J. C. F. TEDROW*

New Brunswick

FACTORS AFFECTING POLAR DESERT SOIL DEVELOPMENT IN THE HIGH ARCTIC**

Abstract

The High Arctic is considered to be mantled with Polar desert soil, largely as described by B. N. GORODKOW. These extreme northern lands have been free of glacier ice only within the past 10,000 or so years. The landforms emerging from postglacial rebound, coupled with active solifluction, have commonly resulted in areas of raw-appearing soils. Accordingly, Polar desert soil may have only minimal development. Further, some of the Polar lands which emerged above the marine limit during late Pleistocene time are low, flat and poorly drained, resulting in only a primitive form of Tundra or Bog soil being present.

Compared with other regions of the globe, soils of the High Arctic remain rather incompletely understood. Apparently it was not until the work of GORODKOW (1939) first appeared that reliable pedologic information on the High Arctic became available. Nonetheless, botanists and geologists had recognized special features of the extreme northern areas at a much earlier time (EGEDE, 1741; HARTZ, 1896; HÖGBOM, 1912; and others). Further, ALEKSANDROVA (1970) summarized early contributions of Soviet naturalists in the High Arctic. Her review showed that botanical zonation in the Soviet Arctic was recognized as early as 1851. Phytogeographic reports from the Canadian High Arctic appeared somewhat later (POLUNIN, 1951; PORSILD, 1957). More recently, WALTON (1972) and TEDROW (1973) addressed the soil zonation problem in the High Arctic on a circumpolar basis.

If, at the outset, we accept the thesis that dominantly wet conditions exist within the main tundra belt immediately north of the forested land, and these hydric landscapes give way northward to noticeably drier conditions, only then will it be possible to realistically address the far northern pedologic problem. All High Arctic lands belong to Canada, Denmark (Greenland), Norway (Svalbard) or the U.S.S.R. Insofar as pedological investigations are concerned, most Canadian workers currently tend to portray the main varieties of High Arctic

* Soils and Crops Department, Rutgers State University, New Brunswick, New Jersey 08903, U.S.A.

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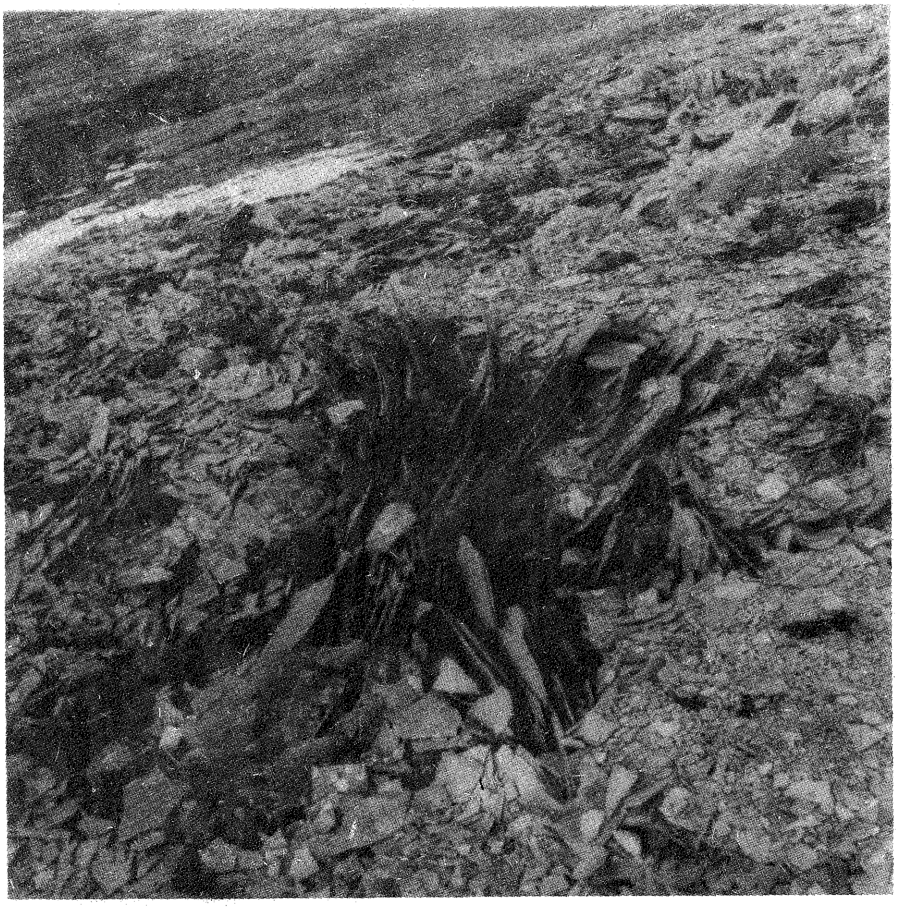
soils as Brunosolic, Regosolic, Gleysolic, Rockland and Organic, with appropriate modifiers (e.g., Cryic Eutric Brunisol). It is probably accurate to state that, in the High Arctic, there is little intra-arctic pedological zonation recognized by Canadian investigators (CLAYTON, *et al.*, 1977). Soviet investigators, however, recognize pedologic zones within the arctic proper. For example, the Soviet soils map (GERASIMOV, *et al.*, 1956) lists "Arctic desert and tundra" in the High Arctic (Arctic deserts and tundra actually extend a little south of that region generally recognized as High Arctic and include such localities as northern Yamal and the northern part of the Taimyr Peninsula) and Tundra gley in the main tundra belt. IVANOVA (1956) used a similar approach in that she described Arctic (which approximates Polar desert) and Tundra soils with further subdivisions. The approach of TURIN (1965) in polar soil classification is virtually the same as that of GERASIMOV, *et al.*, and that of IVANOVA. MAKEEV (1978) and KOROTKOVICH (1967) summarized the various classification methodologies on a global basis. Representatives of the U.S. Department of Agriculture have addressed the problem of soil classification, including the High Arctic sectors (Soil Survey Staff, 1975). The method used is to modify the main soil orders, such as Entisols, Histosols and others, using temperature-derived criteria (e.g., Cryaquents). The FAO/UNESCO soils map of the world follows a similar method, but with slightly different terminology. The term "Gelic Regosol" is used in much of the High Arctic. TEDROW (1977) proposed a soil classification scheme for all High Arctic sectors. This system, which is based on climatic zones and other factors, follows in abbreviated form:

First order	Second order

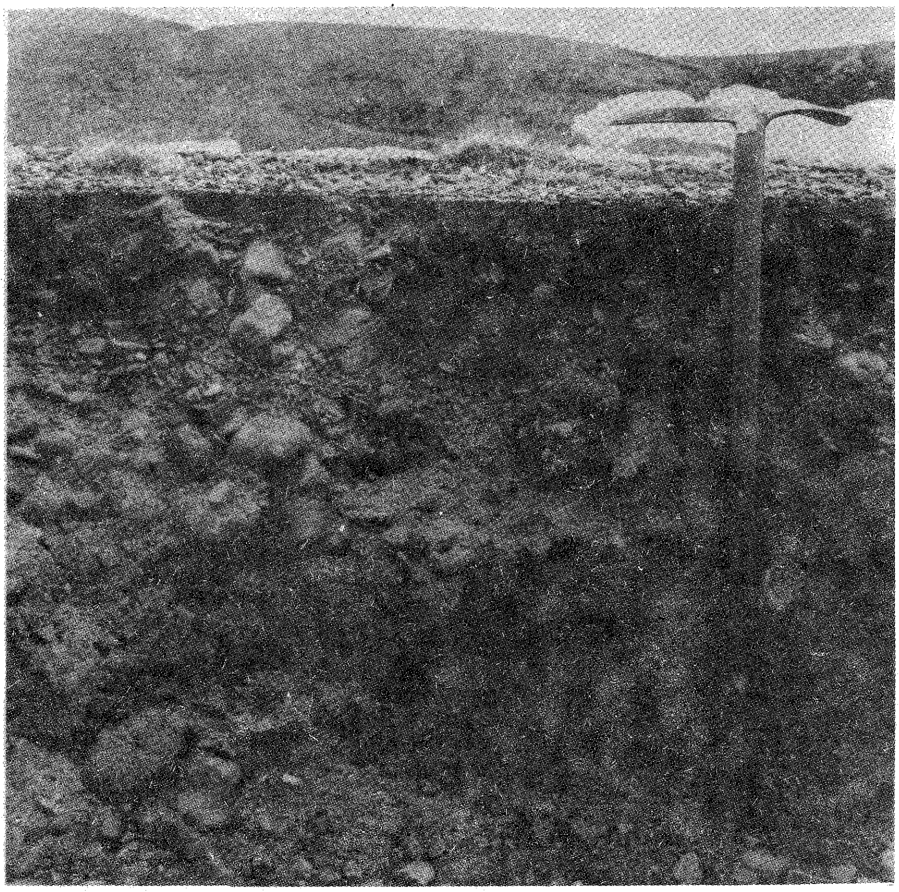
Polar Desert soil zone	Wel-Drained Soils
	  Polar desert soil
	  Arctic brown soil
	Mineral Gley Soils
	  Upland tundra
	  Meadow tundra
	  Soils of the hummocky ground
	  Soils of the polar desert – tundra interjacence
	  Organic Soils
	    Bog soils
	  Other Soils
	Regosols
	Lithosols
	Soils of the solifluction slopes (may be a form of gley soil but usually well-drained)

