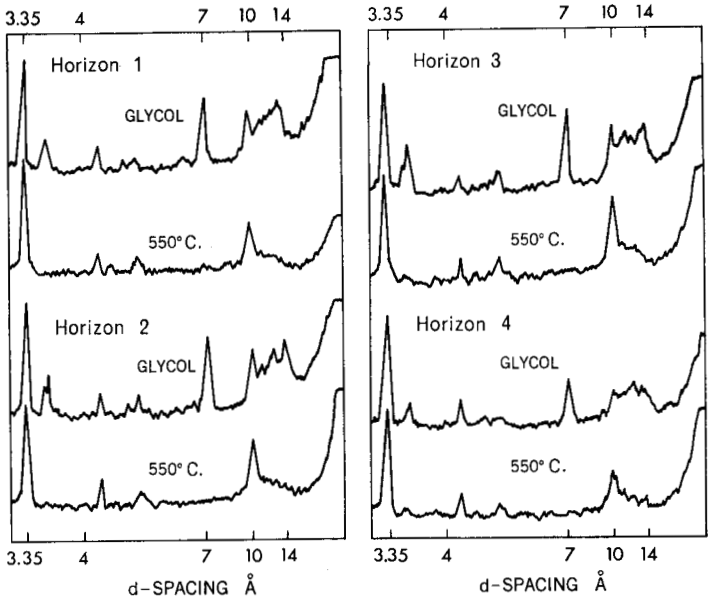

Fig. 1. X-ray diffractometer diagram of profile 2, the coarse clay (2.0 - 0.2μ) fraction.

Papers

THE CHARACTERISTICS OF SOME PERMAFROST SOILS IN THE MACKENZIE VALLEY, N.W.T.*

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Introduction

SOILS in the tundra and subarctic regions of Canada were first described in 1939 when Feustel and others analyzed samples from northern Quebec, Keewatin and Franklin districts. More recently McMillan (1960), Beschel (1961) and Lajoie (1954) described soils in the Canadian Arctic Archipelago and in northern Quebec. In the western part of the Northwest Territories only one profile (Leahey 1947) has been described under tundra vegetation, although other soils under forest, mostly unaffected by permafrost, have been described (Leahey 1954, Day and Leahey 1957, Wright *et al.* 1959).

In Alaska, Tedrow and Hill (1955), Drew and Tedrow (1957), Tedrow *et al.* (1958), Douglas and Tedrow (1960), Hill and Tedrow (1961) and Tedrow and Cantlon (1958) described several groups of soils, weathering processes, and concepts of soil formation and classification in the arctic environment. At least some of the kinds of soil they described in Alaska occur in Canada in a similar environment.

This study was undertaken to investigate the characteristics of soils in a permafrost region under different types of vegetation. The lower Mackenzie River valley is within the area of continuous permafrost (Brown 1960) and both tundra and boreal forest regions are readily accessible from the river. This paper describes soils in three localities, each with a different vegetation, the morphological, chemical, physical and mineralogical characteristics of a number of soil profiles, and the effect of permafrost and vegetation on soil development. The tundra locality at Reindeer Depot is situated on the east channel of the Mackenzie Delta at 68°42′N., 134°07′W.; the tundra — boreal forest transition locality at Inuvik is also on the east channel about 30 miles south of Reindeer Depot, at 68°21′N., 133°41′W. and the boreal forest locality at Norman Wells on the Mackenzie River lies about 280 miles southeast of Inuvik at 66°42′N., 126°51′W. In all localities permafrost is continuous and only slight differences in climate between them were found.

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Methods of investigation

The areas were visited between July 7 and 31, 1960. Observations on landform, topography and vegetation were recorded. The soil morphology was examined in dug pits and is described according to the terminology adopted by the National Soil Survey Committee (1963). The soil colours observed in the field are described using the Munsell notation.

Samples of soil from the various horizons of each profile were air-dried, ground and passed through a 2-mm. sieve. Soil reaction, organic matter and total nitrogen content, cation-exchange capacity and exchangeable cations, were determined by commonly used methods (Atkinson *et al.* 1958). The calcium carbonate equivalent was determined by the method of Skinner *et al.* (1959). Free iron was determined by the Coffin (1963) modification of the method of Aguilera and Jackson (1953).

Particle-size distribution of samples of profiles 1 to 5 were calculated from the fractions prepared for mineralogical analyses, and samples of profiles 6 to 8 inclusive were analyzed by the pipette method (Kilmer and Alexander 1949) modified by using a separate sample for the determination of the organic matter-free, moisture-free, dispersed weight of sample.

The samples examined mineralogically (1 to 5 inclusive) were brought to pH 3.5 to destroy carbonates, washed free of salts, treated with hydrogen peroxide, washed, and dispersed at pH 8.0. They were then separated into sand, coarse, medium and fine silts, and coarse and fine clays by sedimentation and centrifugation. The sand and silt fractions were dried on a water-bath and the clay fractions freeze-dried (Brydon *et al.* 1963).

The silts were examined by X-ray powder diagrams and the clays by oriented X-ray diffractometer diagrams and differential thermal analysis.

Climate

Meteorological records for Reindeer Depot are lacking, but are available for 6 years at Inuvik, for 22 years at Aklavik, which is about 40 miles west of Inuvik, and for 10 years at Norman Wells (Dept. of Transport 1954). Adjusted normals were prepared for Inuvik by assuming that the difference between the Inuvik and the Aklavik temperatures over a long period would be the same as during the short period for which data are available for both sites, that the ratio between the long-term averages of total precipitation at these sites would be the same as the ratio of the short-term averages, and that the proportion of the annual precipitation occurring in each month would be the same at both sites.

