follows: Upper: Matrigranoidic// matrigranoidic-porphyroskelic//matrifragmic-porphyroskelic; Lower: Matrifragmic-porphyroskelic//porphyroskelic. Plasmic: Upper: Mainly insepic; zones of weak lattisepic, occasional orbiculic fabric; rare skelsepic. Lower: Silasepic with occasional skelsepic. **Microstructure:** Complex: Gradation from densely packed granular structure to weak blocky to massive structure; occasional sorting of silt grains in circular patterns. c/f RDP: Porphyric. b-fabric: Upper: Stipple-speckled with weak reticulate striated, rare grano-striated. Lower: Stipple-speckled with occasional granostriated.	**Void Pattern:** Moderate to weak development of pedal structure results in irregular vughs, often with triangular-shaped portions. In the upper Bmy, these vughs are commonly associated with roots, occur frequently, and range from 0.1 to 1.2 mm; in the lower Bmy, these vughs occur occasionally to commonly, ranging from 0.5 to 4.8 mm and are commonly interconnected to planar voids (20–200 μm wide). Former rounded to elliptical root channels (0.2 to 1 mm) contain amorphous clay coatings; only observed within peds, rare occurrence. **Basic Components:** Mineral: Weak to moderate sorting of silt and very fine sand-size mineral grains (mainly 30 – 60 μm, occasionally 60 – 100 μm) into circular patterns; dominantly angular to subangular quartz. Structural units composed of massive fabric of clay to very fine sand-size mineral material increase in size with depth; upper Bmy horizon range from 0.15–3.0 mm; lower Bmy horizon range from 1.6-12 mm. Frequent close packing and aggregation of structural units results in weak granular and massive-appearing morphology. In lower Bmy, rare subangular lithofragments of sandstone (1.4–3.0 mm) included into structural unit, moderately weathered. Organic: Organic tissues (dominantly <10–60 μm) form constituent of groundmass; in the upper Bmy horizon occasional to rare well-humified black tissues 120–480 μm, rare conifer leaf tissues; in lower Bmy horizon strongly decomposed, reddish-brown tissues and well-humified material (100–200 μm) occurs rarely to occasionally in peds, very rare charcoal fragments 200–550 μm, tend to be clustered. (Pl.5:E) Root tissues follow pores between structural units; in lower Bmy, rare occurrence, strongly decomposed, 300–700 μm wide (Pl.5:F); in upper Bmy, occasional occurrence, moderate to strong decomposition of cell tissues, size range 200–800 μm. **Pedofeatures:** Coatings: In former root channels, washed-in material of amorphous to coarse clay to extremely fine silt coatings (<10–200 μ m), continuous, strongly oriented, layered; only rarely observed, most prominent in lower Bmy horizon. Fabric: Close packing of mica particles along grain surfaces of silt-size material; frequently to commonly observed in upper Bmy horizon, occasionally in lower Bmy horizon; very thin, discontinuous stress cutans along ped surfaces adjacent to voids occurs very rarely to rarely in upper Bmy horizon. Nodules: Weathered shale fragments are reddish yellow to dark reddish brown; occur frequently in the lower Bmy, range 0.08–1.2 mm, tend to be clustered, occasionally associated with mottled zones (staining of groundmass with iron oxides, reddish brown). Mottles: Occasional dark reddish-brown iron oxide staining of groundmass adjacent to pores; most obvious in lower Bmy horizon.	Granular structure, compaction with ice lens formation leading to planar voids, triangular shaped voids. Rounded surfaces of granular units, especially in the upper Bmy horizon, indicates saturated conditions, possible movement during freeze–thaw cycles. Blocky structure and planar voids dominate in lower Bmy horizon; result of ice lens formation. (Pl.5:C, D) Sorting of silt-size mineral grains into circular patterns; weak expression. Incorporation of organic fragments into groundmass of structural units; source of organic material, upper organic horizons. (Pl.5:E) Iron oxide staining in pores indicates periods with perched water table. Close packing of mica particles along silt-size mineral grains and stress cutans; result of freeze–thaw cycles.

Table 32. Micromorphological Features for Site 12: Eagle Plain Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmgjy (Bgl)	**Overall:** Dense soil fabric with numerous nodules derived from fragments from mottled zones; sorting of coarse quartz grains; moderate to strong evidence of cryoturbation. (Pl.5:G) **Related DP:** Orbiculic-porphyroskelic// porphyroskelic. Plasmic: Dominantly lattiskel-insepic; in iron-oxide mottled zones strongly expressed, occasional mosepic component. **Microstructure:** Massive with fissure structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled with grano- and reticulate-striated. In iron oxide mottled zones, occasional mosaic-speckled.	**Void Pattern:** Dominant void pattern consists of planar voids; most prominent as horizontal, size range 350–400 μm wide; occasionally to commonly diagonally oriented, size range 30–120 μm wide; origin as desiccation cracks. Rare root channels in massive material; size range 0.28–1.0 mm. **Basic Components:** Mineral: Dense groundmass of silty-clay material with subrounded to subangular, mineral grains dominantly of quartz (80–160 μm), lithofragments of occasional siltstone and rare shale, and frequent, moderately to strongly impregnated nodules. Mineral grains (mainly silt to medium sand size, 20–300 μm) show sorting into clusters and circular patterns; very coarse (0.64–1.6 mm) material consisting of nodules, lithofragments, and rare charcoal are commonly aligned diagonally to near vertical. Clay particles frequently to commonly closely packed onto grain surfaces; clay particles also show alignment in the groundmass around mineral fragments. Organic: Strongly decomposed root material occurs rarely, embedded in groundmass, occasional incomplete discontinuous infillings of washed-in, very fine silt-size material occurs along epidermal remnants. Fragments (<10–350 μm, dominantly <10–50 μm) of well-humified organic material (charcoal) are distributed throughout groundmass; may be infused with iron oxides; coarser fragments show alignment. **Pedofeatures:** Nodules: Very frequent, ferruginous, moderately to strongly impregnated, range from light yellow to dark reddish brown; size range variable 0.01–1.8 mm length, dominantly 250–650 μm; frequently aligned; source from mottled regions that have broken apart and mixed into soil material. (Pl.5:G) Infillings: Rare fine to extremely fine silt and clay infillings; associated with root material, very rarely observed embedded in groundmass. (Pl.5:H)	Mineral grains in groundmass, evidence of sorting in circular patterns and clusters of similar fragments. Close packing of clay particles along grain surfaces as result of freeze–thaw cycles. Alignment of clay particles in groundmass around mineral grains and lithofragments suggests movement of the soil under saturated conditions in presence of freezing fronts. Planar voids, produced by shrinkage of groundmass; may be effect of substantial removal of water during drying or freezing cycles as well as movement of water towards permafrost. Numerous nodules of iron-oxide-impregnated soil material, suggests saturated periods, probable result of perched water table caused by permafrost. Show considerable movement and alignment; source probably from mottled regions similar to those in Bgy horizon, fragmented and rotated by cryogenic processes. (Pl.5:G)

Table 32. Micromorphological Features for Site 12: Eagle Plain Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bgy (Bg2)	**Overall:** Dense soil fabric with frequent prominent mottles occasionally associated with planar voids and channels; well-humified organic fragments are frequently embedded in groundmass; weak to moderate evidence of cryoturbation; sorting of silt-size material into circular patterns. (Pl.5:I) **Related DP:** Orbiculic porphyroskelic//-porphyroskelic. Plasmic: Latti-insepic; in association with diffuse mottled portions occasional strong lattisepic with mosepic and skelsepic component; in strong mottled areas, omnisepic. (Pl.5:J) **Microstructure:** Massive structure with thin planar voids (fissure structure). c/f RDP: Porphyric. b-fabric: Stipple-speckled with reticulate striated. In mottled zones, occasional strong reticulate striated with mosaic-speckled and grano-striated component; in strong mottled portions, random striated.	**Void Pattern:** Thin planar voids (10–120 μm wide) occur occasionally to commonly; rare rounded to elliptical vughs (0.2–1.0 mm wide), often smooth walled, tend to be associated with extremities of planar voids. Larger planar voids occasionally associated with mottled zones. Occasional to rare root channels (0.5–1.3 mm diameter) occur in dense groundmass, occasional mottled zones around channel. **Basic Components:** Mineral: Densely compacted, silty-clay material with rare lithofragments of siltstone (320–520 μm with coarse fraction 5–10 mm); aligned diagonally. Quartz grains 60–150 μm are common and frequently sorted. Prominent ferruginous mottled zones along planar voids and around root channels occur commonly. Clay particle alignment in groundmass and close packing on grain surfaces occur commonly. Organic: Frequent, well-humified organic fragments (charcoal) are distributed randomly throughout the groundmass with tendency for clustering of larger fragments; variable size range <10–350 μm; larger fragments' cell structures occasionally observed. Frequent to common, strong to extremely decomposed plant tissues occur in groundmass; yellow to reddish brown; cell structures frequently separated, tissues often amorphous and compressed (variable size range <0.01–1.5 mm length). Strongly decomposed root remnants in channels are occasionally associated with mottled zones. **Pedofeatures:** Mottles: Prominent ferruginous mottles with successive zones indicating different periods of development; rare occurrences of breaking apart of mottled zone and incorporation into silty-clay matrix; increased intensity of clay particle arrangement in mottled zones. Occasional zones of nodules present; result of intense mottling process.	Clay particles aligned in groundmass (lattisepic or reticulate striated fabric) as result of freeze–drying cycles and movement by cryostatic pressure under saturated conditions. Sorting of coarse silt and fine sand-size material into clusters and weak circular patterns. Size of mineral grains smaller than in upper Bmgjy horizon. Dense groundmass compacted by removal of water for ice formation in zone of permafrost. Intensity of development of mottled zones around root channels and planar voids indicates that oxygenated water maintained in place for extended time periods; probable effect of perched water table caused by underlying permafrost. (Pl.5:I)

Table 32. Micromorphological Features for Site 12: Eagle Plain Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
BCgz (Cgf)	**Overall:** The sample was taken from a zone with considerable included organic material, similar to the soil fabric of the Oh horizon. Closely packed layers of fine silt and clay material with organic fragments and aggregations grade to zones with weak platy secondary structure of horizontally oriented units. (Pl.5:K) **Related DP:** With depth, gradation of fabric zones: Layered//phytogranic-mullgranoidic-porphyroskelic//conglomeric// fragmoidic-porphyroskelic. Plasmic: With depth: Strongly unistrial//insepic//-mo-insepic//skel-lattisepic. **Microstructure:** Extremely complex structure: compact structure of aggregates, fine material and organic particles; secondary layered and platy structure. c/f RDP: Dominantly porphyric with zones of weak enaulic. b-fabric: With depth, fabric zones of unistrial//stipple-speckled//mosaic stipple-speckled//reticulate with granostriated fabric.	**Void Pattern:** Size ranges highly variable; complex packing voids dominate with close packing of fine mineral and organic materials; secondary structure of planar voids (mainly 50–350 μm, rarely 1 mm). **Basic Components:** Mineral: Silty-clay material with occasional subangular quartz and rare lithofragments ranging to fine sand-size (50–250 μm); moderate particle size sorting, tends to be layered. Occasional continuous layers in which extremely fine silt and clay material dominate; strong alignment of clay material at 45° to horizontal. (Pl.5:L) Organic: Prominent horizontal alignment of plant tissues embedded in groundmass, variable size range; leaf and stem tissues can still be occasionally recognized, rare woody material; minor zones of inclusions of single organic particles; well-humified (charcoal) and abundant strongly to extremely decomposed fragments, occasionally with cell structures broken apart and incorporated into groundmass. Rare fungal hyphae observed in groundmass, very rare fungal sclerotia. **Pedofeatures:** Mottles: Common ferruginous staining (gleyed), diffuse; occasional successive distinct boundaries of staining. Faunal: Very rare evidence of former faunal activity observed in root tissues, aged excrements, bright reddish brown.	Morphologic appearance of soil material similar to organic fragments, aggregations observed in the Oh horizon; material has moved into the BCgz; may be under influence of slope gradient and cryostatic pressures. Mineral material shows strong alignment due to stress; suggests extremely wet conditions and considerable pressures to result in preferential alignment; possible result of compression and movement under saturated conditions at time of freezing. (Pl.5:L) Permafrost has prevented significant decomposition of the organic materials; origin is still discernable; evidence of faunal activity remains; integrity of fragments has been preserved, very little fragmentation. Planar void pattern result of ice lens formation; produces secondary structural units; most characterized by conglomeric and fragmic fabric types. Ferruginous mottled areas result of perched water table during thaw periods.

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 5

List of Plates for Site 12: Eagle Plain Site.

Plate 5: A
Inclusions of sphagnum moss occur occasionally in the closely packed aggregations of organic materials of the Oh horizon. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 5: B
Crack penetrates through zone of iron oxide staining in the Oh horizon. The infilled material is composed, in part, of adjacent soil material that moves farther down into the crack. Note the position of the fragments of iron stained soil material as well as finer material transported into the crack. Frame length 4.0 mm. (PPL).

Plate 5: C
Granular structure in the upper part of the Bmy horizon has smoothed, rounded morphology on the ped surfaces. Note the triangular-shaped vughs between the granular units. Frame length 8.5 mm. (PPL).

Plate 5: D
The size and extent of compaction of the granular structural units in the lower part of the Bmy horizon increases with depth from the upper part of the Bmy horizon. Frame length 8.5 mm. (PPL).

Plate 5: E
In the lower part of the Bmy horizon, clusters of well-humified (charcoal) organic fragments occur in the dense soil fabric. Frame length 2.6 mm. (PPL).

Plate 5: F
Roots penetrate between the granular units in the lower part of the Bmy horizon; root tissues are moderately to strongly decomposed. Frame length 4.0 mm. (PPL).

Plate 5: G
Numerous moderately to strongly impregnated nodules occur in the dense soil fabric of the Bmgjy horizon. Note also the alignment of coarse quartz grains. Frame length 4.0 mm. (PPL).

Plate 5: H
Rare occurrence of fine to extremely fine silt and clay infillings are associated with root material in the Bmgjy horizon. Frame length 1.0 mm. (PPL).

Plate 5: I
Extensive mottled zones occur in the dense soil fabric of the Bgy horizon. Note in the mottled region, the break-up and rotation of fragments strongly impregnated with iron oxides. Frame length 8.5 mm. (PPL).

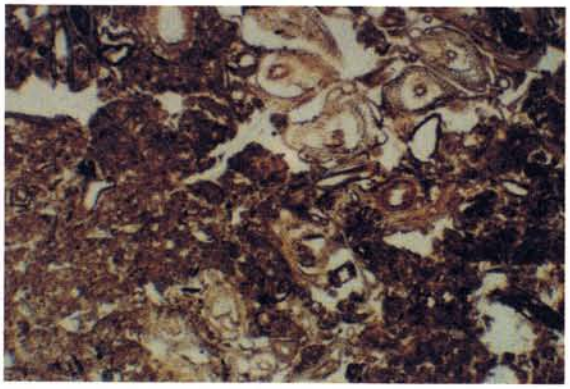
Plate 5: J
In association with mottled regions, occasional strong lattisepic with skelsepic and mosepic components were observed in the Bgy horizon. Frame length 1.0 mm. Crossed polarized light (XPL).

Plate 5: K
Closely packed layers of fine silt and clay with organic fragments and aggregations characterize the morphology of the BCgz horizon. Frame length 4.0 mm. (PPL).

Plate 5: L
Strong alignment of the mineral material is observed around organic fragments and layered material in the BCgz horizon. Frame length 4.0 mm. (XPL).

PLATE 5

Site 12: Eagle Plain Site



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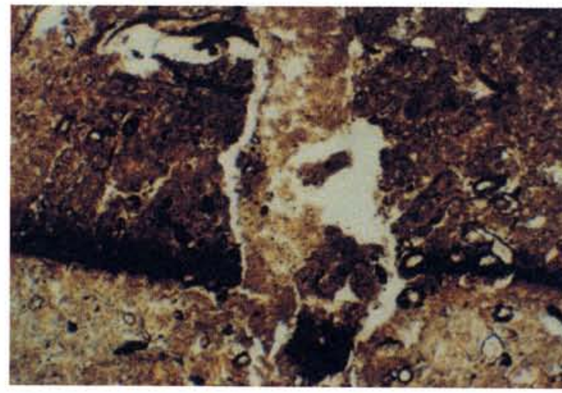

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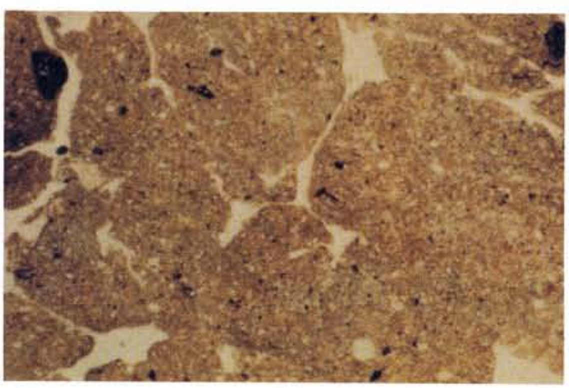

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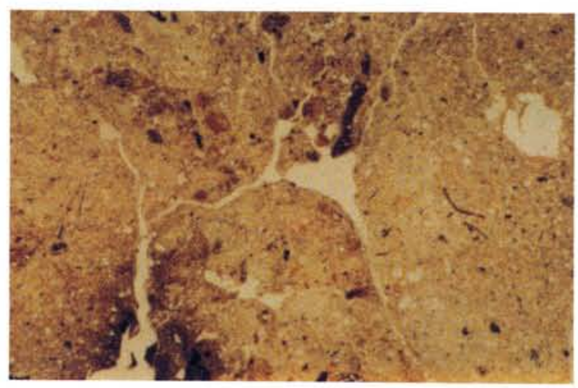

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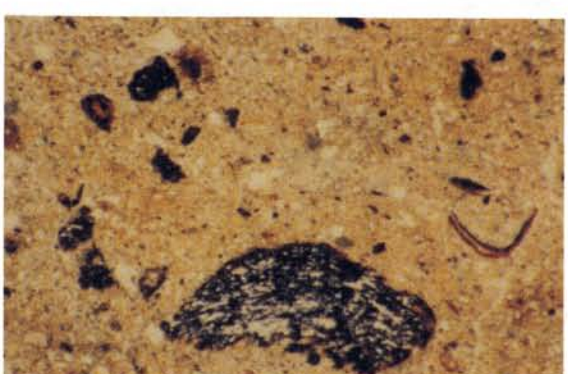

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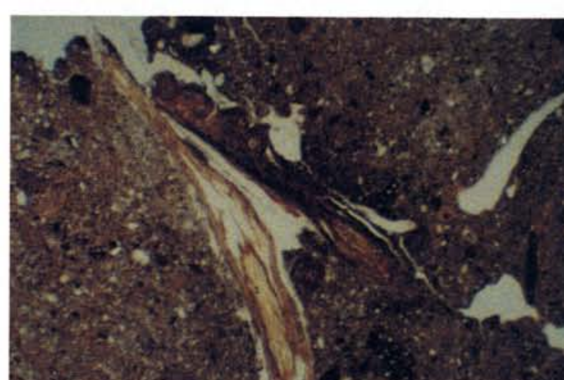

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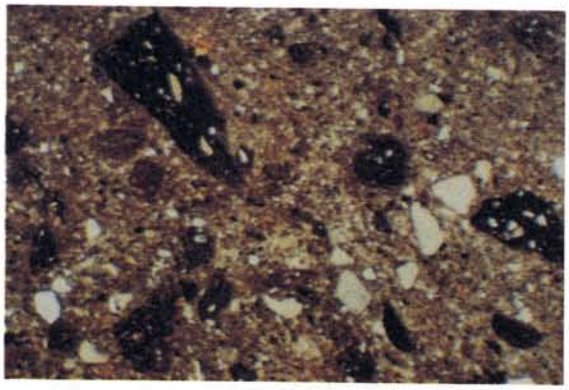
PLATE 5 (cont.)

Site 12: Eagle Plain Site



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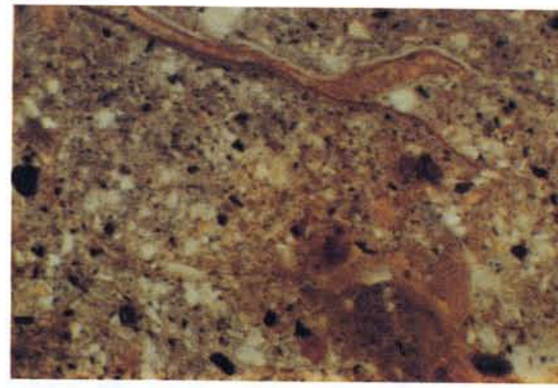

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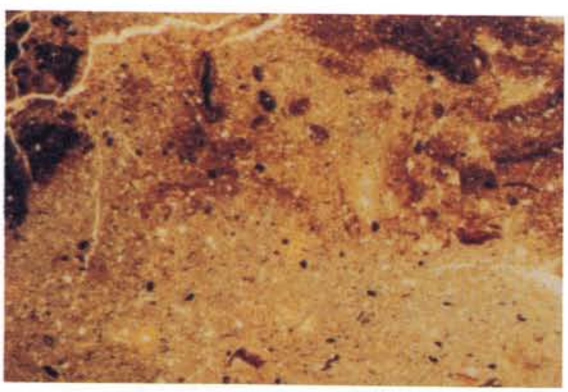

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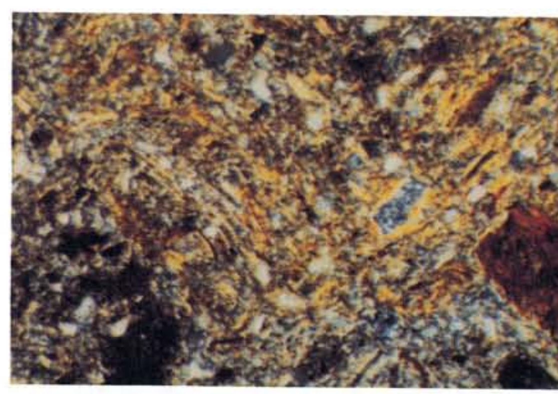

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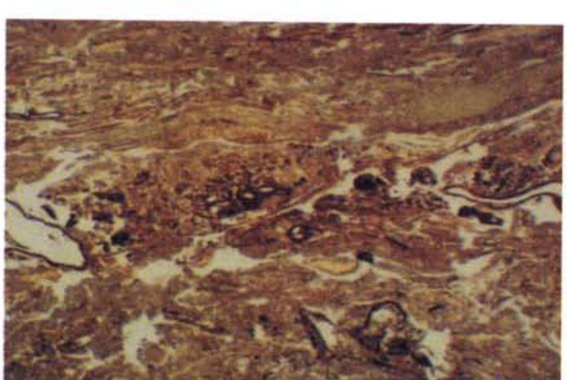


K

L

SITE 13, KM 322: FOREST FIRE SITE

A large fire burned through the southern portion of the Eagle Plain during most of the summer of 1990. The impact of this recent fire can be seen at several places along this section of the highway.

The immediate impact of the fire was to remove some or most of the surface vegetation. In so doing, the permafrost table was lowered under the burned areas relative to the unburned sites. The depth to permafrost under the unburned portion of the forest varies from 25 to 75 cm; under the burned area, the depth of the active layer has approximately doubled, to greater than one metre in some cases.

This increased soil temperature, together with the release of nutrients that have been stored in surface humus layers, result in lush new plant growth. Depending on the severity of the fire, regrowth may occur within one to three years following the fire.

SITE 14, KM 259: PEEL RIVER AND OGILVIE MOUNTAINS OVERVIEW

From this view point (950 m a.s.l.; 65°47'06'N, 137°46'40'W), it is possible to see much of the physiography and geological formations of the southern Ogilvie Mountains. The ranges are composed dominantly of limestones and dolomites of Cambrian to Devonian age (Norris 1984). The highest peaks that can be seen are approximately 1700 m (5600 ft) in elevation. Below the viewpoint is the upper portion of the Peel River. This is the continuation of the Ogilvie River, whose headwaters lie in the Ogilvie Ranges to the southwest. The tour route crossed the lower reaches of the Peel River, near its confluence with the Mackenzie River. At this point we are about 300 km upstream from the ferry crossing near Fort McPherson.

Note the braided floodplain at this point. Most of the Ogilvie Mountains are covered in scree deposits, with little vegetation cover. As a result, there is little storage of runoff waters and dramatic peak flows occur during the spring melt each year, with heavy flows also occurring during precipitation events in the summer.

Most of the landscape within the Peel River valley is underlain by permafrost, except the active alluvial areas and steep, south-facing slopes. Note the change in vegetation cover in relation to permafrost. Seismic exploration in the 1960's and early 1970's produced the linear scars on the vegetation cover in this valley and over much of the Eagle Plain region. They are testament to the long-term impact of surface disturbance in Subarctic environments.

SITE 15, KM 174: SULPHUR SPRINGS

After crossing the Ogilvie River, the highway continues upstream along Engineer Creek. Along its course this creek has numerous sites of groundwater discharge emanating from the black shales of the Cambro-Ordovician Road River Formation. Some of these springs are highly sulphurous and others are high in iron. Near km 174, the highway crosses a small stream of brownish ground-water discharge that has a dissolved-solids content of about 1080 mg/l. Chemical analyses indicate this sulphur spring has a high sulphate content and a relatively low iron content (Table 33). Iron in Engineer Creek originates from the ground water sources as suspended iron hydroxide, giving the water a brownish tinge. The stream bed of Engineer Creek is covered with brown iron hydroxide, indicating that a portion of the original dissolved iron has been lost by deposition. The significant iron and sulphate contents are presumed to be derived from oxidation of iron sulphides within the bedrock materials. The discharge of both the iron-rich and sulphurous waters is perennial and is most likely derived, via open hydrothermal taliks, from subpermafrost flow systems (French and Heginbottom 1983).

There is little water storage of winter precipitation in the Ogilvie Mountains. The scree slopes produce intense runoff each spring, resulting in peak discharge of short duration in late April or early May. A gradient of conductivity values and dissolved cations is evident from the Ogilvie River to the springs at km 174 (Table 33). The wide variation in dissolved constituent concentrations is related to the wide variation in volume of creek discharge.

Table 33. Water chemistry† at Site 15 in the vicinity of Engineer Creek sulphur springs (adapted from French and Heginbottom 1983).

Parameter	**Ogilvie River⁺ (below creek)**	**Engineer Creek⁺ (below springs)**	**Sulphur springs* (km 172)**
pH	7.4 – 8.3	7.6 – 8.2	7.4 – 7.5
Conductivity (µS/cm)	124 – 561	256 – 789	1700 – 1800
Constituents (mg/l)			
Calcium	20.0 – 75.8	35.9 – 115	151 – 159
Magnesium	1.6 – 22.0	8.6 – 37.5	51.2 – 89
Sodium	3.4 – 12.6	1.6 – 15.4	121 – 125
Potassium	0.3 – 0.7	0.3 – 1.2	4.4 – 4.5
Iron	0.18 – 0.37	0.12 – 2.2	0.01 – 0.12
Bicarbonate	48.0 – 250	68.8 – 317	323 – 562
Sulphate	20 – 90	51.0 – 230	320 – 410
Cloride	1.0 – 11.9	1.7 – 19.3	140 – 155

† Sampled October 1977 – August 1978. Ranges of concentrations reflect annual fluctuations.
⁺ Surface water
* Ground water

SITE 16, KM 160 – 180: TORS ON LIMESTONE RIDGES

The highway follows the valley of the Ogilvie River through the northern stretches of the Ogilvie Mountains. We have now passed back into the Arctic drainage system after descending from Eagle Plain. This portion of the Ogilvie Mountains is also unglaciated. Two prominent features of this range are the unvegetated slopes of limestone colluvial rubble and the striking castellated tors that mark the ridge tops and upper slopes of these mountains. The tors are erosional remnants of slightly more resistant bedrock. The limestone bedrock undergoes intense physical weathering through freezing and thawing and intense cold. The fractured limestone does not produce a substrate suitable for plant growth. We will compare vegetation cover differences on differing geologic materials in this area.

Another feature of note are the peregrine falcons that nest among these tors. This region of the northern Yukon is a major breeding area for this endangered bird species.

SITE 17, KM 155: CALCAREOUS SOIL ON MID-PLEISTOCENE DRIFT

Many of the soils derived from calcareous shales or graphitic limestone in this region contain abundant organic carbon in their surface mineral horizons. Humus layers are dominated by relatively thick, well decomposed, humus horizons directly overlying the mineral soil. The soil morphology at this site is typical of lower slopes on calcareous parent materials.

BRUNISOLIC TURBIC CRYOSOL

This site is also near the limit of Pleistocene glaciation emanating from the highest ranges of the southern Ogilvie Mountains to the south. The drift at this site most likely resulted from a mid-Pleistocene glaciation. Bostock (1966) designated this as pre-Reid glaciation. Later in the tour we will view a pre-Reid paleosol (Site 27) that reflects very warm interglacial weathering. The most striking feature of this soil is the abundant accumulation of Ca-rich organic matter within the upper solum. Thick moder humus forms are common on the lower slope soils formed from calcareous parent materials in this region. It appears that slope processes contribute to the accumulation of organic matter on the surface of this soil and that faunal activity is an important process in these horizons (see Micromorphology).

The site and pedon descriptions for this site are given in Table 34 and a cross section of the pedon is shown in Figure 29; analytical data are given in Table 35. The surface mineral horizon is a silt, indicating that slope wash has provided additional material for this profile. The underlying glacial drift has a silt loam to sandy loam texture, with up to 52% coarse fragments (>2 mm). The irregularities in horizon boundaries within the upper portion of the pedon are likely due to cryoturbation, but may also be due to noncryogenic processes. No permafrost table was encountered during the excavation of the pit (to a depth of approximately 130 cm) in July 1991. Although there is no evidence of cryoturbation in the lower B horizons, it has been found that permafrost occurs within a depth of 2 m on undisturbed sites of this type in this region.

The high pH of the humus form at this site is in strong contrast to the generally acidic forest floor materials under black spruce, as viewed on previous sites. There are free carbonates through most of the depth of the solum. Also of note is the abundance of well decomposed organic matter in mineral horizons to a depth of 50 cm (Table 35). Carbon to nitrogen ratios are low in all horizons and perhaps represent the persistence of highly stable Ca-humates (Schrier and Lavkulich 1985). The soils are rich in exchangeable bases, particularly Ca and Mg. Although there is little evidence of accumulation of iron oxides anywhere within the profile, x-ray diffractograms, based on dithionite extractions, indicate that goethite is present.

The clay mineralogy (Table 35) is dominated by kaolinite, vermiculite and mica, with little variation in the suite of phyllosilicates with depth. Since the chemistry of these soils is dominated by free carbonates, little mineralogical alteration or leaching is apparently now occurring. The presence of mild rubification to a depth of over one metre may represent pre-Holocene weathering.

The vegetation community is quite different here, and reflects the enhanced base status, active soil fauna, and nutrient availability of the soil. The tree canopy is composed of white spruce, and there is a rich diversity of forbs that are not found elsewhere, other than on highly calcareous parent materials such as these. A full plant list is given in Table 36.

Micromorphology

The micromorphology for the soil at this site is given in Table 37 and discussed below. Refer also to Plate 6.

Ahyl and Ahy2 Horizons. The Ahylhorizon consists of a close packing of granular units that are, for the most part, derived from faunal activity. Because of the southwest-facing slope, the soil environment is probably warmer for extended time periods and, as a result, could probably support a large faunal population that contributed to the break-down of the plant residues that accumulated in the F horizon. In addition, the near neutral soil pH would provide favourable soil conditions to support diverse faunal populations. Cryogenic processes, together with slope movement, have induced sorting of the larger plant fragments and alignment of the silt-size mineral grains into circular and line patterns. Ice lens formation has also resulted in arrangement of the granular units into a loosely-packed secondary blocky and platy structure. This soil arrangement is continued into the Ahy2 horizon, with fabric zones showing a gradation with depth towards more strongly expressed secondary structure; that is, from a dense packing of granular units, organic fragments and lithofragments to a weak blocky and moderately fine platy structure (Pl.6:C, D). In the Ahyl horizon there are zones of increased silt-size mineral material (visible only with polarized light). In plain light, these zones look very similar to adjacent areas, except for a decrease in organic matter content. It is difficult to determine whether these regions were intruded from the lower horizon and/or concentrated and moved within the Ahyl soil matrix in response to freezing fronts or whether the adjacent zones of dominantly organic material were intruded into the silty material. There is some evidence of vertical alignment of the plant fragments within the increased silty zones, which would suggest that the mineral material moved into the organic material. Later, secondary structure developed as a result of ice lens formation, with planar voids traversing the closely packed granular material and included mineral material.

The Ahyl horizon has none of the calcareous (limestone) lithofragments that are frequently observed in the Ahy2 horizon; other lithofragments are occasional to rare. The lithofragments in the Ahy2 horizon are concentrated into distinct regions. This suggests that the Ahyl horizon is primarily a zone of organic material accumulation, that cryoturbation effects are not sufficient to move the larger lithofragments into the horizon, and that the concentration of silt-size material may be associated with freezing-front sorting of particles. The Ahy2 horizon may be more susceptible to incorporation of the parent material, perhaps influenced to a greater extent by downslope movement. The Ahy2 horizon shows evidence of cracks infilled with organic materials. These cracks are associated with increased concentrations of lithofragments and circular patterns of silt-size material.

Bmky Horizon. The Bmky horizon is characterized by platy structure produced from ice lens formation. The organic material and fragments in the fine fraction of the soil matrix were introduced prior to ice lens formation. Isoband fabric suggests reduced cryoturbation intensity to maintain the regularity of the lenticular structural units. (Pl.6:E, F)

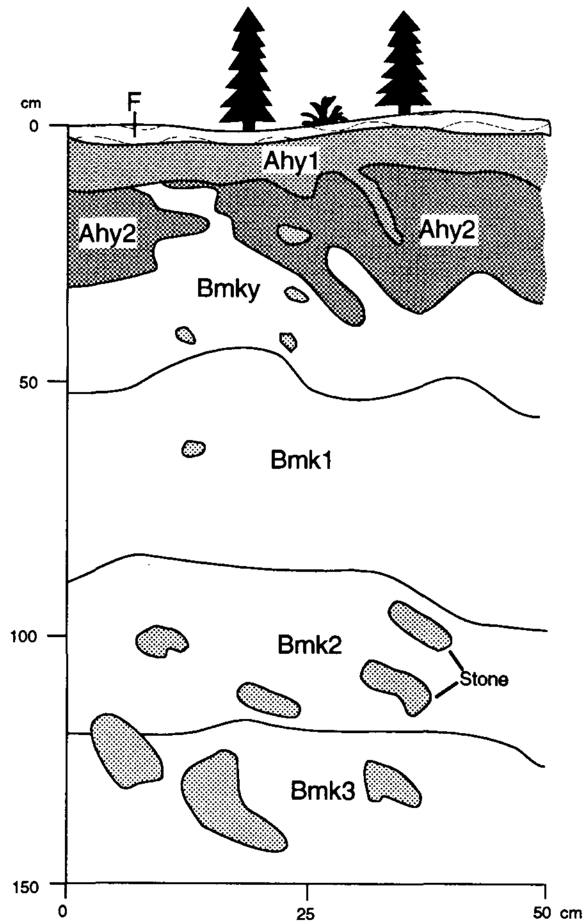


Figure 29. Cross section of the calcareous Brunisolic Turbic Cryosol formed on mid-Pleistocene glacial drift at Site 17.

Table 34. Site and pedon descriptions for Site 17.

Pedon no.: OM – 1, S91-FN-260-005
Location: 65º04'03" N Lat., 138° 16'44" W Long.
Landform: Mid-Pleistocene morainal blanket
Drainage: Moderately well
Parent Material: Calcareous loamy slope wash (colluvium) and/or loess over glacial till
Patterned Ground: None

Elevation: 995 m (a.s.l.)
Slope: 5%
Vegetation: Subalpine
Soil Classification: Can. – Brunisolic Turbic Cryosol
U.S.A. – Typic Cryochrept
F.A.O. – Gelic Cambisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
F	Oe	6 – 0	Black (5YR 2/1); forest litter; 80% unrubbed, 40% rubbed fibre; few, medium roots, and many, very fine and fine roots; abrupt, wavy boundary. [91P5985]
Ahy1	A	0 – 11	Black (5YR 2/1); silt; very friable, slightly sticky, nonplastic; few, medium roots, and many, very fine and fine roots; cryoturbated; abrupt, broken boundary. [91P5986]
Ahy2	A/Bw	11 – 44	30% (Bw) yellowish brown (10YR 5/4), 70% (A) very dark gray (10YR 3/1); silt loam; weak, medium platy structure; very friable, slightly sticky, slightly plastic; common, very fine and fine roots; cryoturbated; 3% 20 to 75 mm rock fragments; abrupt, broken boundary. [91P5987]
Bmky	Bw1	44 – 61	Dark brown (10YR 3/3); silt loam; moderate, fine and medium, subangular blocky structure; very friable, slightly sticky, slightly plastic; few, very fine and fine roots, and few, medium roots; cryoturbated; 10–15% Ah horizon material intermixed; slightly effervescent; 5% 20 to 75 mm rock fragments; gradual, wavy boundary. [91P5988]
Bmk1	Bw2	61 – 89	Olive brown (2.5Y 4/4); silt loam to sandy loam; moderate, fine, subangular blocky structure; friable, slightly sticky, slightly plastic; few, very fine and fine roots; strongly effervescent; 1% cobbles; 15% 20 to 75 mm rock fragments; gradual, wavy boundary. [91P5989]
Bmk2	Bw3	89 – 117	Light olive brown (2.5Y 5/4); sandy loam; moderate, fine, subangular blocky structure; friable, slightly sticky, slightly plastic; few, very fine and fine roots; strongly effervescent; 1% cobbles; 20% 20 to 75 mm rock fragments; gradual, wavy boundary. [91P5990]
Bmk3	Bw4	117 – 127+	Dark grayish brown (2.5Y 4/2), olive brown (2.5Y 4/4); sandy loam; strong, fine and medium, subangular blocky structure; friable, slightly sticky, slightly plastic; few, fine roots; strongly effervescent; 1% cobbles; 20% 20 to 75 mm rock fragments. [91P5991]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 35. Analytical data for the Brunisolic Turbic Cryosol at Site 17.