[1] The Subpolar desert soil zone, which is a transition between the Polar desert and Tundra zones, has virtually the same groups of soils as the Polar desert zone, but there is a higher percentage of poorly drained land in the former.

Pl. 1. Polar desert soil formed on the Beaufort Plain, central Prince Patrick Island. The dark shading below the desert pavement is due to iron coloration plus a little organic matter. This site should be considered one of the oldest (both chronologically and developmentally) in the High Arctic

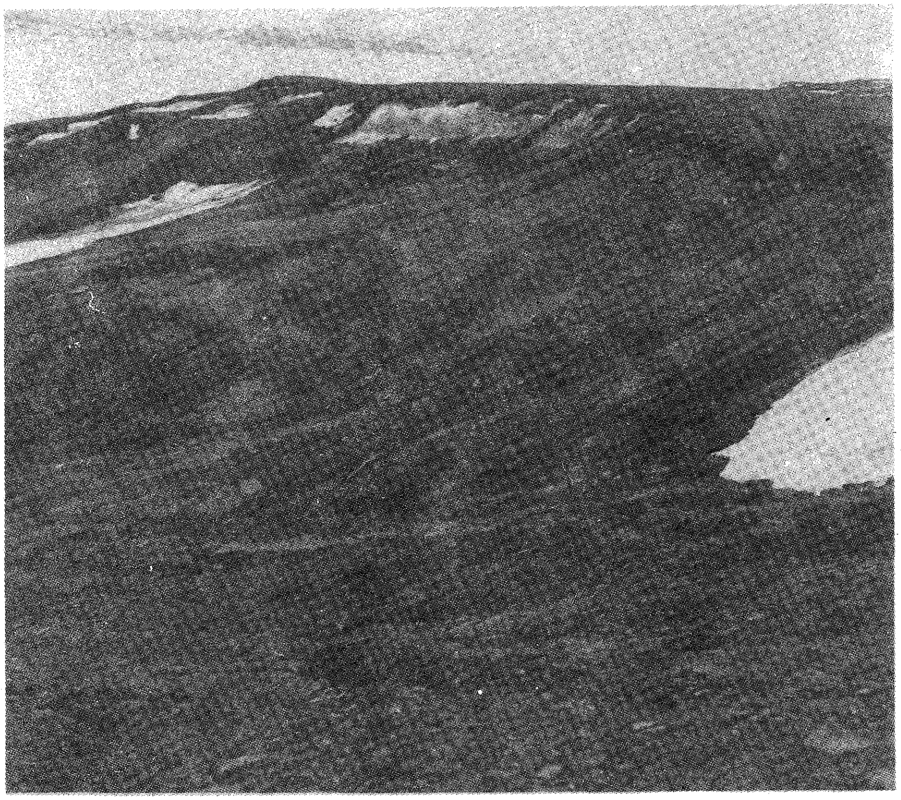


Pl. 2. On many dry, stony sites of the High Arctic, the frost processes are so active that Polar desert soil fails to develop. This site, on Bathurst Island, shows a dry stony ridge with shallow "soil", lacking genetic development. This condition would probably approximate the Arctic hamanda ramark (Kubiëna), Cryic regosol (Can.) or Gelic regosol (FAO/UNESCO)