The data (Table 1) show that Norman Wells is warmer and wetter than Inuvik. On the basis of records for coastal stations (Dept. of Transport 1959) it is inferred that Reindeer Depot has cooler summers and rather lower summer precipitation that Inuvik.

Tundra at Reindeer Depot

Landform

The area examined at Reindeer Depot is on the crest and eastern flank of the Caribou Hills, a ridge paralleling the east channel of Mackenzie River.

The altitude of the ridge is over 500 feet. The landscape to the east of the ridge is generally gently to moderately sloping (2 to 9 per cent) with occasional strongly sloping (10 to 15 per cent) and very strongly sloping (16 to 30 per cent) areas. The crests of slopes are characterized by rough microtopography; roughly circular knolls 2 to 3 feet wide are 1 to 1.5 feet higher than the separating troughs that are about 1 foot wide. The middle of a slope has rougher microtopography and the knolls and troughs tend to be oriented down-slope. Toward the toe of a slope, the downhill face of a knoll is steeper than its uphill face. Depressions between slopes have very gently sloping, level or basin topography and some are characterized by a polygon pattern developed in peat deposits.

Vegetation

The Reindeer Depot area has been assigned to the Forest-Tundra section (Rowe 1959) but the sites sampled are more representative of the tundra. The vegetation forms a nearly continuous mat. Only an occasional willow 1 to 2 feet high is present; along watercourses and in basins protected from the wind alder 6 to 8 feet tall forms fairly dense stands. Among the dominant species are: *Betula glandulosa* (dwarf birch), *Eriophorum vaginatum* (cottongrass), *Ledum palustris* (Labrador tea), *Arctostaphylos alpina* (alpine bearberry), *Vaccinium vitis-idaea* (mountain cranberry), *V. uliginosum* (alpine blueberry), *Empetrum nigrum* (black crowberry), *Carex lugens* (sedge), *Lupinus arcticus* (lupine) and mosses. Other species present in minor amounts include *Salix glauca* (willow), *Castilleja raupii* (Indian paintbrush), *Cladonia* spp. (reindeer moss) and *Rubus chamaemorus* (baked-apple-berry). The vegetation is low and sparse on top of each knoll and some are bare. In the troughs the vegetation is higher and denser; there the main species are mosses and Labrador tea. In peat polygon areas, Labrador tea is

Table 1. Monthly and annual averages of daily maximum and minimum temperature, monthly and annual averages of total precipitation and snowfall.

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Inuvik, adjusted normals													
Mean daily maximum temperature, °F.	−11	−7	2	19	41	63	68	61	46	25	3	−7	25
Mean daily minimum temperature, °F.	−30	−26	−20	−6	22	39	45	40	30	13	−13	−26	6
Total precipitation, inches	0.51	0.43	0.35	0.49	0.44	0.85	1.19	1.35	0.96	0.78	0.65	0.45	8.45
Snowfall, inches	5.4	4.6	3.6	5.1	2.4	1.5	T	0.7	2.9	7.5	6.9	4.5	45.1
Norman Wells													
Mean daily maximum temperature, °F.	−11	−7	10	31	53	68	72	65	50	32	9	−6	31
Mean daily minimum temperature, °F.	−26	−23	−12	7	32	46	50	45	35	20	−4	−21	12
Total precipitation, inches	0.65	0.58	0.34	0.54	0.67	1.40	2.02	2.65	1.66	0.77	0.84	0.67	12.79
Snowfall, inches	6.5	5.8	3.4	4.6	1.8	0.2	0.0	T	2.8	6.5	8.4	6.7	46.7

dominant, with reindeer moss, mountain cranberry, and dwarf birch on the raised centre and grasses in the troughs.

Surficial geology and permafrost

Fine-textured glacial till covers the area to depths of 3 to 4 feet and is underlain by poorly consolidated sands, silts, and gravels (Mackay 1963) of undetermined age. The active layer is thin (6 inches) under the troughs and thick (24 inches) under the knolls, so that its basal face is a mirror image of the ground surface.

Soils

Two sites were selected to represent the main types of soils present.

The first site (profile 1) represents the ridges and upper slopes. It is a microknoll on a 4-per cent south-facing slope near the crest of a ridge about 2 miles east of Reindeer Depot. Soil profile 1 has the following characteristics:

Depth inches	*Horizon*	*Description*
3 - 2.5	1	Litter of twigs and leaves.
2.5 - 0	2	Reddish-black (10R 2/1) muck.
0 - 1	3	Very dark brown (10YR 3/2) silty clay, very weak, very fine granular; pH 5.5.
1 - 7	4	Very dark greyish brown (10YR 3/2) friable clay loam; weak, fine granular; a few pebbles; boundary diffuse; pH 5.3.
7 - 14	5	Very dark greyish brown (10YR 3/2) friable silty clay; moderate, fine granular; noncalcareous; a few pebbles; pH 6.0.
14 - 21	6	Very dark greyish brown (10YR 3/2) noncalcareous clay containing a few small pebbles and stones; weak, fine granular; frozen, segregated ice lenses 0.1 to 0.2 inch thick; pH 5.8.
21 - 25	7	Colour and structure as above; pH 6.0.