Chemical Analysis																
Horizon	pH		Org. C	$CaCO_3$ Equiv.	Total N	C/N	Exchangeable Cations (me/100g)									
							Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)	(%)		Ca	Mg	K	Al	Total	Total	Ca	Mg	Na	K
F	6.9	6.8	32.4		1.97	16	58.3	24.7	1.4	0.1	84.5	179.6	125.0	36.4	0.1	0.9
Ahy1	7.0	6.8	12.2		0.85	14	40.8	15.6	0.2	0.1	56.7	125.9	88.9	27.5	0.2	0.1
Ahy2	7.4	7.1	5.8	19	0.36	16	20.9	6.4	0.1	0.2	27.6			11.8	0.1	0.1
Bmky	7.7	7.2	1.9	19	0.15	13	11.8	4.8	0.1	0.1	16.8			10.4	0.1	0.1
Bmk1	7.9	7.3	0.5	19	0.04	13	6.1	3.0	0.1	0.1	9.3			10.1	0.1	0.1
Bmk2	8.0	7.4	0.4	44	0.05	8	5.1	2.7	0.1	0.1	8.0			10.0	0.1	0.1
Bmk3	8.0	7.4	0.5	44	0.05	10	5.3	3.0	0.1	0.1	8.5			9.8	0.1	0.1

Sesquioxides (%)						
Horizon	Dithionite		Oxalate		Pyrophosphate	
	Fe	Al	Fe	Al	Fe	Al
F	0.52	0.10	0.21	0.09	0.07	0.03
Ahy1	1.08	0.15	0.41	0.19	0.35	0.13
Ahy2	1.09	0.13	0.37	0.14	0.28	0.12
Bmky	1.08	0.15	0.32	0.11	0.22	0.08
Bmk1	1.08	0.11	0.25	0.08	0.10	0.03
Bmk2	0.99	0.08	0.18	0.04	0.07	0.04
Bmk3	1.05	0.11	0.19	0.05	0.09	0.04

Physical Analysis									
Horizon	%	Part. Size Dist. (% <2 mm)				Bulk Den.	Moisture (%)		Texture
	>2 mm	Sand	Silt	Clay	F-Clay	(g/cc)	1/3 atm	15 atm	
F							270.1	31.0	
Ahy1		9.6	79.7	10.7		0.18			Si
Ahy2	16	31.2	51.5	17.3		0.94	55.4	45.4	SiL
Bmky	27	38.5	47.9	13.6	6.0	1.10	22.6	13.7	SiL
Bmk1	39	42.4	46.8	10.8	5.1	1.49	20.7	8.2	SiL–SL
Bmk2	52	48.7	41.5	9.8	4.4	1.64	19.1	5.4	SL
Bmk3	46	44.1	45.8	10.1	4.5	1.73		4.8	SL

Table 35. Analytical data for the Brunisolic Turbic Cryosol at Site 17 (cont.)

Clay Mineralogy (<2μ)											
Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size*)							
	Al_2O_3	Fe_2O_3	K_2O	Kaolin.	Verm.	Mica	Montm.	Quartz	Goeth.	Chlor.	Chlor-Mica
F											
Ahy1											
Ahy2	8.9	7.6		2	3	2	2	1			
Bmky											
Bmk1	16.0	11.6	2.2	3	2	2	2		2	1	
Bmk2											
Bmk3	17.0	13.2	1.6	3	2	2	2		2		1

* Relative peak size: 3 = medium, 2 = small, 1 = very small

Table 36. Vegetation description for Site 17.

Vegetation

TREES (% cover)

Tall Trees		Low Trees	
15.0	*Picea glauca*	5.0	*Picea glauca*

SHRUBS (% cover)

Tall Shrubs		Low Shrubs	
1.0	*Betula glandulosa*	5.0	*Betula glandulosa*
1.0	*Picea glauca*	1.0	*Picea glauca*
5.0	*Salix* sp.	5.0	*Potentilla fruticosa*
		1.0	*Salix planifolia* ssp. *pulchra*

Medium Shrubs		Dwarf Shrubs	
15.0	*Betula glandulosa*	15.0	*Arctostaphylos rubra*
1.0	*Picea glauca*	1.0	*Ledum palustre* ssp. *decumbens*
5.0	*Salix planifolia* ssp. *pulchra*	10.0	*Salix reticulata*
		1.0	*Salix myrtillifolia*

HERBS (% cover)

0.5	*Anemone parviflora*	0.5	*Oxytropis roaldii*
1.0	*Arnica angustifolia*	0.5	*Papaver macounii*
0.5	*Aster sibiricus*	0.5	*Pedicularis labradorica*
1.0	*Chrysanthemum integrifolium*	0.5	*Pedicularis verticillata*
0.5	*Cruciferæ* sp.	0.5	*Polygonum viviparum*
15.0	*Dryas integrifolia*	1.0	*Ranunculus* sp.
1.0	*Dryas octopetala*	1.0	*Saussurea angustifolia*
1.0	*Equisetum arvense*	1.0	*Senecio lugens*
0.5	*Gentiana propinqua*	0.5	*Solidago multiradiata*
10.0	*Hedysarum alpinum*	0.5	*Thalictrum* sp.
0.5	*Lagotis stelleri*	5.0	*Zygadenus elegans*

GRASSES (% cover)

1.0	*Carex* sp.	0.5	*Carex vaginata*
0.5	*Carex scirpoides*	1.0	*Festuca altaica*

MOSSES – LICHENS (% cover)

Mosses		Lichens	
50.0	*Bryophyte* spp.	0.5	*Cetraria cucullata*
5.0	*Pleurozium schreberi*	1.0	*Cladina* spp.
		1.0	*Cladonia* spp.
		1.0	*Cladina stellaris*
		1.0	*Cetraria islandica*

NON-VEGETATION (% cover)

1.0	Bare	1.0	Slash
10.0	Litter	–	Water
–	Rock		

Table 37. Micromorphological Features for Site 17: Calcareous Soil Site.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ahy1 (A)	**Overall:** Primary structure consists of a close packing of granular units (30–150 μm, faunal origin) and plant fragments. Zones of secondary structure occur. Occasional blocky and rare platy structure, resulting from ice lens formation. (Pl.6:A) **Related DP:** Primary soil fabric: Ortho-phytogranic-humi-mullgran-oidic with orbiculic. Zones of secondary fabric: fragmic/ fragmoidic. Plasmic: No colloidal clay present. **Microstructure:** Complex structure: Compacted granular structure with clustering; secondary structure of loosely arranged blocky and platy structure. c/f RDP: Enaulic with zones of porphyric. b-fabric: No colloidal clay.	**Void Pattern:** Dominantly compound packing voids with occasional planar voids between granular units; size ranges highly variable. Rare root channels. **Basic Components:** Mineral: Clay particles (<10–60 μm) of moderately weathered mica are distributed randomly in the soil matrix. Subangular to angular mineral grains occur frequently; dominantly quartz (<10–100 μm, mainly <10–40 μm); usually randomly distributed; but, with depth, commonly concentrated into distinct zones where size range is mainly 50–150 μm and the areal proportion dominates over organic material. Occasional to rare sorting of mineral grains into patterns (lines, circles). Organic: Plant fragments (0.16–1.4 mm) occur frequently to commonly; moderately to strongly decomposed root tissues with occasional extremely decomposed leaf tissues that are often broken apart and incorporated into the soil matrix. Sorting and clustering of large fragments; with depth occasional zones of predominantly organic material. Occasional occurrence of fungal hyphae commonly associated with granular units and occasionally with decomposed root material. **Pedofeatures:** Faunal: Faunal activity is prominent; probable origin of granular material (50–150 μm) and contributor to fragmentation of plant fragments. Rare occurrences remaining of fecal material (50–80 μm) within interior of plant fragments. (Pl.6:B)	Cryogenic processes have affected the soil fabric in producing secondary structure of blocky and platy peds with associated planar voids; result of ice lens formation. Moderate sorting of larger plant fragments into clusters and silt-size mineral grains into patterns expressed as lines and circles. (Pl.6:A) Soil fabric zones with zones of concentrations of mineral grains; possible sorting with respect to size range.
Ahy2 (A/Bw)	**Overall:** Closely packed soil matrix of fine granular units, calcareous lithofragments and plant fragments; zones of secondary structure: granular to blocky to platy with depth. (Pl.6:C) **Related DP:** Ortho-phytogranic-mullgran-oidic. (Agglomeroplasmic, weak orbiculic). Secondary structure: With depth grades to granic//fragmic//frag-moidic. Plasmic: No colloidal clay. **Microstructure:** Complex structure: With depth platy and blocky structure. Compact grain structure of mineral grains, lithofragments and organic material. c/f RDP: Porphyric. b-fabric: No colloidal clay.	**Void Pattern:** At 125X magnification, simple packing voids are dominant between the granular units, mineral and plant fragments. At 25X magnification, secondary structure is associated with planar voids 10–150 μm wide. Vertical crack with organic fragment infilling. (Pl.6:C, D) **Basic Components:** Mineral: Abundant limestone (moderately to strongly weathered, frequent irregular borders and dissolution pores), rare quartzite, igneous lithofragments (variable size range 0.05–1.3 mm, mainly 100–500 μm); subangular to angular mineral grains (<10–120 μm, mainly <50 μm), dominantly quartz; and clay particles (<10–110 μm, dominantly 10–50 μm) of weathered mica. Organic: Strongly decomposed plant fragments (variable size range mainly 0.15–0.6 mm, occasionally 1.0–2.2 mm); dominantly root tissues and rare to occasional stem and leaf tissues, frequently woody; the fragments occur in the soil matrix similar to lithofragments. In addition, amorphous organic masses and extremely decomposed cell structure tissues and strongly to extremely decomposed plant fragments are a dominant constituent of granular units (faunal origin). **Pedofeatures:** Faunal: Granular units (mainly 50–100 μm); major component of the groundmass; close to loosely packed into secondary structure. Infillings: Loose organic fragments and fine granular material in vertical cracks. (Pl.6:C)	Very complex structure of close to loose packing of transported lithofragments and organic fragments into silt-size material and faunal-derived granular units. Appears to be movement from both top and bottom. Alignment of both mineral and organic fragments. (Pl.6:D) With depth, gradation of secondary structure as a result of ice lens formation. Granular units 50–400 μm form loose, weak blocky structural units 200–700 μm to fine platy structural units 280–600 μm wide (fragmoidic fabric). Clustering of lithofragments into distinct zones; zones with predominance of calcareous fragments. Weak expression of circular patterns of silt-size grains. Crack infilled with organic materials and fragments from upper layer; in association with zones of concentrations of lithofragments and circular patterns of silt-size grains. (Pl.6:C)

Table 37. Micromorphological Features for Site 17: Calcareous Soil Site (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmky (Bw1)	**Overall:** Platy structural units composed of close to loose packing of fine sand to silt-size mineral material, abundant calcareous lithofragments and common strongly decomposed plant tissues. (Pl.6:E) **Related DP:** Matrifragmic//matrifragmoidic//isoband; minor zones of very weak banded fabric. Plasmic: Silasepic; rare occurrences of skelsepic. **Microstructure:** Platy structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled, rare granostriated.	**Void Pattern:** Horizontal planar voids (variable size range 20–800 μm wide) dominate the soil fabric. Occasional occurrence of loosely packed structural units in which simple packing voids are common. **Basic Components:** Mineral: The coarse fraction is composed of very frequent lithofragments of dominantly limestone (moderately weathered, with common dissolution pores; 100–1100 μm, mainly 200–400 μm), occasional shale (1.0–5.0 mm) and rare igneous (0.7–3.2 mm) fragments. Finer fraction (10–100 μm) consists of frequent angular quartz, weathered limestone fragments, and common clay particles (weathered mica). (Pl.6:F) Organic: Strongly humified organic fragments (120–900 μm) are occasionally included in the soil matrix material in a similar way to lithofragments. Frequent strongly decomposed plant tissue fragments and abundant amorphous organic material occur in the finer fraction. Very rare root tissues occur in planar voids. **Pedofeatures:** Coatings: Rare to occasional, most often on lithofragments, oriented clay particles packed on surfaces, discontinuous. Very rare textural accumulations on igneous lithofragments; discontinuous, fills irregular surface cavities.	Platy structure result of ice lens formation. Size range of lenticular units variable 0.28–1.6 mm wide, frequently 0.4–0.8 mm, commonly 1.0–1.2 mm, and occasionally 1.4–1.6 mm. Isoband structure suggests reduced cryoturbation intensity to retain regularity of the lenticular units. (Pl.6:E, F) Introduction of organic fragments and material probably took place prior to platy structure development.

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 6

List of Plates for Site 17: Calcareous Soil Site.

Plate 6: A

Close packing of organic fragments (mainly root material) and granular units in the Ahy1 horizon. Note the occasional planar voids and vughs with very fine granular material of faunal origin. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 6: B

The fine granular material in the Ahy1 horizon is mixed with mineral grains and plant fragments, and closely packed together to form secondary structural units. Frame length 1.0 mm. (PPL).

Plate 6: C

Closely packed soil matrix of fine granular units, calcareous lithofragments, and plant fragments characterizes the Ahy2 horizon. On both the right and left side of the micrograph, note the cracks with partial infillings. Frame length 4.0 mm. (PPL).

Plate 6: D

Close-up view of Ahy2 horizon shows portion of crack (See upper right side of Pl.6:C) with infilling of large organic fragment. In the adjacent soil matrix, note also the fine granular material of faunal origin mixed with mineral material. Frame length 1.0 mm. (PPL).

Plate 6: E

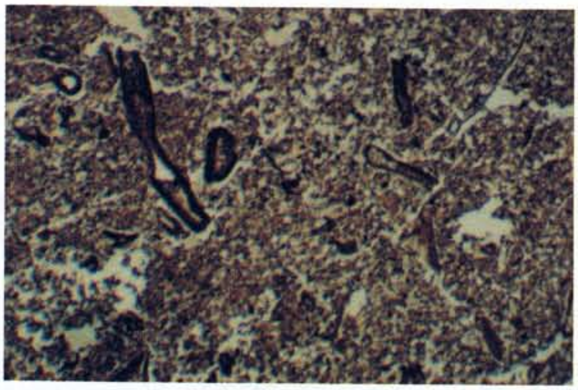
Platy structural units composed of close to loose packing of fine sand to silt-size material and abundant calcareous lithofragments. Isoband fabric grades to matrifragmoidic and matrifragmic in the Bmky horizon. Frame length 8.5 mm. (PPL).

Plate 6: F

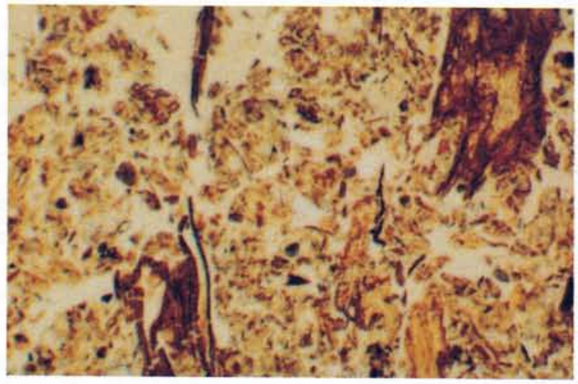
Close-up view of the lenticular units in the Bmky horizon shows loose packing of mineral material, lithofragments, and amorphous organic material. Frame length 1.0 mm. (PPL).

PLATE 6

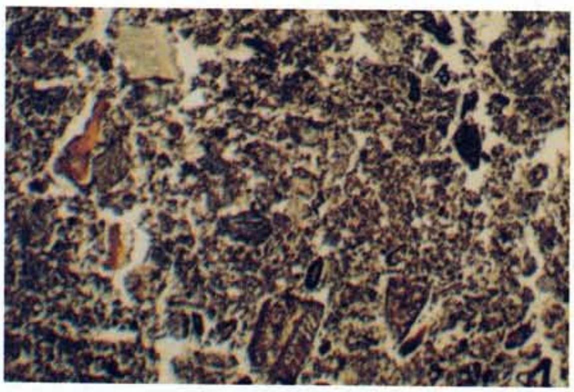
Site 17: Ca-rich forest soil



A



B



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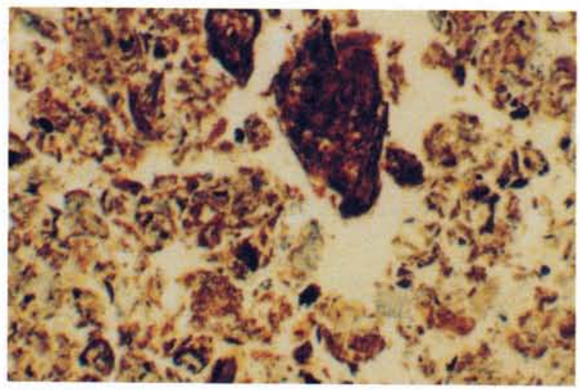

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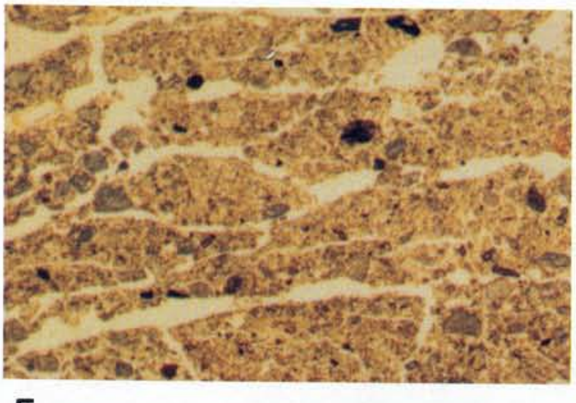
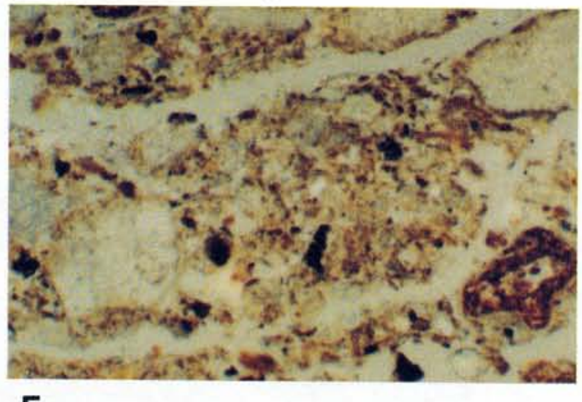


E



F

SITE 18, KM 115.5: OPEN-SYSTEM PINGO

Just beyond the Chapman Lake moraine complex, the highway crosses the Blackstone River, a tributary of the Peel River. Approximately 5 km upstream from the crossing is a pingo. Pingos of this size are not uncommon in regions of discontinuous permafrost. Hughes (1969) described and plotted over 400 pingos in the central Yukon, and Holmes *et al.* (1968) described the distribution of pingos in central Alaska. The vast majority of pingos in the central Yukon are open-system pingos. The open or closed designation refers to the hydraulic regime of pingo formation. Closed-system pingos form when confined, unfrozen, ground water in permafrost regions "freezes back," resulting in growth of an ice core within pervious sediments. Open-system pingos, on the other hand, form through the movement of flowing ground water into an aggrading frost feature, with resultant upward growth of an ice-cored mound. The size of pingos is variable. In the central Yukon they can be as large as 30 m in height and up to 300 m in diameter (Hughes 1969). The Ibyuk pingo in the Mackenzie Delta is one of the largest pingos known, with an elevation of 45 m and a diameter of 500 m (Mackay 1979).

The age of pingos is variable. Holmes *et al.* (1965) report ages of 100 to 7,000 years for pingos in the Yukon, Alaska and the Mackenzie Delta. Pingos grow as long as there is a source of water that allows the ice core to expand. Eventually, the surface insulating vegetation mat is ruptured, the ice core is exposed to melting, and the feature collapses, leaving a crater-like scar on the landscape. The full cycle of pingo development and degradation is then complete.

SITE 19, KM 96.5: ICE-WEDGE POLYGONS

Along both sides of the road at this point is an area of tundra that was disturbed during reconstruction of the right-of-way in 1984. Excavation needed to straighten the road triggered melting of a network of ice-wedge polygons. The topography remaining after the ice wedges have melted is visible at this stop, and actively melting ice wedges can be seen farther from the edge of the road.

Ice wedges are a common feature of tundra areas in both Arctic and alpine situations. The tundra seen here results from the increase in elevation as we approach the hydrologic divide between the Arctic and Pacific drainages. This site (1165 m a.s.l.; 64°41'30"N, 138°24'23"W) is well above the altitudinal tree line in the Ogilvie Mountains, which is at about 900 m a.s.l. on neutral aspects. A listing of the plant species found on this site on the tundra, near melting ice wedges, is given in Table 38. When compared to forested ecosystems formed on calcareous parent materials, this site is much less diverse, but quite typical of tundra communities in the Subarctic Cordilleran, and has many affinities to tundra of the western Arctic, farther to the north.

The soils are acidic under the tundra cover (data not presented), and the depth to permafrost varies from 40 to 75 cm. Massive ice in the shape of wedges can be seen to underlie the entire site. A review of the origin and nature of ice wedges is given in Washburn (1980). He defines ice wedges as V-shaped forms of massive ground ice with a predominantly vertical structure imparted by soil and air bubbles oriented parallel to the wedge edges as a result of the frost-cracking process. Frost cracking of soil and underlying permanently frozen materials occurs under extremely cold conditions. When spring melt occurs, a fine crack or fissure can remain. This can subsequently fill with water and freeze within the permafrost zone. Once such an ice vein forms, cracking will re-occur at the same place. Subsequent flow of water into the crack enlarges the vein into a wedge that may grow to over one metre in width. Ice wedges form in the upper portion of the permafrost layer, with the top of the wedge marking the permafrost table. The thermal equilibrium of this site has been destroyed by road construction and ditching. Subsequent thawing, or "thermokarst," has caused the permafrost table to drop. Ice wedges and frozen soil materials in what used to be the upper portion of the permafrost table are now thawing in a retrogressive pattern, revealing the former extent and configuration of the ice-wedge polygons.

SITE 20, KM 84: FROST MOUNDS*

Seasonal frost mounds are common in this area of gently sloping, wet, alpine tundra situated in the floor of the East Blackstone River valley, downslope from the highway. Each winter, several groups of small, seasonal frost mounds develop. Between 1980 and 1982, more than 30 such frost mounds were noted at this particular site and at least six other similar locations are known.

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* Text modified from Harris *et al.* 1983

Table 38. Vegetation description for Site 19.

Vegetation

SHRUBS (% cover)

Low Shrubs		**Dwarf Shrubs**	
1.0	*Betula glandulosa*	15.0	*Salix reticulata*

HERBS (% cover)

15.0	*Dryas integrifolia*	5.0	*Pedicularis lanata*
1.0	*Lagotis glauca*	0.5	*Polygonum viviparum*
0.5	*Minuartia elegans*	5.0	*Saxifraga hieracifolia*
.0.5	*Parrya nudicaulis*	5.0	*Saxifraga hirculus*

GRASSES (% cover)

1.0	*Carex lugens*	25.0	*Eriophorum vaginatum*
5.0	*Carex rotundata*		

MOSSES – LICHENS (% cover)

Mosses		**Lichens**	
30.0	*Bryophyte* sp.	1.0	*Cetraria cucullata*
20.0	*Pleurozium schreberi*	1.0	*Cetraria nivalis*
		1.0	*Cladonia* spp.
		1.0	*Dactylina arctica*

NON-VEGETATED (% cover)

–	Bare	–	Slash
40.0	Litter	–	Water
–	Rock		

Cold, mineralized, perennial springs discharge from the base of a till–alluvial fan–talus slope. The locations of the outlets and the amount of seepage vary seasonally. Low concentrations of dissolved solids indicate that the springs discharge from local flow systems that presumably receive their recharge at higher elevations in the mountains directly above the highway (maximum elevation approximately 2,000 m). The results of isotope analysis of spring and snowpack samples show that oxygen (^{18}O) and deuterium (^{2}H) values correlate reasonably well with the global meteoric water line (GMWL), indicating that unaltered precipitation probably provides water for the spring discharges.

Seasonal frost mounds occurring in this setting are a ground-water-discharge phenomenon resulting from hydraulic pressures developed in suprapermafrost ground water flowing through, or trapped within, a residual section of the active layer during winter freezeback. The formation of seasonal frost mounds requires low-temperature, perennial, spring discharge, long, cold winters characterized by deep frost penetration, and suitable stratigraphic conditions where a relatively thin aquifer is underlain by a low-permeability aquitard. The perennially frozen mineral soil overlain by peat and fine-grained sand and silt at this location provides a suitable stratigraphic setting. A hydraulic potential to deform and displace overlying materials is also a requirement.

In North American literature, seasonal frost mounds were first defined by Muller (1947), who distinguished between frost blisters, icing mounds, and icing blisters. All three types occur in the North Fork Pass area. Icing mounds and icing blisters differ from frost blisters in that they are composed entirely of ice and frequently form part of an icing accumulation. As such, they may be associated with river icings as well as ground-water (seepage) icings.

SITE 21, KM 80: McCONNELL GLACIAL LIMIT

At this site we view the terminal moraine of a valley glacier of Wisconsinan age (defined as the McConnell glaciation in the central Yukon (Bostock 1966)), which emanated from the East Blackstone River valley. The glacier spread out into the North Fork Pass area and northward a short distance (Vernon and Hughes 1966). The hummocky landforms and U-shaped valley are classic montane glacial features. The terminal moraine has been eroded from the Blackstone Valley to the north, but still remains in the vicinity of the highway at this point.

SITE 22, KM 77: NONSORTED CIRCLE SITE

This site is on cryoturbated material just above the tree line. At this site, an Orthic Turbic Cryosol associated with nonsorted circles will be examined. Although the patterned ground is of the nonsorted circle type, some weak sorting and step formation can be seen on the slopes.

The most obvious process is cryoturbation, with its attendant horizontal and vertical differentiation (Figure 30). Horizons have been differentiated mainly on the basis of subtle variations in soil colour and structure (Table 39). The strong, fine, subangular blocky structure and dark yellowish-brown colour (10YR 4/6 m) of the Bmy horizon set it apart from the other mineral horizons, which tend to be darker and more gray in colour. Even though redoximorphic concentrations are commonly found throughout the profile, the vegetation cover (Table 41) and surface litter layer (F horizon) do not reflect moist site conditions. This site is generally low in organic matter, both overlying the soil surface and within the mineral soil horizons.

The soil is moderately acidic, with low organic carbon and nitrogen values throughout (Table 40). Calcium is the predominant exchangeable cation in all horizons. Extractable iron and aluminum values are low, with iron being more abundant in all extractions. Other than in the Bmy horizon, organically-complexed sesquioxide values are low (Table 40). Iron usually predominates over aluminum in each horizon, which is more typical of poorly-drained horizons than of those undergoing podzolic processes.

The glacial till parent material is composed of a mixed lithology that includes shales, siltstones, and metamorphics (see Micromorphology). The volume of coarse fragments in the lower horizons of the pedon is 50%. The clay mineralogy is dominated by kaolinite, mica and vermiculite. Goethite is prevalent in the Cy3 horizon, along with an interstratified mineral in the Cy1 horizon.

Since the soils are gravelly sandy loams, but have high silt and very low clay contents, they tend to be thixotropic. As a result, the soils become mechanically unstable with disturbance and tend to "flow". Their moisture holding capacity is almost the same at 1/3 atmosphere as it is at 15 atmospheres. This property enhances their susceptibility to cryoturbation, and promotes the formation of the patterned ground features seen on the site.

Micromorphology

The micromorphology for the soil at this site is given in Table 42 and discussed below. Refer also to Plate 7.

Cy1 Horizon. The sample for this horizon was taken approximately 2 cm from the surface. The morphology consists of a loose distribution of finer materials between coarse lithofragments (Pl.7:A). The loose distribution suggests considerable disturbance from surface ice crystal formation and successive freezing cycles. Only occasionally is there organization where the finer materials have been densely packed in the pore space between the lithofragments. Here, rounded (vesicular) and planar voids are observed. The lithofragments have undergone sorting with respect to size. This horizon has a greater frequency of coarse fragments than the Bmy horizon. In addition, the coarse fragments are organized into weak circular patterns and clusters, with the finer material in central portions (Pl.7:B). It was observed that this sorting was more defined with depth.

Bmy Horizon. The effects of cryogenic processes in this horizon are the main influence on the soil morphology. The soil fabric is very complex in that granular material can be delineated in the groundmass by the pattern of vughs and planar voids and fabric textural differences noticeable in polarized light. Considerable movement can be inferred from the very rounded shape of the granular units, from sorting of silt-size quartz into concentrations of similar size, into weak circular and linear patterns, and from accumulations of silt-size material on lithofragments (Pl.7:C, D). Root growth into the Bmy horizon probably occurred in the past, as interpreted from observations of root material. The root tissues are extremely decomposed and coated with very fine silt-size material; the root channels are probably now used as water conduits during thaw periods. Planar voids and vughs are the result of ice lens formation, which breaks up the groundmass into a secondary structure of weak blocky and platy structure.

Cy2 Horizon. The sample for this horizon was taken approximately 10 cm from the surface. The parent material of this horizon consists of lithofragments and silt-size fine material (Pl.7:E). The most prominent cryogenic-related feature is the accumulation of fines beneath, and occasionally at the sides of, the coarse fragments. This is a direct result of infilling of pore spaces once occupied by ice. Up to three successive infillings can be observed with respect to texture and composition of amorphous materials, suggesting successive yearly thaw events in which the fragments are progressively moved towards the surface; or alternatively, one seasonal thaw period of progressive infillings where ice partially thawed, infilled, thawed, then infilled. The orientation of the finer mineral material gives the groundmass the appearance that considerable movement has taken place around the coarser material, probably as a result of cryostatic pressure in a very saturated environment (Pl.7:E, F).

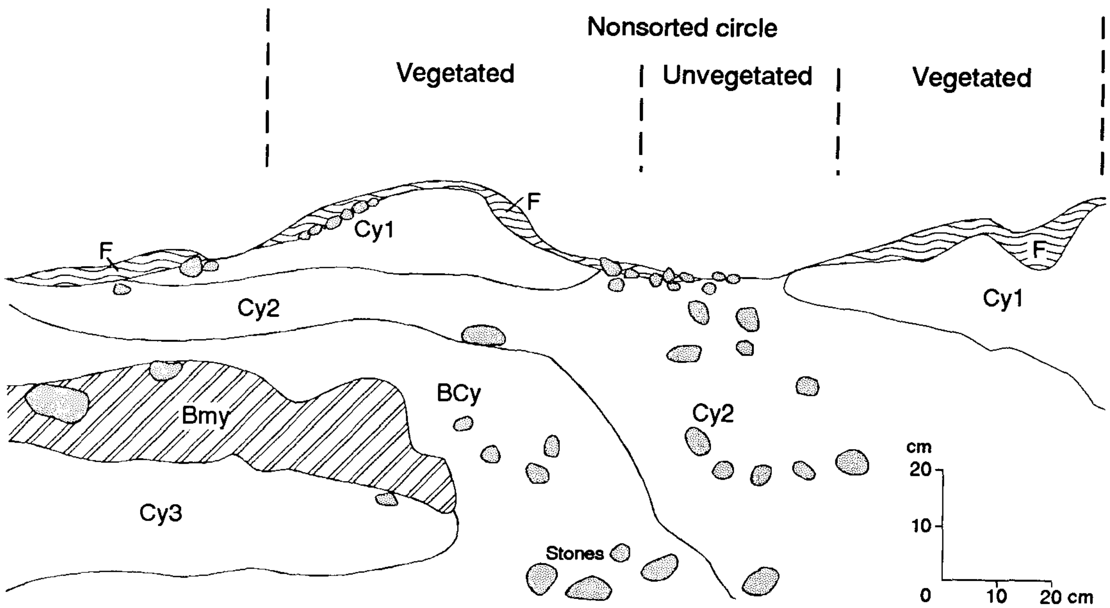


Figure 30. Cross section of the Orthic Turbic Cryosol associated with nonsorted circles at Site 22.

Table 39. Site and pedon descriptions for Site 22.

Pedon no.: S91-FN-260-006
Location: 64°32'50" N Lat., 138°14'02" W Long.
Landform: Undulating morainal blanket
Drainage: Moderately well
Parent Material: Glacial till
Patterned Ground: Nonsorted circle

Elevation: 1219 m (a.s.l.)
Slope: 2%
Vegetation: Alpine shrub tundra
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Ruptic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Thickness	Description
Can.	U.S.	(cm)	
F	Oi	0 – 8	Black (10YR 2/1 m); peat; 95% unrubbed, 70% rubbed fibre; few, coarse roots, and common, medium roots, and many, very fine and fine roots; clear, broken boundary. [91P5992]
Cy1	AC	0 – 25	Very dark gray (10YR 3/1 m); very gravelly sandy loam; moderate, fine and medium, subangular blocky structure; firm, nonsticky, nonplastic; common, very fine and fine roots; many, fine and medium vesicular pores; 10% 20 to 75 mm rock fragments, 25% 2 to 20 mm rock fragments; gradual, broken boundary. [91P5993]
BCy	BC	0 – 40	Dark grayish brown (2.5Y 4/2 m); very gravelly loam; moderate, fine and medium, subangular blocky structure; friable, slightly sticky, nonplastic; few, very fine roots; 10% 20 to 75 mm rock fragments, 30% 2 to 20 mm rock fragments; gradual, broken boundary. [91P5994]
Bmy	Bw	0 – 20	Dark yellowish brown (10YR 4/6 m); sandy loam; few, coarse, distinct, olive brown (2.5Y 4/3 m) redoximorphic concentrations, and common, medium, faint, brown (10YR 5/3 m) depletions; strong, fine, subangular blocky structure; friable, moderately sticky, slightly plastic; common, very fine and fine roots; 10% 2 to 20 mm rock fragments; clear, broken boundary. [91P5995]
Cy2	C1	10 – 40	Very dark gray (10YR 3/1 m); very gravelly sandy loam; massive; firm, nonsticky, nonplastic; few, fine roots; 15% 20 to 75 mm rock fragments, 30% 2 to 20 mm rock fragments; gradual, irregular boundary. [91P5996]
Cy3	C2	–	Very dark gray (10YR 3/1 m); very gravelly sandy loam; massive; friable, nonsticky, nonplastic; 5% 20 to 75 mm rock fragments, 50% 2 to 20 mm rock fragments. [91P5997]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 40. Analytical data for the Orthic Turbic Cryosol at Site 22.

Chemical Analysis										
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)*				
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total
F										
Cyl	5.6	4.8	0.5	.03	17	3.5	1.4	0.1	0.4	5.4
BCy	5.8	4.9	0.5	.03	17	3.5	1.4	0.1	0.3	5.3
Bmy	5.3	4.5	0.7	.04	18	2.0	0.8	0.1	0.8	3.7
Cy2	6.0	5.2	0.4	.03	13	3.5	1.4	0.1	0.1	5.1
Cy3	5.5	4.6	0.4	.02	20	2.3	1.1	0.1	0.2	3.7

* Neutral salt extraction

Chemical and Physical Analysis													
Horizon	Sesquioxides (%)						% >2 mm	Particle Size Dist. (% <2 mm)			Moisture (%)		Texture
	Dithionite		Oxalate		Pyrophosphate						1/3 atm	15 atm	
	Fe	Al	Fe	Al	Fe	Al		Sand	Silt	Clay			
F													
Cyl	1.46	0.14	0.14	0.05	0.03	0.02	35	62.7	33.3	3.9	1.9	1.9	GSL
BCy	1.42	0.13	0.16	0.05	0.04	0.03	40	61.9	34.0	4.1	2.0	2.0	GSL
Bmy	1.57	0.17	0.72	0.15	0.30	0.14	10	44.2	47.4	8.4	1.7	2.0	L
Cy2	1.44	0.09	0.16	0.05	0.03	0.04	45	56.3	40.2	3.5	1.9	1.9	VGSL
Cy3	1.53	0.13	0.17	0.08	0.06	0.06	55	83.9	11.4	4.6	–	–	VGLS

Clay Mineralogy (<2μ)										
Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size*)						
	Al_2O_3	Fe_2O_3	K_2O	Kaolinite	Verm.	Mica	Quartz	Goethite	Chlorite	Interstrat. Montmor.-Chlorite
F										
Cyl	29.0	12.0	2.5	3	1	3	1	1	2	1
BCy										
Bmy	20.0	13.2	2.5	2	2	2		1	1	
Cy2										
Cy3	18.0	13.9	3.0	3	2	3	1	2	1	

* Relative peak size: 3 = medium, 2 = small, 1 = very small

Table 41. Vegetation description for Site 22.