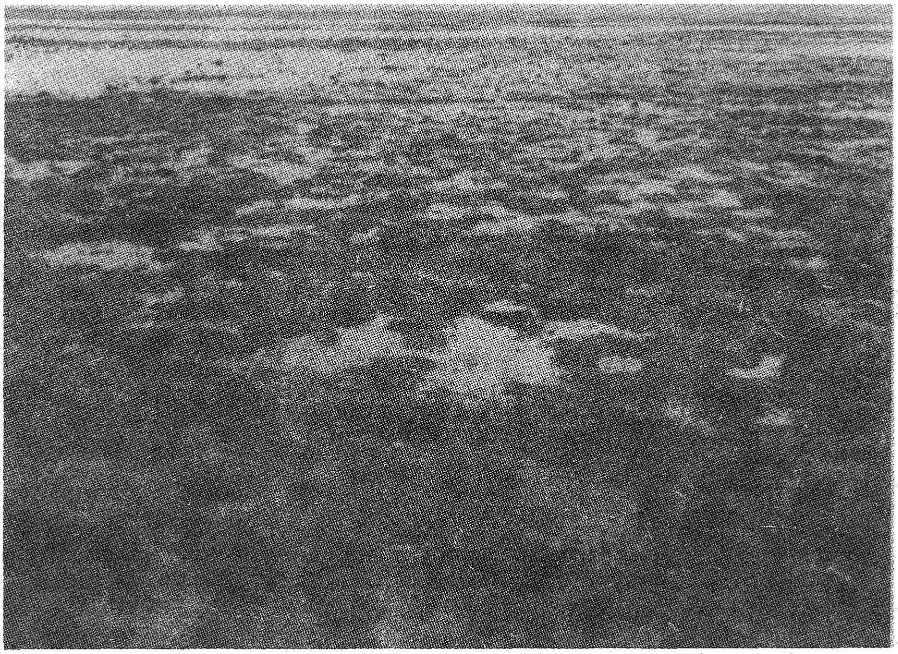


Pl. 3. Soil located on a well-drained terrace on Prince Patrick Island. The soil, without genetic horizonation, is considered to be a Regosol

Pl. 4. View of an emerging, rocky, coastal area at Mould Bay, Prince Patrick Island



Pl. 5. Thermocirque formation in the emerged headlands at Mould Bay, Prince Patrick Island. The upper left corner of the photograph shows the original surface. The remaining field of view consists of a massive solifluction area without genetic soil formation



Pl. 6. Flat, swamplike terrain at Polar Bear Pass, Bathurst Island. This emerged landform is mantled with Meadow tundra and Bog soils (Type E of Fig. 1)

FEDOROFF (1966) proposed an ingenious system for classifying High Arctic soils, which includes zonation, local soil variety and associated patterned ground forms. FEDOROFF recognized a special group of polar soils, which he called Cryosols, plus the various polygonal ground patterns. With this brief review, it becomes apparent that the Soviet systems, as well as those of FEDOROFF and TEDROW, are based more on bioclimatic zonation and genetic principles. On the other hand, the Canadian, FAO/UNESCO and U.S. Department of Agriculture systems rely primarily on factors such as temperature, frost action and drainage, but in the well-drained sites these latter systems, in effect, do not provide for a polar desert soil process in a senso stricto. Further, it is important to record some of KUBIENA'S (1953) views on soil formation in the High Arctic. He listed a common Arctic ramark soil as a climatic soil just beyond the tundra girdle, and an Arctic hamanda ramark soil in the arctic where is a stone pavement present. Thus, KUBIENA recognized the raw-appearing soils north of the tundra zone, but he did not go much beyond recognizing a desert process in the High Arctic other than development of a stone (desert) pavement.

Whereas, ideally, a fully developed Polar desert soil has a set of acquired features, field investigators will soon recognize that there are spatial and temporal relationships which also have to be equated in accounting for soil properties at any one locality. Adhering to the principles of DOKUCHAEV, GLINKA, MARBUT and others that, given the suitable conditions, such as ideal parent material, sufficient time, proper relief features and so on, a set of properties will develop which reflect an idealized normal or zonal soil (Pl. 1). In the High Arctic these acquired properties include the following:

1. Development of a desert pavement.
2. Development of an ABC or A(B)C set of horizons. A "browning effect" develops within the solum (usually of mineral origin), and, in certain situations, a slight translocation of clay takes place. Mud coatings may be present around sand grains (TEDROW, 1970).
3. Chemical properties such as pH values, base saturation, electrical conductivity and salt efflorescence will show extreme ranges, depending upon local conditions (TEDROW, 1966).
4. Organic matter content is nearly always quite small, but in some situations there is a sufficient quantity present to impart a staining effect in the uppermost layers.

FROST ACTION

Frost action plays an active role in modyfying most soil features of the High Arctic. The frost processes alter the morphological features at many well-drained sites (Pl. 2), as well as those having restricted drainage.

PARENT MATERIAL

Parent material has an important influence on the formation of Polar desert soil. Soil development reaches higher levels on the coarse-textured materials such as sandy loams and loamy sands. On the other hand, medium-textured and especially clayey-textured soils tend to have some form of impeded drainage.

