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SOILS OF THE MESTERS VIG DISTRICT, NORTHEAST GREENLAND

2. EXCLUSIVE OF ARCTIC BROWN AND PODZOL-LIKE SOILS

BY

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WITH 3 FIGURES IN THE TEXT
AND 1 PLATE

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Abstract

Different investigators have classified the soils of the Arctic according to genetic, morphologic, genetic-cryopedogenic, and cryopedogenic concepts. Instead of adhering to a specific classification, the soils of Mesters Vig are described and discussed, using terms already introduced in the literature. These soils include Lithosols, Arctic Brown soils, Podzol-like soils, Meadow and Upland Tundra soils, Tundra variant soils (soils of the gelifluction slopes, soils associated with certain patterned ground features, and soils associated with turf-hummocks), Protoranker soils, and Tundra Ranker soils.

A single profile description is given for each one of these soils together with a discussion of the factors affecting the soil morphological properties. The cryopedogenic and gelifluction processes are very important factors affecting the morphology and the occurrence of the different types of soils. Certain megascopic properties such as structure may be indicative of the stability of the soils on slopes, while miniature and shallow profiles in a patterned ground may provide some information on the activity of the cryopedogenic processes. The soils associated with patterned ground may undergo a dynamic evolution because the internal soils properties may be progressively changed by the cryopedogenic processes. Because the arctic soils are shallow and not well developed, they are very sensitive to small climatic changes and to other disturbances. Soil distribution and development reflect, therefore, the dynamic effect of arctic landscape.

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INTRODUCTION

In the Arctic as well as in other parts of the world, there has been a particular emphasis on the zonal well-drained soils of the region.

The recognition of the zonal soil for a given region, while of capital importance in maintaining a trend of continuity among the other zonal soils of the world, is often inadequate in portraying a realistic picture of the soil distribution and of the pedological problems in that region. This consideration is even more valid for the Arctic where stable, well-drained conditions are more an exception than a rule. Furthermore, in Northeast Greenland, it appears that the zonal soil itself, the Arctic Brown, is not entirely immune from disturbances. UGOLINI (1965; 1966) has reported on Arctic Brown soil profiles of the Mesters Vig district together with the enumeration and the discussion of the factors affecting the morphology and the occurrence of these soils.

Although most of the areas of Arctic Brown soils are currently stable, there are some sites where Arctic Brown profiles are undermined by disrupting agents.

Information relative to the location of Mesters Vig district (Plate 1), its physiography, climate, bedrock geology, geomorphology, and vegetation have been provided by WASHBURN (1965) and by RAUP (1965).

Soils

Pedological studies during the summers of 1961 and 1964 revealed that only ten percent or less of the district is covered by the zonal Arctic Brown soils. Depending on the degree of expression of pedogenic and cryopedogenic processes, a spectrum of undisturbed and disturbed soils are found in the district. The concomitant occurrence of undisturbed soils and the multifarious expressions of their disturbed morphology creates a major difficulty in soil classification in the arctic regions. In spite of this situation, attempts have been made to produce adequate classifications. TEDROW *et al.* (1958), following the classical scheme, distinguished for Arctic Alaska, zonal, intrazonal, and azonal soils. Within this broad division major genetic soils were recognized and implications were drawn regarding the nature of the pedologic processes operating on arctic soils. The well-drained Arctic Brown soils were considered weakened podzols, while the poorly-drained Tundra soils were considered to approximate gley conditions.

Soil disturbances in the Arctic are mainly a result of low temperatures and moisture regimen which are reflected in permafrost, congeliturbation phenomena, gelifluction (WASHBURN, 1965), frost cracking, and needle ice. The combined effect of these cryogenic processes on soils or soil material can be viewed as a single process and considered as an additional soil-forming factor. DOUGLAS and TEDROW (1960) have made a similar suggestion for the genesis of Tundra soils where frost action is considered a potential soil-forming factor. An even more definite step in this direction was made by SOKOLOV and SOKOLOVA (1962) who, in certain cases, considered cryogenic processes to be important zonal soil-forming factors. If the cryogenic processes were considered an additional soil-forming factor, then all the recognized cryopedogenic soils and also the related soils that seem at the moment stable, could be encompassed within the range of a single genetic process and the soil complex could be classed as a unit. The advantage of this concept, once extended to all the potential frost-affected soils and including all cryopedogenic features, is that soils could then be considered an integral part of the landscape, and therefore of the geomorphic cycle. This approach appears particularly attractive for the Arctic, where the soils under the impact of short summers, limited rainfall, and frost disturbances are very shallow and apt to reflect the cryopedogenic influences.

Some of the forces which affect the morphology and genesis of the soil profiles also affect the physiography of the landscape. Consequently, in the arctic regions it seems that geomorphic and pedologic processes are intimately related. As a result of these considerations the soils would be seen not as simple physical objects in nature but as tangible expressions of the dynamics of the landscape.

Most classification schemes devised for, or including, arctic soils (KUBIENA, 1953; SMITH, 1956; TEDROW *et al.*, 1958) have followed some of the implications suggested by a genetic or by a genetic-cryogenetic classification. The integration between the environmental aspects and soil morphology and genesis has been extended to catenary drainage sequence (TEDROW *et al.*, 1958), to catenary drainage and stability of the site (SMITH, 1956), and to patterned ground expressions and presence of permafrost (KUBIENA, 1953).

Some of these suggested classifications are the result of local observations and therefore are inadequate for application to the rest of the Arctic. The fundamental limitation of these systems is that soils whose genesis is not yet well understood are classified into genetic groups.

An exception to this trend is the work of HOLOWAYCHUK *et al.* (1962). In a detailed map of the Ogotoruk area, HOLOWAYCHUK and collaborators use only soil properties, such as color, to identify soil class. Other classifications of arctic soils have been presented by KREIDA (1958), IVANOVA *et al.* (1961), and GORSHENIN (1963).

