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A SOIL PATTERN OF CENTRAL BATHURST ISLAND, QUEEN ELIZABETH ISLAND, CANADA

Abstract

Bathurst Island, one of the northern islands of the Canadian Arctic Archipelago, is within the polar desert soil zone. Most of the Polar desert soils on the island, however, do not have well-formed genetic features. A phenomenon ascribed to continuous weathering of the limestone surfaces, as well as to youthful landscape elements. The zonal soil in this report, designated as Polar desert-limestone variant (Polar desert-LV), actually has only minimally developed features. It is similar to the soil described as Arctic råmark by KUBIËNA (1970). Other soils recognized are Soils of the hummocky ground, Soils of the polar desert-tundra interjacence, Tundra, Bog and Rendzina plus associated lithic varieties.

Solifluction and related frost processes are active throughout the island resulting in poorly differentiated soil horizons — especially in the well-drained to moderately well-drained sectors.

Altitude of the marine limit on Bathurst Island rarely exceeds about 90 m with the value increasing to about 120 m in some of the inlets in the northern part of the island (BLAKE, 1964). The pattern in the rebound areas tends to be one of poorly drained soils with much peaty material present as compared to the better drained soils with a mineral character above the marine limit. A number of buried soils are present along the middle course of the Goodsir River, two of which yielded C^{14} dates of 5470 ∓ 60 (GSC-2315) and 5660 ∓ 100 (GSC-2302) yr. Pollen in buried soils consisted mainly of *Cyperaceae* and *Gramineae* and other high arctic elements.

This report describes the nature of the soil pattern in the vicinity of Goodsir River, Bathurst Island, Canada (Fig. 1). An earlier proposal (TEDROW, 1977) provided a generalized scheme for recognizing major soil varieties throughout the polar regions but, more recently, findings on Bathurst Island and beyond require some additional considerations, especially in the overall problem of soil development on the mature, well-drained limestone sites.

Bathurst Island is within the high arctic, or pedologically speaking, the polar desert zone. Despite climatic conditions, seldom is an ortho variety of Polar desert soil present. High-purity limestone sites simply do not have soils with a sequence of horizons as is the case with silicate or silicate plus carbonate materials. There now appears to be sufficient evidence to justify separating deep, well-drained soils of the High Arctic into two categories: (1) those formed on high-purity limestone and (2) those formed on silicate rocks, with transitional conditions more closely allied with the latter. The reason for the existence of this dichotomy is because the high-carbonate soils of the deep, well-drained sites fail to develop differentiated horizons as is the tendency on silicate rock.

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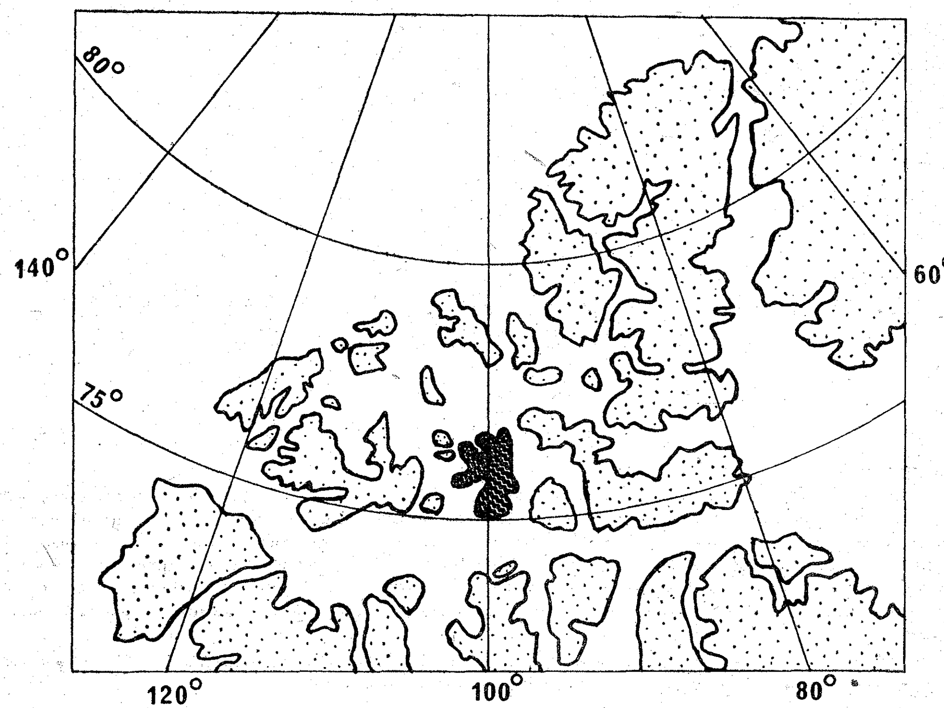


Fig. 1. A map of the northern Canadian Archipelago. The dark area is Bathurst Island

Instead of the soils developing a horizonation as exemplified by silicate rock conditions on Prince Patrick Island (Tedrow, 1966; Tedrow *et al.*, 1968) northern Greenland (Tedrow, 1970) elsewhere, the soils on limestone (including dolomite) closely resemble the Arctic råmark of Kubiëna (1970).

It appears that the lack of soil development on the well-drained sites can be primarily ascribed to two causes, the nature of the substrate and, to a lesser extent, the time factor in soil development.

The general lack of development of genetic horizons in the well-drained, carbonate-bearing sites of the High Arctic had been discussed briefly in earlier reports (Beschel, 1970; Cruickshank, 1971; Walton, 1972; Tarnocai, 1976; Tedrow, 1978 and others).