Mineral composition may also have a dominant influence on development of Polar desert soil. BESCHEL (1970) pointed out that rock deserts made up of limestone in the Queen Elizabeth Island are more barren than the areas of silicate rock. This situation carries through to the soil, with the high-purity limestone deposits having virtually no genetic soil horizon development (TEDROW, 1978). Cornwallis Island, where limestone is present on the emerged landscape, offers excellent examples of minimal Polar desert soil development. In such situations, the soils have the characteristics of a Regosol rather than that of Polar desert soil. Accordingly, under such conditions, terms such as Cryic regosol (Can.) and Gelic regosol (FAO), are quite appropriate.

THE TIME FACTOR IN DEVELOPMENT OF POLAR DESERT SOIL

Most of the High Arctic has been free of glacier ice only within the last 10,000 or so years. But, even within the above locations, extensive areas of glacier ice still persists, particularly in Ellesmere, Axel Heiberg and Devon Islands, Northern Greenland, Svalbard, Franz Josef Land and Severnaya Zemlya. More specifically, the Queen Elizabeth Islands have reverted to their dominantly ice-free condition only within the last 8500- to 10,500-year period (PREST, 1976). In Northern Greenland, the time span is about 8500 years for the ice-free margins of the island (WEIDICK, 1972), in Svalbard, 10,000 years (HOPPE, 1970) and in Franz Josef Land and Severnaya Zemlya, the values also approximate 10,000 years (GROSSWALD, 1972). Thus, in nearly all of the High Arctic, the soils are relatively young chronologically. Plate 3 shows a well-drained soil on a terrace near Landing Lake, Prince Patrick Island, in which no visible signs of pedologic development are evident. Apart from the relatively young land surfaces, the seasonal period of vital soil activity in the High Arctic is short, which results in a compressed "growing season" and a correspondingly low order of biochemical reactions. But on the western margin of the Queen Elizabeth Islands, particularly central and western Prince Patrick Island, where the landscape was subjected to little, if any, glacial activity, Polar desert soils are believed to attain the greatest development of those found anywhere in the Northern Hemisphere.

ISOSTATIC REBOUND AND SOIL DEVELOPMENT

In addition to nearly all High Arctic lands having been glaciated, vast areas were also depressed below sea level during the Pleistocene. Unlike many temperate and tropical sectors where there has been a rise in sea level during and following Pleistocene time, in the High Arctic the landmasses rebounded following the disappearance of the ice, which in effect, has been a general rise of