KREIDA (1958), in discussing the soils of the eastern European Tundra, follows the genetic approach and includes vertical mixing due to freezing effects as one of the genetic processes of Tundra soils. The general geography and classification of soils in the Polar belt of Siberia by IVANOVA *et al.* (1961) are still based on classical genetic principles.

An interesting approach involving the impact of frost action on soils is that of SOKOLOV and SOKOLOVA (1962) who studied the soils of Eastern Transbaikal. Although they distinguish between cryogenic and non-cryogenic soils, they consider both as legitimate zonal soils. According to SOKOLOV and SOKOLOVA, only a "zonal pair or group" reflects completely the climatic characteristics of the soil-forming processes in each zone.

More recently HOLOWAYCHUK (personal communication) and RETZER (1965) have introduced the seventh approximation system (Soil Survey Staff, 1960) to classify arctic and alpine soils. The adoption of this classification system appears particularly promising for the arctic regions. The concept of pedon, where a soil is considered a tridimensional body, may present a more realistic approach to classify soils whose genesis is modified by cryopedogenic processes.

Because of the transition of modern soil classifications, only a list and description of the soils occurring in the Mesters Vig district are given. An effort has been made here to use soil names already common in the literature.

Soils of the Mesters Vig district include: Lithosols, Arctic Brown soils in all phases (normal, shallow, miniature), Podzol-like soils, Meadow and Upland Tundra soils (TEDROW *et al.*, 1958), Tundra variant soils (soils of the gelifluction slopes, soils associated with certain patterned ground features, and soils associated with turf-hummocks), and Protoranker soils and Tundra Ranker soils (KUBIENA, 1953).

Upland Tundra soils, soils of the gelifluction slopes, and Lithosols are most common in the district.

DESCRIPTION OF THE SOILS

Lithosols

Morphologically, lithosols are analogous to the primary accumulative lithomorphic soils described by Targul'yan (1959) in the tundra and taiga zones, and the Polar Desert soils of Gorodkov (1939) and Tedrow and Brown (1962). Gorodkov (1939) recognizes these as the zonal soils for the extreme northern latitudes. Tedrow and Brown (1962) while subscribing to Gorodkov's zonal ideas reported Polar Desert soils as the last segment of an altitudinal soil sequence in the Brooks Range, Alaska. The Lithosols of the Mesters Vig district are not included among the zonal Polar Desert soils of the Arctic because of the relatively low latitude and relief of the district. The properties of these and other primary soils in the Arctic seem to be, in the experience of the writer, the result of local environmental conditions related to topography. Because of wind abrasion, excess drainage, and accelerated evaporation, soils on hilltops no higher than 300 m appear similar to those at higher altitudes.

Occurrence. Lithosols in the Mesters Vig district occur on the flat tops of mountains (Gorms Spids), on ledges, or along the flanks, benches, and crests of the Korsbjerg massif and Hesteskoen. Stony areas, such as talus slopes and Felsenmeer, are not included.

Lithosols are mainly an assemblage of cobbles and pebbles with small amounts of fines. The morphology of these soils is closely related to the nature of the underlying bedrock. Barren conditions are common, with a vascular plant cover not exceeding three percent. A few mats of *Dryas octopetala*, *Salix arctica*, and *Vaccinium uliginosum*, with lichens occur in places.

Profile description. The profile described here is from the northeast flank of Hesteskoen.

Depth cm	Horizon	Morphology
0–2	A_0A_1 (01 or A1)*	A thin organic crust or layer, consisting of desiccated parts of plants very little decomposed. Where plant cover is absent, there is a stony surface.
2–25	C	A very cobbly layer, gritty with coarse sand matrix, very dark gray color (5 YR 3/1).** Secondary carbonate crusts occur below cobbles within the first 10 cm.

* New nomenclature of soil horizons (U.S.D.A. Supplement to Agriculture Handbook No. 18, issued May 1962).

** Munsell Color Notation, Munsell Color Co., Inc., Baltimore, Md. Color determined under moist field conditions.

Regosols

Regosols include not only those soils found on recent alluvium, on water worked glacial deposits, or on recent glacial deposits, but also those which have been kept immature by cryopedogenic processes and gelifluction phenomena. In frost-active areas, frost-susceptible substrata tend to be affected by congeliturbation processes which tend to rejuvenate the soil profile through heaving, sorting, and flowing. When gelifluction takes place, the sliding of surficial layers of different thickness produces a similar effect. Cryoplanation (BRYAN, 1946), considered by RAUP (1951) to be a process that inhibits a climax flora, is also responsible in preventing the soils from reaching a stage of maturity and stability.

Occurrence. Regosols were found on moraines on the flanks of Hesteskoen, along flood plains and river terraces of Tunnelelv, on sections of the kame field adjacent to Tunnelelv, in frost-active portions of patterned ground, and in the active part of gelifluction slopes.

Profile description. It is difficult to describe the soil morphology because of the heterogeneity of the substrata and the weak expressions of pedogenic features. A cover of vascular plants varying from 0 to 30 percent is found at the surface of regosols. The A_0 (02) acquires a thickness of 2 to 3 cm. Below, there is a featureless substratum with variable textures and streaks of buried organic matter. The soil may display silt loam to coarse sand textures. The organic streaks may be 1 to 2 cm thick and show involutions.

Arctic Brown soils and Podzol-like soils have been previously described (UGOLINI, 1966).

