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MORPHOLOGICAL EVIDENCE OF FROST ACTION IN ARCTIC SOILS

Zusammenfassung

Um die Dynamik des arktischen Bodensystems zu verstehen, muss der Prozess verwandt mit der Frostverdrängung mit dem Prozess der streng pedogenischen Natur verglichen werden. In arktischen Regionen herrschen die bestimmten qualitativen Prozesse, die die Einleitung für solche Böden wie Tundra-, Sumpf- und Arktischbraun-Böden geben. In manchen Fällen, allem Anschein nach, gibt es sehr wenig Beweise für die Frosttätigkeit. In anderen Fällen, dagegen, neigt der Frostprozess zur Veränderung und Vernichtung der herrschenden Morphologie.

Als ein Beweis der Frostwirkung und der verwandten Prozesse, die die Änderungen der arktischen Böden verursachen, können folgende Beispiele dienen: Bodenverschiebung an Abhängen, normale Frostverdrängung, verzerrte Profile und die Schmelzung des Grundeises. Die genannten Prozesse verursachen den Zusammenbruch der Böden sowie die Verarbeitung der organisch-mineralischen Ablagerungen in der Nähe der schmelzenden Eisseen. Die Gestaltung der Poligonen verursacht die Kräfte, bei denen die organischen Stoffe des Bodens gefaltet und vergraben werden und die allgemeine Morphologie zerstört wird. Die Morphologie des Bodens in der Nähe der Gesteinringen, -girlanden, -streifen, Felsenpoligonen, zwischen den anderen Formen der modelierten Böden, dienen als Nachweis für die beachtlichen Bodenverdrängungen.

Writing of his botanical experience in the Arctic, Raup (1951) stated: "To put the matter mildly, we have had difficulties in applying the ideas derived from our training and experience in the temperate regions". Those who have tried to use temperate-region terminology in connection with arctic soils have encountered similar difficulties in that arctic soils do not, as a rule, show the clear horizon differentiation commonly apparent in soils of other climatic regions. The horizons of arctic soils tend to have an erratic appearance as a result of physical disturbances that have occurred within the soil; these disturbances obscure, modify, distort, or even destroy the soil horizons.

In one early report dealing with frost action in arctic soils, Leffingwell (1919) mentioned the "upturning of muck beds and the squeezing

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up of lower layers of sand... (and) ..., the surface of the ground being elevated several yards by the growth of ground ice". Nikiforoff (1928) described some of the soil complexities arising from frost action. Meinardus (1930), as well as Polyntseva & Ivanova (1936), presented a good discussion of the soils of the arctic regions with special reference to types of patterned ground. Gorodkov's (1939) work on frost action in arctic soils continues to stand out as one of the most authoritative reports. Evidence of frost action in arctic soils is well illustrated by Filatov (1945). Bryan (1946) introduced into the United States both the European and his own ideas of frost action in soils, a most important contribution from the standpoint of geopedologic studies not only in the arctic but in the boreal regions as well. More recently, Sigafoos (1951), Raup (1951), and Britton (1957) described the dynamics of geologic-botanical-soil systems in arctic and sub-arctic environments in which they indicated considerable instability and displacement within the soil. Kubiena (1953), who made special mention of patterned ground, designated soils of the Arctic as arctic rutmark. Drew's (1957) work on frost action in soils of arctic Alaska marks the first attempt to integrate genetic profiles with frost features and delineate them as compound mapping units. Troll's (1958) treatise is most important, not only from the standpoint of his own observations on frost action but also those reported in the literature. Although these studies open up the field of arctic pedology, we must still consider their nature as being only preliminary.

Studies of such great soil groups as the laterites, and podzols are primarily concerned with pedogenic processes, such as leaching, translocation, precipitation, weathering, formation of new compounds, synthesis, and the decomposition of organic matter. In arctic regions, however, processes related to frost displacement must also be equated and evaluated; these processes sometimes assume leading roles. Although pedogenic processes tend to give rise to a specific profile morphology, a number of other processes, or sets of processes, cause physical displacement in the soil. Those that disturb the soil material during the formation of a stone ring appear to be totally different from those associated with ice-wedge polygons or thaw lake activity. No single theory can be applied to account for all the disturbed and contorted soil horizons throughout the Arctic.