REGIONAL SETTING

GEOLOGY

Bathurst Island consists of a complex of rather low plateaus and NE-SW trending ridged uplands having broad folds (Roots, 1963). Elevations are generally less than 300 m above sea level.

Two prominent fold belts exist on the island. On the eastern margin of the island is the North-South trending Cornwallis Fold Belt and intersecting it about right angles from the west is the East-West trending Parry Island Fold Belt. These fold belts are made up of Paleozoic rocks consisting of evaporites, carbonates, shales and coarse-grained clastic rocks (KERR, 1974). Quaternary deposits are present on the land adjacent to Goodsir Inlet and throughout Polar Bear Pass but the uplands are generally till free (KERR, *l.c.*). BLAKE (1964, 1974a), in outlining the glacial history of the island, reported little evidence that the island as a whole had been overridden by Innuitian ice but till forms, erratics, and meltwater channels are present. As BLAKE stated, most of the surface features, especially at the higher elevations, were probably derived from local ice caps.

During Wisconsin time, the lower parts of the Island were depressed below sea level (BLAKE, 1964; WALCOTT, 1972). Isostatic rebound has been in the order of 90 m over much of the island and at the northern tip postglacial shells were found 120 m above sea level (BLAKE, *l. c.*). Figure 2 shows, in generalized

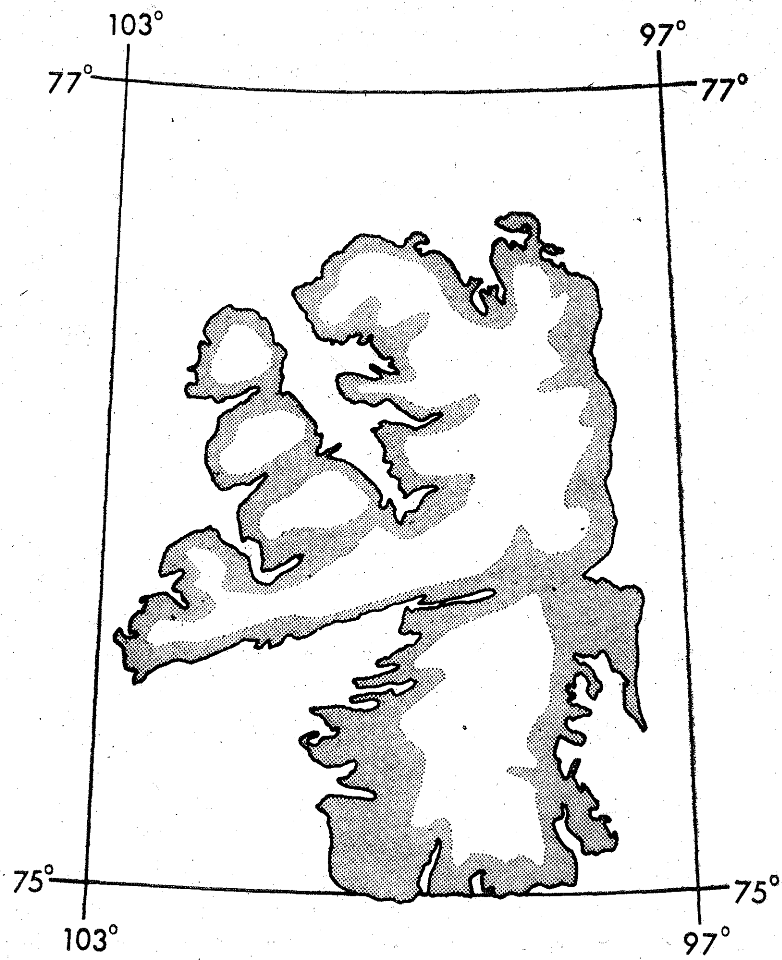


Fig. 2. Map of Bathurst Island. The shaded area which is below an altitude approximating 90 m is believed to have rebounded above sea level since Pleistocene time

fashion, the land presently below an altitude of 90 m. It will be shown for the areas we investigated that the soil pattern below an altitude of ca. 90 m is quite different from that above.

In considering the time factor in soil development, Blake (1964) provided evidence that much of the island has been free of ice for only 9500 to 8500 years, a factor which also contributes to the nature of the soil pattern.

PERMAFROST

Permafrost is assumed to be continuous throughout Bathurst Island. At Resolute Bay on Cornwallis Island, permafrost has an estimated thickness of 400 m (Misener, 1955), a value which can probably approximate conditions on Bathurst Island. The permafrost table is generally within 30 cm of the surface and the permafrost itself has a high quantitity of ground ice present. In the uplands, however, where conditions are drier and more rocky, the permafrost table occurs at a depth of about 60 cm. The upper part of the permafrost in such situations resembles dry permafrost.

CLIMATE

No permanent weather station exists on Bathurst Island, but by extrapolating climatological data from a number of sources, we project the following mean summer temperatures: June, 1 °C, July, 5 °C and August, 3 °C. Annual precipitation values are estimated to be about 12 to 15 cm of water equivalent, one half or more of which occurs in the form of snow.

VEGETATION

Vegetation on the island can be considered as arctic desert, rock desert or fell field. Uplands are noticeably barren with occasional clumps of willow (*Salix*) and *Saxifraga*. Moister sites as exemplified by positions downslope from late snowbanks commonly have hummocky ground colonized mainly by *Dryas*. Low meadows, however, have a continuous sward of cotton grass (*Eriophorum*) and *Carex stans* with *Dupontia* colonizing the sites with standing water.