The other site represents the lower slopes and is also about 2 miles east of Reindeer Depot. This site is a microknoll near the toe of a long 2-per cent east-facing slope. Soil profile 2 has the following characteristics:

Depth inches	*Horizon*	*Description*
0 - 5	1	Olive-brown (2.5Y 4/4) friable silty clay; moderate to strong, fine granular; pH 4.7.
5 - 9	2	Dark greyish brown (2.5Y 4/2) friable clay; moderate to strong, fine granular; yellowish-brown (10YR 5/6) mottles are common, fine and distinct; boundary abrupt and irregular to broken with tongues extending into horizon below; boundary marked by yellowish-brown (10YR 5/8) colour; pH 4.7.
9 - 23	3	Dark grey (5Y 4/1) amorphous silty clay; very plastic and sticky; a few small pebbles; yellowish-brown mottles (10YR 5/4) are few, fine and distinct; thickness and depth are variable because of tonguing with horizon above; pH 5.3.
23 - 28	4	Dark grey (5Y 4/1) amorphous clay; frozen, 0.1-inch lenses of ice; faint olive (5Y 4/3) mottles; pH 5.2.

Both profiles are associated with moss-covered raw peat that is frozen at a depth of 7 inches in the troughs between the microknolls.

The depressions downslope from profile 2 are filled with peat having a well-developed raised-center polygonal pattern. The top 10 inches are black muck underlain by frozen fibrous peat.

Tundra-boreal forest transition at Inuvik

Landform

At Inuvik the area examined includes the gently undulating river terrace on which the settlement is located and the gently to moderately sloping upland plain to the east that rises to an altitude of about 300 feet. Both have a westerly aspect. The microtopography is rather similar to but less rough than that at Reindeer Depot.

Vegetation

The forest-tundra transition (Rowe 1959) is a continuous cover formed by the following dominant species: *Picea mariana* (black spruce), *Betula pumila* (birch), *Alnus crispa* (alder), *Salix glauca.* The continuous ground cover includes the following; *Vaccinium vitis-idaea, Ledum palustris, Hylocomnium splendens* (moss), *Rosa* spp., *Petasites frigidus* (sweet coltsfoot), *Spiraea beauverdiana,* and *Peltigera aphthosa* (lichen). The ground cover is low and sparse on the top of each knoll, higher and denser in the troughs.

Surficial geology and permafrost

In this area, fine-textured glacial till is underlain by argillite and dolomite of Devonian and earlier age, and contains more carbonates and sulfates than that at Reindeer Depot. Mackay (1963) reports that the gravelly delta of Boot Creek at Inuvik was laid down, in part, as a kame complex between ice to the west and the higher land to the east, and that a radiocarbon date of 8,000+ years for peat near the present river level at Inuvik shows that the sea-level was not higher than at present.

The active layer showed the same features as at Reindeer Depot. In the coarse-textured gravelly fan of Boot Creek permafrost was not seen in the face of the gravel pit owing to clearing and excavation, but previously the top of the permafrost layer had been at 3- to 4-feet depth (Pihlainen, pers. comm.). In late August the depth of thaw ranged from 18 to 30 inches for clayey mineral soils with peaty cover to 51 inches for gravelly soil with peaty cover (Pihlainen 1962).

Soils

Two sites were selected to represent the common soils on the upland plain, and one to represent the maximum soil development present on gravelly material.

The first site (profile 3) is about 1.5 miles east of Inuvik. It is a microknoll near the middle of a 9-per cent west-facing slope. Soil profile 3 has the following characteristics:

Depth inches	*Horizon*	*Description*
1 - 0	L	Litter of leaves and twigs, slightly decomposed at the lower limit.
	Ah	A very dark brown (10YR 2.5/2) mineral horizon high in organic matter; ranges from a trace to 0.5-inch thick; field pH 4.5.
0 - 6	Bm1	Yellowish-brown (10YR 5/4) silty clay loam; moderate, fine to medium granular; friable; boundary clear and smooth; pH 4.5.
6 - 10	Bm2	Dark greyish brown (10YR 4/2) clay loam; moderate, fine granular; slightly plastic; a few black pebbles; boundary gradual and smooth; pH 5.8.
10 - 27	BC	Very dark greyish brown (2.5Y 3/2) silty clay; a few pebbles; very weak, fine granular to amorphous; moderately plastic; boundary diffuse, smooth; pH 6.8.
27 - 38.5	Cz	Very dark greyish brown (2.5Y 3/2) amorphous clay loam; frozen, many small disseminated ice crystals; very plastic and sticky when thawed; pH 7.7.

The second site (profile 4) is about 1.5 miles east of Inuvik on a microknoll near the toe of a long 2-per cent west-facing slope. Soil profile 4 has the following characteristics:

Depth inches	*Horizon*	*Description*
5 - 3	L	Raw undecomposed leaves, twigs and moss roots.
3 - 0	F	Moderately well-decomposed mucky peat and living roots, dark reddish brown (5YR 2/2); pH 4.5.
0 - 2	Ah	Very dark brown (10YR 2/2) clay; moderate, fine granular; average thickness 0.5 inch; boundary abrupt, distinct; pH 4.8.
2 - 6	Bm	Dark brown (10YR 4/3) clay, very weak, fine granular to amorphous; slightly plastic; a few pebbles; boundary gradual, smooth; pH 6.1.
6 - 10	BC	Very dark greyish brown (2.5Y 3/2) clay; very weak, fine granular to amorphous; moderately plastic; a few pebbles; pH 6.5.
10 - 16	Cz	Very dark greyish brown (2.5Y 3/2) silty clay; a few pebbles and stones; frozen, disseminated ice crystals; structure and consistence as above; pH 6.6.