Vegetation

SHRUBS (% cover)

Tall Shrubs

0.5 *Betula glandulosa*
0.5 *Salix planifolia* ssp. *pulchra*

Low Shrubs

10.0 *Betula glandulosa*
15.0 *Ledum palustre* ssp. *decumbens*
10.0 *Salix planifolia* ssp. *pulchra*

Medium Shrubs

20.0 *Betula glandulosa*
5.0 *Salix planifolia* ssp. *pulchra*

Dwarf Shrubs

15.0 *Empetrum nigrum*
1.0 *Vaccinium vitis-idæa*

HERBS (% cover)

0.5 *Minuartia* sp.
0.5 *Pedicularis labradorica*
5.0 *Petasites frigidus*

GRASSES (% cover)

1.0 *Calamagrostis stricta*
0.5 *Trisetum spicatum*

MOSSES – LICHENS (% cover)

Mosses

5.0 *Hylocomium splendens*
15.0 *Polytrichum juniperinum*
10.0 *Tomenthypnum* sp.

Lichens

0.5 *Cetraria islandica*
5.0 *Cetraria nivalis*
5.0 *Cladina* spp.
5.0 *Cladina mitis*
0.5 *Cladonia* spp.
15.0 *Cladina rangiferina*
15.0 *Cladina stellaris*
0.5 *Masonhalea richardsonii*
1.0 *Nephroma arcticum*
5.0 *Peltigera* sp.
15.0 *Stereocaulon* sp.

NON-VEGETATED (% cover)

1.0 Bare
– Litter
5.0 Rock
– Slash
– Water

Table 42. Micromorphological Features for Site 22: Nonsorted Circles.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Cy1 (AC)	**Overall:** Extremely porous morphology dominated by coarse lithofragments; finer material and mineral fragments loosely fill pores between the coarse lithofragments. (Pl.7:A) **Related DP:** Agglomeroplasmic; soil material in pores occasional occurrence of granoidic-porphyroskelic and granoidic. Plasmic: In pores, soil material: silasepic. **Microstructure:** Intergrain structure. c/f RDP: Enaulic. b-fabric: In pores, soil material: stipple-speckled.	**Void Pattern:** Extremely porous matrix, complex packing voids between coarse lithofragments and loosely packed finer material; variable size ranges. Between the lithofragments, occasionally closely to densely packed material occurs with irregular to rounded (100–600 μm) as well as planar (50–200 μm) pores. **Basic Components:** Mineral: Coarse lithofragments (0.3–1.8 cm) dominate the soil fabric; frequent siltstone and shale, occasionally metamorphic. Frequent mineral fragments occur in the pores between the coarse lithofragments; similar in composition to the coarse lithofragments, subangular to subrounded; variable size range (0.08–2.8 mm); also commonly in aggregations with groundmass of fine to extremely fine silt-size and amorphous material. (Pl.7:A, B) Organic: Commonly occurring root sections (0.4–1.2 mm) show weak to strong decomposition. Occasional root tissue fragments (70–150 μm) have moderate to extreme decomposition. Fungal hyphae fragments occur rarely in the pore space as single fragments, but are associated commonly with the well-decomposed epidermal layer of root sections and occasionally to rarely with the strongly decomposed organic tissues in aggregations of finer material that occur in pore space between lithofragments. Very rare faunal material; organic in composition, no mineral component. **Pedofeatures:** Faunal: Rare fecal material 50–70 μm; composed of organic tissues and fungal hyphae fragments; probable source epidermal layer of roots; occur as distinct clusters in pore space. Textural: Rare accumulations of silt-size material on grain surfaces (most frequently in surface irregularities and crevices) of coarse lithofragments; very discontinuous; accumulations 10–150 μm wide.	Loose material between coarse lithofragments suggests considerable movement and/or ice crystal formation to prevent structural organization of the soil material. (Pl.7:A, B) Positioning of coarse lithofragments is suggestive of size sorting. Larger fragments delineate weak circular pattern; interior zones occupied by finer material; expressed more with depth. In zones of closely packed material, rounded pores (vesicular) and planar voids. Accumulations of silt-size material occur only in crevices and the surface irregularities of coarse lithofragments; suggests considerable movement of the material is occurring to prevent build-up of materials on grain surfaces.

Table 42. Micromorphological Features for Site 22: Nonsorted Circles (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bmy (Bw)	**Overall:** Complex morphology consisting of dense soil fabric of dominantly silt-size material and lithofragments, with frequent granular structural units observed in the groundmass; blocky structure from ice lens formation. (Pl.7:C) **Related DP:** Porphyroskelic//matricconglomeric-porphyroskelic//-matrigranoidic-porphyroskelic with minor occurrence of fabric zone of matri-fragmoidic. Plasmic: Insepic//silasepic with rare occurrences of skelsepic. **Microstructure:** Complex structure: Channel and vughy structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled with rare occurrences of granostriated.	**Void Pattern:** Common to frequent irregular vughs (0.16–1.2 mm); triangular to prolate; commonly associated with planar voids; vughs frequently delineate weak granular structure. Frequent root channels (400–680 μm wide); tend to be clustered together in distinct regions. Occasional planar voids (mainly 120–240 μm, rarely 400 μm associated with granular material); result of ice lens formation; delineate blocky and granular structural units. **Basic Components:** Mineral: Groundmass is dominated by subangular to angular quartz of silt to fine sand-size (<10–100 μm); evidence for sorting. Clay particles of weathered mica are also frequent. Within the groundmass, subangular to angular single quartz grains of fine to medium sand-size (mainly 100–350 μm, occasionally to 500 μm) commonly occur with occasional to common subrounded to subangular lithofragments (mainly 1.2–2.8 mm, rarely 4.0–4.4 mm) of shale, siltstone, sandstone and metamorphic; evidence of sorting by size. (Pl.7:C) Organic: Extremely decomposed root tissues in voids; cell structure frequently separating; frequently coated (<10–30 μm) with silt-size material; rare occurrences of incorporation of cell structure fragments into adjacent groundmass. Very rare fungal fragments associated with organic root tissues. **Pedofeatures:** Faunal: Very rare fecal material (aggregations 80–300 μm) associated with interior root fragment; composed of root tissue structure and extremely fine silt-size and amorphous material. Textural: Accumulation of silt-size material commonly occurs around lithofragments to form distinct granular unit; variable size of accumulations 0.2–1.2 mm. (Pl.7:D) Fabric: Within groundmass, granular units (0.4–1.6 mm) of very fine silt-size material; recognizable due to fabric change. Rarely units appear to have textural accumulations. Nodules: Rare to occasional occurrence; consist of cemented soil material, ferruginous; 0.2–1.2 mm, rounded; distinct sharp.	Greater proportion of silt-size material than in Cy1 horizon. Suggests particle size redistribution with depth of soil material in presence of freezing front. Very complex morphology of granular units enclosed in groundmass. Units appear to be subjected to movement as evidenced by very rounded shape and weak delineations of successive accumulations of material. Sorting of silt-size quartz in groundmass into zones of concentrations of similar size, into weak circular and linear patterns often around granular units. Soil fabric gives impression of considerable movement and reorganization of materials. (Pl.7:C) Accumulations of groundmass material on lithofragments. Fragments show sorting by size into clusters and weak circular patterns. (Pl.7:D) Root tissues are very decomposed and have thin coatings and aggregations of fecal material in interior root; suggests previous time periods when the horizon was unfrozen, allowing root penetration and faunal activity. Vughs and planar voids delineate granular and blocky structure. Pores subject to ice lens formation; general shape prolate and triangular.

Table 42. Micromorphological Features for Site 22: Nonsorted Circles (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Cy2 (C1)	**Overall:** Soil morphology consists of densely packed silt-size material with extremely frequent lithofragments; movement of fine materials is pronounced with frequent accumulations of fine silt on bottom of lithofragments. (Pl.7:E) **Related DP:** Porphyroskelic//suscitic-porphyroskelic. Plasmic: Silasepic. **Microstructure:** Complex structure: Intergrain structure with fine fraction densely packed between lithofragments. c/f RDP: Porphyric. b-fabric: Stipple-speckled.	**Void Pattern:** Occasional to rare, irregular to rounded vughs (200–800 μm, mainly 400–600 μm) in association with lithofragments; frequently formed from packing of finer material around fragments. **Basic Components:** Mineral: Abundant rounded to subrounded lithofragments consist of frequently occurring siltstone, common shale, rare sandstone and metamorphic fragments; variable size ranges of the fragments result in different levels of soil fabric organization; that is, between the very coarse 0.8–1.5 cm fragments densely packed silt-size groundmass occurs and includes lithofragments ranging from 0.2–3.0 mm as well as single grain quartz particles (60–650 μm). Fine groundmass consists mainly of angular quartz (<10–30 μm), occasional extremely fine-grained fragments of shale and occasional to common clay particles (weathered mica). (Pl.7:E, F) Organic: Organic fragments observed. **Pedofeatures:** Textural: Accumulations/infillings of silt-size material occur frequently on the underside of lithofragments; rarely on side or top of fragments; evidence for occasional sequential accumulation events from sorting of fine material, the finest and most densely packed is closest to the grain surface and consists of greater proportion of dark amorphous material and moderately aligned clay material. Variable size range for accumulations, depending on whether more than one accumulation event has occurred, i.e., finest accumulation is 50–300 μm thick; coarser, 100–500 μm thick; rare occurrence of third layer 50–500 μ, which is the coarsest with least content of amorphous material.	The textural accumulations of finer material on the undersides of lithofragments are the dominant feature of the Cy2 horizon. This feature is characteristic of ice lens melting with the infilling of the space as a result of numerous freeze–thaw cycles and the effect of freezing front immobilizing the lithofragments. (Pl.7:E) Subvertical alignment of coarse lithofragments is common. (Pl.7:E, F) Considerable tilting of fragments in finer material in groundmass around coarse lithofragments suggests considerable movement has taken place; has appearance of flow around coarser material. (Pl.7:E, F)

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 7

List of Plates for Site 22: Nonsorted Circles.

Plate 7: A

Coarse lithofragments, finer material, and mineral grains loosely fill the spaces between very coarse lithofragments in the Cy1 horizon. Note root material, coatings of fine material on upper surfaces of occasional lithofragments, and planar pores along the grain surface of the very coarse lithofragments. Frame length 8.5 mm. Plane polarized light (PPL).

Plate 7: B

Close-up view of the mineral material and lithofragments in the intervening spaces between the very coarse lithofragments in the Cy1 horizon. Note root material and aggregations of silt-sized mineral material. Frame length 4.0 mm. (PPL).

Plate 7: C

Particle size sorting of fine to medium sand-size quartz grains in the Bmy horizon is evident from the linear alignment of the grains. Frame length 4.0 mm. (PPL).

Plate 7: D

Extensive accumulations of fine-grained material on vertically aligned lithofragments occur commonly in the Bmy horizon. Frame length 4.0 mm. (PPL).

Plate 7: E

Lithofragments are extremely frequent in the densely packed, silt-size material of the Cy2 horizon. Note the infilling of silt-size material at the base as well as the alignment of the soil constituents around the coarse lithofragment in the centre of the micrograph. Frame length 8.5 mm. (PPL).

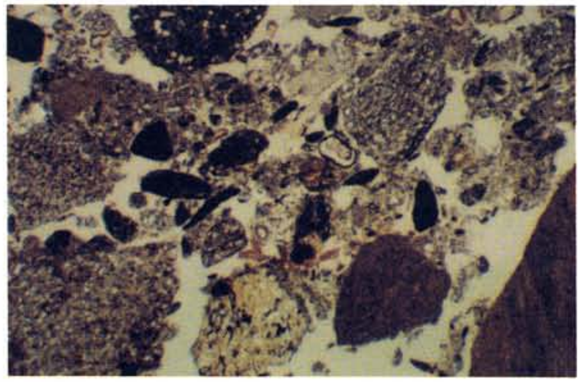
Plate 7: F

Alignment of lithofragments in preferred direction suggests strong effect from cryogenic processes on the soil fabric in the Cy2 horizon. Note also the effect of particle sorting with cluster of quartz grains. Frame length 4.0 mm. (PPL).

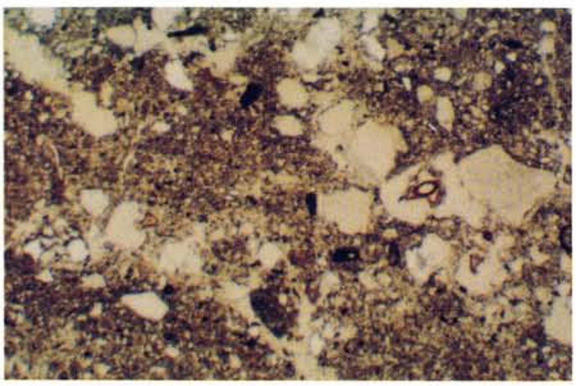
PLATE 7

Site 22: Nonsorted Circles

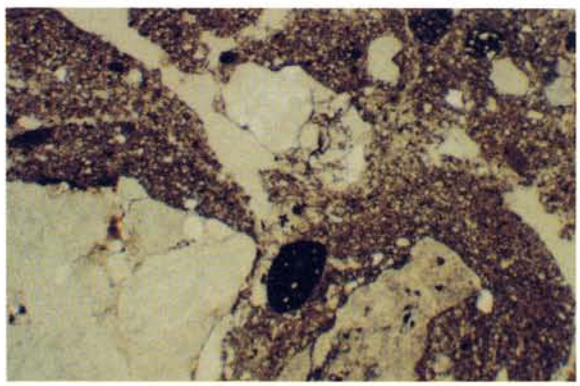
A



B



C



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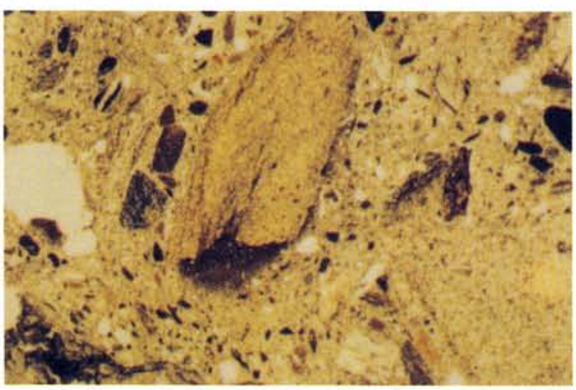

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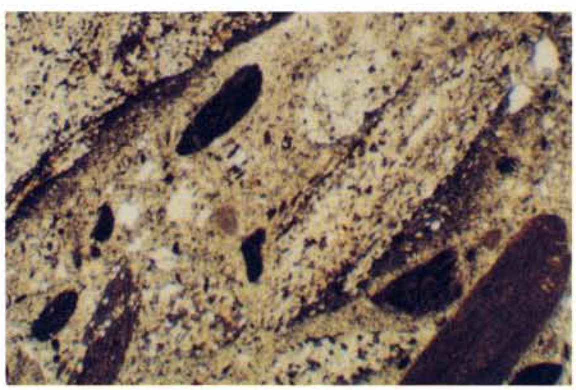


F

SITE 23, KM 74: TOMBSTONE MOUNTAIN LOOKOUT

On clear days it is possible to look west from this point into the heart of the southern Ogilvie Mountains and see Tombstone Mountain. The mountain is approximately 1845 m high (6000 ft) and composed of syenite rock. Although the general form of the river valley (U-shaped) and lowlands is attributable to Pleistocene glaciation, the peaks of the Tombstone Range owe their shape to the elements of strong physical weathering, resulting in the spires and monument-like forms. Early gold prospectors who roamed this area from the Klondike Valley to the south gave the mountain this name because of its unique tombstone-like shape.

SITE 24: MIDNIGHT DOME LOOKOUT

The view from this point displays most of the geomorphic features of the Klondike district and the Yukon River valley. Features of special interest include:

- The general aspect of the Klondike Plateau, with deeply entrenched streams and intervening ridges radiating from domes that surmount the plateau level.
- The bedrock terrace, Tertiary White Channel gravels and Klondike gravels in Jackson Cut on the south side of the Klondike valley.
- The highly irregular pattern of dredge tailings in the Klondike valley, governed at least in part by sporadic distribution of permafrost on the flood plain.
- The patterns of vegetation cover, which are controlled by forest fire history and permafrost distribution.

SITE 25: AGRICULTURE ON PERMAFROST-AFFECTED SOIL

At this site we will examine the effects of clearing on the thermal regime of soils in the Klondike Valley. The site is representative of the soils and climate regime under which agriculture is carried out in this region of the Yukon.

In this area of the Klondike valley, agriculture has been undertaken sporadically since the turn of the century. The landscape is composed of fluvial gravels overlain by alluvial fan deposits emanating from the upland gulches and reworked Pleistocene loess. The soils are productive, and a variety of crops can be grown here. The general nature and thermal characteristics of the Klondike soil association are given in Smith (1990).

SITE 25a. THE CLEARED SOIL

In March of 1991, a block of land, approximately 40 ha in size, was cleared for the first time. The developer (Mike Heydorf) sheared it at the seasonal frost contact, stripping the forest and shrub cover, along with most of the forest floor (mosses and lichens), and piling it into windrows for eventual burning. Pockets of the original forest floor materials (Of and Oh horizons) do still remain on the surface, however. The soil was not cultivated, but seed was spread on the stripped surface later that first year. In July of 1991, soil temperature and moisture sensors were installed on both the cleared and uncleared portions of this landscape. Monitoring has continued since then. The site and pedon descriptions for the cleared soil are given in Table 43 and a cross section of the pedon is shown in Figure 31.

After two years of thaw, the permafrost table has dropped to well below one metre in depth. There is evidence of thaw in the form of thermokarst topography on the field, with the thermokarst depressions revealing the polygon boundaries. Subsurface ice wedges are beginning to melt, with resultant subsidence in trough-like patterns. Eventually the field will have to be leveled in order to operate machinery.

The analytical data for the cleared soil are given in Table 44. The soil is neutral in reaction and rich in well-decomposed organic matter as a result of burial by alluvial action and cryoturbation. The silt loam to very fine sandy loam texture is favourable for moisture retention and plant growth. Most of the free sesquioxides are pyrophosphate-extractable and, therefore, in organically-bound form. A suite of largely inherited phyllosilicates makes up the clay mineralogy (Table 44).

Micromorphology

Ahy Horizon. The sample from this layer is representative of the morphology (Table 45; refer also to Plate 8) near the soil surface. Organic material occurs frequently throughout the densely packed mineral material of dominantly angular to subangular quartz grains (10–110 μm, mainly 10–70 μm). In this horizon, cryogenic processes have resulted in platy structure because of ice lens formation with depth and in the weak formation within the mineral material of lenticular accumulations (silt-dropping features) and granular structures of fine silt-size and amorphous organic material from freeze–thaw cycles. Cracks provide environmental conditions suitable for faunal activity. Root tissues are strongly to extremely decomposed and occasional organic fragments are well-humified, from which one can infer that the organic material is more susceptible to biological and chemical decomposition because of exposure to the atmosphere as a result of stripping of surface vegetation cover. (Pl.8:A, B, C, D)

Ahyb Horizon. This buried lower horizon shows little evidence of being affected by cryoturbation. The mineral and organic materials are in distinct depositional layers. The mineral material is well sorted and variances, such as the layer with increased frequency of lithofragments and coarser quartz grains, occur as a result of deposition. The only evidence of cryogenic influence are cracks, where the layers are downturned, suggesting movement by cryogenic pressure. Two distinct layers of diatomaceous material were observed in the Ahyb horizon, indicating a depositional history that included periodic saturated environments. (Pl.8:E, F, G, H)

SITE 25b. THE FORESTED SOIL

A second soil monitored in the adjacent forest was chosen to represent the condition of the field before clearing. The site and pedon descriptions for this soil are given in Table 46. This soil has formed on the same parent materials as the soil at Site 25a, and has the same very fine sandy loam texture (Table 47). The permafrost table occurs near the contact between the mineral and surface organic horizons (Figure 32). The Ohy horizon is high in mineral content and probably reflects past fluvial depositional activities. The soils are somewhat more acidic under the forest cover, which may indicate that changes have occurred to the cleared soil since it was stripped of surface vegetation. Pyrophosphate, oxalate and dithionite extractions are dominated by Fe with little extractable Al in any horizon, suggesting conditions typical of poor drainage.

The forest cover is composed of tall white spruce (*Picea glauca*) (Table 48). Even though the frost table is near the surface, the presence of tall white spruce indicates a productive site with near neutral soil reaction. The tall willow shrubs indicate the presence of seepage water, as do the *Equisetum* and *Carex* species.

Micromorphology

The Ohy horizon, under forested vegetation, has a very complex morphology (Table 49; refer also to Plate 8) that varies considerably with depth from granular structure, to dense packing of mineral material, organic fragments and amorphous organic material, to an organic layer with horizontal layering of the fragments and organic aggregations. There may have been a faunal origin to the organic aggregations in the organic layer, but there is insufficient evidence of faunal activity to be absolutely confident. This Ohy horizon is affected by cryogenic processes, with inclusion of organic material from the upper horizon, primarily as well-humified plant fragments; sorting of organic fragments into clustered arrangements; and movement of very fine materials in the soil matrix as lenses and textural accumulations. In the organic layer, the horizontal layering of the fragments at the time of deposition is disrupted and bent by probable cryostatic pressure. Movement in the cracks is also indicated by the downturning of the individual layers. Ice lens formations probably contribute to the planar pores delineating the horizontal layers. (Pl.8:I, J, K, L)

THE IMPACT OF DISTURBANCE ON SOIL PHYSICAL PROPERTIES

Figures 33 and 34 and Table 50 show the thermal regimes of the cleared and forested soils, based on data collected between July 1991 and June 1992. Mean July temperatures indicate that the top 50 cm of the cleared soil warms to >5°C during the summer, and near-surface soil temperatures average more than 15°C (Figure 35). On the forested site, however, only the organic humus form, which is approximately 35 cm thick, thaws during the summer. The underlying mineral soil thaws only late in the season to just below the organic horizons. Shading by the forest cover and insulating by the moss peat horizons keep the soil in a frozen, or near frozen, state throughout the year.

Soil moisture levels at the 15 to 30 cm depth appear to be similar at both sites (Figure 36). The surface (0 to 15 cm depth) under the forested site is composed of peat. This peat becomes very dry during the summer, which enhances the insulating capacity of the peat. The mineral soil underlying the peat tends to remain moist all year, and this condition is reflected in the presence of willows and sedges on the forested site.

The cleared soil is warmer in the winter than the forested soil (Figure 35). This is a result of the much deeper snow cover on the open field area (Site 25a) relative to under the forest canopy (Site 25b). Even when winter air temperatures routinely fall below -30°C at this site, the insulating effect of the snow cover maintains soil temperatures above -2°C, as shown by the

January mean temperatures. The slightly higher January soil temperatures at the 50 cm depth in both soils reflect remnant heat from the previous summer.

These data represent the thermal condition during the first full year after clearing. It is interesting to note that the surface disturbance had no apparent impact at the 150 cm depth; both sites share the same temperature values at that depth. Data collected during the second year after clearing may show evidence of warming at greater depths.

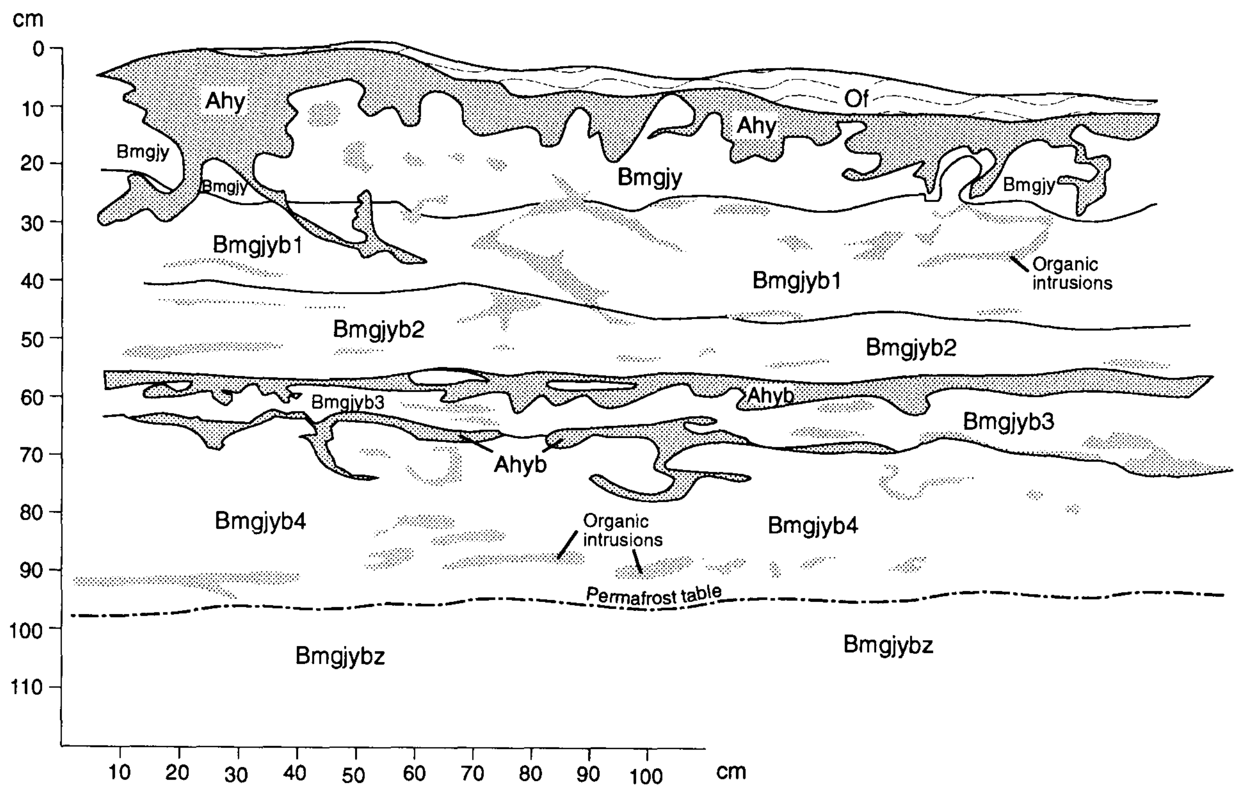


Figure 31. Cross section of the Orthic Turbic Cryosol on the cleared soil at Site 25a (Heydorf farm).

Table 43. Site and pedon descriptions for Site 25a.

Pedon no.: DC – 1, S91-FN-260-007
Location: 64°03'13" N Lat., 138° 59'51" W Long.
Landform: Toe of alluvial fan over river gravels
Drainage: Imperfect; changed by clearing
Soil Temperature (50 cm depth; 1991-92): MAST 0.6°C, MSST 4.2°C
Parent Material: Reworked, mixed loess and alluvium
Patterned Ground: Ice-wedge polygons

Elevation: 410 m (a.s.l.)
Slope: 4%
Vegetation: Cleared field
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
Of	Oe/Oi	5 – 0	Black (10YR 2/1 m); undecomposed peat; abundant, very fine to fine roots; abrupt, broken boundary.
Ahy	A	0 – 5	Dark brown (10YR 3/3 m); silt loam; weak, fine to medium, granular; nonsticky, very friable, nonplastic; plentiful, very fine to medium roots; abrupt, broken boundary. [91P5998]
Bmgjy	Bg	5-23	Very dark grayish brown (2.5Y 3/2 m); silt loam; many, medium, prominent, reddish brown (5YR 4/4 m) mottles; weak, very fine to fine, platy; nonsticky, very friable, nonplastic; plentiful, very fine to medium roots; few, small, pockets of organic material; sand along natural faces – vertical cleavage; very thin platy structure; clear, wavy boundary. [91P5999]
Bmgjyb1	Cg1	23 – 37	Very dark grayish brown (2.5Y 3/2 m); very fine sandy loam; many, medium, prominent, reddish brown (5YR 4/4 m) mottles; weak, very fine to fine, platy; slightly sticky, very friable, nonplastic; plentiful, very fine to medium roots; thin, 1 to 2 cm lenses of turbated organic material; sand along natural faces – vertical cleavage; gradual, wavy boundary. [91P6000]
Bmgjyb2	Cg2	37 – 54	Very dark grayish brown (2.5Y 3/2 m); very fine sandy loam; many, coarse, prominent, dark brown (7.5YR 4/4 m) mottles; weak, very fine to fine, platy; slightly sticky, very friable, nonplastic; very few, very fine to fine roots; abrupt, wavy boundary. [91P6001]
Ahyb	Oi	54 – 58	Black (10YR 2/1 m); very fine sandy loam; plentiful, very fine to fine roots; abrupt, wavy boundary.
Bmgjyb3	Cg3	58 – 63	Dark olive gray (5Y 3/2 m); silt loam; many, medium, prominent, reddish brown (5YR 4/4 m) mottles; weak, very fine to fine, platy; slightly sticky, very friable, nonplastic; very few, medium roots; abrupt, broken boundary. [91P6002]
Bmgjyb4	Cg4	63 – 90	Dark olive gray (5Y 3/2 m); silt loam; many, fine, prominent, dark brown (7.5YR 4/4 m) mottles; weak, very fine to fine, platy; slightly sticky, very friable, nonplastic; few, very fine to fine roots; black (10YR 2/1) organic layers, each about 5 cm thick, containing organic material and charcoal (former surface) parallel to surface; abrupt, smooth boundary. [91P6003]
Bmgjybz	Cgf	90 – 105	Very dark gray (5Y 3/1 m); very fine sandy loam; few, medium, prominent, dark brown (7.5Y 4/4 m) mottles; massive. [91P6004]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 44. Analytical data for the cleared Orthic Turbic Cryosol at Site 25a.

Chemical Analysis														
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)								
						Neutral Salt Extraction					Buffered NH_4OAc (pH 7)			
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total	Total	Ca	Mg	Na
Of	4.7	4.5	44.6	1.56	29	31.6	8.4	2.5	0.2	42.7				
Ahy	7.2	7.0	9.1	0.32	28	24.8	5.8	0.1	0.1	30.8			3.5	0.4
Bmgjy	7.2	6.6	1.8	0.10	18	10.6	3.5	0.1	0.1	15.3	16.9	13.8	3.0	0.1
Bmgjyb1	7.4	6.9	1.4	0.07	20	9.4	2.8	0.1	0.1	12.4	16.3	13.6	2.5	0.2
Bmgjyb2	7.3	6.9	1.3	0.06	22	9.4	2.7	0.7	0.0	12.8	14.1	11.6	2.4	0.1
Ahyb	8.0	7.7	2.5	0.13	19	17.6	2.8	0.1	0.0	20.2				
Bmgjyb3	7.5	7.1	1.6	0.06	27	10.5	2.6	0.1	0.0	13.2	17.4	14.6	2.7	0.1
Bmgjyb4	7.4	6.8	2.5	0.13	19	14.1	3.4	0.1	0.0	17.6	21.6	18.1	3.4	0.1
Bmygjbz	7.2	6.8	2.1	0.12	18	11.2	2.7	0.1	0.0	14.0	22.8	19.1	3.5	0.2

Chemical and Physical Analysis															
Horizon	Sesquioxides (%)						% >2 mm	Part. Size Dist. (% <2 mm)				Bulk Den.	Moisture (%)		Tex-ture
	Dithionite		Oxalate		Pyrophos.										
	Fe	Al	Fe	Al	Fe	Al		Sand	Silt	Clay	F-Clay	(g/cc)	1/3 atm	15 atm	
Of	0.15	0.09	0.14	0.05		0.03									
Ahy	0.77	0.10	0.65	0.10	0.37	0.06	5	31.3	64.8	3.8		1.09	32.7	11.8	SiL
Bmgjy	1.15	0.08	1.25	0.12	0.38	0.07	1	30.0	62.0	7.9	4.8	1.62	30.6	7.9	SiL
Bmgjyb1	1.41	0.11	0.59	0.08	0.23	0.04	3	52.9	41.5	5.7	3.4	1.49	16.7	6.8	VFSL
Bmgjyb2	1.16	0.09	0.38	0.06	0.19	0.03	6	58.2	36.3	5.4	3.6	1.39	19.6	7.6	VFSL
Ahyb	1.33	0.17	1.44	0.37	0.19	0.09		31.1	66.5	2.4					VFSL
Bmgjyb3	0.83	0.10	0.45	0.08	0.27	0.05	3	34.9	57.7	7.4	3.9	1..25	36.0	7.7	SiL
Bmgjyb4	0.87	0.09	0.45	0.05	0.37	0.02	2	48.2	45.3	6.5	3.2	1.20	28.6	9.1	SiL
Bmgjybz	0.72	0.09	0.57	0.04	0.33	0.04	6	54.1	39.0	6.9	3.1	1.15	35.8	8.9	VFSL

Clay Mineralogy (<2μ)											
Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size[*])							
	Al_2O_3	Fe_2O_3	K_2O	Kaolinite	Calcite	Mica	Mont-morill.	Quartz	Hema-tite	Chlor-ite	Chlor-Mica
Of											
Ahy	5.7	15.7		1	2		1		1	1	
Bmgjy											
Bmgjyb1	16.0	25.7				1	2	1		1	1
Bmgjyb2											
Ahyb											
Bmgjyb3	14.0	15.7	3.2			1	2	1		1	1
Bmgjyb4											
Bmgjybz	28.0	24.3	9.4	2		1		1		1	1

[*] Relative peak size: 2 = small, 1 = very small

Table 45. Micromorphological Features for Site 25a: Heydorf Farm (cleared field).