Tundra Soils

Tundra soils were recognized as zonal soils by DOKUCHAEV and by SIBIRTSEV in the early classifications schemes of 1895 and 1896 (IVANOVA, 1956). Recently the zonality of Tundra soils was rejected by TEDROW *et al.* (1958); the Tundra soils were reclassified as an intrazonal soil and further subdivided into Meadow and Upland Tundra soils. The two subgroups reflect degrees in drainage conditions: the Upland Tundra is the poorly drained member, while the Meadow Tundra is the very poorly drained one.

Tundra soil conditions have been investigated in the North Eurasian and American continents and numerous reports are available (SOCHAVA, 1933; GORODKOV, 1939; BROWN and TEDROW, 1958; TEDROW *et al.*, 1958; DOUGLAS and TEDROW, 1960; and MACNAMARA, 1964). Originally coined for the treeless expanses of the northern regions (JOFFE, 1949) and later adopted for the wet mineral soils underlain by permafrost, the term Tundra would probably be abandoned should any revision of the classification of the arctic soils be made.

Different opinions have been held concerning peculiarities of the soil-forming processes of the Tundra soils. Gorodkov (1939), Filatov (1945), and Tedrow *et al.* (1958) contend that tundra soil-forming processes are not qualitatively different from the soil-forming processes of the poorly drained areas of the boreal forest, while Sochava (1933) and Kreida (1958) are willing to recognize unique genetic processes for Arctic Tundra.

Moreover, it has been implied by Filatov, 1945; Douglas and Tedrow, 1960; and Tedrow, 1962, that pedogenic and non-pedogenic processes are taking place in the genesis of Tundra soils. The pedogenic processes are mainly the low temperature gleization, whereas the non-pedogenic are represented by cryoturbation and frost phenomena. The duality of these processes led Douglas and Tedrow (1960) to suggest that frost action could be considered an additional soil-forming factor for Tundra soils. Evidences for frost displacement and burial of organic matter in the Tundra soils, although descriptive in nature, have been well documented (Black, 1954; MacKay, 1958; Douglas and Tedrow, 1960). Lack of quantitative data and detailed observations prevents not only establishing the degree of congeliturbation, but also the frequency of these processes. In the light of present knowledge, only limited areas in the Arctic may be considered stable. These stable areas are occupied mainly by Arctic Brown and related soils. In spite of physical displacements produced by growth of ground ice and its subsequent thaw, some genetic features in Tundra soils are reported by Brown and Tedrow (1958) and Douglas and Tedrow (1960). However, basic information is still lacking on the full impact of congeliturbation on Tundra soils, its quantification, and above all its ability to obliterate the pedological processes.

Meadow Tundra

Occurrence. Meadow Tundra soils occur along the gentle slopes of emerged fjord-bottom deposits at Labben, on flat portions of gelifluction benches on Hesteskoen, and on the valley bottom of the northwest distributary of Tunnelelv. Other Meadow Tundra soils are scattered in low relief areas where very poorly drained conditions exist. These soils are generally associated with sedges and mosses. Only restricted areas, such as old alluvial deposits of Tunnelelv and some wet meadows of Labben, show tussock forming vegetation.

Profile description. The profile described here is from a gelifluction bench at 520 m on the flank of Hesteskoen. The area is covered by

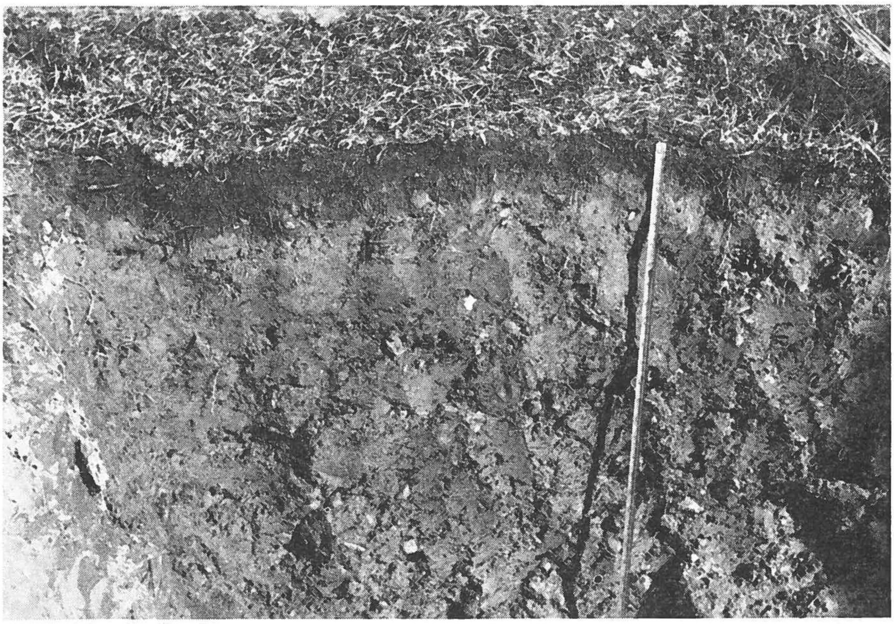


Fig. 1. Upland Tundra soil profile, Nyhavn hills.

Carex sp., *Salix arctica*, *Cassiope tetragona*, and mosses. Black organic crust covers much of the ground (Raup, 1965).

Depth cm	Horizon	Morphology
0–3	A_{00}, A_0 (01, 02)	Dark gray organic layer, fibrous and consisting of partially decomposed sedges and mosses.
3–9	1	Dark grayish brown (10 YR 4/2) sandy loam to loam, penetrated by roots, structureless, viscous.
9–40	2	Dark grayish-brown (10 YR 4/2) sandy loam with few roots, structureless, viscous, very moist.
at 40		Water seeps through the pit. August 11, 1964.

Upland Tundra

Occurrence. Upland Tundra soils occupy gentle slopes or flat areas underlain by clayey substrata. These soils are widespread at Labben along the north flanks of the Korsbjerg massif, and in the Nyhavn hills in the area of experimental sites 7–8 (Washburn, 1965).