SOIL CONDITIONS

Tarnocai (1976) studied the soils on Bathurst Island and his work showed that the soils were formed on predominantly carbonate-bearing rock. Most were alkaline—although pH values as low as 4.4 were recorded. Tarnocai further noted that contrary to published information Tedrow, (1966), Polar Desert soils of the High Arctic, those soils present on Cornwallis, Bathurst and other nearby islands, were found to be very moist. We also observed rather moist soil conditions dominating — even in uplands of Bathurst Island and to also some extent on Cornwallis Island. TARNOCAI (*l. c.*) listed four major soil varieties for Bathurst Island: (1) Regosolic Cryosol, (2) Brunisolic Cryosol, (3) Gleysolic Cryosol and (4) Organo Cryosol. Except the organic soil, the soil varieties were subdivided into static and turbic, depending upon the degree of cryoturbation. We recognize a first order of soils somewhat similar to that of TARNOCAI (1976) but employ a different nomenclature, viz: (1) Raw or regosolic lithosolic soils including some solifluction deposits, (2) Soils of the well-drained sites, most of which show little evidence of genetic horizonation, (3) Gley soils and (4) Organic soils (Tab. I). This categorization does not provide fully for the multiplicity of conditions present nor does it take into consideration the various patterned

Table I

An approximation of some equivalent terms used to described soil conditions in the High Arctic

General conditions	TEDROW (1977) et seq.	Bathurst Island TARNOCAI (1976)	FAO * (1971)
Stony soils, recent alluvium and solifluction	Lithosol, Regosol, undifferentiated alluvium, solifluction deposits	Regosolic turbic cryosol, Regosolic static cryosol	Gelic regosol
Deep, well-drained soils	Polar desert-LV (with little profile development)	Brunisolic turbic cryosol, Brunisolic static cryosol	Gelic cambisol
Hydric (gley) mineral soils	Upland tundra soil, Meadow tundra soil, Soils of hummocky ground, ** Soils of the polar desert tundra interjacence	Gleysolic turbic cryosol, Gleysolic static cryosol	Gelic gleysol
Organic soils	Bog	Organo cryosol	—
Miscellaneous soils	Buried soils, Rendzina (Protorendzina)	—	—

* FAO — Unesco, Paris (1974).
** There would be justification for placing these soils in the category occupied by Lithosol, Regosol, etc.

ground forms, salinity, youthfulness and nature of the surficial deposits. It does, however, provide a generalized grouping of the soil pattern of the Polar Bear Pass area (Fig.3) as idealized in figure 4.

Lithosols and Regosols dominate the higher ground. Most of the landscape has a semicontinuous mantle of shattered rock. Whereas figure 4 depicts a paravariety of Polar desert soil on the high ground, in reality most of these higher positions actually consists of shattered rock with virtually no fine material pre-

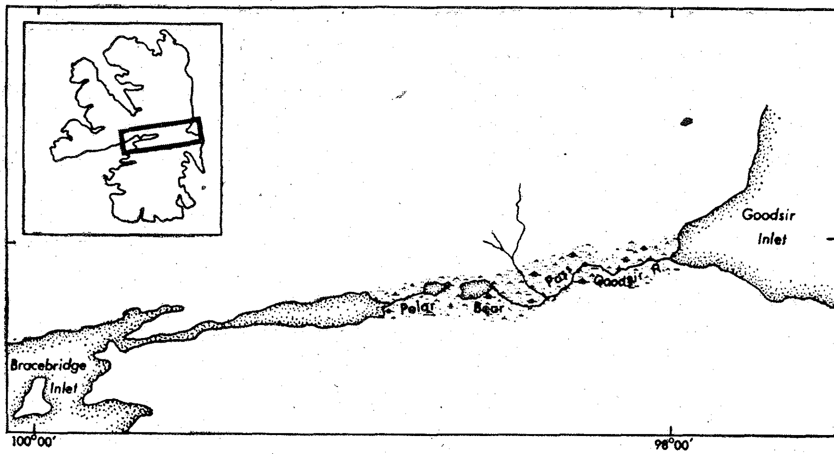


Fig. 3. General location of the study area. The shaded part of the map represents swamp-like conditions

sent. Comparatively few sites have sufficient fine material for a zonal soil to form. Further, of those sites on the higher ground having considerable fine material present, the soils are commonly moist, resembling conditions previously described as soils of the Polar desert — tundra interjacence (TEDROW, 1970).

The ridges are largely free of vascular plants and without any semblance of soil formation. In localities where limestone and carbonate-bearing sandstone dominate, the matrix undergoes major frost displacement as evidenced by the presence of sorted circles, sorted nets, ice-wedge polygons (both sorted and unsorted), and other patterned ground forms. Plate 1 shows an area of frost-shattered rock debris with virtually no fines. A stone stripe pattern is evolving in the shattered rock debris. Downslope from the ridges, stone-stripe and stone-garland patterns generally become more pronounced. Progressing further downslope, the sand, silt and clay increase causing the soil causing a muddy, raw

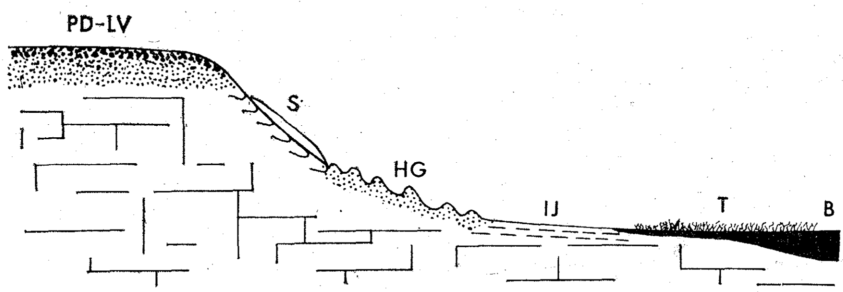


Fig. 4. An idealized diagram showing major soil varieties with respect to landscape elements on Bathurst Island