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ahy (A)	**Overall:** The soil matrix consists of densely packed, well sorted, silt-size mineral material with frequent coarse organic fragments; with depth, platy structure weakly to moderately expressed; zones of increased organic material with faunal evidence. (Pl.8:A, B, C) **Related DP:** Silasepic porphyroskelic (adporphyric). With depth, weak to moderate isoband. Zones with abundant organic material: ortho-phyto-humigranic. Plasmic: Virtually no plasma; silasepic, very rare skelsepic from packing of mica particles on grain surfaces. **Microstructure:** Complex structure: Dominantly compact grain structure; with depth, weak to moderate platy structure; in zones of organic material, granular structure. c/f RDP: Monic/porphyric. b-fabric: No oriented clay; very rare grano-striated from packing of mica particles.	**Void Pattern:** Simple packing voids observed occasionally to rarely between densely packed very fine sand to silt-size mineral grains. With depth, secondary structure (isoband) with planar voids 10–100 µm wide. (Pl.8:B) Occasional to common root channels (400–600 µm). Sub-vertical crack (2.5–4 mm wide) into zone of organic material, infilled with abundant fecal material. (Pl.8:C) **Basic Components:** Mineral: Dominantly angular to subangular quartz grains (10–110 µm, mainly 10–70 µm); very densely packed. Weathered mica particles (<10–150 µm length) occur frequently; very rarely packed along grain surfaces. Organic: Throughout densely packed mineral material, colloidal organic masses frequently occur. (Pl.8:D) Occasional, well-humified (black), woody organic fragments are clustered in distinct region of the densely packed mineral material. Rare root penetrates large woody fragment. Root tissues, moderately decomposed are common in channels; also strongly to extremely decomposed root tissues and cell structures occur frequently in densely packed soil fabric. In organic-rich fabric zone, strongly to extremely decomposed plant structures (unrecognizable as to origin) occur frequently; dominantly <10–150 µm with occasional fragments 200–500 µm; rare well-humified fragments (charcoal) of leaf tissues. Frequently, the fragments are rounded. Frequent faunal activity in this zone. **Pedofeatures:** Faunal: Fecal material composed dominantly of amorphous organic material and strongly decomposed fragments with common occurrence of silt-size quartz; round, smooth boundaries, 200–300 µm; ellipsoidal, with increased quartz content (300–500 µm length, 220 µm diameter); associated with crack and organic-rich fabric zone. Adjacent to crack, in dense mineral fabric zone, occasional rounded units (200–300 µm rarely 500 µm) occur; probably faunal in origin as size ranges and shape comparable to fecal material observed in crack. (Pl.8:C) Fabric: In densely packed zone, concentrations of very fine silt-size material and amorphous organic material occurs occasionally as 'silt-dropping' features (100–300 µm). (Pl.8:D)	Clustering of well-humified woody fragments suggests movement/mixing into densely packed mineral material; possibly cryogenic rather than tillage as fragments aligned in circular pattern. (Pl.8:A) Observed crack stable for time period to facilitate faunal activity. (Pl.8:C) Isoband structure with planar voids result of ice lens formation. (Pl.8:B) Silt-dropping features, accumulations above organic fragments or changes in density of packing; very fine silt material accumulates. Result of freeze-thaw cycles. (Pl.8:D)

Table 45. Micromorphological Features for Site 25a: Heydorf Farm (cleared field) (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ahyb (Oi)	**Overall:** The soil morphology consists of sequential horizontal layering; densely packed, very fine sand to silt-size mineral layers interspersed with layered organic fragments; with depth, the organic layers are less distinct and included in mineral layers. (Pl.8:E) **Related DP:** Mineral layers: Silasepic porphyroskelic (adporphyric). Distinct organic layers: humigranoidic/phyto-humi-granic. Plasmic: Virtually no colloidal clay; plasma, when present, is amorphous organic material. Silasepic. One layer high in mica particle content has insepic appearance. **Microstructure:** Complex structure: Interlayering of very compact grain structure with horizontal layering of organic fragments and granular material. c/f RDP: Mineral material, monic/porphyric. b-fabric: Stipple-speckled due to clay particle content.	**Void Pattern:** Simple packing pores between mineral grains occasionally 30–60 µm. In the organic layers, complex packing voids occur between organic fragments and organic granular units. Rare occurrence of cracks extending from organic layer into mineral material; infilled material. (Pl.8:G) **Basic Components:** Mineral: Mineral material in layers is well sorted, dominantly subangular to angular quartz 30–70 µm; uniform with depth, except one layer has frequent angular to subangular quartz 150–250 µm with abundant lithofragments (350–400 µm) of sandstone and metamorphic (moderately weathered). (Pl.8:F) Abundant weakly to strongly weathered mica particles (<10–160 µm) are distributed randomly throughout the mineral material; very rarely packed along grain surfaces. Above the two major organic layers for approximately 0.5 cm, amorphous mineral aggregations and granular material contain frequent to occasional diatomaceous material. (Pl.8:H) Organic: Strongly decomposed to well-humified plant tissues (variable sizes) occur in layers; slightly compacted, horizontally aligned; fragments interspersed with amorphous granular units (possibly faunal in origin at time of deposition). Occasional fungi, commonly in clusters associated with root tissues; rare fungal sclerotia 480–640 µm. Organic fragments (variable sizes) also occur frequently in mineral material; horizontally aligned; strongly decomposed. Occasional distinct zones of organic amorphous material observed in mineral layers. **Pedofeatures:** Faunal: Associated with organic material; probable origin at time of deposition (Pl.8:H) Infilling: Crack extending from mineral material into organic layers, loose infilling of adjacent soil material. (Pl.8:G)	Soil processes observed in this horizon are depositional in origin. Distinctive layering is maintained, indicating little to no cryoturbation has occurred. Cracks were observed three times; widths range from 200 to 800 µm. The cracks usually extended from the mineral material into the organic layer or areas with organic fragments. When extending into the organic layers, the exposed edges of separate organic layer fragments tended to be down-turned. The cracks were loosely filled with adjacent soil material. The morphologic features of the cracks are suggestive of ice wedge formation.

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976), (Brewer and Sleeman, 1988); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

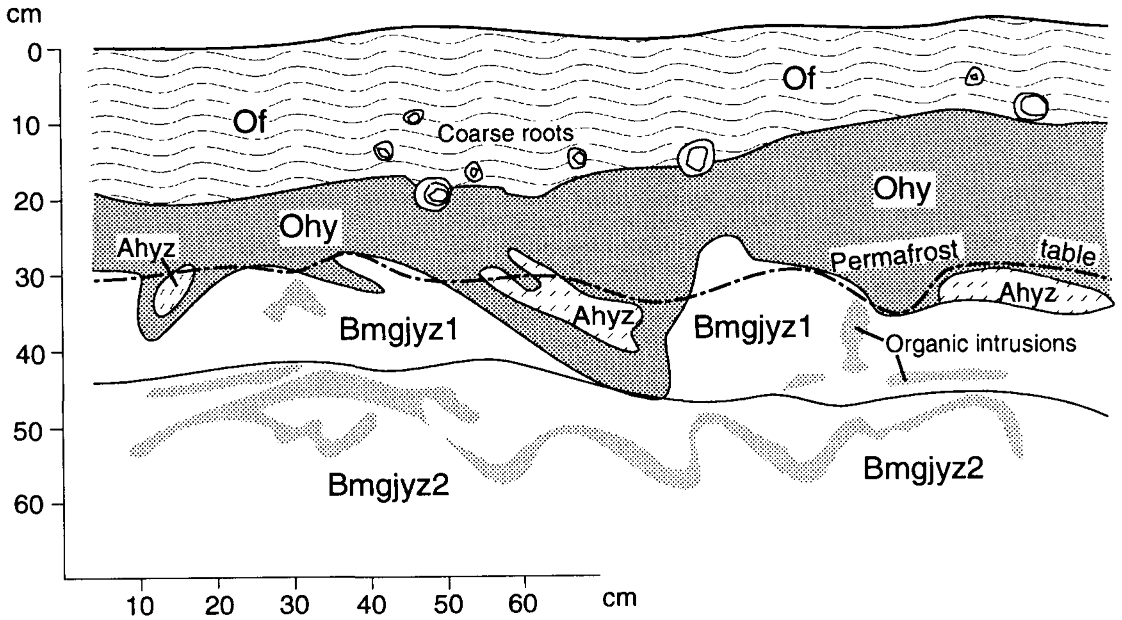


Figure 32. Cross section of the Orthic Turbic Cryosol on the forested soil at Site 25b (Heydorf farm).

Table 46. Site and pedon descriptions for Site 25b.

Pedon no.: DC – 2, S91-FN-260-008
Location: 64°03'11" N Lat., 138° 59'49" W Long.
Landform: Alluvial fan overlying fluvial floodplain
Drainage: Imperfect
Soil Temperature (50 cm depth; 1991-92): MAST -1.4°C, MSST -0.6°C
Parent Material: Mixed alluvium and reworked loess
Patterned Ground: Earth hummocks

Elevation: 349 m (a.s.l.)
Slope: 4%
Vegetation: Boreal forest
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
Of	Oi	30 – 11	Dark reddish brown (5YR 3/2 m); undecomposed peat; 95% unrubbed, 85% rubbed fibre; abundant, very fine to fine roots; abrupt, smooth boundary. [91P6005]
Ohy	Oa	11 – 0	Black (10YR 2/1 m); well decomposed peat; 10% unrubbed, 2% rubbed fibre; plentiful to abundant, very fine to fine roots; abrupt, smooth boundary. [91P6006]
Ahyz	A/Oaf	0 – 5	Black (10YR 2/1 m); silt loam; 15% unrubbed, 2% rubbed fibre; plentiful to abundant, very fine to fine roots; abrupt, wavy boundary. [91P6007]
Bmgjyz1	Cgf1	5 – 12	Very dark gray (5Y 3/1 m); very fine sandy loam; many, medium, prominent, strong brown (7.5YR 4/6 m) redoximorphic concentrations; massive; nonplastic; very few, fine roots; black (10YR 2/1) organic stains; cryoturbated; clear, wavy boundary. [91P6008]
Bmgjyz2	Cgf2	12 – 23+	Very dark gray (5Y 3/1 m); very fine sandy loam; many, medium to coarse, prominent, strong brown (7.5YR 4/6 m) redoximorphic concentrations; massive; very firm, nonsticky, nonplastic; cryoturbated; black (10YR 2/1) organic stains. [91P6009]

Note: numbers in square brackets [ ] following the horizon descriptions are the U.S.D.A. laboratory horizon numbers.

Table 47. Analytical data for the forested Orthic Turbic Cryosol at Site 25b.

Chemical Analysis

Horizon	pH		Org. C (%)	Total N (%)	C/N	Exchangeable Cations (me/100g)									
						Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$				Ca	Mg	K	Al	Total	Total	Ca	Mg	Na	K
Of	4.9	4.4	51.6								64.3	51.1	9.9	0.2	3.1
Ohy	6.2	5.8	17.8	0.86	21	47.3	8.7	0.1	0.1	56.2	80.8	72.7	7.9	0.2	0.0
Ahyz	6.5	6.1	6.7	0.36	19	27.3	3.6	0.1	0.1	31.1	45.1	40.6	4.4	0.1	0.0
Bmgjyz1	6.6	6.1	2.7	0.14	19	13.8	2.0	0.0	0.2	16.0	21.3	19.0	2.2	0.1	0.0
Bmgjyz2	6.7	6.2	1.8	0.08	23	10.9	1.8	0.0	0.4	12.1	14.1	12.5	1.7	0.1	0.0

Chemical and Physical Analysis

Horizon	Sesquioxides (%)						% >2 mm	Part. Size Dist. (% <2 mm)				Bulk Den. (g/cc)	Moisture (%)		Texture
	Dithionite		Oxalate		Pyrophos.										
	Fe	Al	Fe	Al	Fe	Al		Sand	Silt	Clay	F-Clay		1/3 atm	15 atm	
Of														142.3	
Ohy	1.35	0.32	1.48	0.35	1.12	0.24						0.33	65.1	31.7	
Ahyz	0.81	0.12	0.82	0.15	0.64	0.08	0.0	34.0	57.1	9.0		0.77	86.2	15.6	SiL
Bmgjyz1	0.85	0.10	0.76	0.08	0.33	0.06	0.0	53.8	38.8	7.4	3.7	1.55	28.1	7.5	VFSL
Bmgjyz2	0.65	0.06	0.61	0.07	0.22	0.06	0.0	54.6	39.7	5.7		1.64	24.2	5.4	VFSL

Clay Mineralogy (<2μ)

Horizon	Elemental Analysis (%)			Mineralogy (X-ray Diffraction Peak Size*)				
	Al_2O_3	Fe_2O_3	K_2O	Kaolinite	Mica	Montmorillinite	Chlorite	Chlor-Mica
Of								
Ohy								
Ahyz	15.0	15.7		1	1	1		
Bmgjyz1								
Bmgjyz2	21.0	20.0	4.1	2	2	2	1	1

* Relative peak size: 2 = small, 1 = very small

Table 48. Vegetation description for Site 25b.

Vegetation

TREES (% cover)

Tall Trees
20.0 *Picea glauca*

Low Trees
10.0 *Salix* sp.

SHRUBS (% cover)

Tall Shrubs
5.0 *Salix* sp.

Low Shrubs
0.5 *Betula papyrifera*
1.0 *Ledum palustre* ssp. *groenlandicum*
0.5 *Picea glauca*
1.0 *Potentilla fruticosa*
10.0 *Rosa acicularis*
1.0 *Salix* sp.

Medium Shrubs
0.5 *Picea glauca*
5.0 *Salix* sp.

Dwarf Shrubs
15.0 *Arctostaphylos rubra*
0.5 *Empetrum nigrum*
0.5 *Linnœa borealis*
1.0 *Vaccinium vitis-idœa*

HERBS (% cover)

0.5 *Epilobium angustifolium*
0.5 *Equisetum pratense*
1.0 *Equisetum scirpoides*
10.0 *Geocaulon lividum*
10.0 *Mertensia paniculata*
5.0 *Petasites frigidus*
0.5 *Stellaria* sp.

GRASSES (% cover)

5.0 *Calamagrostis canadensis*
15.0 *Carex stylosa*
0.5 *Festuca altaica*

MOSSES – LICHENS (% cover)

Mosses
5.0 *Bryophyte* spp.
15.0 *Dicranum* sp.
20.0 *Hylocumium splendens*
1.0 Liverwort sp.
1.0 *Pleurozium schreberi*
1.0 *Polytrichum juniperinum*

Lichens
10.0 *Cladonia* spp.
1.0 *Cladina stellaris*
5.0 *Peltigera aphthosa*
1.0 *Stereocaulon tomentosum*

NON-VEGETATED (% cover)

– Bare
15.0 Litter
– Rock
10.0 Slash
– Water

Table 49. Micromorphological Features for Site 25b: Heydorf Farm (forested).

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Ohy (Oa)	**Overall:** The soil fabric consists of strongly decomposed organic fragments in silt-size mineral material (loess); increasing tendency with depth for horizontal layering of organic material. (Pl.8:I, J, K) **Related DP:** With depth, grades from ortho-mull-humigranic/mull-granoidic to granoidic-porphyroskelic to silasepic porphyroskelic (adporphyric) to an organic layer of ortho-mull-phyto-humigranic organized in horizontal bands (fragmoidic). Plasmic: No clay present. Zones of silasepic above organic layer. **Microstructure:** Complex: With depth, grades from single grain structure of organic fragments and silt-size mineral grains to zones of close packing of crumb structure to zones of compact grain structure to a layer of closely packed organic tissues, mineral grains and aggregations organized into platy structure. c/f RDP: Enaulic to porphyric to monic. b-fabric: No clay present. Zones of stipple-speckled above organic layer.	**Void Pattern:** Arrangement of pores changes with depth, according to varying soil fabric: frequent simple packing pores to complex packing voids to frequent planar voids associated with occasional irregular vughs and rare vesicles; size ranges highly variable. Former desiccation crack (1.2–2.4 mm) is infilled. (Pl.8:J) **Basic Components:** Mineral: Silt-size (<10–50 μm), occasionally very fine sand size, dominantly subangular to angular quartz; frequency of occurrence varies with depth, i.e., increases with depth then marked decrease in horizontal layer of organic material; size range does not change with depth. Weathered mica particles (<10–70 μm) are frequent. Randomly distributed throughout mainly above organic layer, rare occurrence of diatoms. Organic: Included zones and desiccation crack dominated by well-humified organic fragments of plant tissues (mainly 120–880 μm, occasionally 1.6–3.6 mm); moderately fragmented, resistant epidermal layers of root tissues remain; occasional conifer leaf and woody stem tissues recognizable. (Pl.8:I) In the soil matrix, abundant organic fragments (variable size range <10 μm to 1.6 mm length) and amorphous organic material dominate; strongly decomposed root tissues (0.4–1.4 mm) are frequent; very rare fungal hyphae fragments. With depth, sorting of organic fragments results in moderately expressed clusters. In the organic layer, horizontal layering of strongly to extremely decomposed fragments and amorphous organic aggregations; unrecognizable as to specific plant tissue, but strong ligneous component. **Pedofeatures:** Infilling: Associated with desiccation cracks, infilled material consists of well-humified and strongly decomposed fragments and/or loosely packed amorphous organic material. (Pl.8:J) Textural: Extremely rare accumulations of very fine silt material on upper portions of very coarse organic fragments; extremely discontinuous. (PL.8:L)	In former desiccation crack, infilled zone with organic material; dominantly well-humified ('charcoal-like') fragments, source is probably upper horizon. Edges of crack are downturned, suggesting cryostatic pressures and movement. (Pl.8:J) In distinct zones in upper portion of sample, well-humified fragments intruded into soil matrix material. (Pl.8:I) Planar pores in organic layer delineate an isoband fabric indicative of ice lens formation. (Pl.8:K) Weak to moderate cryoturbation in soil matrix evident with clustering of organic fragments and bending of horizontal layers. Intensity increases with depth. In zone with silasepic porphyroskelic fabric, extremely rare accumulations of very fine silt on upper surfaces of coarse fragments and occasionally in soil matrix as weak lenticular units suggest movement and sorting of the fine materials either to local freezing front or infill of former ice lens. (Pl.8:L)

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976) and Brewer and Sleeman (1988); terms from Fox and Protz (1981).

b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).

Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

PLATE 8

List of Plates for Site 25a: Heydorf Farm (cleared field).

Plate 8: A

The soil matrix of the Ahy horizon consists of densely packed mineral material with coarse organic fragments. Note the alignment of organic fragments in lower part of the micrograph. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 8: B

With depth in the Ahy horizon, platy structure is weakly to moderately expressed: Characterized as isoband fabric. Frame length 4.0 mm. (PPL).

Plate 8: C

Crack in the Ahy horizon infilled by abundant fecal material. Frame length 4.0 mm. (PPL).

Plate 8: D

In the Ahy horizon, very fine silt-size material and amorphous organic material has accumulated on the upper surfaces of well-decomposed organic fragments and as concentrations in the densely packed soil material. Frame length 1.0 mm. (PPL).

Plate 8: E

The Ahyb horizon is characterized by depositional layering of the mineral material with zones of horizontally aligned organic fragments. Frame length 4.0 mm. (PPL).

Plate 8: F

Inclusion of coarse mineral material of angular to subangular quartz with abundant lithofragments and charcoal fragments was observed in the Ahyb horizon. Frame length 4.0 mm. (PPL).

Plate 8: G

Crack with loose infilling of organic fragments in the Ahyb horizon. Note the slight downturning of soil material along the length of the crack. The round, black feature is a fungal sclerotia. Frame length 4.0 mm. (PPL).

Plate 8: H

Amorphous mineral aggregations and granular material in the Ahyb horizon contain abundant diatomaceous material. Frame length 1.0 mm. (PPL).

List of Plates for Site 25b: Heydorf Farm (forested).

Plate 8: I

Zone of well-humified organic fragments included into the densely packed organic and silt-size mineral material composing the Ohy horizon. Frame length 4.0 mm. (PPL).

Plate 8: J

Desiccation crack through horizontal layering of organic aggregates in the Ohy horizon. At bottom of micrograph, note tendency towards platy structure, suggesting ice lens formation. Frame length 4.0 mm. (PPL).

Plate 8: K

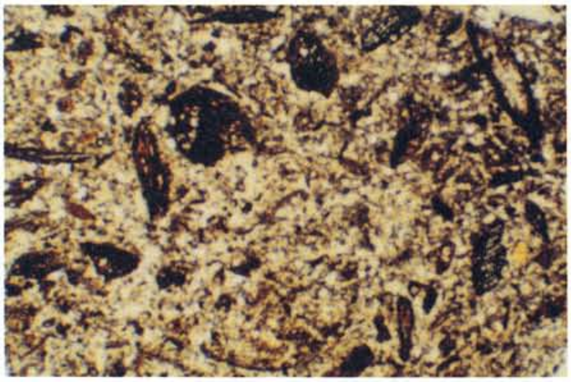
Lenticular units and planar voids produced by ice lens formation in the Ohy horizon. Note strong decomposition of organic material. Frame length 1.0 mm. (PPL).

Plate 8: L

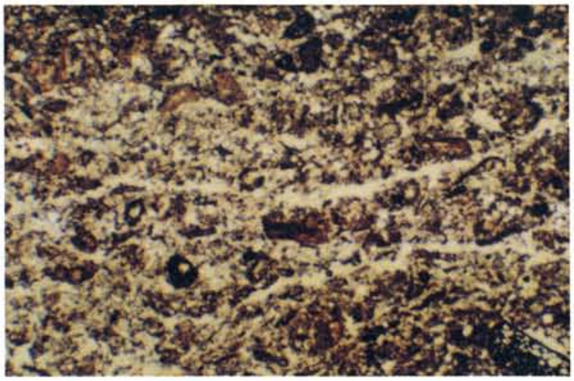
Accumulations of silt-size material on upper surfaces of very coarse organic fragments and weak aggregations in the soil matrix of the Ohy horizon. Frame length 1.0 mm. (PPL).

PLATE 8

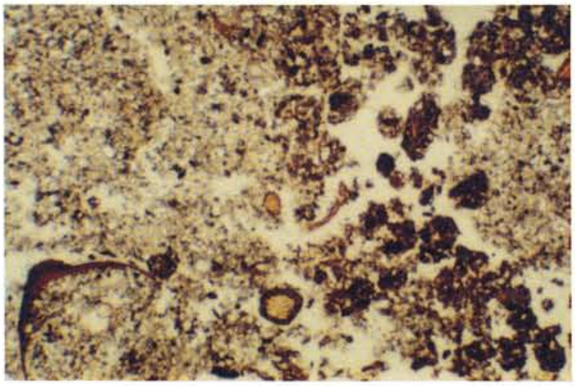
Site 25: Heydorf Farm



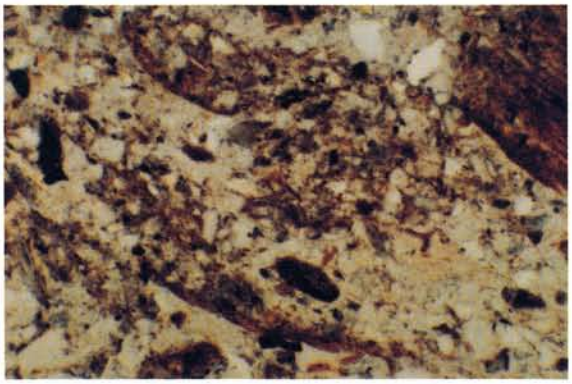
A



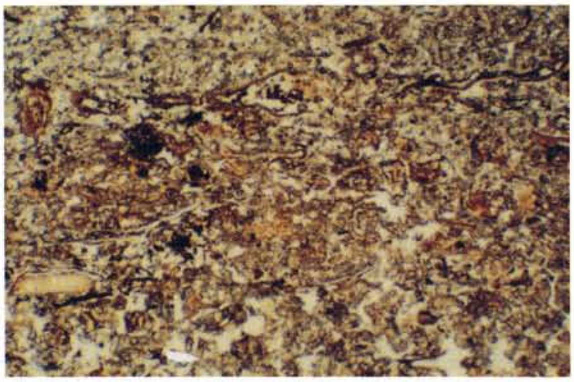
B



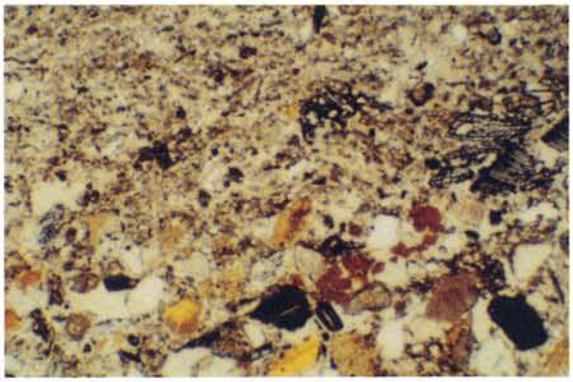
C



D



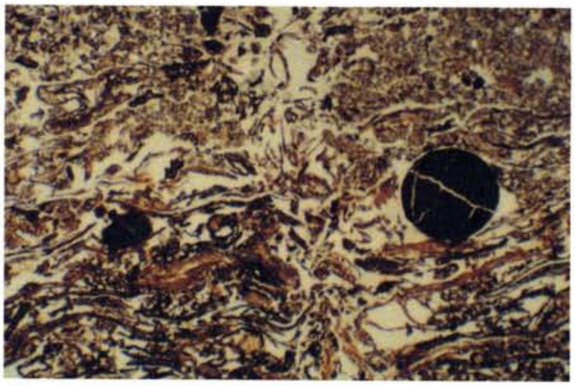
E



F

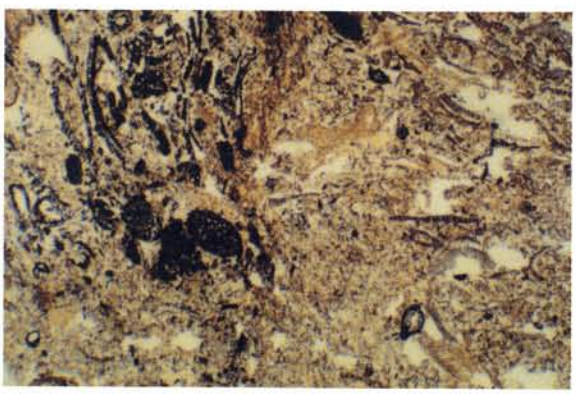
PLATE 8 (cont.)

Site 25: Heydorf Farm

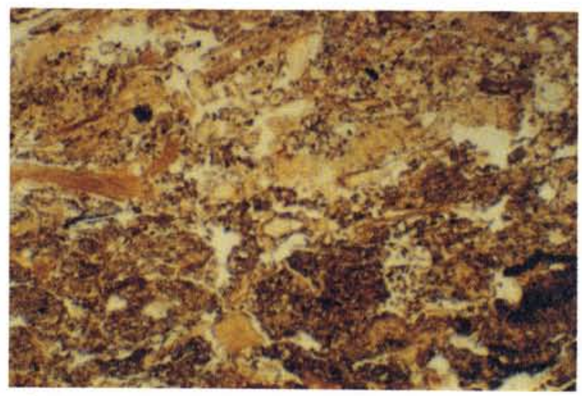


G

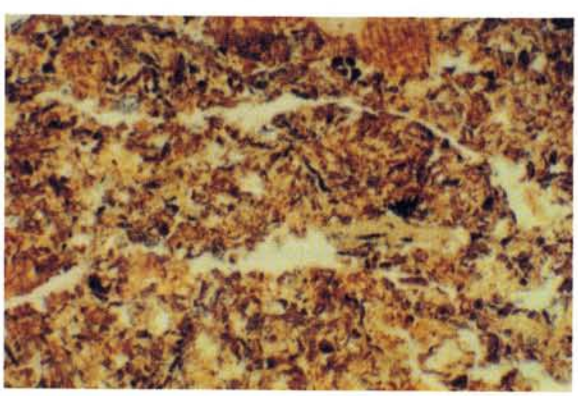
H



I



J



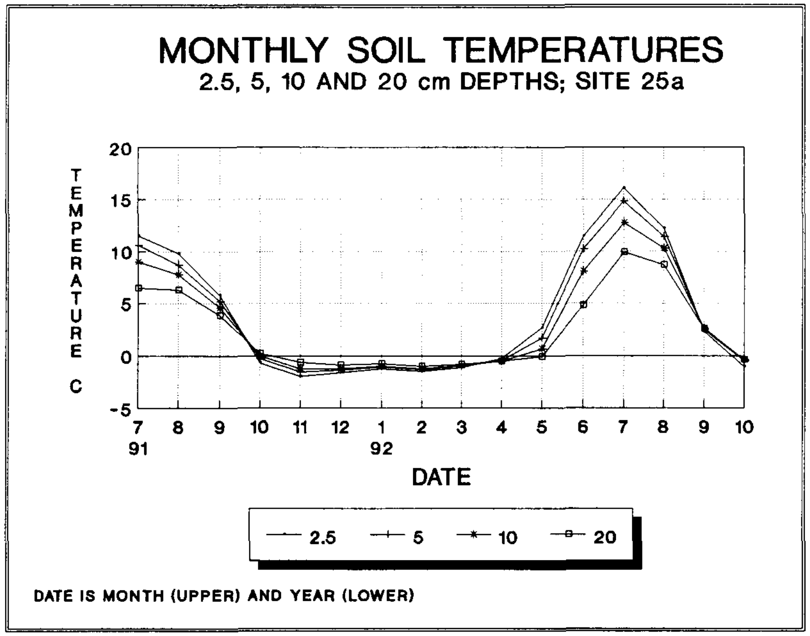
K

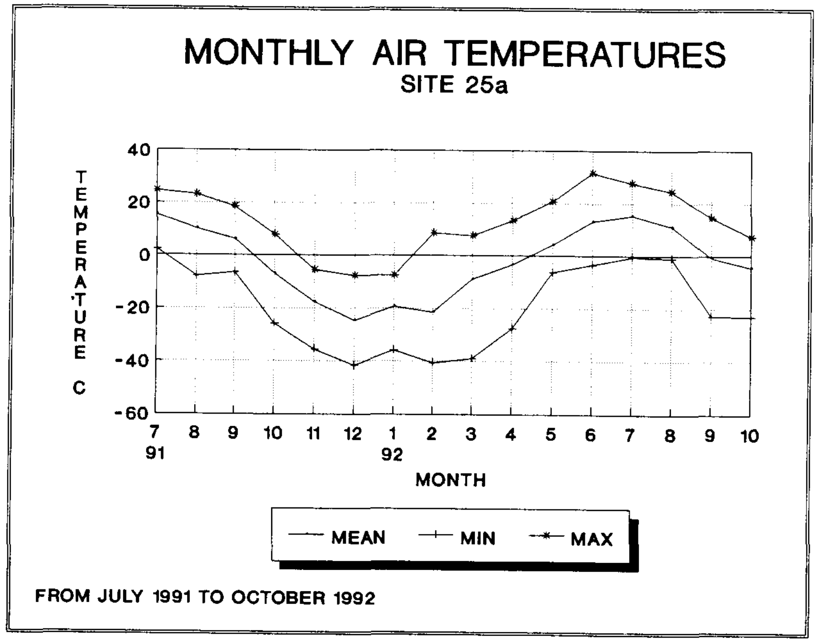
L

Table 50. Mean annual (MAST), minimum and maximum soil temperatures between July 1991 and June 1992 and mean summer* (MSST) soil temperature in 1992 at Site 25a (cleared) and Site 25b (forested).

Depth	MAST (°C)		MIN (°C)		MAX (°C)		MSST (°C)	
(cm)	Site 25a	Site 25b	Site 25a	Site 25b	Site 25a	Site 25b	Site 25a	Site 25b
2.5	2.7	-0.5	-5.0	-12.6	28.7	17.9	13.2	8.6
5	2.5	-0.6	-3.4	-10.7	24.5	14.0	12.1	7.5
10	2.0	-0.8	-2.4	-7.6	17.6	9.3	10.4	5.2
20	1.4	-1.3	-1.2	-5.2	11.4	5.3	7.8	1.0
50	0.6	-1.4	-0.5	-4.5	7.3	-0.1	4.2	-0.6
100	-0.8	-2.6	-1.0	-4.8	1.5	-1.5	0.0	-2.2
150	-1.4	-1.5	-1.7	-3.3	-1.1	-1.0	-1.2	-1.2
Air	-4.4	-4.5	-40.7	-41.4	31.5	31.0	13.4	12.9

* Summer refers to June, July and August





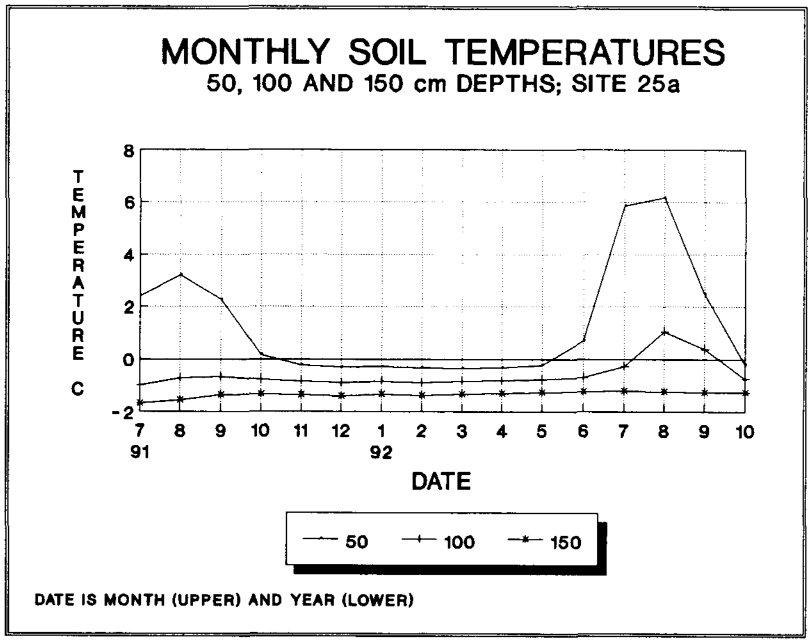
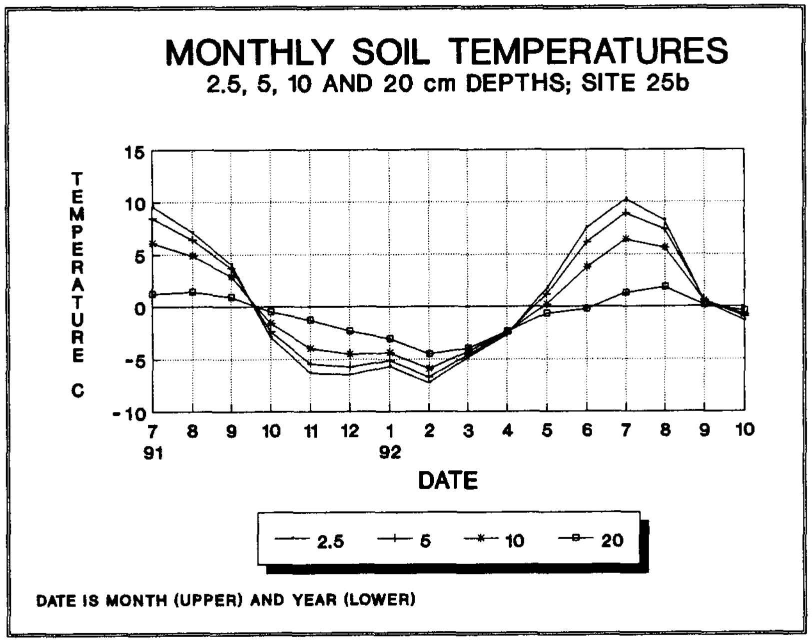
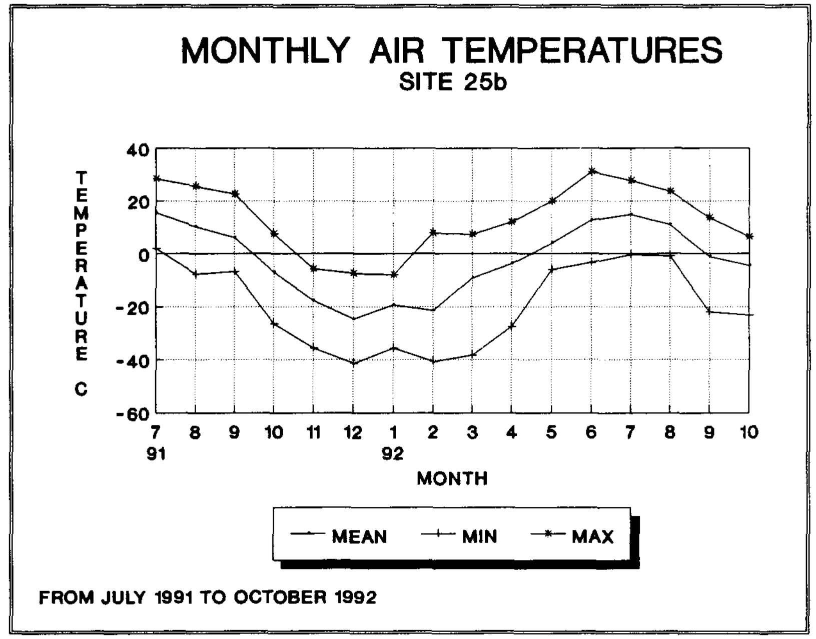


Figure 33. Monthly soil and air temperatures for the cleared soil at Site 25a (Heydorf farm) for the period July 1991 to October 1992.





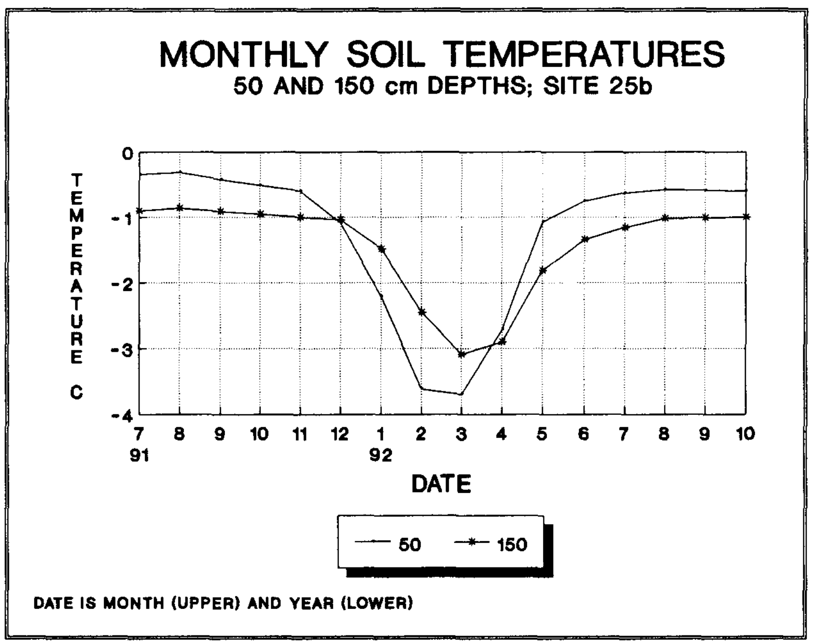
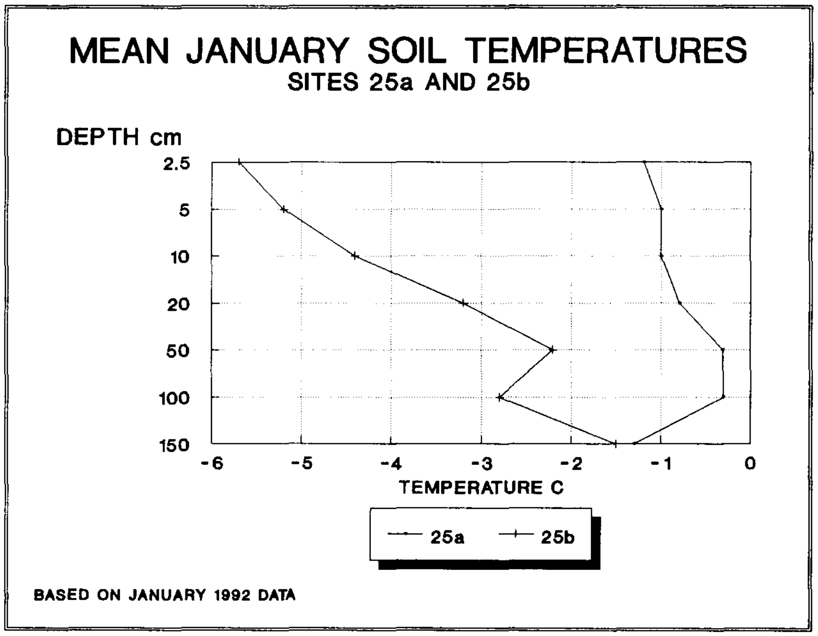


Figure 34. Monthly soil and air temperatures for the forested soil at Site 25b (Heydorf farm) for the period July 1991 to October 1992.