Profile description. The following profile (Fig. 1) is from the south part of the Nyhavn hills; it was formed on the clay loam of emerged fjord-bottom deposits. The area is only 30 percent covered by vascular plants which include *Salix arctica*, *Saxifraga oppositifolia*, and *Silene* *acaulis*. The rest of the surface is covered by a black organic crust, with some lichens and mosses. Many cracks and microrelief of numerous small earth nubbins[1]) 4–5 cm high characterize the surface of the soil.

Depth cm	Horizon	Morphology
1; 1.5	A_{00} (01)	Black organic crust, coriaceous and brittle.
1; 1.5 to 5.8; 11	A_0 (02)	Very dark brown (7.5 YR 3/2) organic layer with well to partially decomposed plant material. The lower part of this horizon becomes darker (2/0 black), fine, greasy, and well humified.
5.8; 11 to 22; 25; 29	B_1 (B1)	Dark grayish-brown (2.5 YR 4/2) mineral horizon, silty loam or silty clay loam; platy structure; firm. Platy structure becomes more pronounced in the lower part of the horizon at about 13 cm. Here the plates are 1 mm thick with vertical fractures. Pockets of dark gray (N 4/0) organic matter are found interspersed in the horizon.
22; 25; 29 to 50	B_2 (B2)	Grayish-brown (2.5 YR 5/2) clay loam layer with fairly well-developed platy structure and showing vertical fissures. The vertical and horizontal cleavage lines tend to produce prismatic peds upon breakage. The tendency to develop vertical fissures with depth is shown by the surfaces delineating the cleavage lines. These surfaces appear smooth, possibly lined with preferentially oriented clay skins. This condition, while it may imply translocation of fines with depth, definitely implies the existence of recurring fractures. The soil is firm and reacts very vigorously with HCl.

Other Upland Tundra soil profiles show a distinct zone of mottling with yellowish-brown streaks (10 YR 5/6). These conditions seem to occur where there is a considerable fluctuation in the water table.

The effect of freezing and thawing cycles has been cited in certain cases as a mechanism in soil aggregation (Gardner, 1945; Baver, 1948; Sillanpää and Webber, 1961). Douglas and Tedrow (1960) have contended that in the Tundra soils of the Coastal Plain of Alaska the prevalent blocky structure has developed in response to freeze-thaw processes. In a more recent investigation, however, (MacNamara, 1964) it was found that other Tundra Soils of arctic Alaska do not conform to this general type of structure.

In the Mesters Vig district, as in any other region, soil structure is controlled by the presence of bonding agents. No structural aggregates

[1]) This term has been adopted by Washburn to designate small round-to-elongate earth lumps, one to several centimeters in diameter (Washburn, written communication).

were found on the sandy substrata of the delta remnants or kames, whereas outstanding examples of platy structure were displayed by the clay loam soils of the emerged fjord-bottom deposits.

From observations made during the thawing season, it seems that, in many of the Meadow Tundra profiles, morphological evidence related to freezing has been subsequently masked by thawing processes. At the height of the summer these profiles appear to consist of an amorphous structureless mass which has lost traces of any features acquired during previous freezing.

A detailed megascopic analysis of the structural features of Tundra soils shows that virtually only the Upland Tundra soils display a consistent structural aggregation. The Meadow Tundra soils at the time the observations were made (July–August) showed no signs of aggregation. Consequently, only the structure of a model Upland Tundra soil is described. In cross-section, the structure of an Upland soil profile shows three zones. The upper one consists of a hard, dry, very massive crust with oblong and round voids in the form of vesicles. In some other instances the massive crust is replaced by a layer of granular structured soil which betrays the effect of needle ice. The middle zone of an Upland Tundra soil very often shows a well-defined platy structure with plates 2–3 mm thick which are separated by fissures and voids. Below this zone the plates become larger, and vertical as well as horizontal fractures tend to develop; this zone acquires a weak prismatic structure.

Although no observations were made during the time the soil was frozen, it is believed that the growing of minute ice lenses plays a considerable role in structure development.

The work of Everett (1963) in Northwest Alaska showed that bare soils with textures comparable to the ones in the Mesters Vig district tend to form a sirloin-type ice (Higashi, 1958). The clayey texture of the emerged fjord bottom deposits also contributes to the structural arrangement. In dry areas desiccation during the warm season may help to stabilize the platy aggregates.

Under certain moisture conditions where the surface soil may be dry but the subsoil relatively moist, freezing seems to have been effective in producing frost-heaving. Evidently there is enough moisture for ice formation during the freeze-up, but not enough during the thawing to make the soil-aggregates coalesce and flow. Freezing under these conditions may be important for structure formation, but is not effective as far as the morphology is concerned, in disrupting the existing soil horizons.

Tundra Variant Soils

There are other soils which cannot be properly classified under the broad division of Meadow and Upland Tundra, although they have characteristics common to Tundra soils. These soils are included within the group of Tundra variant soils, which includes:

a) Tundra soils of the gelifluction slopes,
b) Tundra soils associated with certain patterned ground features,
c) Tundra soils associated with turf-hummocks.

a) Soils of the Gelifluction Slopes

Numerous types of soils may be associated with gelifluction slopes, depending on rate of soil movement and on the configuration of the slopes. Arctic Brown soils may be found on stabilized rims of turf-banked benches, Regosols in areas of very active gelifluction, and Meadow Tundra and Upland Tundra in more or less stable positions. The soils described here are the ones more closely related to Tundra soils but having properties unique to areas affected by gelifluction.