Profile 4 apparently is more poorly drained than profile 3. Both were associated with moss-covered raw peat, frozen in the troughs between the microknolls at a depth of about 6 inches.

The third site (profile 5) is on the edge of a gravel pit in the well-drained, nearly level delta of Boot Creek. Soil profile 5 has the following characteristics:

Depth inches	*Horizon*	*Description*
2.5 - 1	F	Black (5YR 2/1) matted, fibrous organic material bound together by roots; pH 4.7.
1 - 0	H	Black (10YR 2/1) well-decomposed organic material; pH 4.7.
0 - 1.5	Ae1	Light-grey (10YR 7/2) gravelly loam; weak, fine granular;

		friable, slightly hard; boundary abrupt, smooth to wavy; pH 6.0.
1.5 - 3	Ae2	Light brownish grey (10YR 6/2) gravelly sandy loam; very weak, fine granular to amorphous; friable, slightly hard, boundary abrupt, smooth to wavy; pH 5.2.
3 - 4.5	Bf	Dark-brown to dark yellowish brown (7.5YR 4/4 to 10YR 4/4) gravelly sandy loam; very weak, fine granular to amorphous; stones are clean; boundary gradual, smooth to wavy; pH 5.4.
4.5 - 17	BC	Brown (10YR 4/3) very gravelly sandy loam; noncalcareous; some stones have clayey coating on underside; pH 6.7.
17 +	Ck	Brown (10YR 4/3) very gravelly sandy loam with cobbles and stones; some stones have clayey calcareous coating on underside; pH 7.5.

Boreal forest at Norman Wells

Landform

At Norman Wells the area includes the river terrace on which the settlement is located and the slopes rising to the hills in the northeast. The aspect is southwesterly. The topography is gently sloping (2 to 5 per cent) and level and the microtopography nearly smooth.

Vegetation

The vegetation is typical of boreal regions (Rowe 1959). The continuous forest cover in well-drained localities is composed mainly of *Picea mariana, P. glauca* (white spruce), *Betula papyrifera* (white birch), with occasional *Alnus* spp. and *Salix* spp., and a ground cover of moss, rose, *Arctostaphylos alpina* and *Cladonia* spp. In poorly drained localities the dominant species are black spruce, *Larix laricina* (tamarack), willow, and a ground cover of moss, Labrador tea, blueberry and *Carex aquatilis* (sedge). Other species present in minor amounts include *Castilleja raupii, Potentilla fruticosa* (shrubby cinquefoil), *Parnassia palustris* (grass of Parnassus), *Equisetum arvense* (horsetail), *Calamagrostis canadensis* (bluejoint) and *Chamaedaphne calyculata* (leatherleaf).

Surficial geology and permafrost

The undulating alluvial terrace of the Mackenzie River rises to a gently sloping glacial till plain that in turn rises to a scarp composed of marine shale with local lenses of sandstone and of limestone, all of Devonian age (Stewart 1945).

The ground was frozen (July 27) at depths of 2 feet under organic soils, 3 feet under mineral soils on inland sites with tree-moss cover, and at more than 4 feet on the terrace adjacent to the riverbank under trees and sparse ground cover. R. J. E. Brown (pers. comm.) states that this situation is general in the area.

Soils

Three sites were selected to represent the common soils of the area. Two are near the upper limit of the area in which the glacial till is covered by alluvium and the other is on alluvium.

The first site (profile 6) is located about 1.5 miles northeast of the airport and represents the best-drained soils. The slope is 6 per cent with a southern aspect. The parent material is loam alluvium over loam till. Profile 6 has the following characteristics:

Depth inches	*Horizon*	*Description*
5 - 3	L	Roots of moss, lichen and spruce needles.
3 - 0	F	Moderately decomposed woody litter; pH 6.5.
0 - 7	Bm	Brown (7.5YR 4/4) silt loam; friable; moderate, medium granular; boundary abrupt and smooth; noncalcareous; pH 7.2.
7 - 24	IICk	Dark-brown (10YR 3/3) gravelly loam; weak, fine granular to amorphous; stony below a depth of 11 inches; weakly mottled in lower part; calcareous; pH 7.5; free water below a depth of 12 inches.

At the top of the mineral soil there is a discontinuous grey layer about 0.1 inch thick. The soil is frozen below a depth of about 3 feet.

The second site (profile 7) represents the alluvial deposits of the Mackenzie River and is located about 4 miles southeast of Norman Wells near the end of D.O.T. Lake. The site is on a well-drained 3-per cent west-facing slope. The vegetation is predominantly white birch. Profile 7 has the following characteristics:

Depth inches	*Horizon*	*Description*
2.5 - 0.5	L	Litter of leaves and twigs.
0.5 - 0	H	Well-decomposed organic material.
0 - 8	Bm	Brown (7.5YR 4/4) grading to yellowish-brown (10YR 5/4) silt loam; weak, fine granular to bedded; friable; a few pebbles; boundary wavy and smooth; pH 5.4.
8 - 0	BC	Light olive brown (2.5Y 5/4) silt loam; bedded; friable; pH 6.6.
10 - 17	Ck1	Olive (5Y 4/3) bedded silt loam; calcareous; pH 7.5.
17 - 48	Ck2	Olive (5Y 3/2 to 4/3) bedded silt loam; friable; contains old surfaces at depths of 17 and 24 inches; calcareous; pH 8.1.