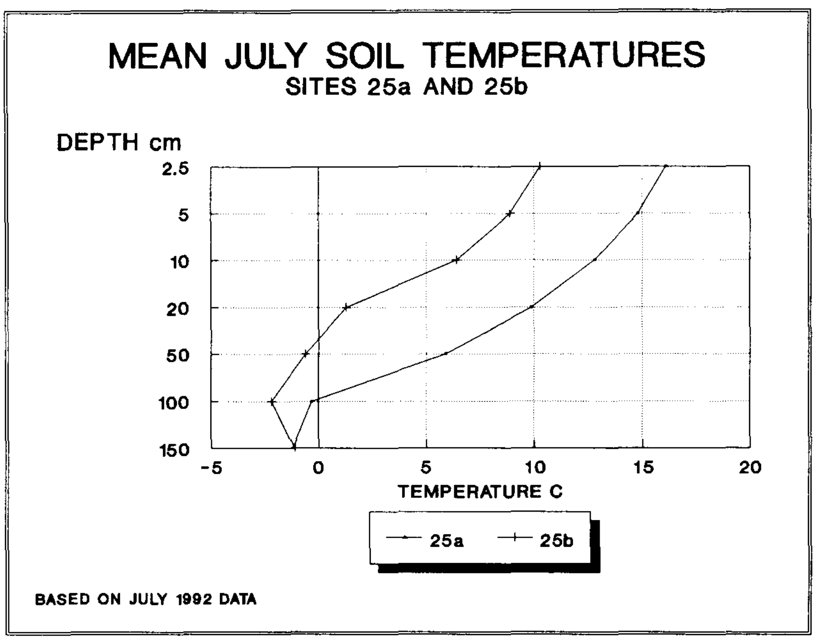
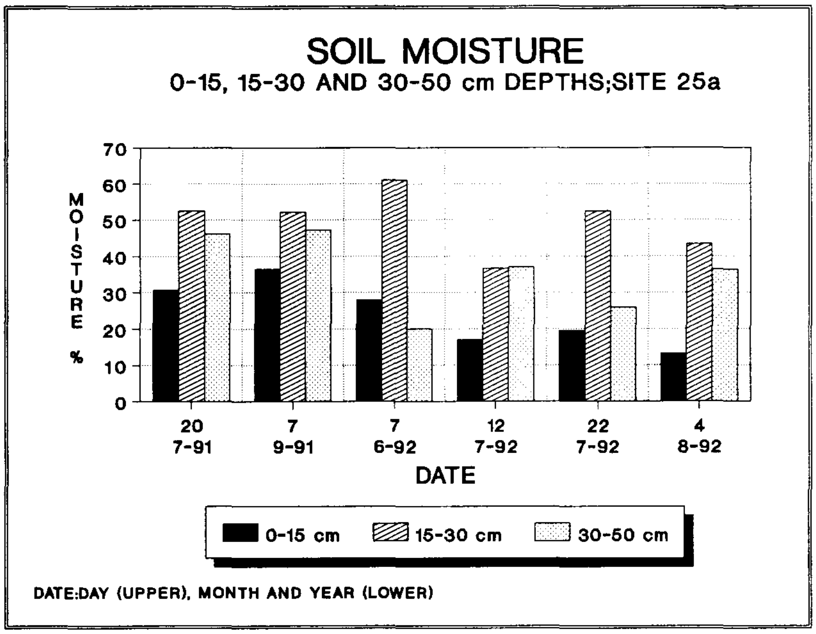


Figure 35. Comparative plots of mean January and July soil temperatures on the cleared and forested pedons at Site 25.



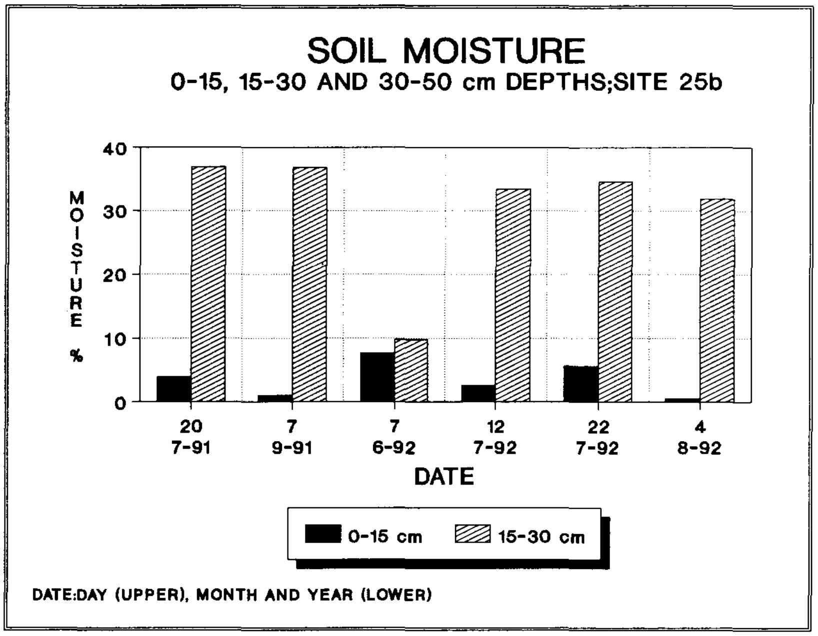


Figure 36. Summer soil moisture (%) for selected depths at Sites 25a and 25b, recorded during the summers of 1991 and 1992.

SITE 26: PLACER GOLD MINING IN THE KLONDIKE DISTRICT

We will visit an active placer gold mining operation near Dawson City. Between 1980 and 1990, annual placer gold production has varied between 75,000 and 170,000 crude ounces per year (Placer Mining Section, 1991). The term "placer mining" refers to the mining of gold contained within the alluvial sediments of the valley floor and adjacent terraces. While there has been some so-called "hard-rock" gold mining in the Yukon, the vast majority of the gold produced in the territory comes from placer mines like this one. Most of the alluvial sediments that are mined are of late Tertiary age, and are derived from the erosion of the broad plateau that extends through much of this region of the Yukon and Alaska. Gold may be concentrated by the erosion of bedrock veins, reworking of older gravel deposits or even possible post-depositional alteration processes.

The distribution of the gold within these sediments is complex and not fully understood. The highest gold concentrations are often found at or near the gravel – bedrock contact. To mine these "pay-streaks," it is often necessary to excavate through tens of metres of overburden – non-gold-bearing gravels and surficial deposits. Because most of these materials in this region are now associated with permafrost, the stripping is a lengthy, and often expensive, activity for the miners. It is the task of each placer miner to optimize his time, equipment and resources in order to make the mine pay.

In the Klondike District, most placer mining operations are family businesses. The families live on the placer claim during the mining season from May until September. By October, freezing temperatures force the shutdown of the pumping and sluicing equipment, and mining ceases for the year. Many of the mining families live in Dawson City, others come from elsewhere in Canada to work the famous Klondike gold fields each year.

SITE 27: PALEOSOLS AS INDICATORS OF PAST CLIMATE

To this point on the tour, all of our sites have reflected modern soil-forming processes. At this site we will view a polygenetic soil, that is, one with morphology that can be ascribed to both temperate weathering environments and polar desert-like conditions. The paleosol is unique to this region of the central Yukon and has received considerable research attention over the last 15 years. It provides evidence for wide fluctuations in climate through the later part of the Pleistocene epoch. This paleosol has been named the Wounded Moose paleosol (Smith *et al.* 1986), after the prominent landform (Wounded Moose Dome) about 50 km southwest of this site, where a particularly well-preserved example of the paleosol exists. The parent material for the paleosol is pre-Reid drift; at this site it is formed on glacial outwash (see Physiography and Geology section). The date of the glaciation is unknown, but is estimated to be an early to pre-Illinoian equivalent.

WOUNDED MOOSE PALEOSOL DEVELOPED ON PRE-REID GRAVEL

The soil on this site is representative of Wounded Moose soil development on glaciofluvial materials deposited during the pre-Reid glaciations. The site and pedon descriptions are provided in Table 51, the analytical data in Table 52 and the vegetation species are listed in Table 53.

The Wounded Moose paleosol underlies a loess cap that was deposited during McConnell time. It has developed on glacial drift and has the most strongly developed soil occurring in this region. This strong soil development is indicated by the deep solum (190 cm), strong red colours, and weathering in both the coarse fragments and in the clay size fraction. The soil has a paleo-argillic horizon (Bt) with a significant buildup of clay. The three Bt horizons are associated with numerous, moderately thick, clay skins and clay bridges. A few, very thin, clay films were still visible in the IIC1 horizon at a depth of 210 cm. The soil is very strongly leached and very strongly acid. The coarse fragments in the solum are strongly weathered to the point that most of the granitic and other rock types, with the exception of quartzite, are strongly altered. Cryogenic processes during the cold climatic periods resulted in the formation of numerous well developed sand wedges. Ventifacts occur at the paleosol surface.

The clay mineralogy shows evidence of strong alteration to a depth greater than 2 m within this profile (Table 52). The presence of a montmorillonite–kaolinite interstratified mineral reported by Kodama *et al.* (1976) for soil material near the site is also in evidence here. Several trends are seen within the paleosol with increasing depth. The interstratified mineral is present in minor amounts, only becoming less abundant in the IIC2 horizon. Discrete kaolinite decreases with depth, as does X-ray amorphous material. Vermiculite and mica become dominant in the lower portion of the solum, while smectite and chloritic intergrade material are present in minor amounts throughout the profile. The clay mineral assemblage reflects the influence of strong pedogenic alteration through the entire profile. Foscolos *et al.* (1977) have speculated on the various environmental conditions that could lead to such an assemblage.

Wounded Moose soil development took place largely in the pre-Reid interglacial periods. In order to achieve this higher degree of soil development, the climate was much milder than during later interglacial periods. This Wounded Moose soil was also affected by strong cryogenic processes during succeeding glacial periods, resulting in the development of the sand wedges that are visible in this pedon. During the glacial periods, strong winds also affected these paleosols. These winds caused strong erosion and the formation of ventifacts, which are found on the paleosol surface. More recently, very weak soil development has taken place, mainly in the recent loess layer. In the paleosol, however, minimal additional development probably occurred.

Micromorphology

The micromorphology of this soil is given in Table 54 and discussed below. Refer also to Plate 9.

F and Ae Horizons. The F horizon is very thin and the coarse plant fragments are usually incorporated into the mineral material, probably as a result of frost-heaving, with ice lenses and wet conditions at the surface. Faunal activity is common to frequent, contributing to the fragmentation of the organic particles. The organic fragments are moderately to strongly decomposed and consist mainly of stem and leaf tissues (resistant conifers). Coarse, well-humified (charcoal) fragments are common with depth, having been incorporated into the Ae horizon, most likely by cryogenic processes. Very fine to fine fragments are distributed throughout the soil matrix of the Ae horizon, with occasional well-humified fragments observed in the granular units and aggregations, or as single fragments coated with fine silt material. Amorphous organic material and extremely fine mineral material are the dominant constituents of the granular units and aggregations. Fine granular units and aggregations characterize the Ae horizon. From the morphologic distribution, it is difficult to completely infer that the granular material is entirely faunal derived because of its abundant occurrence, irregular aggregated appearance, and size distribution, that increases and becomes increasingly lenticular with depth. Faunal activity has probably contributed by increasing the amorphous organic matter content of the soil through dissemination of the organic fragments, and by producing very fine granular units that become incorporated into aggregations. For the most part, the aggregations were probably formed as the result of dispersion of the fine materials during saturated thaw or wet conditions and subsequent flocculation on freezing or drying. Because of the very thin vegetative cover, this soil probably experiences extremes of temperature and numerous freeze–thaw cycles. Surface ice crystals further enhance disruption of the soil material. Cryogenic processes and faunal activity have resulted in a granic and granoidic fabric distribution. With depth, freeze–thaw cycles have also contributed to the formation in the Ae horizon of very weak banded fabric that includes lenticular-shaped units of accumulations of fine silt. (Pl.9:A, B)

Bm Horizon. The effect of cryogenic processes is especially pronounced in the Bm horizon. The Bm horizon has a very complex sequence of morphology, grading from distinct entities of lenticular and granular silt accumulations in the upper portion to strongly developed banded fabric in the lower. In the upper portions, there is a predominant orientation of the lenticular units at 28° from the horizontal which, with depth, grades to strongly horizontal platy structure (banded fabric zones). In the upper part of the Bm horizon, there is considerable evidence of rotation of lenticular structures to form granular units, as well as fragmentation and rotation of portions of thick grain accumulation into the soil matrix material. This decreasing gradation of movement of the soil constituents with depth suggests that solifluction processes may be active in the upper portion of the Bm horizon, with decreasing influence towards the lower part of the Bm horizon. In addition, particle sorting occurs, leaving the fine sand and silt-size mineral grains surrounding concentrations of fine silt and amorphous material; circular patterns result. This morphology is observed predominantly in the upper part of the Bm horizon, suggesting that there is considerable influence from freeze–thaw cycles. In the lower part of the Bm horizon, the presence of a parent material discontinuity may produce a textural barrier by which fines are concentrated in the lower portion of the Bm horizon in increasing amounts and, together with ice lens formation, probably results in the formation of continuous, stable, banded fabric. Freeze–thaw cycles have also affected movement of the mica particles, with close packing along grain surfaces; in the Ae horizon, this process was observed extremely rarely; whereas, in the Bm horizon, it was observed predominantly in the silt aggregations. (Pl.9:C to H)

IIBt1 Horizon. In this horizon, clay coatings around the lithofragments have developed by different soil genetic processes than are currently present in the upper loess covering; that is, illuviation of clay material. The effects of cryogenic processes were observed in sorting of the lithofragments into zones of similar size material, and in bridges of fine material in the upper portion linking the fragments. There is also occasional evidence of frost shattering of the fragments, resulting in sharp grain edges. (Pl.9:I, J)

IIBt3 Horizon. Material, ranging from fine amorphous clay material and silt to coarse sand-size material, occurs in the pore spaces between the gravel-size lithofragments. The finer material between the gravel-sized lithofragments has a banded fabric, with evidence of particle size sorting of the mineral material. Banded morphology is very common in the IIBt3 horizon as a result of cryogenic influences. In addition, infillings with dominantly uncoated mineral grains were rarely observed in channels; this morphology suggests that, in the past, wind-blown material entered a crack developed as a result of cryogenic processes. (Pl.9:K, L)

Table 51. Site and pedon descriptions for Site 27.*

Location: 63°56'25" N Lat., 138° 30'59" W Long.
Landform: Glaciofluvial terrace
Drainage: Moderately well
Parent Material: (I) Loess (McConnell age) underlain by
(II) Glaciofluvial gravel (pre-Reid age)
Patterned Ground: Sand wedges; ventifacts at surface

Elevation: 683 m (a.s.l.)
Slope: Level
Vegetation: Aspen – white spruce forest
Soil Classification: Can. – Brunisolic Gray Luvisol (paleo)
U.S.A. – Pergelic Cryoboralfs
F.A.O. – Albic Luvisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
L	Oi	5 – 4	Dark yellowish brown (10YR 4/6); forest litter, composed dominantly of leaves, needles, and twigs; undecomposed; very strongly acid; broken, clear horizon boundary; 0 to 1 cm thick.
F	Oe	4 – 0	Black (2.5Y 2/0 m); forest litter, composed dominantly of leaves, needles, lichens, and twigs; plentiful, fine and medium, horizontal roots; very strongly acid; 2 to 4 cm thick.
Ae	E	0 – 1	Light gray (10YR 7/1.5 m); silt loam; weak, fine, platy; nonsticky, loose, nonplastic; 10% coarse fragments; strongly acid; broken, clear horizon boundary; 0 to 1 cm thick.
Bm	Bw	1 – 24	Light yellowish brown (10YR 6/4 m); silt loam; weak to moderate, medium, subangular blocky; slightly sticky, loose, nonplastic; plentiful, fine and medium, horizontal roots; 10% coarse fragments; extremely acid; wavy, clear horizon boundary; 20 to 40 cm thick; ventifacts are common at the contact between the Bm and IIBt1 horizons.
IIBt1	2Bt1	24 – 48	Reddish brown (5YR 4/3 m); gravelly clay loam; fine to medium, subangular blocky; sticky, friable, very hard, slightly plastic; few, fine, random roots; small (up to 15 cm) fossil sand wedges; frost-shattered pebbles; many, moderately thick, clay films on ped surfaces and as visible bridges between sand grains; 20% coarse fragments; extremely acid; wavy, gradual horizon boundary; 8 to 40 cm thick.
IIBt2	2Bt2	48 – 79	Yellowish red (7.5YR 4/6 m); gravelly sandy clay loam; moderate, fine to medium, granular; slightly sticky, very friable, nonplastic; thin clay films as visible bridges between sand grains; 30% coarse fragments; extremely acid; wavy, diffuse horizon boundary; 31 to 42 cm thick.
IIBt3	2Bt3	79 – 120	Dark brown (7.5YR 4/4 m); gravelly sandy loam; moderate, fine to medium, granular; nonsticky, loose, nonplastic; common, thin, clay films as visible bridges between sand grains; 50% coarse fragments; very strongly acid; wavy, diffuse horizon boundary; 31 to 34 cm thick.
IIBC	2BC	120 – 190	Dark yellowish brown (10YR 4/6 m); gravelly loamy sand; very weak to moderate, fine to medium, granular; nonsticky, loose, nonplastic; few, very thin, clay films as visible bridges between sand grains; 40% coarse fragments; very strongly acid; diffuse, wavy horizon boundary.
IIC1	2C1	190 – 210	Brown (10YR 5/3 m); gravelly loamy sand; weak, medium, granular; single grain secondary; nonsticky, loose, nonplastic; few, very thin, clay films as visible bridges between sand grains; 40% coarse fragments; very strongly acid; diffuse, wavy horizon boundary.
IIC2	2C2	210 – 395	Light olive brown (2.5Y 5/4 m); gravelly sand; single grain; nonsticky, loose, nonplastic; 40% coarse fragments; very strongly acid.

* Taken from Tarnocai 1987c.

Table 52. Analytical data for the Brunisolic Gray Luvisol (paleo) at Site 27.*

Chemical Analysis										
Horizon	pH ($CaCl_2$)	Org. C (%)	$CaCO_3$ Equiv. (%)	Total N (%)	CEC (me/100g)	Exchangeable Cations (me/100g)*				
						K	Ca	Mg	Al	Total
L	5.0	37.53	0	0.98	–	1.3	43.8	11.8	–	56.9
F	5.3	15.80	0	0.76	–	1.2	25.6	6.8	–	33.6
Ae	–	–	–	–	–	–	–	–	–	–
Bm	4.4	0.39	0	0.04	11.6	0.1	3.0	2.3	1.2	6.6
IIBt1	4.4	0.15	0	0.02	25.5	0.1	9.8	6.3	0.5	32.8
IIBt2	4.4	0.13	0	0.01	15.9	0.1	6.5	4.3	0.3	11.2
IIBt3	4.7	0.11	0	0.01	11.7	0.1	6.5	3.3	–	9.9
IIBC	4.9	0.03	0	0.02	7.8	0.1	5.2	2.1	–	7.4
IIC1	4.9	0.10	0	0.01	9.0	0.1	5.2	1.8	–	7.1
IIC2	4.8	0.08	0	0.01	5.0	0.1	2.4	0.7	–	3.2

* Neutral salt extraction

Sesquioxides (%)						
Horizon	Dithionite		Oxalate		Pyrophosphate	
	Fe	Al	Fe	Al	Fe	Al
L	–	–	–	–	0.01	
F	–	–	–	–	0.19	0.16
Ae	–	–	–	–	–	–
Bm	1.44	0.20	0.34	0.22	0.06	0.12
IIBt1	1.62	0.18	0.20	0.21	0.05	0.06
IIBt2	1.24	0.13	0.14	0.10	0.07	0.06
IIBt3	0.97	0.12	0.16	0.11	0.05	0.04
IIBC	0.79	0.10	0.12	0.08	0.05	0.04
IIC1	0.74	0.11	0.13	0.08	0.05	0.04
IIC2	0.42	0.06	0.06	0.04	0.03	0.02

* Taken from Tarnocai 1987c.

Table 52. Analytical data for the Brunisolic Gray Luvisol (paleo) at Site 27 (cont.)

Clay Mineralogy (<2μ)*								
Horizon	Mineralogy							
	Smect.	Verm.	Mica	Chlor. Interg.	Kaolin	Quartz	Interstrat. Mineral	X-ray Amorph.
L	–	–	–	–	–	–	–	–
F	–	–	–	–	–	–	–	–
Ae	–	–	–	–	–	–	–	–
Bm	–	–	–	–	–	–	–	–
IIBt1	1	1	1	1	1	tr	1	1
IIBt2	1	1	1	1	1	tr	1	tr
IIBt3	1	1	1	1	1	tr	1	tr
IIBC	1	2	1	1	1	tr	1	tr
IIC1	1	2	2	1	1–tr	tr	1	tr
IIC2	1	2	2	1	1–tr	tr	tr–1	tr

* Amount estimated from x-ray diffractograms: tr = trace (less than 10%)
1 = minor (10–25%)
2 = dominant (25–50%)

Particle Size Distribution (% <2 mm)									
Horizon	Sand						Silt	Clay	Texture
	v. coarse	coarse	medium	fine	v. fine	Total			
L	–	–	–	–	–	–	–	–	–
F	–	–	–	–	–	–	–	–	–
Ae	–	–	–	–	–	–	–	–	–
Bm	0.5	0.6	0.3	1.1	10.7	13.2	75.3	11.5	SiL
IIBt1	4.2	7.3	5.5	4.7	9.0	30.6	35.5	33.9	CL
IIBt2	10.2	26.8	21.1	8.7	3.6	70.4	6.8	22.8	SCL
IIBt3	35.5	29.8	8.0	4.0	1.7	79.0	4.3	16.7	SL
IIBC	31.4	40.5	10.5	2.8	1.1	86.3	2.5	11.2	LS
IIC1	26.4	33.0	16.7	7.0	2.5	85.7	4.4	10.0	LS
IIC2	32.9	22.0	14.6	15.1	6.1	90.7	6.1	3.1	S

Table 53. Vegetation description for Site 27.

Vegetation			
TREES (% cover)			
Tall Trees		**Low Trees**	
25.0	*Populus tremuloides*	10.0	*Picea mariana*
		20.0	*Populus tremuloides*
SHRUBS (% cover)			
Tall Shrubs		**Low Shrubs**	
1.0	*Picea mariana*	5.0	*Ledum palustre* ssp. *groenlandicum*
10.0	*Populus tremuloides*	10.0	*Picea mariana*
1.0	*Salix* sp.	5.0	*Populus tremuloides*
		1.0	*Salicaceæ* sp.
		1.0	*Vaccinium uliginosum*
Medium Shrubs		**Dwarf Shrubs**	
10.0	*Picea mariana*	35.0	*Arctostaphylos uva-ursi*
5.0	*Populus tremuloides*	1.0	*Empetrum nigrum*
1.0	*Salix* sp.	1.0	*Linnæa borealis*
		5.0	*Vaccinium vitis-idæa*
HERBS (% cover)			
1.0	*Geocaulon lividum*	1.0	*Pedicularis labradorica*
5.0	*Lupinus arcticus*		
GRASSES (% cover)			
10.0	*Festuca altaica*		
MOSSES – LICHENS (% cover)			
Mosses		**Lichens**	
5.0	*Bryophyte* spp.	1.0	*Cetraria cucullata*
15.0	*Hylocomium splendens*	5.0	*Cladina mitis*
		5.0	*Cladonia* spp.
		1.0	*Cladina stellaris*
		0.5	*Peltigera aphthosa*
		5.0	*Stereocaulon tomentosum*
NON-VEGETATED (% cover)			
–	Bare	–	Rock
10.0	Slash	–	Water
35.0	Litter		

Table 54. Micromorphological Features for Site 27: Pleistocene Paleosol.

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
F (Oe)	**Overall:** Extremely thin horizon of moderately to strongly decomposed and well-humified organic fragments intermixed with mineral grains; extremely porous; occasional faunal activity. (Pl.9:A) **Related DP:** Ortho-phyto-humigranic-humi-mullgranoidic. Plasmic: Not applicable. **Microstructure:** Granular c/f RDP: Enaulic. b-fabric: Not applicable.	**Void Pattern:** Extremely porous, simple and complex packing pores, size range highly variable. **Basic Components:** Mineral: Loose, angular, quartz grains (mainly 10–100 μm) occur commonly; frequently forms matrix material of granular units. Occasional weathered mica particles; rare to occasional opal phytoliths. Organic: Commonly fragmented leaf, stem tissues dominantly 100-500 μm; frequently moderately to strongly decomposed; with depth, well-humified (charcoal) fragments are more common; occasional fungal hyphae, rare fungal mass (probable lichen); rare pollen. **Pedofeatures:** Faunal: Common occurrence; 40–80 μm, associated with pore space; produce granular component of soil fabric.	Weak sorting and mixing of coarser organic fragments into mineral material. Faunal activity may be a contributing factor.
Ae (E)	**Overall:** The soil morphology consists of closely packed fine granular units (30–150 μm) with abundant organic fragments distributed throughout; with depth, grades to weak banded structure. (Pl.9:B) **Related DP:** Ortho-phyto-humi-mullgranic-mullgranoidic/mullgranoidic-porphyroskelic/ banded. Plasmic: Silasepic. **Microstructure:** Complex: close packing of granular units grades to spongy structure; with depth, very weak lenticular structure. c/f RDP: Soil material between coarse organic fragments weak enaulic; granular units result in monic fabric zones. b-fabric: Stipple-speckled.	**Void Pattern:** Simple and complex packing voids (50–200 μm) are dominant; common root channels 200–400 μm wide. **Basic Components:** Mineral: Loess material with frequent angular quartz grains (10–100 μm), common weak to moderately-weathered mica particles, occasional hornblende, rare feldspar and chert. Organic: Amorphous colloidal organic material forms dominant component of groundmass of granular units. Frequent, well-humified (charcoal) organic fragments (mainly 40–280 μm, occasionally to 1.2 mm) incorporated into soil matrix, smaller fragments (<200 μm) are occasionally incorporated into granular units or coated with very fine matrix material, with fragments (<10–30 μm) frequently distributed randomly in the groundmass. Common occurrence of weak to moderately decomposed root material. Rare fungal sclerotia 950 μm. **Pedofeatures:** Textural: Extremely rare packing of mica particles along grain surfaces. Very rarely, well-humified fragments have loose coatings of fine matrix material; very discontinuous. Faunal: Associated occasionally to commonly with organic fragments in root channels; 20–50 μm, circular to elliptical, amorphous material; becomes incorporated into matrix material.	Incorporation of organic fragments into soil matrix material. Extensive granular material occurs; held intact loosely by colloidal amorphous organic material and extremely fine silt and clay, suggesting that flocculation of dispersed fines from soil solution may have occurred; this process has resulted in formation of irregular aggregations. In addition, faunal activity has resulted in distinct granular structural units. Cryogenic processes and faunal activity are complementary in that faunal activity breaks down the organic material, producing amorphous organic material that is susceptible to movement by cryogenic processes.

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

Table 54. Micromorphological Features for Site 27: Pleistocene Paleosol (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bm (Bw)	**Overall:** Cryogenic processes have strongly affected the soil morphology; with depth, silt accumulations increase; fabric zones of platy structure with lenticular and granular structural units grade to prominent banded fabric. (Pl.9:C to H) **Related DP:** With depth, grades from banded-orbiculic-silasepic-porphyroskelic to banded-orbiculic-conglomeric-porphyric to conglomeric-porphyric to matrigranoidic to banded matri-fragmic-matri-fragmoidic to banded. Plasmic: Dominantly silasepic; with depth, fabric of silt accumulations grade from silasepic to weak insepic. Rare skelsepic. **Microstructure:** Complex: Fabric zones varying with depth from platy, granular and blocky to platy structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled. Rare granostriated.	**Void Pattern:** Simple and compound packing voids (variable size ranges, dominantly 30–150 µm) are frequent between closely packed fine sand to silt-size mineral grains and silt aggregations; planar voids in zones of banded fabric occur more frequently with depth, mainly 80–200 µm; occasional to common root channels range from 0.4–1.4 mm. **Basic Components:** Mineral: Sorting of fine sand and silt-size mineral grains between silt accumulations, most prominent in upper Bm, dominantly subangular to angular quartz, common weathered mica particles, rare hornblende, feldspar. Occasional to commonly occurring subangular to subrounded lithofragments (variable size range 0.2–4.2 mm), frequent sandstone, siltstone, rare chert; subvertical alignment increasingly pronounced with depth; occurrence of lithofragments decreases with depth. Organic: Root material, strongly decomposed, is associated with occasional faunal activity. Strongly to extremely decomposed fragments of organic particles (50–250 µm) occur commonly to frequently; randomly distributed. Amorphous, medium to dark brown material of silt aggregations may have organic component. **Pedofeatures:** Textural: Silt accumulations dominate on coarse lithofragments, accumulations vary from 40–640 µm with occasional occurrence to 1.6 mm; tend to be thicker in the upper Bm horizon. Thick accumulations become commonly fragmented from the grain surfaces and form granular aggregations in the soil matrix. Occasional to common evidence of successive layering of material. Rare packing of mica particles on grain surfaces of silt-size grains; observed predominantly in silt accumulations. (Pl.9:D, E, F) Faunal: Faunal activity occasionally associated with root material; fecal material occurs most frequently within root fragments; irregular aggregations, 10–50 µm, consist of amorphous material and plant tissue fragments.	Sorting of material: fine silt and amorphous material is concentrated into distinct types of silt accumulations, such as granular units, lenses, and thick textural accumulations on grain surfaces of coarse lithofragments. In the upper Bm horizon, fine sand to silt-size mineral grains remain in distinct zones surrounding the silt accumulations, and result in circular patterns. This morphology is the result of numerous freeze–thaw cycles; decreasing intensity with depth whereby ice lens formation is the dominating influence. (Pl.9:C to F) Dominance of banded fabric in lower Bm horizon suggests stability in contrast to the upper Bm, where considerable movement of material by rotation takes place, resulting in granular units, fragmentation of thick grain accumulations, and alignment of coarse mineral grains. Successive layering is observed in accumulations, suggesting periods of stability. (Pl.9:G, H) Banded fabric strongly developed in the lower Bm horizon; suggests greater influence of ice lens formation. (Pl.9:H) Alignment of lithofragments is dominantly subvertical. (Pl.9:D, E, F) In upper Bm horizon, may be downslope movement as lenticular units show predominant alignment 28° from the horizontal and become increasingly horizontal with depth, as in the lower Bm. Packing of mica particles on silt-size grains mainly observed in densely packed silt accumulations; suggests drying effect and movement of fines during freeze–thaw cycles.

Table 54. Micromorphological Features for Site 27: Pleistocene Paleosol (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
IIBt1 (2Bt1)	**Overall:** Loosely packed lithofragments with clay coatings; extremely porous matrix with very fine sand to coarse sand-size lithofragments that occupy spaces between the very coarse sand- to gravel-size fragments; weak sorting of fragments evident. (Pl.9:I, J) **Related DP:** Granular-intertextic intergrade. Plasmic: Matrichlamydic// matriplectic. **Microstructure:** Complex fabric with intergrain structure consisting of bridged, pellicular and single-grain structure; all grains coated with fine material. c/f RDP: Chitonic-enaulic with zones of gefuric. b-fabric: Granostriated.	**Void Pattern:** Simple packing pores dominate the morphology; size range is highly variable. Occasional thin (<10 μm) planar pores and very rare vughs result from the drying of amorphous clay material; observed in zones of matriplectic fabric and as coatings on grain surfaces of lithofragments. **Basic Components:** Mineral: Lithofragments dominate; frequent sandstone, siltstone, occasional chert, shale, metamorphic (phyllite, quartzite). Extremely coarse to coarse fragments (0.5–12 mm) are subangular to frequently subrounded; fragments (<400 μm) commonly subangular. Complex morphology results from silt- to medium sand-size grains that occupy spaces between coarse fragments. All lithofragments are coated with amorphous clay. Rare, opaque particles (30–150 μm) are distributed in amorphous clay material; probable iron oxide content as shows brownish-red interference colours; two sources: opaque minerals derived from lithofragments as well as possible replacement of highly-humified charcoal fragments. Organic: No recent organic material observed; possibility that some of the opaque particles may have had an organic origin. **Pedofeatures:** Coatings: All lithofragments coated with amorphous clay; range in thickness <10–200 μm mainly 10–50 μm, thicker in crevices and irregularities of fragments, producing a smoothing and rounding of the fragments; amorphous clay strongly oriented, weak suggestion of successive layering; in matriplectic zones forms bridges and fills spaces between lithofragments. (Pl.9:I, J)	Lithofragments occurring in spaces between extremely coarse fragments show weak sorting into zones with concentrations of fragments of similar size range; most noticeable with fragments of 300–500 μm. (Pl.9:J) Clay coatings generally surround only the individual loose particles, suggesting movement of the fragments; this may be supported by the smooth outer surfaces and enhanced rounded shapes from the infilling of irregularities. In some zones, amorphous clay and silt material forms bridges between lithofragments to produce a weak banded appearance; such features are characteristic of cryogenic processes. Frost shattering of fragments observed rarely to occasionally; quartz and sandstone fragments show sharp, angular edges.
IIBt3 (2Bt3)	**Overall:** Complex morphology consisting of amorphous, silt- and sand-size material that forms bridges and aggregations (banded fabric) with coarse lithofragments that incompletely fill the void spaces between gravel-size lithofragments; strongly expressed effect from cryogenic processes with banded fabric and sorting of fragments. (Pl.9:K, L) **Related DP:** Complex morphology of intertextic fabric with intergranular material banded-porphyric fabric. Plasmic: In intergranular material, skel-vo-omnisepic fabric with unistrial fabric. **Microstructure:** Complex morphology with intergrain structure consisting of zones of banded fabric, massive, and granular structure. c/f RDP: Enaulic with intergranular spaces porphyric. b-fabric: Unistrial with porostriated and granostriated.	**Void Pattern:** Intergranular material is dominated by simple and compound packing voids with occasional to common channels frequently with smoothed, rounded pore walls. Size ranges highly variable. **Basic Components:** Mineral: Lithofragments of gravel size (>4mm–15 mm) are rounded to subrounded; consist dominantly of sandstone, siltstone, and shale. Lithofragments in intergranular spaces similar in composition to gravel-size fragments, but are commonly subrounded to subangular and occasionally angular; size ranges 20–800 μm; evidence of zones of particle size sorting with concentration of coarser material. Channels commonly contain lithofragments (orthochlamydic-granic) where grains have very thin to no coatings; concentrations of similar sized grains. Intergranular material of clay material result of extreme weathering. Organic: No organic material observed. **Pedofeatures:** Coatings: On gravel-size lithofragments, discontinuous coatings of yellowish-brown amorphous clay are common; near the grain surface of the lithofragments, brownish-red coatings with silt-size quartz material suggest separate genetic origin from yellowish-brown amorphous clay. Yellowish-brown amorphous clay dominates in the pore space between the gravel-size lithofragments, forming bridges between particles and frequently in parallel aligned masses incompletely filling the pore spaces.	Smoothed pore walls of channels suggest ice lens formation below gravel fragments; fragments uplifted leaving rounded, smoothed imprint in pore walls. Channels are occasionally associated with zones of loose mineral material with very thin to no coatings, suggesting wind blown material has entered cryogenic cracks. Banded fabric commonly occurs in the intergranular spaces; clay material occurs dominantly on upper surface of band; soil texture of the bands becomes coarser with depth.

PLATE 9

List of Plates for Site 27: Pleistocene Paleosol.

Plate 9: A

Moderately to strongly decomposed and well-humified organic fragments characterize the extremely porous F horizon. Frame length 4.0 mm. Plane polarized light (PPL).

Plate 9: B

Iin the Ae horizon, loose to close packing of fine granular organic material with mineral material and plant fragments results in secondary structural units. Frame length 4.0 mm. (PPL).