PD-LV — Polar desert-limestone variant. This is largely an in potentia soil condition with shattered rock generally mantling most of the higher positions; S — solifluction slopes with little soil development and with late snow cover; HG — soils of the hummocky ground; IJ — soils of the Polar desert-tundra interjacence; T — tundra (undifferentiated); B — bog appearance. This soil material is saturated for irregular periods during the summer months. Water frequently seeps out of the ground and it is common for suspended silt and clay to be in the water. Mineral material from the suspension accumulates in the seep areas in lobate forms up to 6 m long and 1 m wide. The silt-clay mixture accumulating from the suspension has a yellowish brown color. The non-carbonate clay ($< 2\mu$) component from one location consisted mainly of illite with a prominent kaolinite component. There were also minor contributions from dolomite, smectite, quartz and goethite. The origin of the sediment is believed to have been from the higher, rocky limestone areas (TEDROW and KRUG, 1982).

Gently sloping to steep locations, downslope from the ridges, generally have a multiplicity of patterned ground forms present. These forms are dominantly linear with the lineations trending with the slope and consist of stripes (Pl. 2), rills, garlands and related forms in which the processes involve a combination of frost-sorting and gravitational forces. Genetic horizonation of soils in such locations is virtually nil. The soils are raw-like and could justifiably be included within the term Cryic regosol, or Arctic råmark, or because of the high seasonal amplitude of moisture content, as Soils of the polar desert-tundra interjacence. We refer to these conditions however, as solifluction deposits. Solifluction is so intense that lobes of debris may have an accumulated thickness exceeding 1 m (Pl. 3).

Silty to clayey textured, limestone-derived soils, even on the more stable, level sites of the rolling uplands and plateaus, usually lack genetically developed features (CRUICKSHANK, 1971; TEDROW, 1978). Earlier, MCMILLAN (1960) recognizing the paucity of soil formation on the well-drained sites of Axel Heiberg, Cameron and Ellesmere Islands, stated that the soils in this area should be regarded as equivalents of Lithosols and Regosols. MCMILLAN further suggested that KUBIËNA's term Rawmark and Arctic råmark be adopted for the predominantly well-drained sites of the polar environment. There appears to be justification for considering two distinct pathways of soil formation on well-drained sites of the High Arctic, depending upon the nature of substrate. On silicate rocks Polar desert soils generally form as outlined by TEDROW (1966). The process includes the development of a desert pavement, iron staining within the solum, small production of humus forms, occasional movement of clay substance (probably resulting from cryogenic forces) and possibly other changes. Much of Bathurst Island, however, is underlain by limestone and dolomite, and where such material is present, Polar desert soil generally exists in embryonic form. As a tentative proposal, we designate these conditions as Polar desert-limestone variant (Polar desert-LV). Lack of advanced formation of Polar desert soil on limestone is probably due to a combination of factors *viz.*

1. Relatively high solution rate of the limestone which is generally without plant cover, even epipetric lichens are generally absent.

2. Translocation of the weathering products downward beyond the "potential" soil solum.

3. Intense frost processes.
4. Lack of humus production.
5. Generally medium to fine-textured soils resulting from the weathering limestone as opposed to the coarser textures usually present with silicate-derived soils.

Occasionally one encounters Polar desert soil with minimal genetic features, especially in situations where the matrix has an appreciable silicate mineral content. We record such a condition at the crest of kame-like deposit about midway between Bracebridge and Goodsir Inlets just south of the Goodsir River.

On the summit of a kame-like feature at an altitude of about 140 m a Polar desert — LV soil had the following morphology:

Depth (cm)		Morphology
0—2	—	Desert pavement;
2—13	—	Brown (10YR 4/3) gravelly sandy loam with a very weak subangular structure. The 2—4 cm depth had a slightly lighter color (10YR 6/2) than the 4—13 cm depth;
13—45	—	Brown (10YR 4/3) loamy sand. Moisture content increased with depth giving a corresponding darker appearance. Mud coatings and carbonate crusts were present;
45+	—	Variegated grayish brown sands. Dry frost present (July 12, 1974).

Lower slopes are usually quite wet for extended periods during the summer months, especially if there is seep from the higher rock masses or from late snow banks. Mainly because of the high seasonal amplitude of moisture content and the lack of soil development the term Soils of the polar desert-tundra interjacence has been retained for these conditions.

Lower positions or depressions without drainage outlets are frequently mantled with frost hummocks, commonly described as hummocky ground. Such conditions are quite common and may be considered as a para-variety of Tundra soil or as a Cryic gleysol, but we prefer to recognize the distinct characteristics of these conditions and continue use of the term Soils of the hummocky ground.

Raw earthy conditions with no evidence of genetic horizonation are also present on some of the rather low, flat areas. These conditions approximate the Arctic råmark of Kubiëna (1970). In such situations solifluction is generally minimal, but patterned ground is frequently present in the form of non-sorted circles (Pl. 4), sorted-circles, nets and other configurations.

In low, flat positions where there is a reliable water supply during the summer months, the landscape is covered with a continuous sward. Such mineral sites generally have some form of Tundra soil present. The soil profile, however, tends to be rather shallow (Pl. 5), Both Upland tundra soil and Meadow tundra soil can be delineated, with the latter soil representing wetter conditions.