There is a discontinuous grey layer about 0.25 inch thick at the top of the mineral soil (Ae). Frozen layers are absent to a depth of 4 feet.

The third site (profile 8) represents the poorly drained soils in the higher upland area and is located about 1 mile northeast of the airport. The topography is level to very gently sloping and the parent material is loamy alluvium over loam glacial till. Profile 8 has the following characteristics:

Depth inches	*Horizon*	*Description*
7 - 5	L	Moss roots.
5 - 0	H	Black (10YR 2/1) granular muck; pH 6.9.
0 - 10	Ahk	Black (10YR 2/1) silt loam; friable; weak, fine granular to amorphous; a few small pebbles and cobbles; boundary abrupt and smooth; weakly calcareous; pH 7.1.

Table 2. Chemical characteristics of some permafrost soils.

Horizon	*Depth* inches	pH	*Organic Matter* %	*Total Nitrogen* %	C/N	*$CaCO_3$ equivalent* %	*Free Fe* %	*C.E.C.*	*Ca*	*Mg*	*K*	*Na*	*Saturation* %
								meq.* per 100 gms. soil					
				Profile 1, Reindeer Depot									
2	2.5—0	4.8	—	1.56	—	—	—	—	—	—	—	—	—
3	0—1	5.5	16.5	0.53	18	—	2.8	46.2	22.2	7.4	0.4	0.1	65
4	1—7	5.3	5.0	0.14	21	—	2.8	25.0	12.8	5.7	0.2	0.1	75
5	7—14	6.0	5.2	0.17	19	—	3.0	26.1	16.9	6.9	0.2	0.1	92
6	14—21	5.8	10.6	0.31	20	—	2.4	34.9	19.0	5.9	0.4	0.1	73
7	21—25	6.0	8.1	0.22	21	—	3.3	30.7	20.0	7.3	0.2	0.1	90
				Profile 2, Reindeer Depot									
1	0—5	4.7	5.0	0.14	21	—	3.5	26.0	5.9	3.3	0.3	0.1	37
2	5—9	4.7	4.9	0.16	18	—	3.8	23.9	5.3	4.2	0.3	0.2	41
3	9—23	5.3	4.3	0.15	17	—	2.5	22.8	8.2	5.9	0.3	0.1	64
4	23—28	5.2	31.2	0.71	26	—	2.7	47.5	11.6	6.9	0.5	0.1	40
				Profile 3, Inuvik									
Bm1	0—6	4.5	2.9	0.12	14	—	4.6	24.5	11.0	4.5	0.3	0.1	65
Bm2	6—10	5.8	2.1	0.10	12	—	4.4	25.9	16.5	5.8	0.2	0.1	87
BC	10—27	6.8	2.4	0.11	13	—	4.7	27.9	19.0	5.7	0.2	0.1	90
Cz	27—37	7.7	1.9	0.08	14	1.7	5.0	17.2	17.5	4.0	0.3	0.1	—
Cz	37—38.5	1.7	7.7	0.08	12	—	5.3	15.4	15.9	3.0	0.4	0.1	—
				Profile 4, Inuvik									
F	3—0	4.5	—	1.47	—	—	—	—	—	—	—	—	—
Ah	0—2	4.8	21.6	0.62	20	—	4.1	63.5	26.8	8.1	0.3	0.1	56
Bm	2—6	6.1	2.4	0.10	14	—	4.7	34.2	23.2	7.3	0.2	0.1	90
BC	6—10	6.5	3.0	0.12	15	—	4.4	37.3	26.3	7.8	0.2	0.1	92
Cz	10—16	6.6	2.4	0.11	13	—	4.5	29.6	22.8	6.4	0.2	0.1	100
				Profile 5, Inuvik									
F	2.5—1	4.7	80.2	2.10	22	—	—	—	—	—	—	—	—
H	1—0	4.7	59.7	1.45	24	—	—	—	—	—	—	—	—
Ae1	0—1.5	5.0	2.1	0.10	12	—	10.2	24.6	11.6	3.1	0.1	0.1	61
Ae2	1.5—3	5.2	1.4	0.07	12	—	13.3	26.7	12.1	3.6	0.1	0.1	60
Bf	3—4.5	5.4	1.8	0.07	15	—	18.3	27.3	11.6	3.3	0.1	0.1	55
BC	4.5—17	6.7	2.4	0.09	15	—	11.8	25.4	17.6	4.2	0.1	0.1	87
Ck	17+	7.5	1.8	0.06	17	7.7	15.4	17.8	20.1	2.6	0.1	0.1	—
				Profile 6, Norman Wells									
F	3—0	6.5	—	0.14	—	—	—	—	—	—	—	—	—
Bm	0—7	7.2	3.8	0.13	17	0.0	4.1	23.9	21.4	5.2	0.2	0.1	—
IICk	7—24	7.5	1.9	0.09	12	10.4	2.1	14.5	21.0	3.6	0.1	0.1	—
				Profile 7, Norman Wells									
Bm	0—8	5.4	2.2	0.08	16	—	2.3	20.8	11.9	6.4	0.2	0.1	89
BC	8—10	6.6	2.3	0.11	12	—	2.3	19.2	13.8	6.5	0.2	0.1	—
Ck1	10—17	7.5	2.1	0.10	12	11.1	1.8	14.6	14.4	5.5	0.1	0.1	—
Ck2	17—48	8.1	1.4	0.09	9	15.0	2.2	13.0	22.4	11.1	0.2	0.1	—
				Profile 8, Norman Wells									
H	5—0	6.9	—	1.24	—	—	—	—	—	—	—	—	—
Ahk	0—10	7.1	16.5	0.42	23	3.2	2.3	65.0	56.5	10.2	0.2	0.1	—
IICk	10—38	7.7	1.2	0.08	9	12.0	2.8	12.2	21.7	3.4	0.2	0.1	—

Milliequivalents

Table 3. Mechanical analysis of some permafrost soils on the organic-, salt-, water-free basis.