[Note: Plate 9: C to H represents a sequence, with depth in the Bm horizon, of morphologic changes in response to cryogenic processes.]

Plate 9: C

Particle sorting of the finer fraction into lenticular units in the Bm horizon at a depth of approximately 1–2 cm. Frame length 4.0 mm. (PPL).

Plate 9: D

Silt-size material has accumulated on the grain surfaces of lithofragments; the varying positions of the accumulated material suggest considerable rotation and movement of the lithofragments in the soil matrix. Particle sorting of the finer fraction into lenticular units continues. Note that the size of the individual lenticular units increases with depth. Sample from the Bm horizon at a depth of approximately 2–3 cm. Frame length 4.0 mm. (PPL).

Plate 9: E

The rounded granular units indicate considerable rotation is taking place in the soil matrix of the Bm horizon at a depth of approximately 3.5–5 cm; there is a downward trend to the lenticular accumulations. Note the crack in the substantial accumulation of fine materials on the large lithofragment, indicating possible eventual break-up. The origin of some of the granular structures may be from such accumulations and incorporated into the soil matrix. Strong particle sorting has occurred, with the coarser material remaining around the aggregations of finer material. Frame length 4.0 mm. (PPL).

Plate 9: F

Zone of granular units of finer material, together with substantial accumulation on grain surfaces of lithofragments, indicates strong effect of cryogenic processes. There is a downward trend of the soil constituents, probably as a result of cryogenic pressures. Extreme particle sorting has occurred, with the coarse material remaining in zones around the aggregations and granular units of finer material. Sample from the Bm horizon at a depth of approximately 5–7 cm. Frame length 4.0 mm. (PPL).

Plate 9: G

At a depth of approximately 12–14 cm, the Bm horizon is characterized by weakly blocky to platy structure. It appears to be a transition zone between movement of the soil constituents by cryogenic pressures and the effect of ice lens formation. Particle sorting is not as pronounced as in the upper portions, but still takes place as evidenced by zones of coarse quartz grains in the lenticular units. Frame length 4.0 mm. (PPL).

Plate 9: H

At a depth of approximately 14–16 cm, the Bm horizon is dominated by banded fabric as a result of ice lens formation. Separation of the coarse fraction from the fines is minimal. Frame length 4.0 cm. (PPL).

Plate 9: I

Iin the IIBt1 horizon, extremely porous matrix of loosely packed lithofragments with amorphous clay coatings. In some zones, the amorphous clay forms bridges and fills spaces between the lithofragments. Frame length 4.0 mm. (PPL).

Plate 9: J

Same as Pl.9:I, showing strongly oriented clay between lithofragments and mineral grains in the IIBt1 horizon. Frame length 4.0 mm. Crossed polarized light (XPL).

Plate 9: K

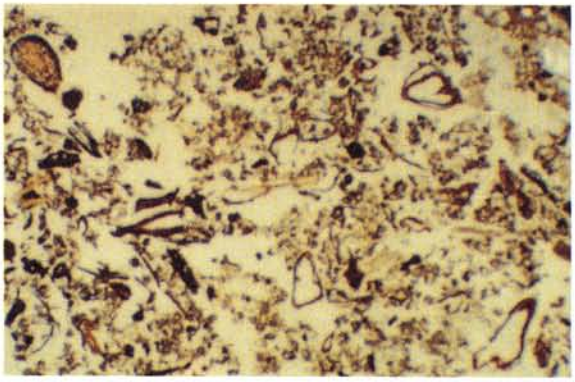
Complex morphology in the IIBt3 horizon of amorphous clay, silt and sand-size material forming bridges between coarse lithofragments. Note vertical alignmemt of lithofragments and positioning of planar voids along grain surfaces. Frame length 4.0 mm. (PPL).

Plate 9: L

Similar view to that in Pl.9: K, showing strong orientation of clay material and possible particle sorting of silt and sand-size material in the IIBt3 horizon. Frame length 5.5 mm. (PPL).

PLATE 9

Site 27: Pleistocene Paleosol



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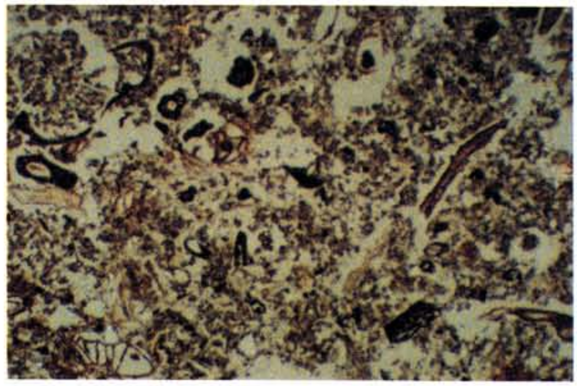
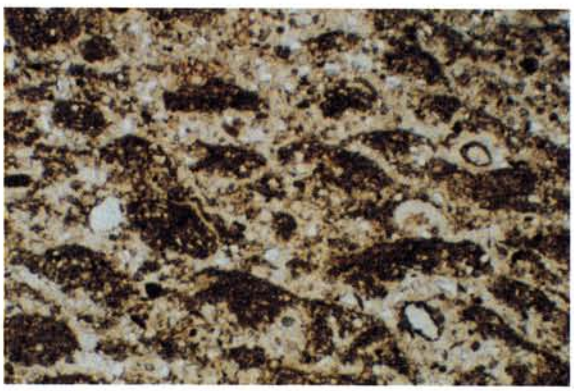


B



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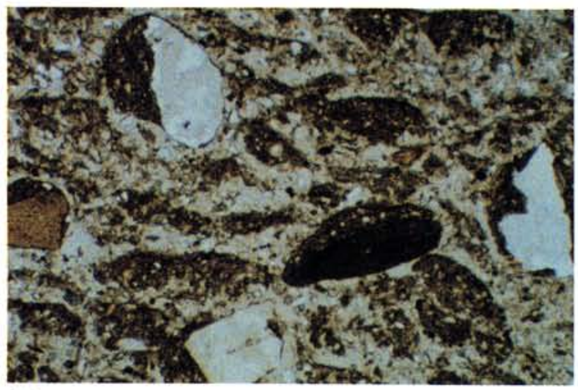

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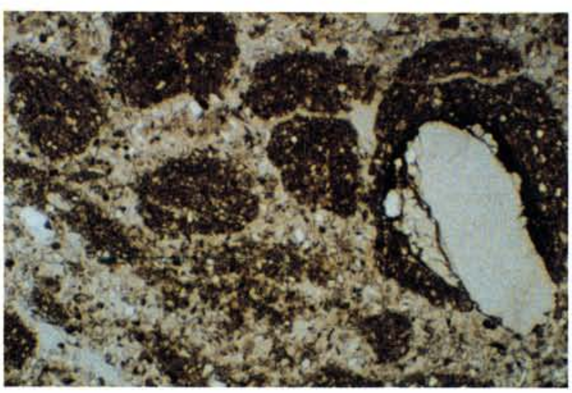
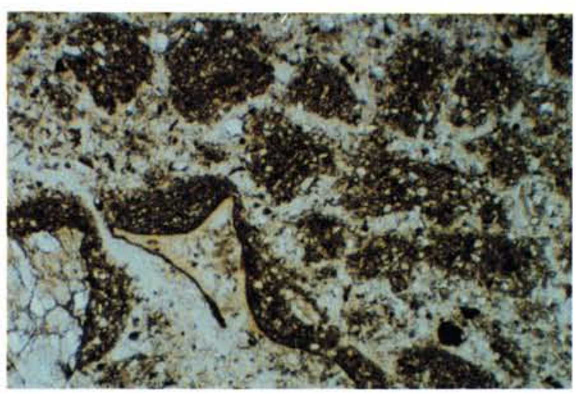


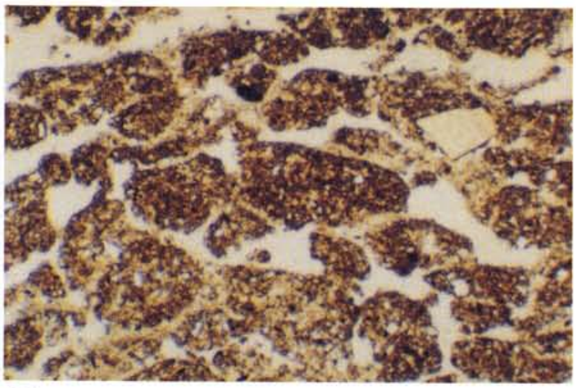
E



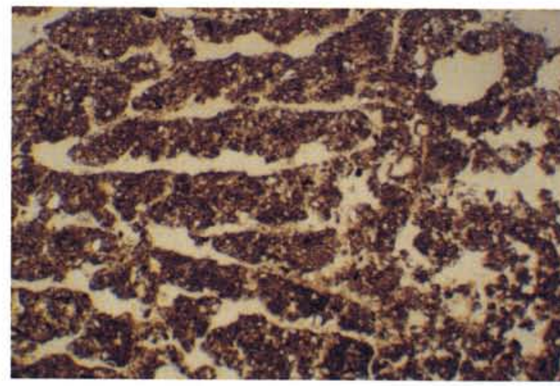
F

PLATE 9 (cont.)

Site 27: Pleistocene Paleosol



G



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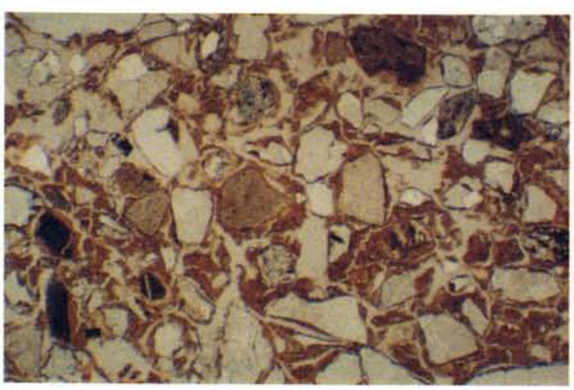

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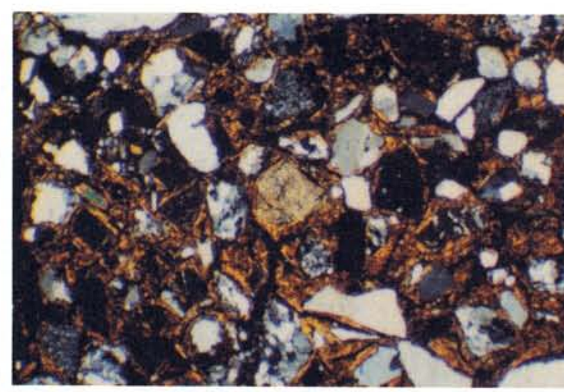

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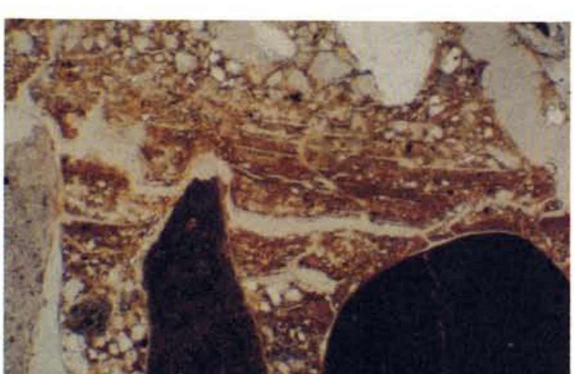

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SITE 28: THE EFFECT OF ASPECT ON SOIL DEVELOPMENT

TOO MUCH GOLD CREEK was probably the only stream radiating from "King Solomons Dome" to the south that did not yield much gold. The two sites in this area do, however, offer a good opportunity to look at the impact of aspect on soil and vegetation development at this latitude (Figure 38). This region lies within the Discontinuous Permafrost Zone, where the presence or absence of permafrost is dependent on many site factors, one of them being aspect. As can be seen here, the south-facing slopes are significantly warmer than the northern aspects, but they are also drier.

Several features of soil development are rather unique here. First, there has been a long weathering history because this area was not glaciated, at least during the Pleistocene. In addition, the predominantly metamorphic rocks are rather easily broken down. Therefore, there is commonly a weathering profile up to 1 m or more in depth in the more stable landscape positions. Several complicating factors, however, result in a wide variety of profile and material types. Foremost is the instability of the landforms, with their steep slopes and active cryogenic phenomena, particularly at higher elevations, which results in a good deal of colluvial activity and profile disruption. Another factor is the occurrence of post-glacial loess, which is 30 or 40 cm thick in the most favourable locations and in which modern profiles have formed.

SITE 28a: ORTHIC DYSTRIC BRUNISOL (SOUTHEAST ASPECT)

The soil on the warm, well-drained, southeast-facing slope at this site is an Orthic Dystric Brunisol (Figure 37; Table 55) that has no permafrost within the control section. The main pedological process is oxidation of the material, associated with some hydrolysis and release of iron. Organic matter accumulation is very low because of the light ground cover and the relatively high mineralization potential of the site. Colluviation is obviously a factor, but where the slopes are less steep and the material more stable, eluvial (Ae) horizons may be seen over the brown Bm horizons. The eluviation is quite weak and in no instances have Bt (Argillic) horizons been identified in the modern profiles. Analytical data for this soil are given in Table 56.

This site has mixed Boreal forest conditions, and the vegetation (Table 57) consists of a white birch forest with minor amounts of white spruce and aspen and scattered shrub and herb layers. There is a well-developed mor humus form under a forest canopy of aspen and spruce. In these respects, the site is similar to Boreal forest sites in more temperate environments.

Micromorphology

The micromorphology is given in Table 58 and described below. Refer also to Plate 10.

L-H Horizon. This horizon is dominated by well-humified and strongly decomposed organic material. No features attributable to cryogenic processes were observed. Amorphous granular and lenticular units containing frequent diatoms are interspersed between the organic fragments. This suggests that the L-H horizon experienced shallow flooding periodically, probably from meltwater pools when spring conditions were warm enough to allow the growth of diatoms. Faunal activity would have taken place during the drier periods. There is a sharp boundary to the Bm1 horizon. (Pl.10:A)

Bm1 Horizon (Upper boundary with L-H horizon). At the contact with the L-H horizon, the Bm1 horizon is characterized by platy peds that have resulted from cryogenic processes of freezing and thawing cycles, and possibly from ice lens and ice crystal formation. The structural units would also be affected by any wetting and drying cycles experienced throughout the summer on the drier slope aspect. The effect of drying cycles is very weakly expressed by the packing of mica particles along mineral grain surfaces. (Pl.10:B)

Bm1 Horizon. This horizon shows the strong influence of cryogenic processes with the movement of finer soil material. Silt accumulations and silt lenses are frequent. There is a preferential alignment of the lithofragments. The positioning of the silt accumulations on the grain surfaces and the diagonal direction of the silt lenses suggest movement downslope by solifluction processes. The directional alignment of the structural units and lithofragments corresponds to the slope angle. (Pl.10:C)

Bm2 Horizon. This horizon has more strongly developed platy structure and thicker grain surface accumulations than the Bm1 horizon, indicating that this horizon experiences greater stability, with decreased movement from cryogenic processes and little effect from solifluction since the structural units are horizontally aligned. There is considerable downward movement of the finer material (amorphous colloidal organic material, iron oxide and clay-size material) as a result of numerous freeze–thaw and wetting–drying cycles. The frequent planar voids suggest considerable ice lens formation occurs and contributes to the formation of the platy structure. During the summer period, this horizon is free of ice, as evidenced by root material and penetration of soil fauna along former root channels. (Pl.10:D, E, F)

SITE 28b: REGOSOLIC TURBIC CRYOSOL (NORTHWEST ASPECT)

This site is on the cool, moist, northwest-facing slope. The soil has permafrost within 30 cm of the surface and is classified as a Regosolic Turbic Cryosol (Table 59). Analytical data for this soil are given in Table 60.

The vegetation (Table 61) is a typical Subarctic community, consisting of an open black spruce forest with a continuous moss – lichen ground cover. This is in marked contrast to Site 28a, and indicates a much cooler, moister microclimate, including the soil climate. In fact, permafrost is very close to the surface (within 30–40 cm) and helps maintain a very cool, wet climate in the rooting zone, which in turn favours the development of a thick, insulating moss cover. A possible distribution of permafrost at this stop is presented in Figure 38. In such a setting, pedogenic activity is very slow and it is further disrupted by the active mass wasting (solifluction) that results in continual burial and mixing of surface material. This is clearly shown in the exposed soil profile. The other major process at this site is the accumulation of rather raw organic materials, mainly from the decay of the thick moss and lichen cover.

The microclimate associated with the northerly exposure, the strongly acidic pH of the Om horizon, and the very shallow active layer promote the growth of black spruce (*Picea mariana*) on this site (Table 61), rather than white spruce (*Picea glauca*) as on the warmer southeast-facing slope at Site 28a (Table 57). Also noteworthy on this site are the tall shrub species, alder (*Alnus crispa*), willow (*Salix glauca*) and birch (*Betula glandulosa*, *B. occidentalis*).

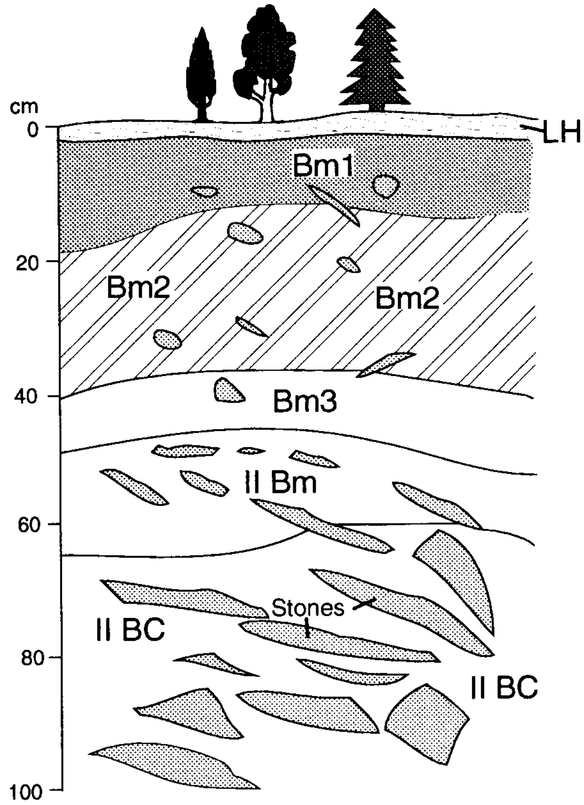


Figure 37. Cross section of the well-drained Orthic Dystric Brunisol (unaffected by permafrost) on the southeast aspect at Site 28a.

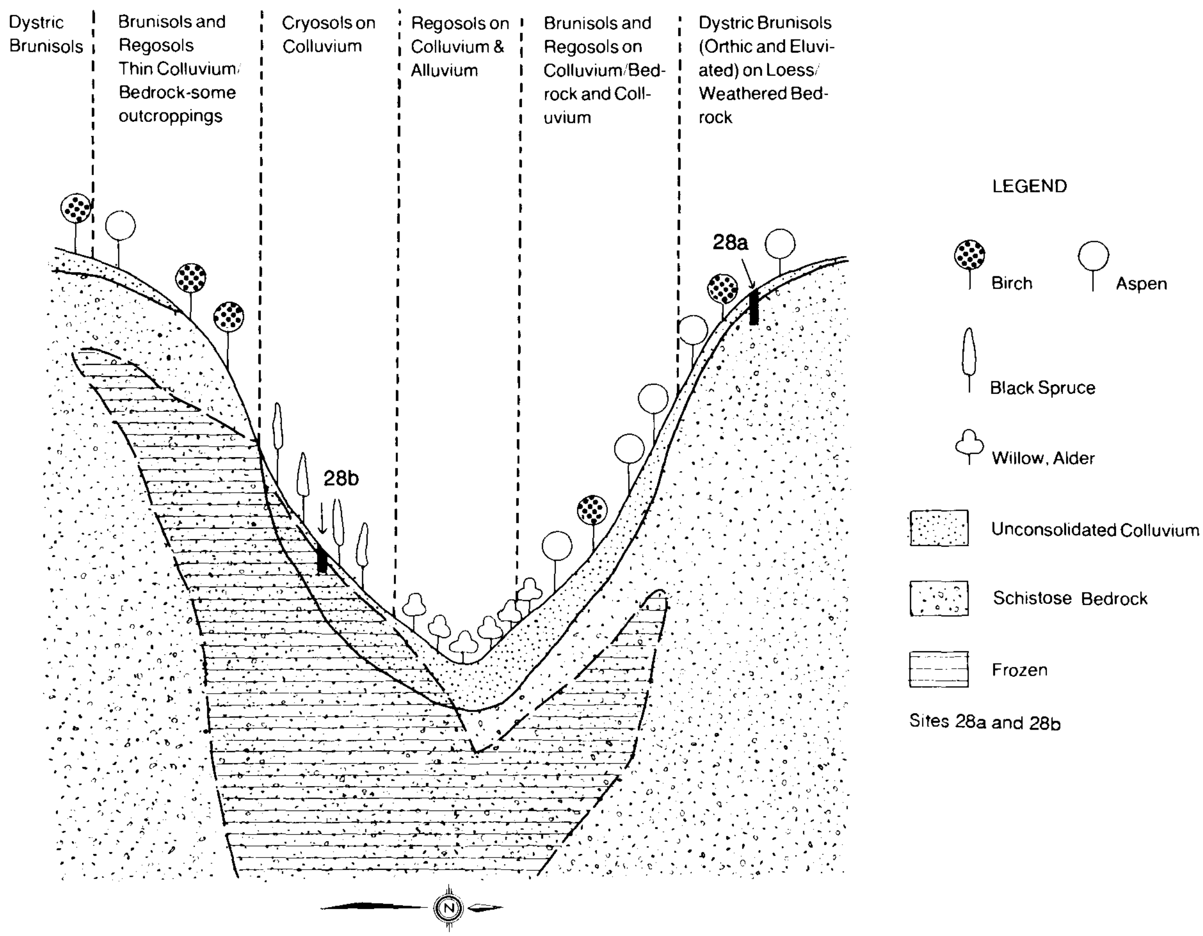


Figure 38. Schematic cross section of the north- and south-facing slopes at Site 28.

Table 55. Site and pedon descriptions for Site 28a.

Location: 63°57'25" N Lat., 138° 42'37" W Long.
Landform: Colluvial veneer over schist bedrock
Drainage: Well
Parent Material: Mixed loamy colluvium over skeletal colluvium
Patterned Ground: None

Elevation: 485 m (a.s.l.)
Slope: 40%, southeast aspect
Vegetation: Mixed Boreal forest
Soil Classification: Can. – Orthic Dystric Brunisol
U.S.A. – Typic Cryocrept
F.A.O. – Dystric Cambisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
L–H	Oi	3 – 0	Black (2.5YR 2.5/1 m); undecomposed and well decomposed, forest litter of moss, twigs and leaves; abundant, horizontal roots; abrupt, smooth boundary; 2 to 5 cm thick.
Bm1	Bw1	0 – 14	Brown (7.5 YR 4/4 m); silt loam; weak to moderate, fine to medium, subangular blocky breaking to weak to moderate, fine granular; plentiful, fine and coarse, horizontal roots; slightly sticky, friable, slightly plastic; few, thin silt films on pebble surfaces; 10% rounded and angular coarse fragments; clear, wavy boundary; 10 to 15 cm thick.
Bm2	Bw2	14 – 35	Yellowish brown (10YR 5/4 m); gravelly silt loam; moderate, fine to medium, subangular blocky and weak, fine to medium, platy; plentiful, fine, random roots; slightly sticky, friable, slightly plastic; common, thin, silt coatings on ped and coarse fragment surfaces; 10% rounded and angular coarse fragments; clear, wavy boundary; 15 to 25 cm thick.
Bm3	Bw3	35 – 45	Brown (7.5YR 4/4 m); gravelly silt loam; moderate, medium subangular blocky; plentiful, medium, random roots; slighty sticky, friable, slightly plastic; many, moderately thick, silt and clay films on coarse fragments and ped surfaces; 20% rounded and angular coarse fragments; abrupt, smooth boundary; 8 to 15 cm thick.
IIBm	2Bw	45 – 60	Dark grayish brown (10YR 4/2 m); very gravelly sandy loam; weak, fine to moderate, subangular blocky breaking to single grain; few, fine and medium, random roots; nonsticky, very friable, nonplastic; 40% angular gravels and cobbles; gradual, wavy boundary; 15 to 25 cm thick.
IIBC	2BC	60 – 100	Dark brown (10YR 4/3 m); very gravelly sandy loam; nonsticky, very friable, nonplastic; 50% angular gravels and cobbles.

Table 56. Analytical data for the Orthic Dystric Brunisol at Site 28a.

Chemical Analysis										
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)*				
	H_2O	$CaCl_2$	(%)	(%)		Ca	Mg	K	Al	Total
L–H	5.3	4.7	27.7	0.91	30					
Bm1	5.1	4.4	1.5	0.07	20	8.7	3.2	0.1	1.6	13.6
Bm2	5.0	4.4	0.5	0.07	7	6.8	3.0	0.1	1.8	11.7
Bm3	5.0	4.3	0.5	0.05	10	6.5	3.6	0.1	2.7	12.9
IIBm	5.4	4.7	0.2	0.05	4	5.9	5.4	0.1	1.4	12.8
IIBC	5.3	4.7	0.2	0.05	4	7.5	5.3	0.2	1.1	14.1

* Neutral salt extraction

Chemical and Physical Analysis											
Horizon	Sesquioxides (%)						% >2 mm	Part. Size Dist. (% <2 mm)			Texture
	Dithionite		Oxalate		Pyrophosphate						
	Fe	Al	Fe	Al	Fe	Al		Sand	Silt	Clay	
L–H	0.69	0.07	0.18	0.04	0.05	0.07					
Bm1	1.17	0.07	0.25	0.12	0.12	0.06	10	44.9	42.5	12.6	L
Bm2	1.20	0.07	0.29	0.12	0.08	0.06	10	39.8	46.2	14.0	L
Bm3	1.23	0.09	0.29	0.08	0.12	0.07	20	41.8	45.9	12.3	GL
IIBm	0.93	0.07	0.14	0.02	0.04	0.03	40	78.1	15.4	6.5	VGLS
IIBC	1.24	0.09	0.22	0.04	0.06	0.04	50	79.0	15.1	5.9	VGLS

Table 57. Vegetation description for Site 28a.

Vegetation

TREES (% cover)

Tall Trees		**Low Trees**	
5.0	*Betula papyrifera*	5.0	*Picea glauca*
10.0	*Picea glauca*	5.0	*Populus tremuloides*
85.0	*Populus tremuloides*		

SHRUBS (% cover)

Tall Shrubs		**Low Shrubs**	
1.0	*Salix* sp.	1.0	*Juniperus communis*
		1.0	*Populus tremuloides*
		15.0	*Rosa acicularis*
		1.0	*Shepherdia canadensis*
Medium Shrubs		**Dwarf Shrubs**	
5.0	*Populus tremuloides*	1.0	*Arctostaphylos uva-ursi*
5.0	*Salix* sp.	15.0	*Linnœa borealis*
1.0	*Viburnum edule*	1.0	*Vaccinium vitis-idœa*

HERBS (% cover)

1.0	*Epilobium angustifolium*	5.0	*Geocaulon lividum*
0.5	*Equisetum pratense*	0.5	*Mertensia paniculata*
0.5	*Gentiana propinqua*	1.0	*Stellaria* sp.

GRASSES (% cover)

1.0	*Agropyron subsecundum*	0.5	*Carex* sp.
1.0	*Calamagrostis purpurascens*		

MOSSES – LICHENS (% cover)

Mosses		**Lichens**	
5.0	*Dicranum fuscescens*	1.0	*Cladina mitis*
1.0	*Drepanocladus uncinatus*	10.0	*Cladonia* spp.
10.0	*Hylocomium splendens*	5.0	*Peltigera aphthosa*
1.0	*Pleurozium schreberi*	0.5	*Stereocaulon tomentosum*
5.0	*Polytrichum juniperinum*		

NON-VEGETATED (% cover)

–	Bare	5.0	Slash
65.0	Litter	–	Water
–	Rock		

Table 58. Micromorphological Features for Site 28a: Aspect Site (southeast).

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
L-H (Oi)	**Overall:** The soil fabric consists of frequent well-humified and strongly decomposed organic fragments, common amorphous granular and occasional lenticular units; extremely porous; sharp boundary to Bm1 horizon. (Pl.10:A) **Related DP:** Phyto-humi-mullgranic- mull-granoidic. Plasmic: Not applicable. **Microstructure:** Organic fragments with crumb structure. c/f RDP: Enaulic with minor zones of porphyric. b-fabric: Not applicable.	**Void Pattern:** Simple and complex packing voids (highly variable size range). **Basic Components:** Mineral: Associated with amorphous granular and lenticular units (0.5–4.0 mm); common occurring mineral grains, dominantly silt-size (<50 μm), occasionally to fine sand-size (<100 μ m); mainly subangular to angular quartz, minor amphiboles and mica; frequent diatoms. Organic: Well-humified (black) organic fragments and masses; variable size range, mainly 50–300 μm, occasionally large fragments to 650 μm. Strongly decomposed root sections and tissues (0.05–1.0 mm) are common; commonly associated with fungal hyphae and occasionally with faunal activity. Extremely fine (colloidal) organic material associated with amorphous granular and lenticular units. **Pedofeatures:** Faunal: Observed occasionally in interior of root fragments; commonly in adjacent pore space; irregular edges, circular 70–110 μm.	No cryogenic features observed.
Bm1 (Bw1) [upper boundary with L–H]	**Overall:** Dense soil fabric consisting of silt-size mineral material with lithofragments and common occurring root material showing occasional weak platy structure; secondary structure strong platy to banded structural units (5–7 mm wide). (Pl.10:B) **Related DP:** Fragmoidic-porphyroskelic/ porphyroskelic. Secondary structure fragmic/banded. Plasmic: Silasepic with rare skelsepic from close packing of mica particles. **Microstructure:** Complex: Massive-appearing fabric with platy secondary structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled with rare granostriated from close packing of mica particles.	**Void Pattern:** Major void space occurs between platy secondary structural units; planar voids (0.4–1.0 mm wide); associated with root material. Within structural units, occasional planar voids 80–120 μm wide, common to frequent root channels (400–600 μm wide) penetrate units frequently horizontal to soil surface. **Basic Components:** Mineral: Dominantly silt size mineral grains of mainly quartz and weak to moderately weathered mica particles; common occurring single quartz grains to medium sand size. Rounded to subrounded lithofragments of shale, siltstone, sandstone, metamorphic; variable size range, mainly 0.6–2.4 mm, occasionally to 6.0 mm. Organic: Root material occupying planar voids between secondary structural units is commonly associated with faunal activity. Root tissues within platy units are commonly moderately to strongly decomposed; those in planar voids between peds range from weak to strongly decomposed. Occasional to common, strongly to extremely decomposed, organic fragments and tissues distributed randomly throughout soil matrix of peds. **Pedofeatures:** Faunal: Associated only with root tissues in planar voids between peds; interiors of root material removed; irregular edges, circular in shape, 70–150 μm wide; consist of fragmented root tissues. Textural: Very rare packing of mica particles along grain surfaces; <10 μm thick, extremely discontinuous.	Marked diagonal trend to structural units (40 to 55° from horizontal). Platy structure probable result of ice lens development and successive freeze–thaw and/or wetting–drying cycles breaking up densely packed soil material. Weak cryogenic processes on soil fabric, packing of mica particles on grain surfaces; rare occurrences.

[1] Plasmic and Related DP: Plasmic fabric and Related Distribution Pattern after Brewer (1976); terms from Fox and Protz (1981).
b-fabric and c/f RDP: Birefringent fabrics and coarse/fine Related Distribution Pattern after the terminology of Bullock *et al.* (1985).
Plasmic fabrics, b-fabrics, related distribution patterns, soil fabric attributes described at 25 to 125X magnification.

Table 58. Micromorphological Features for Site 28a: Aspect Site (southeast) (cont.)

Horizon	Soil Material Arrangement[1]	Soil Fabric Attributes	Cryogenic Attributes
Bm1 (Bw1)	**Overall:** Close packing of mineral material and coarse lithofragments with frequent surface accumulations; prominent lenses occur in the dense soil fabric; weak secondary blocky to granular structure. (Pl.10:C) **Related DP:** Matrigranic/fragmic/fragmoidic-porphyroskelic/banded silasepic-porphyroskelic. Plasmic: Silasepic, rare skelsepic from close packing of mica particles along grain surfaces. **Microstructure:** Complex: Massive-appearing soil fabric with zones of banded structure between lithofragments; common occurrence of weak blocky structure; minor granular structure. c/f RDP: Porphyric b-fabric: Stipple-speckled with rare granostriated from close packing of mica particles.	**Void Pattern:** Size ranges highly variable; simple and complex packing voids; in zones of dense soil fabric, frequent planar voids observed. **Basic Components:** Mineral: Subrounded to subangular lithofragments (wide range 0.6–6 mm, rarely >1 cm) of commonly occurring shales and siltstone, rare sandstone, and frequent metamorphic (gneiss, schist); frequently with textural accumulations. Finer matrix material consists of abundant, weakly to moderately weathered mica particles (mainly <10–200 μm) and angular quartz grains dominantly silt-size with common to occasional occurrence of single quartz grains to fine sand-size. Mica particles rarely packed along grain surfaces of quartz. Organic: Amorphous (colloidal) organic matter distributed throughout; tendency to be concentrated in grain surface accumulations and lenses in soil fabric. Rare to occasional well-humified (charcoal) fragments (0.8–1.3 mm) in dense soil fabric; often fragmented or with textural accumulations on particle surfaces. Rare root sections 200–720 μm are strongly to extremely decomposed. Rare fungal sclerotia 600 μm. **Pedofeatures:** Textural: Dominantly on the upper and side grain surfaces; frequently occur on the lithofragments and occasionally on mineral grains of fine sand-size; accumulations (mainly 30–200 rarely to 440 μm) of finer soil matrix material (silt-size), frequent parallel alignment of mica particles to grain surface. Faunal: Rare occurrence in root channel; consist of soil matrix material 40–60 μm, irregular edges, circular in shape.	Strong evidence for cryogenic processes with formation of silt accumulations on the coarser fragments and the silt lenses in soil fabric. These features suggest movement of the finer material resulting from freeze–thaw cycles and freezing fronts. Wetting and drying cycles in the warmer months may also contribute. (Pl.10:C) Silt accumulations are dominantly on the upper surface and the left side of the fragments, suggesting movement of fine materials in direction of the slope and rotation of the lithofragments and mineral grains downslope. (Pl.10:C) Alignment of lithofragments, occasional distinct zones of preferential alignment (i.e., most grains in zone aligned subvertical or diagonally 35–50°). Silt lenses often show similar preferential alignment diagonally.
Bm2 (Bw2)	**Overall:** The mineral material has a complex morphology of weak to strong platy structure; frequent lithofragments with silt accumulations occur throughout. (Pl.10:D, E, F) **Related DP:** Granoidic-porphyroskelic// fragmoidic-porphyroskelic// banded Plasmic: Silasepic, very rare skelsepic from packing of mica particles along grain surfaces. **Microstructure:** Complex: Platy (banded) to weak granular structure. c/f RDP: Porphyric. b-fabric: Stipple-speckled; very rare granostriated from packing of mica particles.	**Void Pattern:** Planar voids (mainly 80–400 μm wide) are dominant; occasional complex packing voids between structural units and lithofragments, variable size range. **Basic Components:** Mineral: Medium sand size to very coarse lithofragments dominate (mainly 0.4–1.6 mm, occasionally gravel size, 0.7–1.5 cm); frequently with textural accumulations. The finer matrix material consists of very abundant, weak to moderately weathered mica particles (mainly <10–100 μm, occasionally to 350 μm) and angular quartz (dominantly <10–30 μm, with occasional single grains 70–150 μm), rare amphiboles, magnetite. Organic: Amorphous, colloidal, dark brown material, probably organic material, but may be iron oxide/fine clay component, is concentrated in silt accumulations on lithofragments and upper portions of platy structural units of banded fabric. Moderate to strongly decomposed root sections (50–350 μm) occur rarely to occasionally, very rarely affected by faunal activity. Rare, well-humified and strongly decomposed, organic fragments (200–400 μm) and cell structures in soil matrix. **Pedofeatures:** Textural: Frequent occurrence of silt-size accumulations of soil matrix material on upper grain surfaces; associated with lithofragments; range 150–1000 μm, thicker than in Bm1. Gradations of staining on the gravel-size and very coarse lithofragments suggest successive accumulations and/or sorting of material. On the upper surface of platy structural units, concentration of fines increases; approximately 100 μm thick, diffuse boundary. Faunal: Rare occurrence, only associated with root material; irregular edges, circular in shape, 30–70 μm.	Platy structure more strongly developed than in Bm1; distinct banded fabric results from numerous freeze–thaw and wetting–drying cycles. Ice lens development contributes to formation of the platy structure. The freezing fronts have led to micro-sorting of the fines, with concentrations of amorphous colloidal material increasing on the upper portions of the structural units. (Pl.10:D, E) Thick silt accumulations on the lithofragments suggest considerable movement of material. In addition, rotation of the fragments has probably not occurred, thus facilitating build-up of the fine material; successive events of accumulation are suggested on the coarse and gravel fragments; these fragments may be more resistant to rotation. (Pl.10:F) There is a definite horizontal alignment to the platy structural units and frequently the coarsest lithofragments, suggesting no marked movement downslope as in the Bm1 horizon. (Pl.10:D) Placement of mica particles along grain surfaces resulting from freeze–thaw cycles.