Of special interest is soil formation on and around the patch reefs (tor-like structures) of Bathurst Island. A few such prominences are present in the vicinity of Goodsir River. Shallow Rendzina formation has been reported on limestone ledges and bedrock cavities of these carbonate-bearing prominences (Tedrow and Walton, 1977). Deeper Rendzina forms are present on the spalled limestone fragments peripheral to the base of the outcrop. Rendzina occurs in these detrital accumulations with the soil consisting of little more than a mass of rock fragments and humus forms.

It should be stated that no Arctic brown soil was located in the study area.

ISOSTATIC REBOUND AND THE SOIL PATTERN

Polar Bear Pass is a lowland about 20 km long and up to 3 to 5 km wide with the floor of the pass being below the 30 m contour. Blake (1974b), in reconstructing Pleistocene and Holocene events, indicated that the sea occupied Polar Bear Pass and some of the adjacent upland beginning about 8.500 years ago with marine waters extending about 45 m above the present floor of the pass. Arms of the sea persisted in the western and eastern ends of Polar Bear Pass until about 4.500 years ago. During isostatic adjustment a number of beach ridges formed, particularly on what now are slopes of the pass. These beach ridges, although generally well drained within the upper 30 to 60 em are quite wet at depth and show virtually no soil development. The top layer generally consists of a dark grayish brown (10YR 2/2) gravelly sandy loam with loose consistence, a single grained structure, and at times with a little diffused organic staining. At a depth of about 0—15 cm and extending to as much as 55 cm, carbonate crusts are present on some of the surfaces of the gravel. This soil shows only the most primitive evidence of development. Accordingly, we designate it as Polar desert-LV. There is perhaps equal justification for placing it in the category of Cryic regosol.

On the floor of Polar Bear Pass, the soils consist of a mosaic of Bog and a few islands of a wet phase of Meadow tundra. Much of this area remains water-saturated throughout most of the summer months (Pl. 6). A few peat mounds are elevated up to a meter above surrounding areas. Non-sorted ice wedge polygons are extensive on the floor of the pass with both high center and low center varieties being present. Ice mounds, string bogs, beaded drainage and other frozen ground features are also present (Blake, 1974a, b). The entire area has such a poorly developed drainage pattern that the rate of surface runoff is extremely slow.

Along the lower course of the Goodsir River, about midway between Bracebridge and Goodsir Inlets, is a prominent expanse of fluvial material of comparatively recent origin (Fig. 3). This material consists of a dark gray (5 YR 4/1) to reddish gray (5YR 5/2) sandy loam with barely discernible evidence of soil formation (Pl. 4). The mineral material contains some shells and the gravel has some carbonate crusts present. The entire soil matrix also has extensive mud coatings. Most of this area is moderately well-drained but there is evidence of only incipient soil formation in well-drained as well as poorly drained sites.

BURIED SOILS

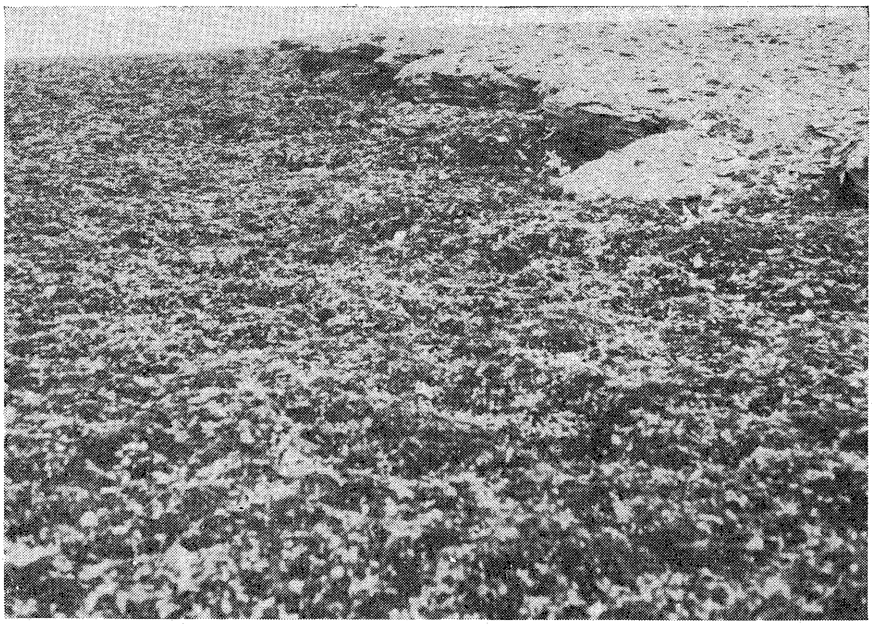
Of special interest in the Goodsir River area is the presence of a number of buried soils. BLAKE (1974a) has already reported a number of peats buried beneath marine silts in the area. BLAKE'S sample of marine mollusks, including the C^{14} dating (GSC-377) helps to establish the time frame when Polar Bear Pass was an arm of the sea with the radiocarbon date yielding an age of 8.440 $\pm$ 150 years. In the same general area organic material buried beneath alluvium or slope wash yielded an age of 4.070 $\pm$ 140 yr (Radio Carbon 8 : 122 (1966) W. BLAKE). The buried soils are primarily in the lower, gently sloping positions (Pl. 7). It is uncertain whether burial was a result of solifluction, marine inundation, or a combination of the two. Field evidence indicates that solifluction has been very active and the processes continue at present. Following burial of the soils, ice wedge polygons formed. Subsequently there was extensive erosion of the ice wedges between the polygons, leaving buried soils exposed along the peripheries of the raised polygon centers. The morphology of one of these sites follows (Tab. II, Bath-2):

Depth (cm)		Morphology
0—20	—	Light yellowish brown (10YR 6/4) very fine sandy loam with some pea-size gravel, loose consistence, well drained, structureless;
20—40	—	Dark yellowish brown (10YR 3/4) very fine sandy loam, loose, well drained, structureless. Some humic staining with a greasy feel;
40—55	—	Frozen dark reddish brown to black peat formed in situ (Sample Bath-2, 5.660 $\pm$ 100 yr (GSC-2302) from this horizon at the 40—48 cm depth);
55 +	—	Frozen, gray, fine sand.