Occurrence. The morphology of the soils occurring on active gelifluction slopes reflects burial and overturning processes. Buried organic layers, abrupt changes in texture, and lobes of intruding material indicate the disruption of the normal soil morphology. These conditions were observed along the slopes of the Korsbjerg massif, Domkirken, and in the Nyhavn hills.

Profile description. The profile described here is from the south slope of Domkirken. The area is only partially covered with vascular plants (*Salix arctica*, *Silene acaulis*, and grasses), most of the ground being covered with black organic crust and lichens. The soil surface shows a pronounced microrelief produced by small (5 to 10 cm) earthy nubbins separated by fissures.

Depth cm	Horizon	Morphology
0 to 1	A_{00} (01)	Dry leaves and stems of *Salix arctica* with dry or dead mosses.
1 to 3	A_0 (02)	Very dark grayish brown (10 YR 3/2) fibrous organic layer, well filled with roots and containing some mineral matter.
3 to 12; 17; 19	1	Dark grayish brown (10 YR 4/2) layer with heterogenous texture, loam to sandy loam; many roots, single grained; firm. The bottom of this layer is marked by patches and streaks of buried organic matter.

(continued)

Depth cm	Horizon	Morphology
12; 17; 19 to 15; 20; 22	2	A brown (7.5 YR 5/4) sandy layer single grained; firm.
15; 2; 22 to 19; 23; 28	3	A brown (7.5 YR 4/3) silty layer single grained, a few roots, firm.
19; 23; 28 to 50	4	A dark brown (7.5 YR 3/2) coarse, sandy layer with a wavy distribution; some of the tongues contain clay. A band of sandstone slabs at 30 cm; below, the coarse sand with clay persists. The entire layer is structureless and firm.

In excavations made across a slope mantled by clay loam soils, where mass-wasting experiments were conducted (WASHBURN, 1965), it was found that the degree of structure development was a function of soil moisture. The best platy and prismatic structures were observed in the soils of the dry end of the transect. The wettest soils, which were also the most active in the downslope movement, were genetically amorphous and structureless. In this same area, where gelifluction movements were apparently somewhat less, the soils, while still structureless, displayed genetic horizons. Lack of structure in Meadow Tundra soils cannot be entirely related to the effects of gelifluction processes. There are numerous wet, flat areas where, with virtually no soil movement, the soil is still structureless. This would indicate that the soil tends to lose its structure where the moisture content goes above certain limits, irrespective of the slope gradient. The absence of structure in certain soils found on gelifluction slopes is not a direct effect of the gelifluction processes; on the contrary, the downslope movement has probably been aided by the progressive deterioration of the soil structure.

b) Soils Associated with certain Patterned Ground Features

Some nonsorted and sorted circles as well as nonsorted and sorted nets show barren to semi-barren surfaces where congeliturbation is now or has been active. These frost-active areas show a unique type of tundra soil whose prominent characteristic is the massiveness of the soil and the presence of voids in the form of vesicles or alveoli (Fig. 2). These soils have been described by BROWN (1962) under the name of Raw Tundra. The Arctic Frost Earth mentioned by KUBIENA (1953) may also approximate this condition. SPRINGER (1958) describes vesicular material in some desert soils, with wetting and drying being a possible cause of the vesicular nature. Numerous examples of this material were observed in patterned-ground areas of northern Alaska. No detailed information is available on the mechanism of vesicle formation in soils of cold regions. Escaping gases from the water in thawing soil may induce

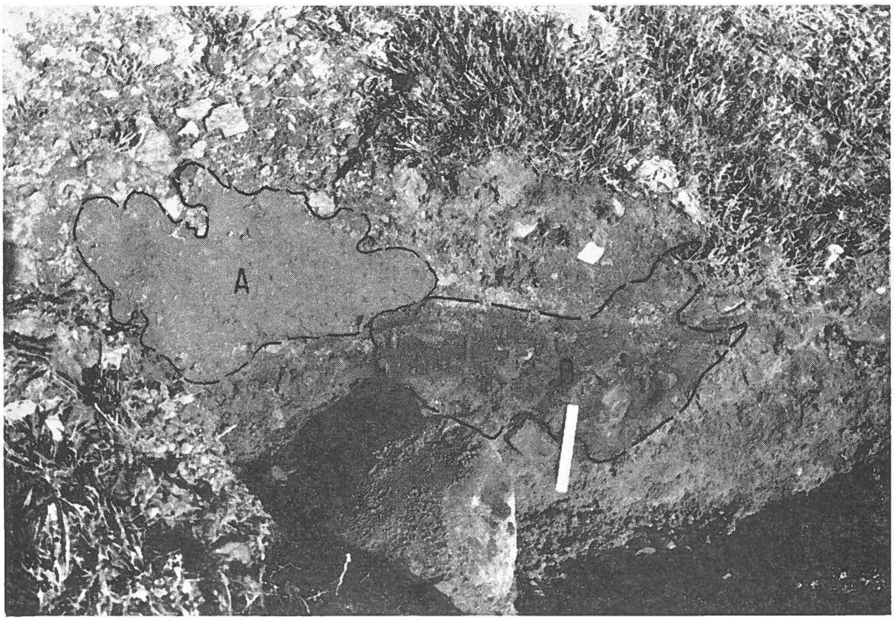


Fig. 2. Cross-section of a small gelifluction lobe.
A — Upland Tundra soil (massive with vesicles) B — Buried organic matter

air bubbles to permeate the soil in response to changes in soil temperature. Also, cold water penetrating a warm soil may evolve some gases which, if entrapped, may leave vesicle imprints in the soil. These conditions have been verified in the soils of the temperate regions, but they are only intuitive speculations for arctic soils.

Occurrence. Vesicular soils are found in connection with patterned-ground areas. Examples of these soils were found in sorted nets on the lower northeast slope of the Korsbjerg massif and in turf-banked benches on the lower northeast slope of Hesteskoen.