PLATE 10

List of Plates for Site 28: Aspect Site (Southeast).

Plate 10: A

Well-humified and strongly decomposed organic fragments commonly occur as granular aggregations and lenticular units in the extremely porous L–H horizon. Frame length 5.5 mm. Plane polarized light (PPL).

Plate 10: B

Dense soil fabric of the upper part of the Bm1 horizon at the contact with the L–H horizon consists of silt-size mineral material and fine organic material that is distributed throughout the mineral material. Root fragment has evidence of faunal activity. Note marked diagonal trend of planar void and structural units. Frame length 4.0 mm. (PPL).

Plate 10: C

Mineral material and coarse lithofragments are closely packed in the Bm1 horizon. Note the accumulation of finer soil material, mainly on the upper and left side of the lithofragments, suggesting preferential movement of fines downslope. Frame length 8.5 mm. (PPL).

Plate 10: D

Banded fabric in the Bm2 horizon, with fine material sorted on the upper portion of the lenticular units. Frame length 8.5 mm. (PPL).

Plate 10: E

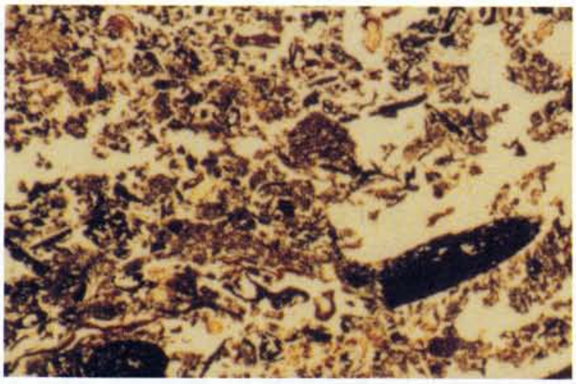
Close-up view of lenticular units (See upper left portion of micrograph in Pl.10: D) in the Bm2 horizon, showing particle sorting and staining of upper surface, probably by iron oxides. Frame length 4.0 mm. (PPL).

Plate 10: F

Thick accumulations of silt-size material on upper grain surfaces of lithofragments (range 0.15–1.0 mm) in the Bm2 horizon. Note platy structure and particle sorting of coarse material between aggregations of fines. Frame length 4.0 mm. (PPL).

PLATE 10

Site 28: Aspect Site



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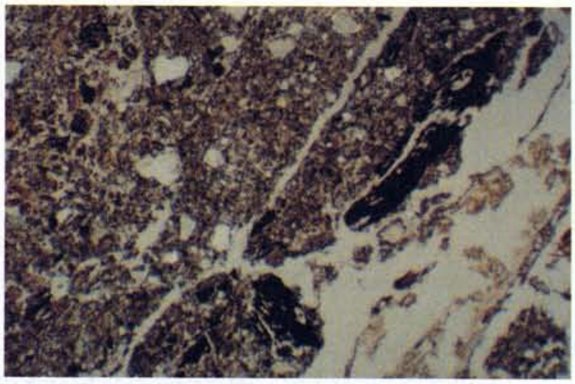

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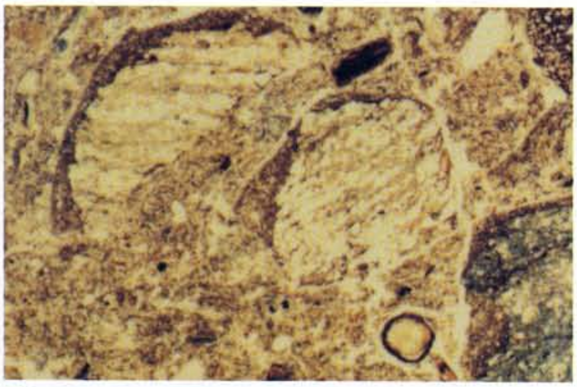

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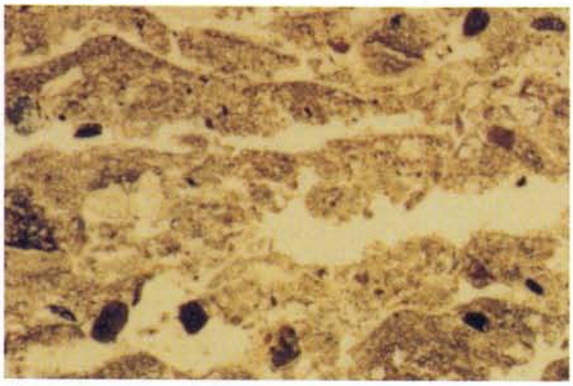

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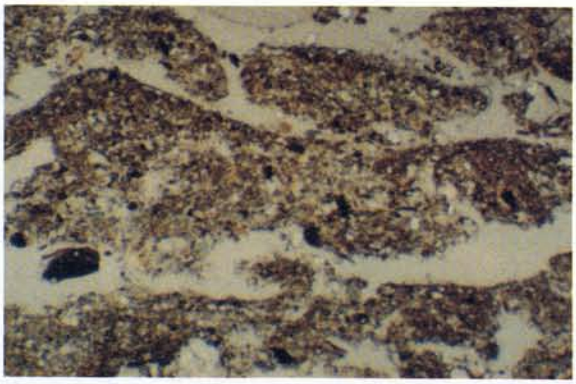
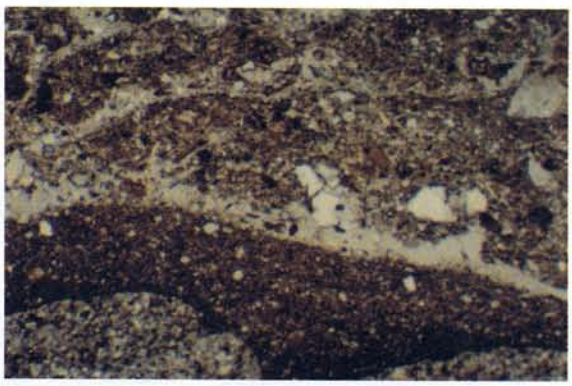


E



F

Table 59. Site and pedon descriptions for Site 28b.

Location: 63°56'30" N Lat., 138° 43' W Long.
Landform: Dissected plateau
Drainage: Poor
Parent Material: Coarse loamy colluvium

Elevation: 650 m (a.s.l.)
Slope: 10%, northwest aspect; site is on lower slope
Vegetation: Subarctic forest of black spruce – moss
Soil Classification: Can. – Regosolic Turbic Cryosol
U.S.A. – Pergelic Cryofluvent
F.A.O. – Gelic Regosol

Horizon		Depth	Description
Can.	U.S.	(cm)	
Om	Oe	11 – 0	Very dark brown (10YR 2/2 m); moderately decomposed moss; few, fine horizontal roots; very strongly acid; abrupt, smooth boundary.
Cz1	Cf1	0 – 28	Dark gray (10YR 4/1 m); sandy loam; amorphous; slightly sticky, friable; about 20% coarse fragments; strongly acid; gradual, irregular boundary.
Ahbz	Oif	28 – 47	Very dark gray (10YR 3/1 m); sandy loam; amorphous; slightly sticky, friable; about 15% coarse fragments; medium acid; clear, irregular boundary.
Cz2	Cf2	47 – 80+	Dark gray (10YR 4/1 m); gravelly sandy loam; amorphous; friable; about 30% coarse fragments; medium acid.

Table 60. Analytical data for the Regosolic Turbic Cryosol at Site 28b.

Chemical Analysis										
Horizon	pH		Org. C	Total N	C/N	Exchangeable Cations (me/100g)*				
	H_2O	$CaCl_2$	(%)	(%)		Total	Ca	Mg	Na	K
Om	4.6	3.9	44.9	1.51	30	108.3	27.3	5.4	tr	1.5
Cz1	5.3	4.4	1.8	0.10	18	11.3	4.4	1.0	tr	0.1
Ahbz	5.6	4.8	2.1	0.12	18	12.3	6.7	0.9	tr	0.1
Cz2	5.9	5.1	1.2	0.07	17	8.3	5.8	0.8	tr	0.1

* Buffered NH_4OAc (pH 7)

Mineralogy and Chemical Analysis																	
Horizon	Available Nutrients (ppm)				Organic Matter					Clay Mineralogy (<2μ)*							
					Extracted		Cha /Cfa	FA	HA								
	N	P-Bray	K	S	%C	%N		E4/E6	E4/E6	Mica	Chlor.	Kaol.	Smect.	Verm.	Quartz	Felds.
Om	1	21	99	5						tr	tr	tr	tr	1	1	tr
Cz1	1	2	31	2												
Ahbz					58	59	0.87	8.9	4.5							
Cz2																

* Amount estimated from x-ray diffractograms: tr = trace, 1 = 2–20%

Table 60. Analytical data for the Regosolic Turbic Cryosol at Site 28b (cont.)

Physical Analysis							
Horizon	% Ash	% >2 mm	Part. Size Dist. (% <2 mm)				Texture
			Sand	Silt	Clay	F-Clay	
Om	8.0						
Cz1		26.8	47	47	6	2	SL
Ahbz		15.6	47	47	6	2	SL
Cz2		35.6	46	49	4	2	GSL

Table 61. Vegetation description for Site 28b.

Vegetation			
	Trees 20%		
80	*Picea mariana*	20	*Betula papyrifera* ssp. *humilis*
	Tall shrubs 10%		
40	*Alnus crispa* ssp. *crispa*	20	*Betula glandulosa*
20	*Salix glauca*	20	*Betula occidentalis*
	Low shrubs 30%		
70	*Ledum palustre* ssp. *groenlandicum*	10	*Ledum palustre* ssp. *decumbens*
20	*Vaccinium uliginosum*		
	Dwarf shrubs 30%		
80	*Vaccinium vitis-idæe*	5	*Rubus chamæmorus*
15	*Oxycoccus microcarpus*		
	Herbs 2%		
100	*Pedicularis labradorica*		
	Grasses 40%		
50	*Eriophorum brachyantherum*	20	*Carex lugen*
30	*Carex bigelowii*		
	Mosses – Lichens 50%		
20	*Sphagnum girgensohnii*	2	*Nephroma arcticum*
20	*Sphagnum fuscum*	2	*Stereocaulon tomentosum*
20	*Pleurozium schreberi*	1	*Dicranum undulatum*
10	*Sphagnum rubellum*	1	*Jamesoniella autumnalis*
5	*Sphagnum subsecundum*	1	*Ptilidium ciliare*
5	*Sphagnum magellanicum*	1	*Peltigera aphthosa*
5	*Aulacomnium turgidum*	1	*Icmadophila ericetorum*
5	*Tomenthypnum nitens*	1	*Cladonia* spp.

SITE 29, KM 4: SUNNYDALE VIEW

Below the highway at this point you can see the extent of farmland that has existed here since the turn of the century. It was from these lands that vegetable gardens, livestock herds, and a dairy produced some of the food for a population of almost 30,000 people. With the decline in population and the increased effectiveness of transportation systems during the early part of this century, farm production shrank and many of the properties reverted to the government. The farms you see represent the second round of development, which was initiated during the 1980s (see section on Agriculture) in an attempt to diversify the local economy and provide fresh quality produce for the Dawson City market.

The gently sloping terrain has a southerly aspect and the soils are of fine sandy loam and loam texture. Thus, this area is ideally suited to agriculture. The landform, referred to as a "slip-off slope," is formed by the downcutting and movement of the Yukon River main stem towards the opposite bank (O.L. Hughes 1987, pers. comm.). Experimental plots have shown that this slope has the finest microclimate in the Yukon for the production of cereals. It is one of the few sites where wheat can be matured in most years. Development, however, is limited by the problem of gaining access to this side of the river, especially during the spring and fall. At those times, residents of Sunnydale are cut off from Dawson City for up to three weeks at a time while the river breaks-up or freezes. An ice-road provides access to these properties in the winter.

SITE 30, KM 53: UNGLACIATED TERRAIN – TORS AND CRYOPLANATION TERRACES

To the south is an example of a tor (castellated erosional remnant). You have seen many examples of these on the skyline throughout the Ogilvie Mountains.

Tors and cryoplanation (altiplanation) terraces occur widely in the unglaciated portion of the Yukon Plateau (Hughes *et al.* 1972). They have developed mainly on gneisses and quartzites, but examples occur on all rock types. Development of both forms is judged to have been essentially preglacial.

Cryoplanation terraces are considered to be the product of parallel retreat of scarps in a periglacial environment (Demek 1969). Some tors doubtless are the final stage in the reduction of larger masses that have been removed by cryoplanation. A possible process is that of downwasting by solifluction, rather than scarp retreat. Tors would be left where the rock was more resistant to weathering. Some rows of tors on sloping ridges appear to be interrupted outcrops of resistant quartzite. Individual tors may be rock masses in which jointing is more widely spaced than in surrounding rock, or rock which is locally more resistant by reason of secondary alteration such as silicification.

SITE 31, KM 102: SOLIFLUCTION LOBES AND SOIL STRIPES

On this site, well-developed solifluction lobes are generally found on slopes greater than 20%. These solifluction lobes are similar to those seen at Site 7, in the Northwest Territories.

The stripes occurring on lower slope gradients are also a characteristic type of patterned gound in this area. These stripes are generally sorted, and their pattern is marked by the unvegetated line of coarse fragments.

SITE 32, KM 107: SOILS ASSOCIATED WITH SORTED NETS

Some of the periglacial geomorphic features common in the unglaciated region can be observed at this stop, 1.5 km east of Little Gold Creek Custom House. The main process has been the development of a series of cryoplanation terraces. The road runs southward across an upper terrace for 1 km, then diagonally down a stabilized, frost-riven scarp. Superimposed on the upper terrace is strong frost sorting, which has resulted in a field of sorted nets (stone polygons). Good discussions of patterned ground phenomena can be found in Washburn's work (1956, 1973, 1980). Note, for example, how many of the rocks in the nets are standing on edge, a position of least resistance to frost heaving. It would appear that these periglacial processes are now inactive, judging from the lichen growth on exposed rock surfaces. In the areas where fine material has been concentrated, however, cryogenic processes are quite active.

ORTHIC TURBIC CRYOSOL

This site is situated within a sorted net on the upper cryoplanation terrace. The central part of the net is composed of fine soil materials, while the rim is composed dominantly of sorted rock fragments. The soil, which was sampled in the central part of the net, is classified as an Orthic Turbic Cryosol (Table 62).

The analytical data for this soil are given in Table 63. The soils are acidic in reaction and, like most Turbic Cryosols, there is appreciable organic matter in all mineral horizons. The soil material is dominated by silt-sized particles, and the BCgy horizons are cryoturbated and very unstable, causing the soil to have a thixotropic character. The liquid limit and the plastic limit are very similar (Table 63). In this respect, the site has certain affinities with Site 22, which occurs within an alpine environment at North Fork Pass.

The vegetation on this site (Table 64) is an alpine tundra, dominated by low and dwarf shrubs, mosses and lichens.

Table 62. Site and pedon descriptions for Site 32.*

Location: 64° 04' N Lat., 140° 57' W Long.
Landform: Cryoplanation terrace
Drainage: Internal – well to poor; external – imperfect to poor
Parent Material: Loamy-skeletal with fines concentrated by frost sorting
Patterned Ground: Large sorted nets; average diameter 3 m (stone polygon)

Elevation: 1250 m (a.s.l.)
Slope: Level
Vegetation: Low shrub tundra
Soil Classification: Can. – Orthic Turbic Cryosol
U.S.A. – Pergelic Ruptic Cryaquept
F.A.O. – Gelic Cambisol

Horizon		Depth	Description
Can.	U.S.	(cm)	
Bm	Bw	0 – 5	Very dark grayish brown (10YR 3/2 m); very gravelly silt loam; moderate, coarse granular; friable to firm; plentiful, fine random roots; about 60% coarse fragments; strongly acid; clear, wavy and broken boundary; 0 to 7 cm thick.
BCgy1	BCg1	5 – 35	Gray to dark gray (5Y 4.5/1 m); gravelly silty loam; many, coarse, prominent, very dark grayish-brown (10YR 3/2 m) and strong brown (7.5YR 4/6 m) mottles; amorphous, but flows when disturbed; firm, few, fine vertical roots; variable coarse fragment content averaging about 40%; strongly acid; gradual, irregular and broken boundary; 0 to 40 cm thick.
BCgy2	BCg2	35 – 60+	Very dark grayish brown (10YR 3/2 m); very gravelly silt loam; many, medium distinct gray (5Y 4.5/1 m) and strong brown (7.5YR 4/6 m) mottles; amorphous, but flows when disturbed; firm; no roots; about 60% coarse fragments; strongly acid.

Table 63. Analytical data for the Orthic Turbic Cryosol at Site 32.*

Chemical Analysis															
						Exchangeable Cations (me/100g)									
Horizon	pH		Org. C	Total N	C/N	Neutral Salt Extraction					Buffered NH_4OAc (pH 7)				
	H_2O	$CaCl_2$	(%)	(%)		K	Ca	Mg	Al	Total	Total	Ca	Mg	Na	K
Bm	5.4	4.4	1.6	0.08	20	0.2	1.9	0.4	0.3	2.7	8.1	2.0	0.5	0.1	0.1
BCgy1	5.4	4.2	1.0	0.05	20	0.1	1.0	0.2	0.6	1.8	6.1	0.7	0.2	0.1	0.1
BCgy2	5.3	4.3	1.5	0.07	21	0.1	0.6	0.1	0.7	1.4	6.4	0.3	0.0	0.1	tr

* Taken from Pettapiece *et al.* 1978.

Table 63. Analytical data for the Orthic Turbic Cryosol at Site 32 (cont.)

Physical Analysis								
Horizon	% >2 mm	Part. Size Dist. (% <2 mm)				Atterberg		Texture
		Sand	Silt	Clay	F-Clay	PL	LL	
Bm	61	21	69	10	3	24	28	SiL
BCgy1	45	24	70	6	3	22	23	SiL
BCgy2	64	32	61	7	2	22	26	SiL

Table 64. Vegetation description for Site 32.

Vegetation

Trees 0%

Tall shrubs 0%

Low shrubs 20%

Betula glandulosa
Salix phlebophylla
Ledum palustre ssp. *decumbens*
Vaccinium uliginosum

Dwarf shrubs 35%

Arctostaphylos alpina
Loiseleuria procumbens
Dryas octopetala
Cassiope tetragona

Herbs 5%

Anemone narcissiflora
Pedicularis kanei
Polygonum bistorta ssp. *plumosum*
Minuartia arctica
Artemisia arctica ssp. *arctica*

Mosses – Lichens (soil) 50%

Rhacomitrium lanuginosum
Rhytidium rugosum
Tetraplodon mnioides
Dicranum elongatum
Alectoria nitidula
Cetraria cucullata
Cetraria islandica
Cetraria richardsonii
Cladina mitis
Cladina rangiferina
Nephroma arcticum
Thamnolia vermicularis

Lichens (rock) 100%

Umbilicaria hyperborea
Rhizocarpon geographicum
Parmelia centrifuga
Alectoria minuscula
Cetraria hepatizon

REFERENCES

Associate Committee on Geotechnical Research (ACGR). 1988. Glossary of permafrost and related ground-ice terms. National Research Council of Canada, Technical Memorandum 142, 156 p.

Atmospheric Environment Service. 1982. Canadian climate normals, temperature and precipitation: the North – Yukon Territory and Northwest Territories. Environment Canada, Atmospheric Environment Service, UDC:551.582 (712), 55 p.

Agriculture Branch. 1993. Summary of Yukon agriculture production survey. Agriculture Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Canada.

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. (2nd ed.) Research Branch, Agriculture Canada, Ottawa, Canada. Publication 1646, 164 p.

Berton, P. 1958. *Klondike*. McClelland and Stewart Ltd., Toronto.

Bostock, H.S. 1936. Carmacks District, Yukon. Geological Survey of Canada Memoir 189, 67 p.

Bostock, H.S. 1948. Physiography of the Canadian Cordillera with special reference to the area north of the fifty-fifth parallel. Canada Geological Survey Memoir 247, 106 p.

Bostock, H.S. 1961. Physiography and resources of the Yukon. Canadian Geographical Journal, 63:112–119.

Bostock, H.S. 1966. Notes on glaciation in central Yukon Territory. Canada Geological Survey Paper 65–36, 18 p.

Bostock, H.S. 1970. Physiographic subdivisions of Canada. Pages 9–30 in: R.J.W. Douglas (ed.), Geology and Economic Minerals of Canada. Canada Geological Survey Economic Geology Report 1, 5th edition.

Brewer, R. 1964. Fabric and Mineral Analysis of Soils. John Wiley and Sons, New York, 470 p.

Brewer, R. 1976 (Revised). Fabric and Mineral Analysis of Soils. R.E. Krieger Publ. Co., Huntington, New York, 482 p.

Brewer, R. and S. Pawluk. 1975. Investigations of some soils developed in hummocks of the Canadian Sub-Arctic and Southern-Arctic regions. 1. Morphology and micromorphology. Canadian Journal of Soil Science, 55:301–319.

Brewer, R. and J.R. Sleeman. 1988. Soil Structure and Fabric. CSIRO, Division of Soils, Adelaide, Australia, 173 p.

Brown, R.J.E. 1978. Permafrost. Plate 32 in: Hydrologic Atlas of Canada. Fisheries and Environment Canada, Ottawa, Ontario.

Bullock, P., N. Fedoroff, A. Jongerius, G. Stoops and T. Tursina. 1985. Handbook for Thin Section Description. Waine Research Publications, Wolverhampton, England, 152 p.

Burn, C.R. 1990. Implications for palaeoenvironmental reconstruction of recent ice-wedge development at Mayo, Yukon Territory. Permafrost and Periglacial Processes, 1:3–14.

Burn, C.R. and F.A. Michel. 1988. Evidence for recent temperature-induced water migration into permafrost from the tritium content of ground ice near Mayo, Yukon Territory, Canada. Canadian Journal of Earth Sciences, 25:909–915.

Burn, C.R., F.A. Michel and M.W. Smith. 1986. Stratigraphic, isotopic and mineralogical evidence for an early Holocene thaw unconformity at Mayo, Yukon Territory. Canadian Journal of Earth Sciences, 23:794–803.

Burns, B.M. 1973. The climate of the Mackenzie Valley Beaufort Sea. Environment Canada Climatological Studies 24, v. 1, 227 p.; v. 2, 239 p.

Cheng, G. 1983. The mechanism of repeated-segregation for the formation of thick-layered ground ice. Cold Regions Science and Technology, 8:57–66.

Cinq-Mars, J. 1979. Bluefish Cave I: a late Pleistocene eastern Beringian cave deposition, eastern Yukon. Canadian Journal of Archæology, 3:1–32.

Chapin, F.S. and G.R. Shaver. 1981. Changes in soil properties and vegetation following disturbance of Alaskan Arctic tundra. Journal of Applied Ecology, 18:605–617.

Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day and I.B. Marshall. 1977. Soils of Canada (Vol. I). Research Branch, Canada Department of Agriculture, 243 p.

Demek, J. 1969. Cryogenic processes and the development of cryoplanation terraces. Biul. Peryglacjalny, 18:115–125.

Duk-Rodkin, A. and O.L. Hughes. 1991. Age relationships of Laurentide and montane glaciations, Mackenzie Mountains, Northwest Territories. Géographie physique et Quaternaire, 45:78–90.

Duk-Rodkin, A. and O.L. Hughes. 1992. Pleistocene montane glaciations in the Mackenzie Mountains, Northwest Territories. Géographie physique et Quaternaire, 46:69–83.

Dumanski, J. and R.J. St. Arnaud. 1966. A micropedological study of eluvial soil horizons. Canadian Journal of Soil Science, 46:287–292.

Foscolos, A.E., N.W. Rutter and O.L. Hughes. 1977. The use of pedological studies in interpreting the Quaternary history of central Yukon Territory. Canada Geological Survey Bulletin 271, 48 p.

Fox, C.A. 1983. Micromorphology of an Orthic Turbic Cryosol – A permafrost soil. Pages 699–705 in: P. Bullock and C.P. Murphy (eds.), Soil Micromorphology, Vol. 2. Soil Genesis. A.B. Academic Publishers, Berkhamsted, Herts, England.

Fox, C.A. and R. Protz. 1981. Definition of fabric distributions to characterize the rearrangement of soil particles in the Turbic Cryosols. Canadian Journal of Soil Science, 61:29–34.

French, H.M. and J.A. Heginbottom (eds.). 1983. Guidebook to permafrost and related features of the northern Yukon Territory and Mackenzie Delta, Canada. 4th International Conference on Permafrost, Fairbanks, Alaska, 186 p.

French, H.M. and D.G. Harry. 1992. Pediments and cold-climate conditions, Barn Mountains, unglaciated northern Yukon, Canada. Geogr. Ann. 74A (2-3):145–157.

Gairns, C.H. 1968. The Yukon economy, its potential for growth and continuity. Vol. VIII. Reference Study of Forest Resources. Industrial Forestry Service Ltd., Prince George.

Harris, S.A., R.O. van Everdingen and W.H. Pollard. 1983. The Dempster Highway – Dawson to Eagle Plain. Pages 71–73 in: H.M. French and J.A. Heginbottom (eds.), Guidebook 3, Guidebook to Permafrost and Related Features of the Northern Yukon Territory and Mackenzie Delta, Canada. Fourth International Conference on Permafrost, University of Alaska, Fairbanks, July 1983.

Harry, D.G. and K.L. MacInnes. 1988. The effect of forest fires on permafrost terrain stability, Little Chicago–Travaillant Lake area, Mackenzie Valley, N.W.T. Geological Survey of Canada Paper 88–1D, p. 91–94.

Hirvonen, R.P. 1968. Report on the forest conditions in the Nisultin River area, Yukon Territory. Northern Survey Report No. 5, Forest Management Institute, Ottawa, 11 p.

Hirvonen, R.P. 1975. Forest Resources of the Mackenzie River Valley. Information Report FMR–X–71, Forest Management Institute, Ottawa, 42 p.

Holmes, G.W., H.L. Foster and D.M. Hopkins. 1965. Distribution and age of pingos of interior Alaska. Proceedings of the International Permafrost Conference, Lafayette, Indiana, Nov. 1963, p. 88–93.

Holmes, G.W., D.M. Hopkins and H.L. Foster. 1968. Pingos in central Alaska. U.S. Geological Survey, Washington, Bulletin 1241–H, 40 p.

Hughes, O.L. 1969. Distribution of open-system pingos in central Yukon Territory with respect to glacial limits. Geological Survey of Canada Paper 69–34, 8 p.

Hughes, O.L. 1987. Late Wisconsinan Laurentide glacial limits of northwestern Canada: the Tutsieta and Kelly Lake phases. Geological Survey of Canada Paper 85–25, 19 p.

Hughes, O.L., R.B. Campbell, J. Muller and J.O. Wheeler. 1969. Glacial limits and flow patterns, Yukon Territory south of 65°N latitude. Canada Geological Survey Paper 68–34, 9 p. (includes Map 6–1968).

Hughes, O.L., V.N. Rampton and N.W. Rutter. 1972. Quaternary geology and geomorphology, southern and central Yukon. Guidebook for Field Excursion A–11, International Geological Congress, 24th, Montreal 1972, 59 p.

Hughes, O.L., C.R. Harington, J.A. Janssens, J.V. Matthews Jr., R.E. Morlan, N.W. Rutter and C.E. Schweger. 1981. Upper Pleistocene stratigraphy, paleoecology and archaeology of the northern Yukon interior, eastern Beringia I, Bonnet Plume Basin. Arctic, 34:329–365.

Indian and Northern Affairs Canada (INAC). 1993. Yukon Exploration and Geology 1992. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, 87 p.

Jackson, L.E. Jr., R. Barendregt, E. Irving and B. Ward. 1990. Magnetostratigraphy of early to middle Pleistocene basalts and sediments, Fort Selkirk area, Yukon Territory. Current Research, Part E, Geological Survey of Canada Paper 90–1E, p. 277–286.

Kodama, H., N. Miles, S. Shimoda and J.E. Brydon. 1976. Mixed-layer kaolinite–montmorillonite from soils near Dawson, Yukon Territory. Canadian Mineralogist, 14:159–163.

Mackay, J.R. 1977. Changes in the active layer from 1968 to 1976 as a result of the Inuvik fire. Geological Survey of Canada Paper 77–1B p. 273–275.

Mackay, J.R. 1978. Freshwater shelled invertebrate indicators of paleoclimate in northwestern Canada during late glacial times: Discussion. Canadian Journal of Earth Sciences, 15:461–462.

Mackay, J. R. 1979. Pingos of the Tuktoyaktuk Peninsula area, Northwest Territories. Géographie physique et Quaternaire, 23:3–61.

Mackay, J.R. 1980. The origin of hummocks, western Arctic coast, Canada. Canadian Journal of Earth Sciences, 17:996–1006.

Mackay, J.R. 1983. Downward water movement into frozen ground, western Arctic coast, Canada. Canadian Journal of Earth Sciences, 20:120–134.

Mackay, J.R. 1992. The frequency of ice-wedge cracking (1967–1987) at Garry Island, western Arctic coast, Canada. Canadian Journal of Earth Sciences, 29:236–248.

Mackay, J.R. and D.K. MacKay. 1976. Cryostatic pressures in nonsorted circles (mud hummocks), Inuvik, Northwest Territories. Canadian Journal of Earth Sciences, 13:889–897.

McConnell, R.G. 1905. Report on the Klondike gold fields. Annual Report of the Geological Survey of Canada, XIV, 1901, Part B, p. 1–71.

McConnell, R.G. 1907. Report on gold values in the Klondike high-level gravels. Canada Geological Survey Publication 979.

McMillan, N.J. and J. Mitchell. 1953. A microscopic study of platy and concretionary structures in certain Saskatchewan soils. Canadian Journal of Agricultural Science, 33:178–183.

Mankinen, E.A. and G.B. Dalrymple. 1979. Revised geomagnetic polarity time scale for the interval 0–5 m.y. B.P. Journal of Geophysical Research, 84:615–626.

Merrill, D.F. 1961. Lumbering in the Yukon Territory. Dept. North. Affairs and Natural Resources, Whitehorse.

Morlan, R.E. 1986. Pleistocene archæology in the Old Crow basin: a critical reappraisal. Pages 27–48 in: A.L. Bryan (ed.), New Evidence for the Pleistocene Peopling of the Americas. University of Maine, Center for the Study of Early Man, Orono, Maine.

Muller, S.W. 1947. Permafrost or permanently frozen ground and related engineering problems. U.S. Army Office Chief of Engineers, Military Intelligence Division of Strategic Engineering Studies Special Report 62, 231 p. (Reprinted, 1947, Ann Arbor, Michigan, J.W. Edwards.)

Naeser, N.D., J.A. Westgate, O.L. Hughes and T.L. Péwé. 1982. Fission track ages of late Cenozoic distal tephra beds in the Yukon Territory and Alaska. Canadian Journal of Earth Sciences, 19:2167–2178.

Norris, D.K. 1984. Geology of the northern Yukon and northwestern Mackenzie District. Geological Survey of Canada Map 1581A, Scale 1:500,000.

Owen, E.B. 1959a. Fort Selkirk dam site. Geological Survey of Canada, Topical Report No. 15, 12 p.

Owen, E.B. 1959b. Fort Selkirk saddle dam site. Geological Survey of Canada, Topical Report No. 16, 9 p.

Pawluk, S. and R. Brewer. 1975. Micromorphological, mineralogical and chemical characteristics of some alpine soils and their genetic implications. Canadian Journal of Soil Science, 55: 415–437.

Peaker, J.P. 1968. Report on the forest conditions in the upper Liard River area. Northern Survey Report No. 6, Forest Management Institute, Ottawa, 9 p.

Pettapiece, W.W., C. Tarnocai, S.C. Zoltai and E.T. Oswald. 1978. Soil, permafrost and vegetation relationships in the Yukon and Northwest Territories of Northwestern Canada. Guidebook for Tour 18, 11th Congress of the International Society of Soil Science, Edmonton, Canada, 165 p.

Placer Mining Section. 1991. Yukon Placer Industry 1989 to 1990. Mineral Resources Directorate, Yukon, Indian and Northern Affairs Canada, 125 p.

Rampton, V.N. 1982. Quaternary geology of the Yukon coastal plain. Geological Survey of Canada Bulletin 317, Ottawa, Ontario, 44 p. and maps.

Rampton, V.N. 1988. Quaternary geology of the Tuktoyaktuk Coastlands, Northwest Territories. Geological Survey of Canada Memoir 423, 98 p.

Ricker, K.E. 1968. Quaternary geology of the southern Ogilvie Ranges, Yukon Territory. Vancouver, University of British Columbia, M.S. thesis.

Ringrose-Voase, A.J. 1991. Micromorphology of soil structure: Description, quantification, application. Australian Journal of Soil Research, 29:777–813.

Rostad, H.P.W., L.M. Kozak and D.F. Acton. 1977. Soil survey and land evaluation of the Yukon Territory. Saskatchewan Institute of Pedology Publication S–174, Saskatoon, Saskatchewan, Canada, 495 p. and maps.

Rowe, J.S. and G.W. Scotter. 1973. Fire in the Boreal forest. Journal of Quaternary Research, 3:444–464.

Ruddiman, W.F. and J.E. Kutzbach. 1989. Forcing of late Cenozoic Northern Hemisphere climate by plateau uplift in southern Asia and the American West. Journal of Geophysical Research, 94:18409–18427.

Schrier, H. and L.M. Lavkulich. 1985. Rendzina-type soils in the Ogilvie mountains, Yukon Territory. Soil Science, 139:2–12.

Schweger, C.E. and J.V. Matthews. 1992. The last (Koy–Yukon) interglaciation in the Yukon: comparisons with Holocene and interstadial pollen records. Quaternary International, 10–12:85–94.

Scoggan, H.J. 1978, 1979. The Flora of Canada. (4 vols.) National Museum of Natural Sciences, National Museums of Canada, Ottawa, Publications in Botany, No. 7. Vol. 1 (1978) p. 1–89; Vol. 2 (1978) p. 93–545; Vol. 3 (1978) p. 547–1115; Vol. 4 (1979) p. 1117–1711.

Shackleton, N.J., A. Berges and W.R. Peltier. 1990. An alternate astronomical calibration of the lower Pleistocene time scale based on ODP Site 677. Transactions of the Royal Society of Edinborough: Earth Sciences, 81:251–261.

Sheldrick, B.H. (editor). 1984. Analytical Methods Manual. 1984. Land Resource Research Institute, Agriculture Canada, Ottawa, Canada.

Shilts, W.W. 1978. Nature and genesis of mudboils, central Keewatin, Canada. Canadian Journal of Earth Sciences, 10:1053–1068.

Smith, C.A.S. 1990. Nature of the cryic thermal regime of agricultural soils in the Yukon Territory, Canada. Pages 11–20 in: K.R. Cooley (ed.), Frozen Soil Impacts on Agricultural, Range and Forest Lands. CRREL Special Report 90–1, Hanover, NH.

Smith, C.A.S., C. Tarnocai and O.L. Hughes. 1986. Pedological investigations of Pleistocene glacial drift surfaces in the central Yukon. Géographie physique et Quaternaire, 40:29–37.

Smith, C.A.S. and C.A. Fox. In press. The development of granular structure in the surface horizons of strongly cryoturbated soils. In: Proceedings of the 1st International Conference on Cryopedology (2nd vol.). Russian Academy of Sciences, Pushchino, Russia.

Smith, C.A.S., C.A. Fox and A.E. Hargrave. 1991. Development of soil structure in some Turbic Cryosols in the Canadian low Arctic. Canadian Journal of Soil Science, 71:11–29.

Smith, C.A.S., A.D. Tomlin, J.J. Millar, M.J. Tynen and K.A. Coates. 1990. Large enchytraeid (Annedlida: Oligochaeta) worms and associated fauna from unglaciated soils of northern Yukon, Canada. Geoderma, 47:17–32.

Smith, M.W. 1988. The significance of climatic change for the permafrost environment. Pages 18–23 in: Proceedings, Fifth International Conference on Permafrost. Vol. 3. Tapir, Trondheim.

Smith, M.W. and D.W. Riseborough. 1983. Permafrost sensitivity to climatic change. Pages 1178–1183 in: Proceedings, Fourth International Conference on Permafrost. Vol. 1. National Academy of Sciences, Washington, D.C.

Soil Survey Laboratory Staff. 1992. Soil Survey Laboratory Methods Manual. National Soil Survey Center, Soil Conservation Service, USDA, Soil Survey Investigations Report No. 42, Version 2.0, 400 p.