The buried peat was samples for radiocarbon dating as well as identification of pollen and other plant parts. A second buried soil site on the south side (right bank) of the Goodsir River at about the same altitude and under similar conditions was also sample (Tab. II, Bath-1). The two sites yielded C^{14} dates in the 5400 to 5700 year range. Pollen can be characterized as mid-arctic. The higher percentage of *Gramineae* pollen in Bath-2 suggests slightly drier, and better dra-

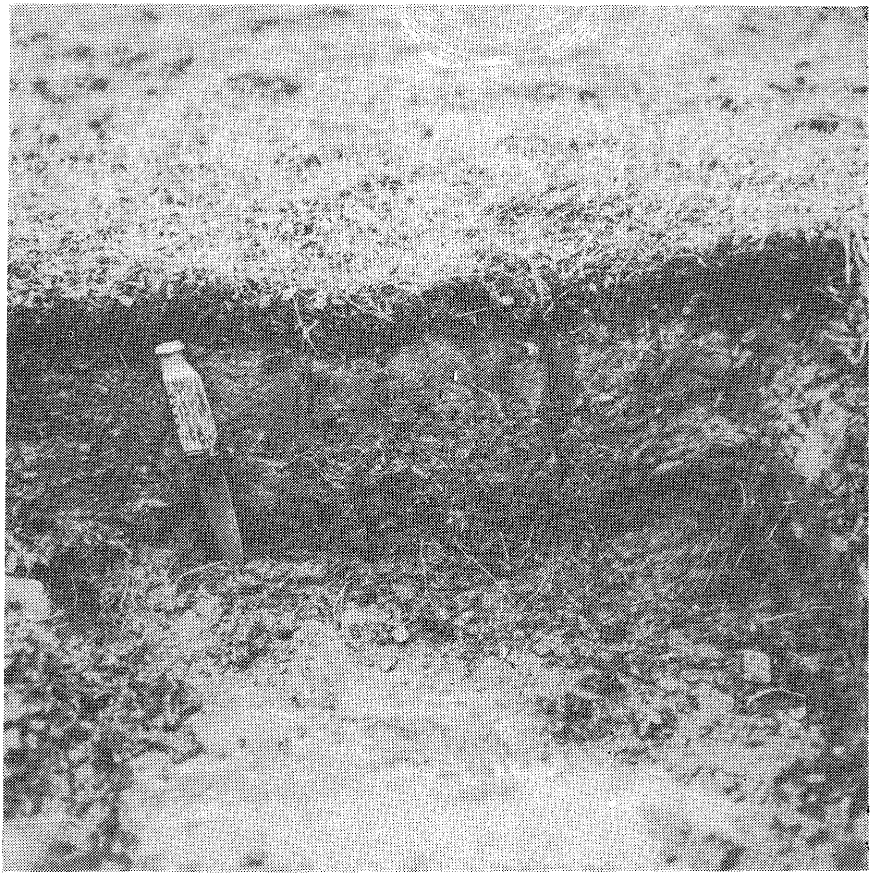
Pl. 1. Shattered limestone and platy, carbonate-bearing sandstone near the Goodsir River. There are virtually no fines present. The first stages of stone stripe development are visible

Pl. 2. Soil stripes on sloping land of Bathurst Island. The soil is without genetic horizonation and is quite wet for extended periods during early summer

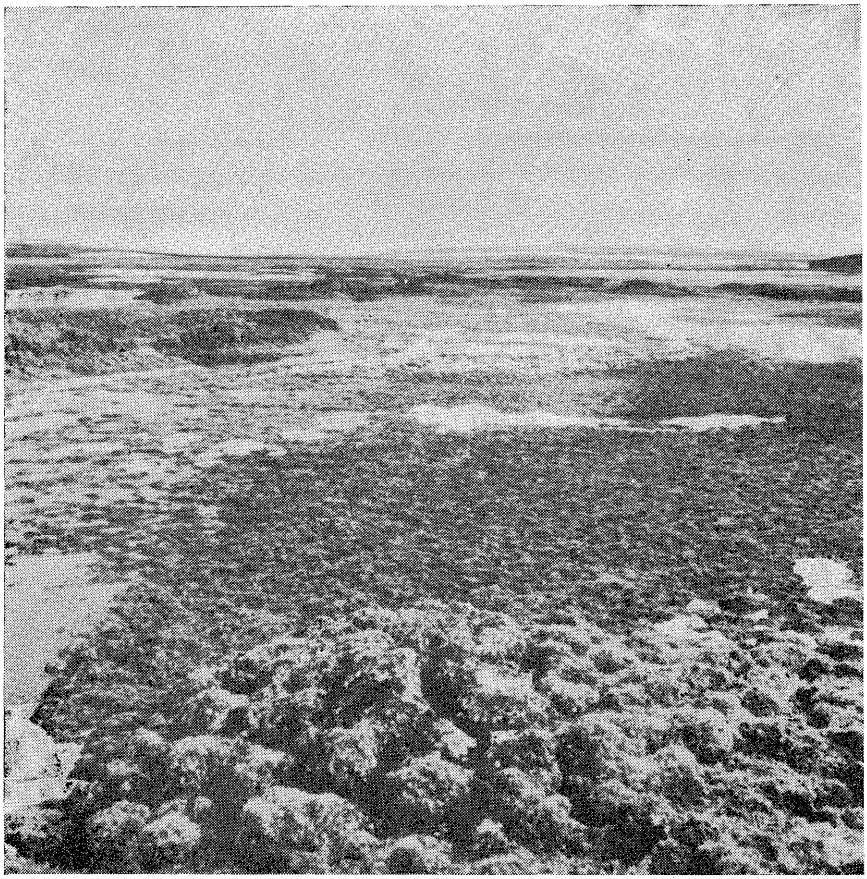


Pl. 3. Mass movement of material downslope near Polar Bear Pass. The soil is considered as regosolic (Cryic regosol) or Arctic råmark