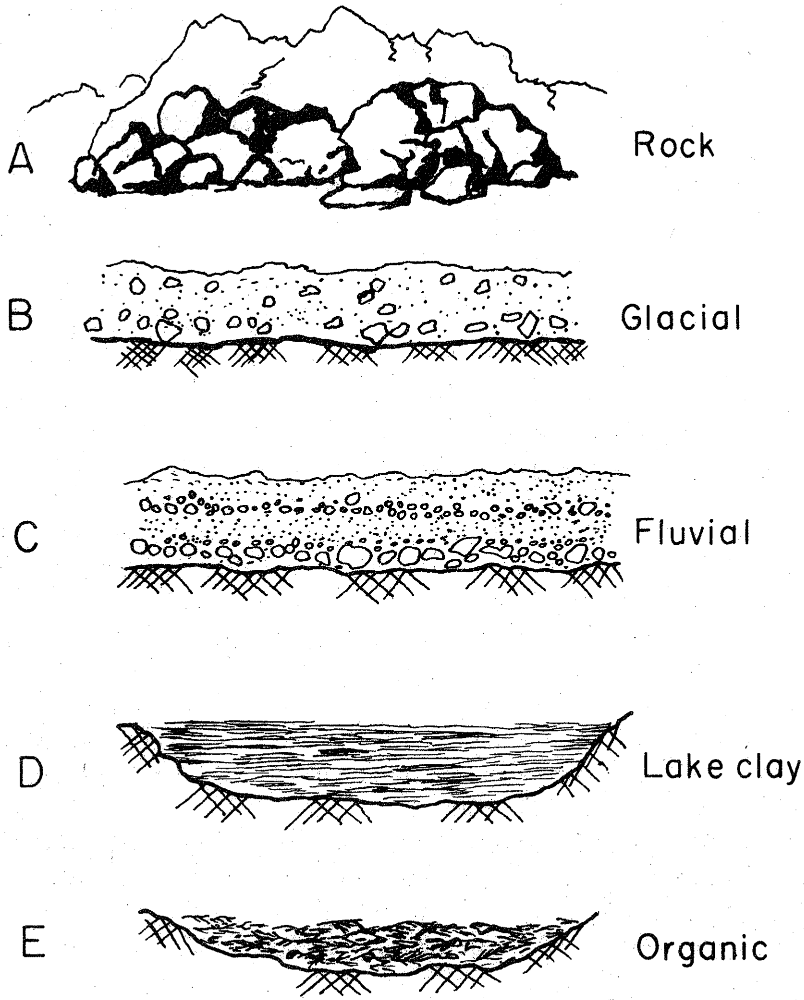


Fig. 1. Diagrammatic presentation of various kinds of emerging landforms

A – rocky conditions with exposed bedrock; B – constructional landform with rolling relief features. The higher positions will generally be well drained with a primitive form of Polar desert soil, but the lower sites will generally have impeded drainage; C – stratified, coarse-textured sediments as exemplified by outwash terraces afford ideal material for Polar desert soil formation; D – flat, heavy textured materials such as lake clays will generally have some form of Meadow tundra or Bog soil present; E – some emerged organic-enriched swamp (lagoon) deposits have boglike features the land with respect to sea level. The isostatic rebound has affected virtually all far northern lands, resulting in the generation of many new surfaces and development of sloping land. Globally, there were two great centers of ice accumulation and subsequent rebound during the Wisconsin (Würm) epoch; northern Canada plus Greenland and northern Europe. In Canada, ANDREWS (1973) projected the maximum postglacial marine limit to be up to about 400 feet in the vicinity of Cornwallis Island, and 500 feet in the Ellesmere-Axel Heiberg complex. But the value drops to nearly zero along the western margin of the Queen Elizabeth Islands. In northern Greenland, DAVIES (1961) projected the marine limit to be about 350 feet (107 – 130 m). In the vicinity of Svalbard, HOPPE (1970) constructed an isobase map showing shore features up to nearly 100 feet (30 m) above tide water. Postglacial rebound in the Laptev sea area has been discussed by a number of investigators (SAKS and STRELKOV, 1961; GROSSWALD, 1972; VIDORCHIK, 1980 and others). GROSSWALD (*loc. cit.*) indicated a crustal uplift of about 110 feet (35 m) in Franz Josef Land.

Following thinning and disappearance of the ice sheets, postglacial rebound resulted in an uplift of the land, and consequently a "seaward shift" of coastal zones. In some locations only cliffs, rock walls and talus-covered slopes emerged from beneath the sea, leaving extreme shallow, raw soils or rocky areas with little soil cover (Pl. 4). During uplift there was a tendency for thermocirques to form under certain situations. Where such is the case, the cirque area will have mud flows, solifluction and areas of wet earthy debris without genetic soil development (Pl. 5).

Where there is an accumulation of driftlike material creating a constructional landform, the material may have undergone only minimal soil development; therefore, in such situations, it is proper to speak of a low-temperature Regosol or Polar desert soil *in potentia* (Fig. 1-A). With areas of glacial outwash or river alluv um, then, the same principle will generally apply, in that the older deposits will tend to have well-developed Polar desert soil present. However, with the more recent deposits, the soil will consist of little more than a raw, earthy deposit. The soil will generally have a raw appearance, with little evidence of genetic horizontations (Pl. 3; Fig. 1-B and 1-C).

In certain High Arctic sites the emerging landforms consist of finely textured silts and clays on flat relief with extremely slow surface drainage (Fig. 1-D). In such situations, primitive Meadow tundra or some form of Bog soil forms (WALTON and TEDROW, 1983). These emerging flat, swampy areas may also be enriched from the organic residues initially accumulated on floors of the original lagoons, bays and inlets. Under such conditions, the soil will be a Meadow tundra-Bog complex (Fig. 1-E). Plate 6 shows a meadow at Polar Bear Pass on Bathurst Island in which the flat, swamplike deposits emerged from beneath marine waters. This lowland, connecting Bracebridge and Goodsir Inlets, has been free of glacier ice only within the past 8500 years (BLAKE, 1974). With such a setting, it is evident that Bog and hydric mineral soils will occupy the landscape for millennia.

With the foregoing discussions it appears that, within the High Arctic, there is a lithogenic-hydric catena of soils present, but, further, the soil pattern needs to be equated with the complete spectrum of Holocene events before an adequate explanation can be projected relative to the soil pattern.

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