Horizon	*Depth* inches	*Gravel* >2000 μ %	*Sand* 2000-50 μ %	*Silt* 50-20 μ %	*Silt* 20-5 μ %	*Silt* 5-2 μ %	*Clay* 2-0.2 μ %	*Clay* <0.2 μ %
			Profile 1, Reindeer Depot					
3	0—1	—	15.0	10.7	19.1	12.1	21.9	21.3
4	1—7	—	21.0	12.0	19.0	8.9	23.5	15.6
5	7—14	—	17.8	11.0	20.0	8.4	23.4	19.4
6	14—21	—	18.7	8.6	15.0	9.0	23.4	25.3
7	21—25	—	18.0	10.1	15.6	10.1	23.0	23.2
			Profile 2, Reindeer Depot					
1	0—5	—	6.9	10.9	18.2	11.7	26.1	26.1
2	5—9	—	6.4	10.1	15.0	13.6	31.2	23.7
3	9—23	—	7.7	11.8	17.0	16.4	22.4	24.7
4	23—28	—	5.4	13.7	11.3	12.3	26.2	31.2
			Profile 3, Inuvik					
Bm1	0—6	—	19.4	12.2	17.9	11.1	20.5	18.8
Bm2	6—10	—	21.6	12.4	19.6	13.1	24.8	8.5
BC	10—27	—	18.8	13.9	15.7	13.9	28.9	13.2
Cz	27—37	—	31.1	11.0	15.0	9.0	23.4	11.6
Cz	37—38.5	—	27.5	13.5	15.0	10.8	19.5	13.7
			Profile 4, Inuvik					
Ah	0—2	—	12.1	10.8	11.5	11.5	21.7	32.3
Bm	2—6	—	24.1	9.3	11.0	10.9	26.0	18.7
BC	6—10	—	15.0	10.5	16.4	10.4	34.8	13.0
Cz	10—16	—	16.9	11.7	18.9	11.2	25.5	15.9
			Profile 5, Inuvik					
Ae1	0—1.5	41	51.8	15.4	12.9	5.8	8.5	5.6
Ae2	1.5—3	28	73.5	4.9	4.5	3.7	8.2	5.5
Bf	3—4.5	36	74.0	6.0	4.2	3.9	9.0	2.9
BC	4.5—17	61	62.0	9.8	8.7	6.3	12.3	0.8
Ck	17+	70	68.4	8.4	6.7	5.1	10.6	0.9
			Profile 6, Norman Wells					
Bm	0—7	—	27.2	21.2	19.8	9.4	5.1*	17.3*
IICk	7—24	28	44.5	15.8	14.1	8.6	5.4	11.6
			Profile 7, Norman Wells					
Bm	0—8	—	20.0	35.4	19.2	5.5	3.2*	16.7*
BC	8—10	—	26.4	32.1	16.6	5.4	3.1	17.3
Ck1	10—17	—	29.7	35.6	15.1	4.5	2.5	12.6
Ck2	17—48	—	3.5	23.3	35.2	11.3	5.6	21.2
			Profile 8, Norman Wells					
Ahk	0—10	—	21.6	23.0	24.2	25.7	2.2*	3.3*
IICk	10—38	37	44.4	10.7	13.2	7.9	5.8	18.0

*Coarse clay 2—1 μ, fine clay <1 μ.

10 - 38	IICk	Dark grayish brown (2.5Y 4/2) gravelly loam; mottled; amorphous; plastic; calcareous; pH 7.7.
38 +	Cz	Frozen gravelly loam; not sampled.

Chemical, physical, and mineralogical characteristics of the soils

Chemical analysis (Table 2) shows that profiles 1 and 2 from Reindeer Depot have certain features not found in the other soils. The pH values are low in the surface horizons, increasing slightly with depth. The organic matter content is medium in horizons 4 and 5 and increases markedly in horizon 6. The saturation percentage in horizon 7, profile 1, suggests the possible presence of calcareous parent material below the active layer (solum). For this reason numbers were used to designate horizons, rather than the letter symbols used for the other profiles.

Profiles 3 and 4 from Inuvik also have strongly acidic surface mineral horizons, but their parent materials are nearly neutral to moderately alkaline. They have lower organic matter contents in all horizons (excepting the Ah in profile 4), and lack the organic matter-rich substrata present in profiles 1 and 2.

Profile 5 from Inuvik has a well-developed free-iron profile. Although the values are very high, they clearly indicate eluvial (Ae) and illuvial (Bf) horizons.

Profiles 6, 7 and 8 from Norman Wells have strongly acidic to neutral surface horizons and alkaline parent materials. None of the profiles has an organic matter-rich subsoil as those present in profiles 1 and 2.