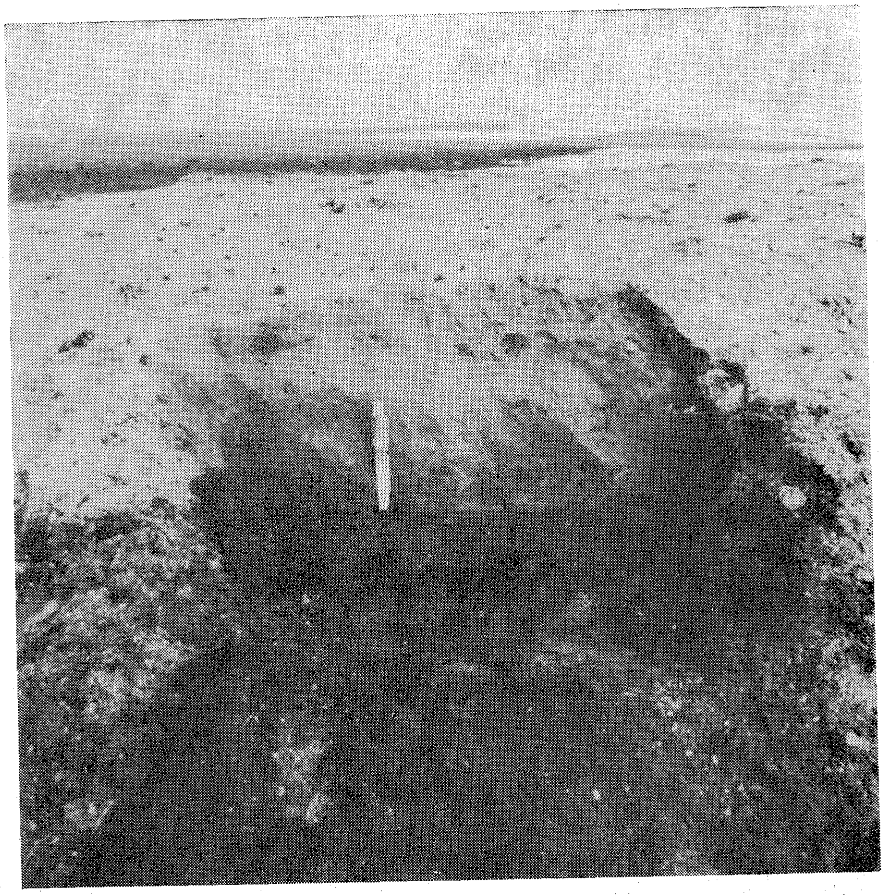
Pl. 4. Non-sorted circles on fluvial deposits along the Goodsir River. The soils have only embryonic development