Profile description. This profile was excavated in a turf-banked bench on the lower northeast slope of Hesteskoen.

Depth cm	Horizon	Morphology
0 to 2; 3; 5	1	A desiccation crust with only a few mats of vascular plants. The crust may be fractured showing micropolygons. With exception of a thin massive surficial layer, the crust appears porous with voids or vesicles, silty or clayey textures are common.
2; 3; 5 to 50	2	Olive brown (2.5 YR 4/4) or light olive brown and dark gray brown massive soil material with vesicles. The single alveolus or vesicle is oblong or ovoid in shape with diameters ranging from a few millimeters to 1 cm. Layers or streaks of silt or sand are found in the loamy silt soil mass. Buried organic layers are common.

c) Soils Associated with Turf-Hummocks

Where tundra land surface acquires a hummocky configuration due to a definite pattern in the accumulation of vegetation, including mosses, the Tundra soils show a unique profile. Hummocky features, described in Mesters Vig district with the name of turf hummocks by Raup (1963), occupy large segments of wet Tundra. Similar conditions were described by Kubiena (1953) as Tundra Moss. This writer feels, however, that the soils associated with turf-hummocks do not have enough characteristics of their own to warrant a new class of soils at a category level. They are considered as a segment of Tundra Soils with specific properties.

Occurrence. The soils in the turf-hummock area include the soils of each individual turf hummock as well as the soils between them. Since the soils between the hummocks are comparable to the Meadow Tundra conditions previously described, only the description of the soils of a turf hummock will be given. The soils of the turf hummocks occur on gentle slopes in sites where trickling water is common. They were found on the lower northeast slopes of Hesteskoen, on the south slopes of the Nyhavn hills, and in Skeldal.

Profile description. The turf hummock is covered by a dense vegetation in which, according to Raup (1965), *Vaccinium uliginosum*, *Salix arctica*, and *Carex bigelowii* are primary species, and *Cassiope tetragona* and *Polygonum viviparum* are secondary species.

Depth cm	Horizon	Morphology
24 to 15	01	Dark yellowish-brown (10 YR 4/4) living and dead organic material, poorly decomposed with a feltlike consistency.
15 to 8; 9	02	Black (N 2/1) organic layer, fibrous, partially decomposed with abundant roots, moist and fluffy.
8; 9 to 0	1	Black (N 2/1) organic layer well humified, with a greasy feel, penetrated by roots and with some mineral soil in the lower part; loose.
0 to 5	2	Very dark gray (10 YR 3/1) mineral layer, silt loam with cobbles, massive and firm.
5 to 25	3	Very dark gray (10 YR 3/1) silt loam layer with pockets of sand and cobbles; firm.

Soils of Limited Extent

Because of limited distribution, these soils are considered together. They include the Protoranker and Tundra Ranker (Kubiena, 1953).

Protoranker

Occurrence. Protorankers having a cushion shape are found in sorted nets and sorted circles. They occupy the inner edge of the stony borders (Fig. 3).

Profile description. Protoranker soils consist of loose organic material in which mosses are major constituents. The humus layer varies in thickness. It becomes deeper where it penetrates the interstices between the boulders flanking the fines, and is generally fibrous, black and dry. The soil is so shallow that it cannot be separated into horizons.

Protoranker soils were found in stone nets on the east side of the Korsbjerg massif.

Tundra Ranker

Occurrence. Tundra Ranker are found on bedrock ledges, benches, and in bedrock niches.

Profile description. The following profile was observed on a bedrock bench of a trap knob in the Nyhavn hills. The area displayed a luxuriant growth of *Vaccinium uliginosum*, *Cassiope tetragona*, *Betula nana*, and *Salix arctica*.

Depth cm	Horizon	Morphology
10; 5 to 0	A_0 (02)	A dark brown (7.5 YR 3/2) organic horizon, well humified, consisting of heavily interwoven roots and plant debris.
0 to 10	A_1 (A1)	Brown (7.5 YR 4/4) mineral layer with considerable amount of well-humified organic matter; silt loam, loose.
at 10	C	Bedrock, broken fragments, and trap grus.

DISCUSSION

Pedological studies in the arctic regions of the Eurasian and North American continents have revealed a number of genetic soils which, following classical scheme, have been classified as zonal, intrazonal and azonal soils. Some of the zonal soils of arctic Alaska do not correspond, however, to the zonal soils of the arctic regions of the Eurasian continent. Tundra soils, considered in the early and recent Russian classifications as zonal, are included among the intrazonal soils by some North American pedologists (Tedrow *et al.*, 1958). In other classifications of arctic soils, there has been more emphasis on soil properties than on their genetic implications, while in still other classifications genesis and cryopedological features have been considered. Sokolov and Sokolova (1962), realizing the climatic implications of cryogenic processes, consider both cryogenic and non-cryogenic soils as zonal. Although not fully appreciated by many pedologists, the separation of arctic soils on a drainage catena basis implies also a separation of frost and non-frost active soils. Well-drained soils could be considered the non-cryogenic and the poorly drained soils the cryogenic. While the soils of Mesters Vig district have not been arranged in any classification scheme, a close relationship appears to exist between the type of surficial deposit, cryogenic processes, and soil type. Emphasis has been placed on the description of the soils and related cryogenic events. The soils developed along slopes which display different degrees of mass-wasting are of particular interest.

The instability of soils on the slopes underlain by permafrost has attracted considerable interest, and qualitative and quantitative data are available on the subject (e. g. Hopkins and Wahrhaftig, 1961).