The mechanical analyses (Table 3) show that in profiles 1 and 2 the amount of fine clay was greatest at the lowest depth, whereas in profiles 3 and 4 it was greatest at the surface. The total clay in profiles 1 and 2 tends to increase with depth whereas it tends to decrease with depth in profiles 3 and 4. In profiles 5 to 8 there is considerable textural variation with depth.

A summary of the mineralogical analysis is given in Table 4. Generally there were only slight variations between horizons and between profiles.

Table 4. Mineralogical characteristics of some permafrost soils.

	Silts	*Coarse clay*	*Fine clay*
Profiles 1 and 2	Largely quartz, some feldspar and smaller amounts of kaolinite and illite.	Largely mixed-layer montmorillonite — illite, quartz, and kaolinite plus small amounts of feldspar.	Largely mixed-layer montmorillonite — illite, with some illite and kaolinite.
Profiles 3 and 4	Largely quartz with considerable feldspar and small amounts of illite and kaolinite.	Considerable illite, some montmorillonite — illite, and smaller amounts of kaolinite and quartz.	Mostly montmorillonite-illite and a small amount of kaolinite.
Profile 5	Mostly quartz, some illite and small amounts of kaolinite.	Mostly montmorillonite, minor amounts of illite and quartz with traces of kaolinite.	Montmorillonite only.

Profiles 1 and 2, and profiles 3 and 4 were very similar, and have been grouped together, even though there was only slight variation among all four. The coarse clay fraction (Fig. 1 shows profile 2 as an example) was largely mixed-layer montmorillonite—illite, quartz and kaolinite, plus small amounts of feldspar. The fine clay fraction differed from the coarse clay in being free of quartz. Profile 5 differed from the others mainly in lacking the mixed-layer montmorillonite — illite in both clay fractions and in lacking illite and kaolinite in the fine clay fraction. The differential thermal analysis substantiated the X-ray analysis in all profiles.

Discussion and conclusions

Since profile 1 was located near the crest of a gentle slope and had strong, randomly oriented, microtopography and weak or absent solifluction lobes, the organic matter-rich horizon 6 is attributed to the process of differential freezing and thawing postulated by Mackay *et al.* (1958, 1961). Considering that the soil colour in the upper horizons was of low chroma and mottling was absent, and that the chemical data indicate a relatively limited stage of weathering, the soil is therefore regosolic in character.

Tedrow *et al.* (1958) have described Regosols as a group of youthful soils, usually with permafrost at from 4 to 6 feet, that lack a genetic profile. The radio-carbon date of 8,000+ years B.P. for peat at Inuvik (Mackay 1963) indicates that profile 1 is regosolic by virtue of the short time since frost action disrupted any morphological features then present and buried the organic material present in horizon 6. In the Canadian system of classification profile 1 is a Subarctic Orthic Regosol. In the system proposed in the 7th approximation (U.S.D.A. 1960) it is an Orthic Cryudent.

Profile 2, located near the toe of a long gentle slope, has developed under wetter conditions than profile 1. The chroma of 4 in the surface mineral horizon, the distribution of free iron and the lower base saturation values, indicate that this profile has had a longer time since frost action buried the organic material present in horizon 4 or more favourable conditions in which to develop its morphology than profile 1. The differences in clay content with depth are thought to be inherited from the parent material. The Arctic Brown soils described in Alaska (Tedrow and Hill 1955, Drew and Tedrow 1957 and Hill and Tedrow 1961) have A horizons containing 11 to 19 per cent organic matter, whereas profile 2 has only 5 per cent at the surface and shows little variation with depth, above horizon 4. Profile 2 has characteristics more closely related to those described for the Upland Tundra group in Alaska (Tedrow *et al.* 1958, Douglas and Tedrow 1960). In the Canadian system of classification this soil is best classified as a Subarctic Gleyed Acid Brown Wooded, and as an Orthic Cryaquent in the U.S. 7th approximation.

Profile 3 has a chroma of 4 in the Bml horizon. The free-iron content and base saturation are lower in the B than in the C horizon, indicating a weak podzolic process. The low organic matter content throughout the profile is a characteristic that differentiates this soil from the Arctic Brown

group. The trends in clay contents evident in Table 3 are thought to be inherited from the parent materials. However, the greater total clay content in the surface horizons over the subsoils, like that reported in Arctic Brown soils (Tedrow and Hill 1955, Hill and Tedrow 1961), may have resulted from frost effects (Corte 1962). In the Canadian classification scheme it is classified as a Subarctic Brown Wooded. In the U.S. 7th approximation it is an Orthic Cryudent.

Profile 4 differs from profile 3 in having a thin Ah horizon and lower chroma in the Bm horizon. It is classified the same as profile 3.

Profile 5 has well-developed eluvial (Ae) and illuvial (Bf) horizons although they are thinner than comparable horizons in Podzols in southern Canada. Tedrow *et al.* (1958) have suggested that such a soil could possibly develop in northern Alaska. Its presence at Inuvik is attributed to the permeable, gravelly sandy loam parent material. It is classified as a Subarctic Minimal Podzol in the Canadian system and an Orthic Cryochrept in the U.S. 7th approximation.

Profiles 6 and 7 have brown sola and resemble profile 3 in most respects. They are classified in the same way.

Profile 8, developed under the influence of poor drainage, has an Ah horizon high in organic matter. It is classified as a Subarctic Peaty Carbonated Rego Humic Gleysol in the Canadian system and as a Histic Umbreptic Cryaquept in the U.S. 7th approximation.