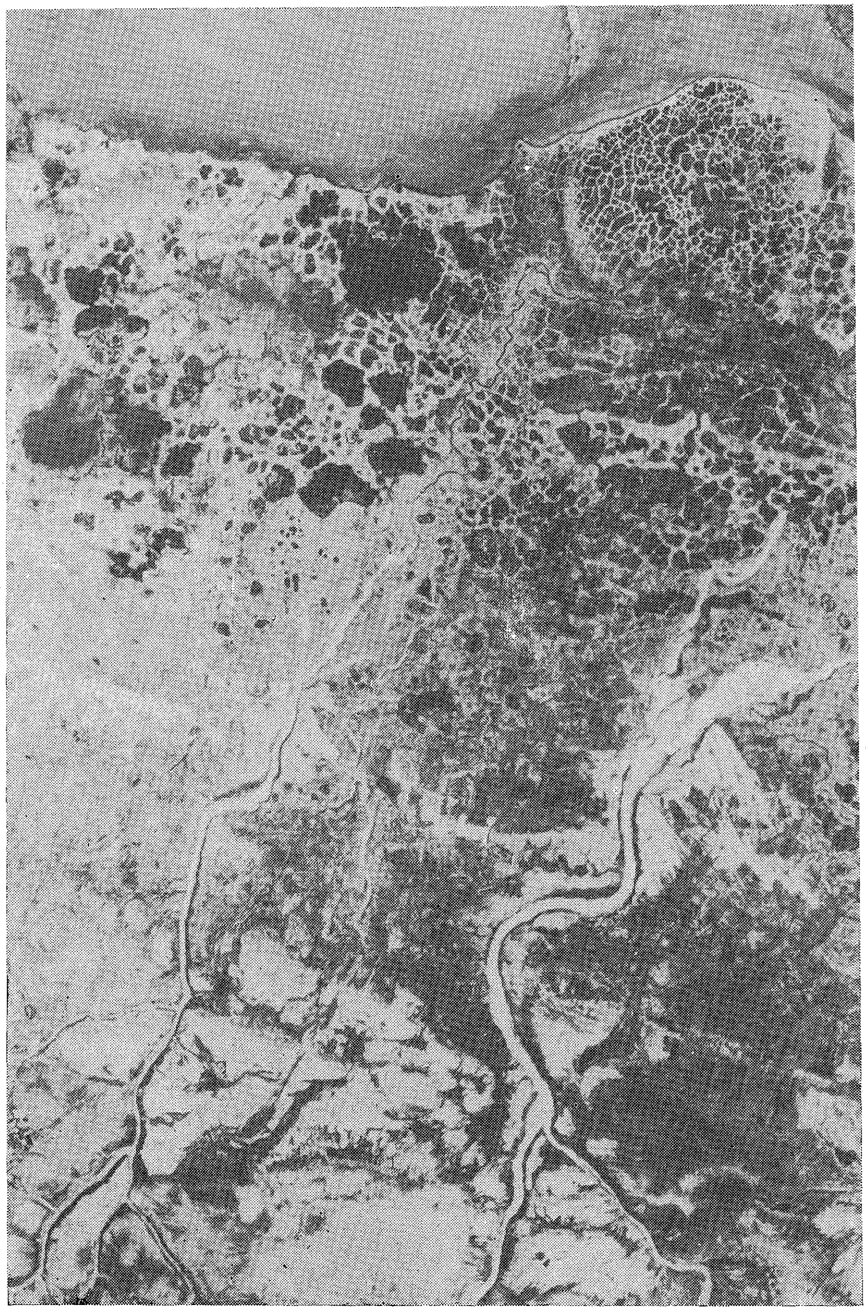
Pl. 5. Tundra soil near Polar Bear Pass



Pl. 6. View of Polar Bear Pass showing very wet, organic conditions



Pl. 7. Buried soil (see Tab. II, Bath-2) along the edge of a high-center, ice wedge polygon



Pl. 8. Aerial view of conditions of the south side of Polar Bear Pass. The top edge part of the photograph shows polygonized bog-like soils on flat terrain, whereas the bottom part shows mainly regosolic conditions with some Polar desert-limestone variant soils. Photograph from the National Air Photo Library (Can.)

image of the site during the time of deposition, than was the case at the Bath-1 site. *Alnus*, *Betula*, *Picea*, *Pinus*, and *Ambrosia* pollen probably was from long distance dispersal. Presence of the single *Tilia* pollen grain is ascribed to contamination.

Table II

Analysis of buried peats from Bathurst Island, N.W.T.

Sample No.	Bath-1	Bath-2
(GSC No.)	2315	2302
Location	75°45′N	75°44′N
	98°27′W	98°23′W
Altitude (estimated)	25 m	30 m
Depth of sample	35 cm	40—48 cm
C^{14} age (uncorrected)	5,470 ± 60 yr	5,660 ± 100 yr
Pollen and spores		
Cyperaceae	83.81%	57.09%
Gramineae	10.24%	32.67%
NAP	1.54%	6.39%
Salix	2.09%	2.21%
Alnus	0.88%	0.58%
Betula	—	0.12%
Picea	0.22%	—
Pinus	0.11%	0.12%
Tilia	0.11%	—
Jun./Thuja	—	0.12%
Polypodiaceae	0.33%	—
Equisetum	—	0.12%
Sphagnum	0.11%	0.23%
Unknown	0.55%	0.35%
Pollen and spore total	908	860
Megafossils		
Carex stans Drej-Achene(s)	1	5
Carex stans-achene(s)	2	—
Dryas integrifolia M. Vahl	—	leaf fragments

Of importance is making the identification of pollen and other plant parts and using this information to aid in reconstruction of the plant cover and prevailing climate in the area some 5.700 to 5.400 years ago. In addition, field investigations suggest that there was the possibility of an interval of soil formation during post-glacial rebound. The question arises then as to whether isostatic rebound was fairly uniform or whether there was a rebound pause in which soil formation took place, followed by renewed uplift. At the present time we do not have sufficient information to do more than raise the question of the possibility.

GEOMORPHIC EVENTS AND THE SOIL PATTERN

When pedologists address the problem of soil formation, relief is one of the cardinal points of the thesis. GLINKA (1927) said it quite ably "The Russian pedologist did not confine himself to the establishment of soil zones [...] he was called upon to pay attention to the topography of the soils of one and the same zone [...] not only by comparatively important elevations and depressions [...] but also by almost unnoticeable changes in the features of micro relief." Perhaps this important statement can now be extended somewhat. In addition to relief features *per se* one needs to recognize the total relief evolution and the associated soil pattern. Within the High Arctic geomorphic processes during and following the Pleistocene epoch played a dominant role in determining the soil pattern. We cite the Polar Bear Pass area as an example in which Pleistocene events overshadowed the zonal pedologic processes in a number of ways. With the surface drainage pattern so poorly formed, including the presence of massive ground ice beneath the meadows and coupled with barely measurable stream gradients, soils develop a nearly continuous array of bog features. In contrast to the low meadows, the higher elevations have developed a more favourable set of relief elements for zonal soils to form. On the other hand, surface features of the uplands have generally developed to such an extent that runoff is not inhibited, which, coupled with the presence of much bedrock detritus, has produced mesic to xeric conditions. Further stream development patterns above the marine limit tend to be well entrenched as compared to those flat, recently emerged areas (Pl. 7). If that land above the marine limit is compared to the lower elevation, it can be seen from the areial mosaic that geomorphic processes in the High Arctic are sometimes as important as are the other soil-forming factors. BOROWIEC (1960) discussed the problem of soils forming on stagnant-water deposits and the influence of detrital organic matter in the substrate. Boggy soils on the floor of Polar Bear Pass owe much of their dark appearance to the organic material in the shallow water deposits.

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