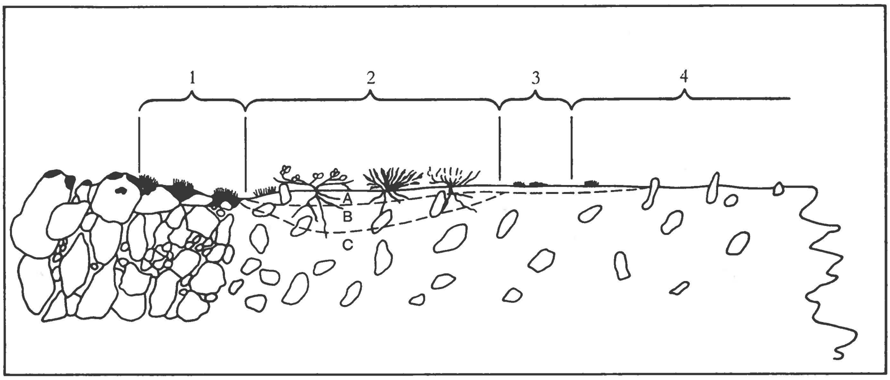
Recent pedological studies in the permafrost regions of Alaska have also provided information on the morphology of soils associated with slopes affected by gelifluction. Drew (1957), Brown (1962), and MacNamara (1964) discussed the complexity and the erratic and irregular morphology of these soils. To introduce convenient mapping units, Brown (1962) and MacNamara (1964) suggested, respectively, the terms "amorphous solifluction tundra soils" and "soil complex of the solifluction slope". The second unit would be more satisfactory for the soil conditions on the gelifluction slopes of the Mesters Vig district. In fact, as pointed out earlier in this report, several soils may be found on a gelifluction slope, depending on the moisture, nature of the substratum, and degree of soil movement. The soils will not be the same unless a slope of a given gradient shows a very uniform moisture regimen and similar parent material, and consequently a comparable degree of gelifluction. Normally, as Everett (1963) points out, soil movement does not affect the entire slope, but only a portion of it; the result is that soil distribution is also erratic and segmented. In the solifluction units, MacNamara (1964) distinguishes a mosaic of soils which include: Lithosols, Regosols, Rutmark soils and Tundra soils. In the Mesters Vig district, Upland Tundra, Meadow Tundra, and Regosols occur on active gelifluction slopes. The Upland Tundra is found in the dry portion of the slope, the Meadow in the wet, and the Regosols in the wet and very active part. A large active and characteristically wet gelifluction lobe, experimental site 17 (Washburn, 1965), with a turf-banked front, shows mainly Regosols and Regosol-Meadow Tundra soils. In spite of the prevalence of sandy material at the surface, no Arctic Brown soils were found. A different situation was encountered in a partially stabilized small gelifluction lobe. Here as shown in Figure 2, a lobe of soil with vesicles, approximating an Upland Tundra soil, rests against a well-vegetated rim which delineates the feature. The rim shows miniature Arctic Brown soil and bands of buried organic matter below the Arctic Brown profile. The soils in this gelifluction lobe include Tundra variant soils with massive structure with vesicles and Miniature Arctic Brown soils.

Mass-wasting studies conducted by WASHBURN in the Mesters Vig district revealed that on a slope of 10° to 14° the cumulative effect of gelifluction and creep ranged from 0 cm/yr to 6 cm/yr and that moisture is probably the dominant factor in both frost creep and gelifluction. Also it was found that moisture was more important than the presence or absence of vegetation (WASHBURN, 1965).

Although the association of certain soil types with certain drainage conditions involves a rather obvious relationship, the degree of soil structure development and moisture regimen becomes a more subtle one. Moisture influences the rate of soil movement and the degree of structure development, and a qualitative prediction can be made of the potential instability or stability of soils along slopes affected by gelifluction in the Mesters Vig district.

Another aspect of the dynamics of the landscape and its impact on soil genesis and distribution is found in patterned ground areas. Here, processes of displacement, collapse, burial, and sortings are evident, even if not completely understood. Under these conditions, soil formation may be forcibly impeded or disrupted, and segments of soil types may become clustered within confined areas.

The types of patterned ground depend in part on the type of material on which the genetic processes are acting; thus, no sorted forms can be expected in homogeneous silty or clayey soil. Soils also reflect the textural characteristics of the parent material. The presence of Arctic Brown soils in silty or clayey parent material is very improbable, but the statistical probability of finding Tundra soils in such material is very high. Consequently, the association of certain soil types with certain substrata and with certain patterned ground sections is easy to predict in places. However, there are cases where the type of soil depends largely on the degree of activity or inactivity of the different patterned-ground forms. The preferential association of some Arctic Brown soils with sorted nets is mainly due to the inactivity of the nets and not to the cryopedogenic processes involved in forming a sorted form, although the existence of stony borders facilitates drainage of the soil. Cryopedogenic processes are not conducive in producing Arctic Brown soils. Actually, it is where these processes have subsided that Arctic Brown soils can develop. In the Mesters Vig district the writer has seen active sorted nets occupied by types of Tundra soils, and even examples of sorted polygons at the bottom of water-filled kettle holes or small lakes. Sorted nets which are probably still partially active show miniature Arctic Brown soils only at the periphery or in isolated spots. Inactive sorted nets may be covered with Arctic Brown. The same considerations are also valid for turf-banked benches where Arctic Brown soils may develop, depending on the texture and degree of activity. It seems, therefore, that unless the



1 Protoranker soils
2 Arctic brown soils (shallow phase and miniature)
3 Lithosols
4 Upland tundra (massive with vesicles) and regosols

Fig. 3. Diagrammatic cross-section of a mesh in a sorted net showing the distribution of soils.

stage of activity of a certain patterned-ground form is known, its association with a genetic soil or soils cannot be safely generalized.