Tarnocai, C. 1972. Some characteristics of cryic organic soils in northern Manitoba. Canadian Journal of Soil Science, 52:485–496.

Tarnocai, C. 1973. Soils of the Mackenzie River area. Environmental – Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 73–26, 136 p.

Tarnocai, C. 1978. Distribution of soils in northern Canada and parameters affecting their utilization. 11th International Congress of Soil Science, Edmonton, Canada, Symposia Papers, 3:281–304.

Tarnocai, C. 1984. Characteristics of soil temperature regimes in the Inuvik area. Pages 19–37 in: Northern Ecology and Resource Management. Rod Olson *et al.* (eds.), The University of Alberta Press.

Tarnocai, C. 1987a. Quaternary soils. Pages 16–21 in: S. R. Morison and C.A.S. Smith (eds.), Guidebook to Quaternary Research in Yukon. XII INQUA Congress, Ottawa, Canada, National Research Council of Canada, Ottawa.

Tarnocai, C. 1987b. Stop 17: Diversion Creek paleosol developed on Reid gravel. Pages 56–57 in: S. R. Morison and C.A.S. Smith (eds.), Guidebook to Quaternary Research in Yukon. XII INQUA Congress, Ottawa, Canada, National Research Council of Canada, Ottawa.

Tarnocai, C. 1987c. Stop 22: Wounded Moose paleosol developed on pre-Reid gravel. Pages 61–65 in: S. R. Morison and C.A.S. Smith (eds.), Guidebook to Quaternary Research in Yukon. XII INQUA Congress, Ottawa, Canada, National Research Council of Canada, Ottawa.

Tarnocai, C. 1990. Paleosols of the interglacial climates in Canada. Géographie physique et Quaternaire, 44:363–374.

Tarnocai, C. and C.E. Schweger. 1991. Late Tertiary and early Pleistocene paleosols in northwestern Canada. Arctic, 44:1–11.

Tarnocai, C., S. Smith and O.L. Hughes. 1985. Soil development on Quaternary deposits of various ages in the central Yukon Territory. Current Research, Part A, Geological Survey of Canada Paper 85–1A, p. 229–238.

Tarnocai, C. and C.A.S. Smith. 1989. Micromorphology and development of some central Yukon paleosols, Canada. Geoderma, 45:145–162.

Tarnocai, C. and C.A.S. Smith. 1992. The formation and properties of soils in the permafrost regions of Canada. Pages 21–42 in: Proceedings, 1st International Conference on Cryopedology, Russian Academy of Sciences, Pushchino, Russia.

Tarnocai, C. and S. C. Zoltai. 1978. Earth hummocks of the Canadian Arctic and Subarctic. Arctic and Alpine Research, 10:581–594.

Tarnocai, C. and S.C. Zoltai. 1988. Wetlands of Arctic Canada. Pages 27–53 in: National Wetlands Working Group, Wetlands of Canada. Ecological Land Classification Series, No. 24, Sustainable Development Branch, Environment Canada, Ontario, and Polyscience Publications Inc., Montreal, Quebec.

Thorsen, R.M. and E.J. Dixon, Jr. 1983. Alluvial history of the Porcupine River: role of glacial lake overflow from northwest Canada. Geological Society of America, Bulletin, 94:576–589.

Tynen, M.J., K.A. Coates, C.A.S. Smith and A.D. Tomlin. 1991. *Henlea yukonensis,* (Oligocaeta: Enchytreidae), a new species from the Yukon Territory, with comments on *Henlea michaelsen,* 1889 and *Punakenlea murminen* 1989. Canadian Journal of Zoology, 69:1375–1388.

Van Vliet-Lanoe, B. 1985 Frost effects in soils. Pages 117–158 in: J. Boardman (ed.), Soils and Quaternary Landscape Evolution. John Wiley and Sons, Chichester.

Veillette, J.J. 1980. Nonsorted circles in cohesionless fine silty sand, north-central District of Keewatin. Geological Survey of Canada Paper 80–1B, p. 259–267.

Vernon, P. and O.L. Hughes. 1966. Surficial geology of Dawson, Larsen Creek and North Creek map areas, Yukon Territory. Canada Geological Survey Bulletin 136, 25 p. (includes Maps 1170A, 1171A, 1172A).

Washburn, A.L. 1956. Classification of patterned ground and review of suggested origins. Bulletin of the Geological Society of America, 67:823–866.

Washburn, A.L. 1967. Instrumental observations of mass-wasting in the Mesters Vig district, Northeast Greenland. Medd. om Groenland, 166 (4), 318 p.

Washburn, A.L. 1973. Periglacial Processes and Environments. Edward Arnold Publ. Ltd., London, England, 320 p.

Washburn, A.L. 1980. Geocryology. John Wiley and Sons, Inc., New York, 406 p.

Westgate, J.A. 1989. Isothermal plateau fission-track ages of hydrated glass shards from silicic tephra beds. Earth and Planetary Science letters, 95:226–234.

Williams, P.J. 1968. Ice distribution in permafrost profiles. Canadian Journal of Earth Sciences, 5:1381–1386.

Williams, P.J. and M.W. Smith. 1989. The frozen earth: fundamentals of geocryology. Cambridge University Press, Cambridge. 306 p.

Zoltai, S.C. 1975. Tree ring record of soil movements on permafrost. Arctic and Alpine Research, 7:331–340.

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

Zoltai, S.C. and C. Tarnocai. 1974. Soils and vegetation of hummocky terrain. Environmental - Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 74–5, 86 p.

Zoltai, S.C. and C. Tarnocai. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences, 12:28–43.

Zoltai, S.C. and C. Tarnocai. 1981. Some nonsorted patterned ground types in northern Canada. Arctic and Alpine Research, 13:139–151.

Zoltai, S.C., C. Tarnocai and W.W. Pettapiece. 1978. Age of cryoturbated organic material in earth hummocks from the Canadian Arctic. Proceedings of the Third International Conference on Permafrost, Edmonton, Canada, p. 325–331.

Zoltai, S.C., C. Tarnocai, G.F. Mills and H. Veldhuis. 1988. Wetlands of Subarctic Canada. Pages 54–96 in: National Wetlands Working Group, Wetlands of Canada. Ecological Land Classification Series, No. 24, Sustainable Development Branch, Environment Canada, Ontario, and Polyscience Publications Inc., Montreal, Quebec.

APPENDICES

APPENDIX 1: THE CANADIAN SYSTEM OF SOIL CLASSIFICATION

In Canada, soils are classified according to a hierarchical system given in The Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987). Classes of all five categories (order, great group, subgroup, family and series) are based on observable or measurable soil properties. Diagnostic properties at the order, great group, and subgroup levels reflect soil genesis and, hence, the environmental factors that influence soil genesis. The nine soil orders, arranged alphabetically, are defined in brief, general terms and the great groups are also listed.

BRUNISOLIC ORDER: Soils having genetic horizons but lacking the horizons diagnostic of other orders. They occur dominantly in subhumid to humid forested regions and usually have brown B horizons. Great groups are:
- **Melanic Brunisol** – has a mineral-organic surface horizon (Ah) and is not strongly acid
- **Eutric Brunisol** – lacks a well developed Ah horizon and is not strongly acid
- **Sombric Brunisol** – has an Ah horizon and is strongly acid
- **Dystric Brunisol** – lacks a well-developed Ah horizon and is strongly acid

CHERNOZEMIC ORDER: Soils of the grasslands. They have a well-developed, base-rich, mineral-organic surface horizon (Ah). The four great groups are based on the colour of the surface horizon, which reflects soil climate:
- **Brown**
- **Dark Brown**
- **Black**
- **Dark Gray**

CRYOSOLIC ORDER: Soils of the permafrost zone, which includes about one-third of Canada. They may be composed of either mineral or organic material and have permafrost near the surface (1 to 2 m). The three great groups are:
- **Turbic Cryosol** – strongly cryoturbated mineral soils, as indicated by microrelief or by mixed horizons
- **Static Cryosol** – mineral soils that are not strongly cryoturbated
- **Organic Cryosol** – organic material having permafrost within 1 m

GLEYSOLIC ORDER: Soils having drab colors, prominent mottling or other features resulting from periodic or permanent high water table and reduction. They occur commonly in depressions and level areas that either receive run-off water or are groundwater discharge areas. The three great groups are:
- **Humic Gleysol** – has a well-developed mineral-organic surface horizon (Ah)
- **Gleysol** – lacks a well-developed Ah horizon
- **Luvic Gleysol** – has a B horizon (Btg) with significant clay accumulation

LUVISOLIC ORDER: Soils, usually in forested regions, in which leaching has resulted in significant translocation of clay from the A to the B horizon (Bt). They usually they have a light gray eluvial horizon (Ae). The great groups are:
- **Gray Brown Luvisol** – has a mild soil climate and forest mull Ah horizon
- **Gray Luvisol** – has a cold to cool soil climate, usually with an Ah horizon less than 5 cm thick

ORGANIC ORDER: Soils composed dominantly of organic materials (more than 17% organic carbon) of the required thickness (60 cm for fibric materials, 40 cm for others). The great groups are:
- **Fibrisol** – composed mainly of fibres that are not decomposed
- **Mesisol** – more decomposed than Fibrisol
- **Humisol** – highly decomposed, few fibres
- **Folisol** – composed mainly of thick leaf litter over rock

PODZOLIC ORDER: Acid soils developed under forest and heath. They have a B horizon enriched in humified organic matter and Al and Fe weathering products, usually underlying a light gray, weathered Ae horizon. The great groups are:
- **Humic Podzol** – has a B horizon depleted of Fe
- **Ferro-Humic Podzol** – has a B horizon rich in organic matter combined with Al and Fe

Humo-Ferric Podzol – has a B horizon rich in Al and Fe, but containing less organic matter than Ferro-Humic Podzol

REGOSOLIC ORDER: Development of genetic horizons is absent or very weakly expressed. The great groups are:
Humic Regosol – has a dark, mineral-organic surface horizon (Ah)
Regosol – either lacks or has a thin Ah horizon

SOLONETZIC ORDER: Soils associated with saline materials and having prismatic or columnar structured, Na-rich, B horizons that are hard when dry and nearly impermeable when wet. They occur mainly in the grasslands and are associated with Chernozemic soils. The great groups are:
Solonetz – lacks a well-developed eluvial Ae horizon
Solodized-Solonetz – has a well-developed Ae horizon
Solod – has an Ae horizon and an AB horizon in which the structure of the former B horizon has disintegrated

Subgroups are formed by subdivisions of great groups according to kind and arrangement of horizons indicating conformity to the central concept of the great group, intergrading to other orders, or additional special horizons. Families are differentiated from subgroups on the basis of parent material characteristics, soil climate factors and soil reaction. Series are differentiated from families on the basis of detailed soil features.

Correlation of Canadian, U.S., and F.A.O. Soil Classifications

Canada	U.S.	F.A.O.
Brunisol	Inceptisol	Cambisol
Chernozem	Mollisol	Kastanozem, Chernozem, Rendzina
Cryosol	Pergelic subgroups	Gelic subgroups
Gleysol	Aqu subgroups	Gleysol, Planosol
Luvisol	Alfisol	Luvisol
Podzol	Spodosol	Podzol
Organic soil	Histosol	Histosol
Regosol	Entisol	Regosol, Fluvisol
Solonetz	Natric great groups	Solonetz

APPENDIX 2: METHODS

SOIL TEMPERATURE

A 175-cm-long probe made from 2.5 cm diameter PVC pipe is used to support the thermistors. The YSI #44033 thermistors are positioned at 2.5, 5, 10, 20, 50, 100 and 150 cm from the zero mark on this pipe. Each thermistor is connected to a 3 m cable that terminates in a 28 pin MS connector. The probe is installed in an auger hole and positioned so that the zero mark on the probe matches the soil surface. An eight-channel Brancker type of data logger is used to monitor soil temperatures. This logger is programmed to record data every 3 hours on the hour. The data is downloaded approximately twice a year using a laptop computer and then analyzed using a Lotus 123 data manager.

AIR TEMPERATURE

A thermistor is positioned in a Gill multiplate radiation shield (Model 41004-5) that is fastened to a pole 120 cm above the ground. This thermistor is then connected to the same data logger that is used to collect soil temperatures. Air temperature data is also collected every three hours. The same method is then used to analyze the air temperature data as is used for soil temperatures.

SOIL MOISTURE

Soil moisture is measured by using an IRAMS-type, time domain reflectometry (TDR) soil moisture analyzer. Stainless steel rods were installed at the 15, 30 and 50 cm depths to determine the soil moisture.

ACTIVE LAYER DEPTH

The active layer depth is measured by inserting a steel probe into the unfrozen part of the soil. The measurements are taken annually, in mid-September.

SNOW DEPTH

Calibrated 1.5 m snow stakes are installed on the sites. Snow depths were determined by reading the snow depth on the snow stakes during visits to the sites.

SUBSIDENCE

Increasing thaw depth results in melting of the near-surface, ice-rich permafrost, causing the soil surface to subside. A 2.5 m long pipe is frozen in the permafrost and the subsidence of the surface is determined by measuring the level of the soil surface in relation to a permanent marker on this pipe.

SOIL DESCRIPTIONS

Soil descriptions follow the standard conventions outlined in the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987).

ANALYTICAL METHODS: The analytical methods are described in Sheldrick (1984)[1] and Soil Survey Laboratory Staff (1992).[2]

General procedures are as follows:

pH: saturated paste (H_20) and neutral salt (0.01 M $CaCl_2$)
Total C: induction furnace method
$CaC0_3$ equiv: calcimeter method
Total N: semi-micro Kjeldahl
Total (elemental) analysis: HF dissolution[2]
Exchangeable cations:
  a. Neutral salt – extraction with 2 N NaCl
  b. pH 7 – buffered ammonium acetate
Iron and aluminum:
  a. dithionite – citrate – bicarbonate
  b. acid ammonium oxalate (pH 3)
  c. sodium pyrophosphate (0.1 M)
Water soluble salts: ions were determined on saturated extracts
Available nutrients:
  a. N – modified Pl Bray (NH_4F-H_2S0_4) extract
  b. P – modified Pl Bray (NH_4F-H_2S0_4) extract
  c. K – ammonium acetate (1 N)
  d. S – 0.1 M $CaCl_2$
Organic matter: classical NaOH/$Na_4P_2O_7$ extractions
Mineralogy:
  a. x-ray diffraction of the <2 um soil fraction[1]
  b. x-ray diffraction (7C3) – resin pretreatment (7A2i)[2]
Fibre content: syringe method for fibres retained on 100 mesh sieve
Bulk density:
  a. core method[1]
  b. saran-coated clods on oven-dry basis (4A1h)[2]
Water holding capacity: pressure plate method
Atterberg limits: standard procedure

MICROMORPHOLOGICAL ANALYSIS

The samples were prepared following methods outlined in Sheldrick (1984). Prior to impregnation under vacuum with polyester resin, the samples were acetone exchanged to remove any water remaining in the soil as well as to maintain the soil pore pattern and prevent the excessive shrinkage of organic material. The thin sections (2 x 4 cm) were described using a Leitz Ortholux II Pol-Bk polarizing light microscope at magnifications ranging from 25 to 125X. Reference was made to the following descriptive systems: Brewer (1964, 1976), Pawluk and Brewer (1975), Fox and Protz (1981), Bullock *et al.* (1985), and Brewer and Sleeman (1988).

The micromorphological descriptions contain a qualitative measure of frequency of occurrence of the observed features as follows:

Very rare:	isolated occurrence
Rare:	very hard to find, but can be located
Occasional:	few occurrences
Common:	very easily found, but not abundant
Frequent:	numerous
Very frequent:	extremely abundant

VEGETATION DESCRIPTIONS

Vegetation descriptions are given by physiognomic group: Grasses includes all graminoids; mosses includes liverworts.

APPENDIX 3: GLOSSARY OF MICROMORPHOLOGICAL TERMS

Bullock *et al.* (1985) define micromorphology as the branch of soil science that is concerned with the description, interpretation and, to an increasing extent, the measurement of components, features and fabrics in soils at the microscopic level. Micromorphological concepts and procedures provide unique methodology for describing the spatial arrangements of the soil constituents. No other chemical or physical analyses of the soil can provide similar information about the soil. Micromorphology is based on samples that are prepared to maintain the field *in situ* properties; chemical analyses, for the most part, are applied to samples that have been sieved to a size fraction less than 2 mm, and sometimes ground to 50 μm prior to analysis.

Micromorphology is used to evaluate the spatial arrangement of the soil constituents (mineral, organic, and biological components) and the associated soil pores by confirming whether the soil constituents are distributed uniformly or as heterogeneous materials; by determining how the soil constituent arrangement changes across boundaries, and, most important, by assessing where soil processes have affected the soil and to what degree of intensity.

The following are some definitions of the concepts and terminology frequently used to describe the micromorphology of the soils presented on this tour. The following were used as references: Brewer (1964, 1976); Brewer and Pawluk (1975); Pawluk and Brewer (1975); Bullock *et al.* (1985); Fox and Protz (1981); and Brewer and Sleeman (1988). For additional discussion of the terms and concepts that may not be included below, please refer to the above references.

MICROMORPHOLOGICAL CONCEPTS:

Soil Fabric:

Deals with the total organization of a soil, expressed by the spatial arrangements of the soil constituents (solid, liquid and gaseous), their shape, size and frequency, considered from a configurational, functional and genetic viewpoint. (Bullock *et al.* 1985).

The physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids. (Brewer 1976).

Related concepts:

A ***pattern*** of soil constituents is concerned with the spatial arrangement of solid soil constituents and associated voids. (Bullock *et al.* 1985)

Each soil fabric may be composed of a number of discrete, more or less homogeneous entities, seen in thin sections as homogeneous zones. Such zones are termed ***fabric units*** defined as follows: A ***fabric unit*** is a part of the soil material, homogeneous at the scale of observation and for the method of observation used. (Bullock *et al.* 1985).

Skeleton grains of a soil material are individual grains larger than colloidal size; they consist of mineral grains originally present in the parent material and resistant siliceous and organic bodies. (Brewer 1976)

Plasma of a soil material is all of the material of colloidal size, and relatively soluble material that is not bound up in skeleton grains; it consists of mineral (amorphous and crystalline) and organic material. (Brewer 1976)

TYPES OF SOIL MATERIAL ARRANGEMENTS:

A: Related Distribution Patterns (RDP)

Terms from Brewer (1976), Brewer and Pawluk (1975), Pawluk and Brewer (1975).

Agglomeroplasmic: The plasma occurs as loose or incomplete fillings in the intergranular spaces between the skeleton grains.

Banded: A succession of subhorizontal bands, each of which shows a gradation in colour and porportion of plasma (matrix) from the top to the bottom; the upper part of each band is relatively darker (denser) with a sharp boundary between it and the overlying band. [After McMillan and Mitchell (1953); Dumanski and St. Arnaud (1966)]

Chlamydic: The matrix occurs as complete coatings or uniformly discontinuous coatings on the framework members, otherwise the intergranular spaces are essentially empty.

Fragmic: Relatively densely packed, accommodated discrete units without coatings on, or bridges between units. Similar prefixes as for granic can be used.

Fragmoidic: Relatively densely packed, accommodated discrete units without coatings on, or bridges between units. Similar prefixes as for granic can be used.

Granic: Unaccommodated, typically loosely packed, discrete units without coatings on, or bridges between units.
Orthogranic: Loosely packed mineral grains and/or rock nodules;
Phytogranic: Loosely packed, partially decomposed plant fragments;
Humigranic: Loosely packed, dark, usually isotropic, moder-like organic fragments;
Mullgranic: Loosely packed mull-like units consisting of plasma plus skeleton grains with the birefringence of the plasma masked by finely disseminated, probably colloidal organic matter.
Matrigranic: Loosely packed units composed of "normal" soil material.

Granoidic: Forms like those of the granic fabrics, but the units are not discrete, appearing in thin section to be fused together at contact points. Similar prefixes can be used as above except for ortho, which is not expected.

Granoidic porphyroskelic: A variety of porphyroskelic fabric with interconnected vughs whose size, shape, and arrangement are such that the material has an overall appearance that suggests it could be formed by the strong coalescence of units of the granic type, other than orthogranic. Can also be applied to fragmic and fragmoidic arrangements (i.e. ***fragmic porphyroskelic***, and ***fragmoidic porphyroskelic***).

Granular: There is no plasma, or all the plasma occurs as pedological features.

Intertextic: The skeleton grains are linked by intergranular braces or are embedded in a porous groundmass (matrix in the sedimentary petrological sense).

Isoband: A succession of subhorizontal bands that show no change in fabric or proportion of plasma throughout the thickness of the bands; the bands are separated by subhorizontal cracks.

Plectic: The matrix coats the framework members (skeleton grains) and broadens and extends to form bridges between them; the walls of the large voids consist of matrix material.

Porphyroskelic: The plasma occurs as a dense groundmass in which skeleton grains are set after the manner of phenocrysts in a porphyritic rock.

Terms from Bullock *et al.* (1985)

Chitonic: The coarser units are surrounded by a cover of smaller units.

Enaulic: There is a skeleton of larger fabric units with aggregates of smaller units in the interstitial spaces. These aggregates do not completely fill the interstitial spaces, and the larger units support each other.

Gefuric: The coarser particles are linked by braces of finer material.

Monic: Only fabric units of one size group, or amorphous material are present.

***Porphyric*:** The large fabric units occur in a dense groundmass of smaller units.

Terms adapted from Fox and Protz (1981)

***Conglomeric*:** A compound fabric arrangement in which the primary units are discrete framework members (coarser units, usually derived from granic fabric distributions) that are randomly set into a groundmass of finer material about which the associated voids delineate a secondary fabric of elliptical to rounded framework members such as fragmic, fragmoidic or granoidic.

***Conglomeric porphyroskelic*:** The rounded to elliptical framework members (usually originating from a granic fabric distribution) are randomly set in a dense groundmass of finer material.

***Conglomeric porphyric*:** The rounded to elliptical framework members (usually from a granic fabric distribution) are randomly set in a groundmass of coarser material (usually silt-size and greater). The framework members are very large in relation to the surrounding soil material.

***Orbiculic*:** The skeleton grains or framework members are distributed in a circular or ellipsoidal arrangement.

***Orbiculic porphyroskelic*:** The skeleton grains are arranged as regular to irregular circles or ellipsoids within the groundmass of dense, fine-grained material (usually clay and very fine silt-size). There may be a gradation in particle size of the skeleton grains towards the circumference of the circles or ellipsoids.

***Orbiculic porphyric*:** The coarser particles are arranged as regular to irregular circles or ellipsoids within a closely to densely packed mass of finer materials (usually silt to very fine sand-size).

***Suscitic*:** The skeleton grains (or framework members) are oriented vertically or nearly vertically. Usually, but not always, there may be accumulations or infillings at the base of the skeleton grains.

***Suscitic porphyroskelic*:** A dense, fine-grained soil matrix in which the skeleton grains show vertical or nearly vertical alignment and usually, but not always, have an accumulation of finer material at the base.

***Suscitic porphyric*:** The coarser particles within a close to densely packed groundmass of finer material (usually silt to very fine sand-size) show vertical or nearly vertical alignment and usually, but not always, have an accumulation of the finer materials at the base.

Terms from Brewer and Sleeman (1988)

***Adporphyric*:** The interstices between the coarser particles are filled with closely packed, successively finer particles so that, in thin section, the fabric appears dense and framework members and framework matrix are indistinguishable except by setting an arbitrary size limit between them.

B: Plasmic Fabrics (Brewer, 1976) or Birefringent Fabrics (Bullock *et al.* 1985)

Note: The first term is taken from Brewer (1976) with the equivalent birefringent fabric in brackets. See also Ringrose-Voase (1991).

***Argillasepic (Stipple-speckled)*:** The plasma of this fabric consists dominantly of anisotropic clay minerals and exhibits a flecked orientation pattern with recognizable domains. No zones of oriented clay.

***Silasepic (Stipple-speckled)*:** A wide range of particle sizes with relatively high proportions of silt-size grains so that domains are difficult to recognize. No zones of oriented clay.

***Insepic (Stipple-speckled)*:** Plasma separations with striated orientation (that is, oriented clay) occur as isolated patches within the plasma.

***Mosepic (Mosaic-speckled)*:** This is an extreme development of insepic fabric. The patches of oriented clay adjoin each other or are separated by small areas of clay material.

***Masepic (Striated)*:** Oriented clay occurs as zones within the s-matrix; all the zones may be subparallel to each other (that is, a single direction of preferred orientation) or occur as two or three sets of subparallel zones, each set being inclined at a definite angle.

***Lattisepic (Reticulate striated)*:** There are two sets of very short, discontinuous plasma separations usually oriented approximately at right angles to each other.

***Skelsepic (Granostriated)*:** Oriented clay occurs on the surfaces of skeleton grains; the striated orientations are parallel to the surfaces of the grains.

Strial (Strial)*:** Whole matrix consists of streaks of oriented clay in one (unistrial***) or two (***bistrial***) directions.

***Omnisepic (Striated)*:** The clay material of the plasma exhibits a complex striated orientation pattern.

***Vosepic (Porostriated)*:** Oriented clay is associated with the walls of voids; the orientation is often parallel.

APPENDIX 4: SCIENTIFIC AND COMMON NAMES OF PLANT SPECIES

(Scoggan 1978, 1979)

SCIENTIFIC NAME	COMMON NAME
TREES	
Abies lasiocarpa (Hook.) Nutt.	Alpine fir
Betula papyrifera Marsh. ssp. *humilis* (Regel) Hult	White birch, Alaska white birch
Larix laricina (Du Roi) K. Koch	Tamarack, American larch
Picea glauca (Moench) Voss	White spruce
Picea mariana (Mill.) BSP.	Black spruce
Pinus banksiana Lamb.	Jack pine
Pinus contorta Dougl.	Lodgepole pine
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen, quaking aspen
SHRUBS	
Alnus crispa (Ait.) Pursh	Green alder, mountain alder
Andromeda polifolia L.	Bog-rosemary
Arctostaphylos alpina (L.) Spreng.	Alpine bearberry
Arctostaphylos rubra (Rehd. & Wilson) Fern.	Bearberry, red fruit bearberry
Arctostaphylos uva-ursi (L.) Spreng.	Kinnikinnick, common bearberry
Betula glandulosa Michx.	Shrub birch, resin birch
Betula nana L	Dwarf arctic birch
Betula occidentalis Hook.	Hybrid birch, water birch
Cassiope tetragona (L.) D. Don	Lapland cassiope, arctic white heather
Chamaedaphne calyculata (L.) Moench	Cassandra, leather-leaf
Dryas integrifolia Vahl	Entire-leaf mountain avens
Dryas octopetala L.	White mountain-avens
Empetrum nigrum L.	Black crowberry
Ledum palustre L. ssp. *decumbens* (Ait.) Hult	Labrador tea, narrow-leaf Labrador-tea
Ledum palustre L. ssp. *groenlandicum* (Oeder) Hult	Labrador-tea
Linnaea borealis L.	Twinflower
Loiseleuria procumbens (L.) Desv.	Alpine azalea
Juniperus communis L.	Common juniper, dwarf juniper
Oxycoccus microcarpus Turcz.	Bog cranberry
Potentilla egedii Wormsk.	
Potentilla fruticosa L.	Shrubby cinquefoil, bush cinquefoil
Rhododendron lapponicum (L.) Wahlenb.	Lapland rosebay
Rosa acicularis Lindl.	Wild rose, prickly rose
Rubus arcticus L.	Ground raspberry, nagoon-berry
Rubus chamaemorus L.	Cloudberry, baked-apple berry
Salicaceæ sp.	
Salix alaxensis (Anderss.) Cov.	Alaska willow, feltleaf willow
Salix arbusculoides Anderss.	Littletree willow
Salix arctica Pallas	Arctic willow
Salix barclayi Anderss.	Barclay willow
Salix depressa L. ssp. *rostrata* (Anderss.) Hiitonen	Longbeaked willow
Salix glauca L.	Grayleaf willow
Salix glauca L. ssp. *acutifolia* (Hook.) Hult	Willow
Salix myrtillifolia	

SCIENTIFIC NAME	COMMON NAME
Salix phlebophylla Anderss.	Skeletonleaf willow
Salix planifolia	
Salix pulchra Cham.	Diamondleaf willow, tundra dwarf willow
Salix reticulata L.	Netleaf willow, netvein dwarf willow
Salix richardsonii Hook.	Richardson's willow
Shepherdia canadensis (L.) Nutt.	Soapberry, russet buffaloberry
Spiraea beauverdiana Schneid.	Alaska spirea, Beauverd spirea
Vaccinium uliginosum L.	Bog-blueberry, al pine bilberry
Vaccinium vitis-idaea L.	Mountain cranberry, rock cranberry
Viburnum edule (Michx.) Raf.	High bush cranberry, squashberry

HERBS OR FORBS

Anemone narcissiflora L.	
Anemone parviflora	
Antennaria stolonifera Porsild	Pussytoes
Arnica angustifolia	
Arnica cordifolia Hook.	
Artemisia arctica Less. ssp. *arctica*	Wormwood
Aster sibiricus	
Chrysanthemum integrifolium	
Corallorhiza trifida Chatelain	Northern, early, or pale coral root
Cruciferæ sp.	Mustard family
Draba nivalis Liljebl.	Whitlow grass
Drosera rotundifolia L.	Round-leaved sundew
Dryas integrifolia (see Shrubs)	
Dryas octopetala (see Shrubs)	
Epilobium angustifolium L.	Fireweed
Erigeron sp.	Fleabanes
Equisetum arvense L.	Common horsetail, field horsetail
Equisetum fluviatile L. ampl. Ehrh.	Water horsetail
Equisetum pratense Ehrh.	Meadow horsetail
Equisetum scirpoides Michx.	Dwarf scouring rush
Equisetum sylvaticum	
Galium boreale	Northern bedstraw
Gentiana propinqua	
Geocaulon lividum (Richards.) Fern.	Toad flax, northern comandra
Hedysarum alpinum L.	Liquorice root
Lagotis sp.	
Lagotis glauca	
Lagotis stelleri	
Lupinus arcticus S. Wats.	Lupine
Lycopodium annotinum L. ssp. *pungens* (La Pyl.) Hult	Stiff clubmoss
Lycopodium clavatum L.	Running clubmoss
Lycopodium obscurum L.	Tree clubmoss, ground pine
Menyanthes trifoliata L.	Buckbean, bogbean
Mertensia paniculata (Ait.) G.Don	Bluebell
Minuartia arctica (Stev.) Aschers. & Graebn.	Arctic sandwort
Minuartia elegans	
Minuartia rubella (Wahlenb.) Graebn.	
Moehringia lateriflora (L.) Fenzl.	Grove sandwort
Oxytropis roaldii	

SCIENTIFIC NAME	COMMON NAME
Papaver sp.	Poppies
Papaver macounii	
Parrya nudicaulis (L.) Regel ssp. *interior* Hult	
Pedicularis kanei E. Durand	Woolly lousewort
Pedicularis labradorica Wirsing	Labrador lousewort
Pedicularis lanata	
Pedicularis langsdorfii Fisch.	Lousewort
Pedicularis verticillata	
Petasites frigidus (L.) Fries	Sweet coltsfoot
Petasites hyperboreus Rydb.	Coltsfoot
Pinguicula villosa L.	Butterwort
Polemonium pulcherrimum Hook.	Jacob's ladder
Potentilla palustris (L.) Scop.	Marsh fivefinger, marsh cinquefoil
Potentilla villosa Pallas	
Polygonum alaskanum	Eskimo rhubarb
Polygonum bistorta L. ssp. *plumosum* (Small) Hult	Bistort
Polygonum viviparum L.	Alpine bistort, alpine smartweed, knotweed
Pyrola grandiflora Radius	Large flowered wintergreen
Ranunculus sp.	Buttercups
Rubus chamaemorus (see Shrubs)	
Saussurea angustifolia (Willd.) DC.	
Saxifraga hieracifolia	
Saxifraga hirculus	
Saxifraga tricuspidata Rottb.	Prickly saxifrage
Selaginella sibirica (Milde) Hieron.	Spike moss
Senecio lugens	
Senecio resedifolius Less.	Ragwort
Solidago sp.	Goldenrods
Solidago multiradiata	
Stellaria sp.	Chickweeds
Thalictrum sp.	Meadow-rues
Tofieldia pusilla (Michx.) Pers.	False asphodel
Valeriana capitata Pallas	Valerian
Zygadenus sp.	
Zygadenus elegans pursh	Death camus

GRASSES (GRAMINOIDS)

Agropyron subsecundum	
Agrostis scabra Willd.	Bentgrass
Arctagrostis latifolia (R. Br.) Griseb.	Polar grass
Arctophila fulva (Trin.) Rupr.	
Calamagrostis canadensis (Michx.) Beauv. ssp. *canadensis*	Bluejoint
Calamagrostis lapponica (Wahlenb.) Hartm.	
Calamagrostis purpurascens	
Calamagrostis stricta	
Carex aquatilis Wahl.	Sedge
Carex bigelowii Torr.	Sedge
Carex concinna R. Br.	Sedge
Carex lugens Holm	Sedge
Carex obtusata Lilj.	Sedge
Carex physocarpa	

SCIENTIFIC NAME	COMMON NAME
Carex rotundata	
Carex scirpoides	
Carex stylosa	
Carex vaginata	
Dupontia fisherii R. Br.	Marshgrass
Eriophorum angustifolium Honck. ssp. *subarcticum* (Vassilijev) Hult	Tall cotton grass
Eriophorum brachyantherum Trautv. & Mey.	Cotton grass
Eriophorum russeolum E. Fries	Cotton grass
Eriophorum vaginatum L.	Cotton grass
Festuca sp.	
Festuca altaica Trin.	Fescue grass, rough fescue
Gramineæ sp.	
Hierochloe alpina (Sw.) Roem & Schult.	Sweetgrass
Juncus arcticus Willd.	Bog rush
Luzula rufescens Fisch. & Mey.	Wood rush
Trisetum spicatum	

MOSSES

Aulacomnium turgidum (Wahlenb.) Schwaeger	
Bryophyte spp.	
Calliergon giganteum (Schimp.) Kindb.	
Ceratodon purpureus (Hedw.) Brid.	Horn-tooth moss
Diacranum acutifolium (Lindb. & Arn.) C. Jens.	
Dicranum elongatum Schleich.	
Dicranum flagellare Hedw.	
Dicranum fuscescens Turn.	
Dicranum undulatum Brid.	
Drepanocladus uncinatus (Hedw.) Warnst.	Hair-cap moss
Hylocomium splendens (Hedw.) Bry. Eur.	Stair-step moss
Hypnum crista-castrensis Hedw.	Plume moss
Hypnum plicatulum (Lindb.) Jaeg. & Sauerb.	
Jamesoniella autumnalis (DC) Steph.	
Leptobryum pyriforme (Hedw.) Schimp.	
Pleurozium schreberi (Brid.) Schwaegr.	Schreber's moss
Polytrichum commune Hedw.	Hair-cap moss
Polytrichum juniperinum Hedw.	
Polytrichum piliferum Hedw.	
Ptilidium ciliare (L.) Hampe	Liverwort
Rhacomitrium lanuginosum (Hedw.) Brid.	Wooly fringe moss
Rhytidium rugosum (Hedw.) Kindb.	
Sphagnum fuscum (Schimp.) Klinggr.	
Sphagnum girgensohnii Russow	
Sphagnum magellanicum Brid.	
Sphagnum rubellum Wils.	
Sphagnum subsecundum Ness.	
Tetraplodon mnioides (Hedw.) Bry. Eur.	
Tomenthypnum nitens (Hedw.) Loeske	

SCIENTIFIC NAME	COMMON NAME
LICHENS	
Alectoria americana	
Alectoria minuscula	
Alectoria nitidula	
Alectoria ochroleuca	
Cetraria cucullata (Bell) Ach.	
Cetraria hepatizon (Ach.) Vain.	
Cetraria islandica (L.) Ach.	Iceland moss
Cetraria nivalis (L.) Ach.	
Cetraria richardsonii Hook.	
Cladina alpestris (L.) Harm.	
Cladina mitis (Sandst.) Hale & W. Culb.	
Cladina rangiferina (L.) Harm	Reindeer moss
Cladina stellaris	
Cladonia amaurocrea (Florke) Schaer.	
Cladonia cornuta (L.) Hoffm.	
Cladonia gonecha (Ach.) Asah.	
Cladonia gracilis (L.) Willd.	
Cladonia uncialis (L.) Wigg.	
Cornicularia muricata (Ach.) Ach.	
Dactylina arctica (Hook.) Nyl.	Deadman's finger
Icmadophila ericetorum (L.) Zahlb.	
Masonhalea richardsonii	
Nephroma arcticum (L.) Torss.	
Nephroma expallidum (Nyl.) Nyl.	
Parmelia centrifuga (L.) Ach.	
Peltigera aphthosa (L.) Willd.	Spotted peltigera
Rhizocarpon geographicum (L.) DC.	
Stereocaulon tomentosum Fr.	
Thamnolia vermicularis (Sw.) Ach.	
Umbilicaria hyperborea (Ach.) Ach.	Rock tripe

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