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References

Aguilera, N. H., and M. L. Jackson. 1953. Iron oxide removal from soils and clays. Soil Sci. Soc. Am. Proc. 17:359-364.

Atkinson, A. J., G. R. Giles, A. J. MacLean, and J. R. Wright. 1958. Chemical methods of soil analysis. Can. Dep. of Agr., Chem. Div. Contrib. No. 169 (rev.). Ottawa.

Beschel, Roland E. 1961. Botany: and some remarks on the history of vegetation and glacierization. *In* Jacobsen-McGill Arctic Research Expedition to Axel Heiberg Island, Prelim. rept. 1959-60. McGill University, Montreal.

Brydon, J. E., H. M. Rice, and G. C. Scott. 1963. The recovery of clays from suspension by freeze-drying. Can. J. Soil Sci. 43:404.

Coffin, D. E. 1963. A method for the determination of free iron in soils and clays. Can. J. Soil Sci. 43:7-17.

Corte, Arturo E. 1962. Vertical migration of particles in front of a moving freezing plane. J. Geophys. Res. 67:1085-90.

Day, J. H., and A. Leahey. 1957. Reconnaissance soil survey of the Slave River Lowland in the Northwest Territories of Canada. Can. Dept. Agr. Exp. Farms Ser. Ottawa.

Department of Transport, Meteorological Division. 1954. Addendum to Vol. 1 of climatic summaries for selected meteorological stations in Canada. Toronto.

Department of Transport, Meteorological Branch. 1959. Climate of the Canadian Arctic, July-October. Ottawa.

Douglas, L. A., and J. C. F. Tedrow. 1960. Tundra soils of arctic Alaska. Seventh Int. Congr. Soil Sci., Madison, Wis., U.S.A., 4:291-304.

Drew, J. V., and J. C. F. Tedrow. 1957. Pedology of an arctic brown profile near Point Barrow, Alaska. Soil Sci. Soc. Am. Proc. 21:336-9.

Feustel, I. C., A. Dutilly, and M. S. Anderson. 1939. Properties of soils from North American arctic regions. Soil Sci. 48:183-99.

Hill, D. E., and J. C. F. Tedrow. 1961. Weathering and soil formation in the arctic environment. Am. J. Sci. 259:84-101.

Kilmer, W. J., and L. T. Alexander. 1949. Method of making mechanical analysis of soils. Soil Sci. 68:15-24.

Lajoie, P. 1954. Exploratory soil survey of the Fort Chimo district. Can. Dept. Agr. Unpubl. rept.

Leahy, A. 1947. Characteristics of soils adjacent to the Mackenzie River in the Northwest Territories of Canada. Proc. Soil Sci. Soc. Am. Vol. 12:458-61.

———————1954. A summary report on an exploratory soil survey along the water route from Waterways, Alberta, to Aklavik, Northwest Territories. Appendix B *in* Gilbey, J. A. Dominion Experimental Substation, Fort Simpson, N.W.T., Prog. Rept., 1947-53, pp. 42-5.

Mackay, J. Ross. 1958. A subsurface organic layer associated with permafrost in the western Arctic. Geogr. pap. No. 18, Dept. of Mines and Tech. Surveys. Ottawa.

Mackay, J. R., W. H. Mathews, and R. S. MacNeish. 1961. Geology of the Engigstciak archaeological site, Yukon Territory. Arctic 14:25-52.

Mackay, J. R. 1963. The Mackenzie Delta Area, N.W.T. Mem. 8, Geogr. Br., Mines and Tech. Surveys. Ottawa.

McMillan, N. J., 1960. Soils of the Queen Elizabeth Islands (Canadian Arctic). J. Soil Sci. 11:131-9.

National Soil Survey Committee of Canada. 1963. Report of the meetings at the University of Manitoba, Winnipeg, held in March 1963. Ottawa. Mimeo.

Pihlainen, J. A. 1962. Engineering site information, Inuvik, N.W.T. Can. Nat. Res. Coun., Div. Bldg. Res. Tech. pap. 135. Ottawa.

Rowe, J. S. 1959. Forest regions of Canada. Bull. 123, Can. Dept. of Northern Affairs and Nat. Resources, For. Br. Ottawa.

Skinner, S. I. M., R. L. Halstead and J. E. Brydon. 1959. Quantitative manometric determination of calcite and dolomite in soils and limestones. Can. J. Soil Sci. 39:197-204.

Stewart, J. S. 1945. Recent exploratory deep well drilling in Mackenzie River Valley, Northwest Territories. Geol. Sur. Can. Pap. 45-29.

Tedrow, J. C. F., and D. E. Hill. 1955. Arctic Brown soil. Soil Sci. 80:265-75.

Tedrow, J. C. F., J. V. Drew, D. E. Hill, and L. A. Douglas. 1958. Major genetic soils of the Arctic slope of Alaska. J. Soil Sci. 9:33-45.

Tedrow, J. C. F., and J. E. Cantlon. 1958. Concepts of soil formation and classification in Arctic regions. Arctic 11:166-79.

United States Department of Agriculture. 1960. Soil classification, a comprehensive system. 7th approximation. Soil Conservation Service.

Wright, J. R., A. Leahey, and H. M. Rice. 1959. Chemical, morphological and mineralogical characteristics of a chronosequence of soils on alluvial deposits in the Northwest Territories. Can. J. Soil Sci. 39:32-43.