When cryopedogenic processes have ceased to act because of changes in climate or moisture regime, then that particular patterned ground becomes relict. The distribution of soil types on relict patterned ground depends mainly on previous history, texture, and all other soil-forming factors affecting the landscape.

However, numerous excavations in patterned-ground areas in the Mesters Vig district have shown that in places different kinds of soil may be associated with different patterned-ground forms. A relationship between patterned ground and major genetic soils was presented by Drew and Tedrow (1962) for northern Alaska. The nonsorted circles formed on the emerged fjord-bottom deposits at Labben are associated with Upland Tundra soils (with or without a massive structure with vesicles) and with Regosols.

Sorted nets as well as gelifluction lobes provide examples of how the stage of activity of the features can affect soil distribution. Excavations across a single mesh in a sorted net show that in the frost-active fines, soil formation is prevented or disturbed. It cannot always be established whether pedogenic and sorting processes are occurring simultaneously in an area of patterned ground. It seems, however, that certain types of soils (e. g. Arctic Brown) can develop only when congeliturbation processes have subsided. Active frost-boil-like features in the fines of a sorted net are free of vascular plants and lack marked horizon differentiation. Peripheral zones around the frost-active area show a gradual establishment of miniature Arctic Brown profiles. A cross-section of a mesh in a sorted net shows the following soils, starting from the border of stones and moving toward the central area of the mesh: Protoranker, Arctic Brown soils (shallow phase and miniature), Lithosols and Upland Tundra (massive with vesicles) and Regosols. Figure 3 presents diagrammatically this horizontal soil distribution. This condition depicts an example of partially active sorted nets. When the whole feature is active, however, no differentiation in soil development was observed in the fines. The soils were approximating regosol conditions and had a tendency to develop into an Upland Tundra as evidenced by structural characteristics. To a large extent, the distribution of these soil types reflects the activity status of the patterned ground. Theoretically, a detailed profile analysis across a sorted circle or net should reveal zones of stability and instability. Soil formation can become, if only qualitatively, a tool to evaluate the degree of congeliturbation.

Moreover, the soils of patterned ground present an interesting situation with respect to soil evolution. Theoretically, for example, when the processes forming sorted forms are at maximum activity, the predominant soil should be a Regosol. Interruption of cryopedogenic processes during part of the year may allow a pedogenic process to act on the frost-stirred material. However, renewal of frost action may cancel any incipient soil development. The subsidence of cryopedogenic processes in some part of a patterned-ground form marks the initiation of pedogenic processes and the inception of genetic soils. If cryopedogenic processes decrease to the extent that only a few sections of patterned ground remain active, the pedological processes may gain control of the area.

Some cryopedogenic processes are irreversible, such as the accumulation of stones at the border of a sorted pattern. Consequently the soil-forming factors have only limited effect in these conditions. Irreversible processes also include segregation of textures in the fines. The development of the soils in the fines of a sorted pattern is not only influenced by the current degree of activity of cryopedogenic processes but also by the manner in which they originated the sorted form. The complexity of the soils in sorted patterns becomes quite evident.

When cryopedologic processes are not entirely extinguished or are intermittently active, then soil formation in the fines of a sorted pattern offers an interesting problem in soil development and soil evolution at a microlevel. While soil development in inactive or relict patterned ground may follow the pattern of any segment of landscape, a new cycle of soil evolution may be suddenly introduced in response to a renewal of cryogenetic processes. The progressive chemical, physical and biological changes brought about by cryogenetic processes may induce enough environmental differentiation to alter the makeup of the substratum. The newly induced alterations may prevent or favor the formation of new types of soils. Furthermore, since cryogenic processes may be strongly influenced by purely local changes in conditions, for instance by a drainage change leading to a different moisture regime, the evolution of soils affected by such changes may differ from that of soils whose cryogenic history reflects the influence of climate only.

The evolution and genesis of the soils in the Mesters Vig district, as in any other region, reflect the impact of the local climatic, pedologic, geomorphic, and cryogenic elements. However, because of the slight development of many arctic soils, the critical threshold of any process between the normal and the destructive becomes narrower. The sensitivity of arctic soils becomes dramatically portrayed in some patterned ground areas and on gelifluction slopes. Here the intensity of the cryopedogenic processes rule the formation and destruction of genetic soils.

The concept of intensity of cryogenic processes as a major control implies the existence of a time factor. Time becomes, then, an important element not only in measuring the endurance of a phenomenon but also in marking a catastrophic event that may trigger dormant processes. Annual or seasonal freezing and thawing may produce gradual changes in a soil profile. However, a climatic fluctuation such as an unusually wet year may reactivate processes with consequent disruptive effects in soils that were in a steady-state condition. The uniqueness of arctic soils is due not to selected pedological processes but more to the physical and chemical disturbances produced by cryogenic processes. Arctic soils are affected by qualitatively different disturbances with respect to soils of the temperate regions.

Certain disturbances prevalent in the temperate regions—uprooting of trees, sheet erosion, ants—become rather insignificant in the Arctic, while others—gelifluction, deep-seated sorting processes, ice-wedge growth, and other processes related to the formation of patterned ground, which are at a low order of activity or are absent in temperate regions—become highly significant in the Arctic. Unfortunately, our state of knowledge is such that a comparative evaluation of disturbance factors in these two environments can be stated only qualitatively. Only little data are available when similar processes are concerned. EVERETT (1963) in comparing mass-wasting rates in Ohio and in northwest Alaska concluded that the rate of soil movement in Ohio was only about one-twentieth of that in northwest Alaska in the places he studied.

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Færdig fra trykkeriet den 26. august 1966.

TOPOGRAPHIC MAP OF THE MESTERS VIG DISTRICT, NORTHEAST GREENLAND

0 1 2 3 4 km

CONTOUR INTERVAL 50m