MAJOR GENETIC SOILS

Before listing in this brief report some of the major kinds of frost displacement in arctic soils, it is first necessary to describe the major genetic soils of this region. Field observations throughout northern Alaska and parts of Canada permit the following grouping:

TUNDRA

A poorly drained mineral soil covering wide expanses of the Arctic. Permafrost is usually at a depth of less than 2 feet. The surface organic mat varies from a thin, discontinuous layer to a thick mat approximating 6 inches. Directly underneath the organic mat is a wet, mineral horizon, conspicuously gleyed. This gleyed mineral horizon, approximating a foot in thickness, is predominantly gray and becomes darker with depth. Organic inclusions may be present. The upper part of the frozen layer has inclusions of organic matter and organic-stained ice. At a depth of 2—4 feet below the surface the mineral material is free of organic staining (Tedrow *et al.* 1958; Brown & Tedrow 1958; Douglas & Tedrow 1960). The permafrost in northern Alaska extends to a maximum depth approximating 1300 feet (McCarthy 1952).

BOG

In depressions and in broad, flat areas, organic matter commonly accumulates to a thickness of 2—5 feet, but under special circumstances it may exceed 20 feet. The frost table generally exists a little higher in bog soil than in mineral soils. This is particularly true if the peat is in a well-drained environment (Douglas & Tedrow 1959).

ARCTIC BROWN

On ridges and escarpment areas the permafrost table may be 3—5 feet deep. The deep, well-drained mineral soil commonly present at these sites, showing the full impact of the regional soil-forming processes, has been designated arctic brown (Tedrow & Hill 1954). Arctic brown soil has a brown solum grading into gray and related colors at a depth of 18—24 inches. The chemical properties of this soil indicates a weak podzolic process (Drew & Tedrow 1957).

MISCELLANEOUS SOILS

Lithosols and bedrock outcrops are very extensive in the mountains and on other steep slopes. In most of these shallow-soil areas, soil formation has not gone beyond the early stages of development. Many stony and bouldery areas are virtually void of fine mineral matter. Since active sand dunes, recent glacial deposits, and recent alluvium show very little soil development, they are included, for lack of better terminology, with regosols. Other miscellaneous soils have been recorded, but they are not included in this discussion.

FROST ACTION AND RELATED PROCESSES

DOWN-SLOPE MOVEMENT

On steep terrain, solifluction processes are very active. On slopes of 20—30 per cent, there is a pronounced tendency for the soil to move at a sufficiently rapid rate to prevent any orderly profile morphology from developing (Sigafoos 1951; Tedrow & Cantlon 1958). The organic matter becomes infolded and is overridden with mineral matter. Clumps of organic matter become incorporated with mineral matter, at depth of many feet. Even on gentle slopes, down-slope movement is evidenced in many locations.

Solifluction processes present a major obstacle in the development of a classification scheme for arctic soils. On the steep slopes it appears to operate at such magnitude that one may seriously question whether a genetic classification approach is permissible. On many of the steep slopes we not only must face the absence of "genetic soils" but also marked changes in character of the profile from one location to another.

SOME FROST FEATURES IN TUNDRA SOILS

Tundra soils, even on flat terrain, show considerable evidence of frost displacement, organic matter occurring erratically throughout the active layer (fig. 1). Gorodkov (1939), Hopkins & Sigafoos (1951), Sigafoos (1951), and Mackay (1958) described this erratic organic--matter pattern that is found in many arctic soils. Organic matter is also concentrated in the upper part of the permafrost (Tedrow *et al.* 1958; Brown & Tedrow 1958; Douglas & Tedrow 1960). It seems unlikely that this deep-seated organic matter reached its present location under climatic conditions such as exist today; it may have been deposited during the period of a once much warmer climate. Broecker, Ewing, and Heezen (1960), postulate an abrupt climatic change approximately eleven thousand years ago. Numerous other investigators have found fragmentary evidence of warmer climate in northern Alaska. C-14 dates of organic matter in the upper part of the permafrost of three sites in northern Alaska varied between 8 200 and 10 900 years (Douglas & Tedrow 1960), suggesting that during this earlier period of warmer climate soils thawed to a greater depth than they do now.

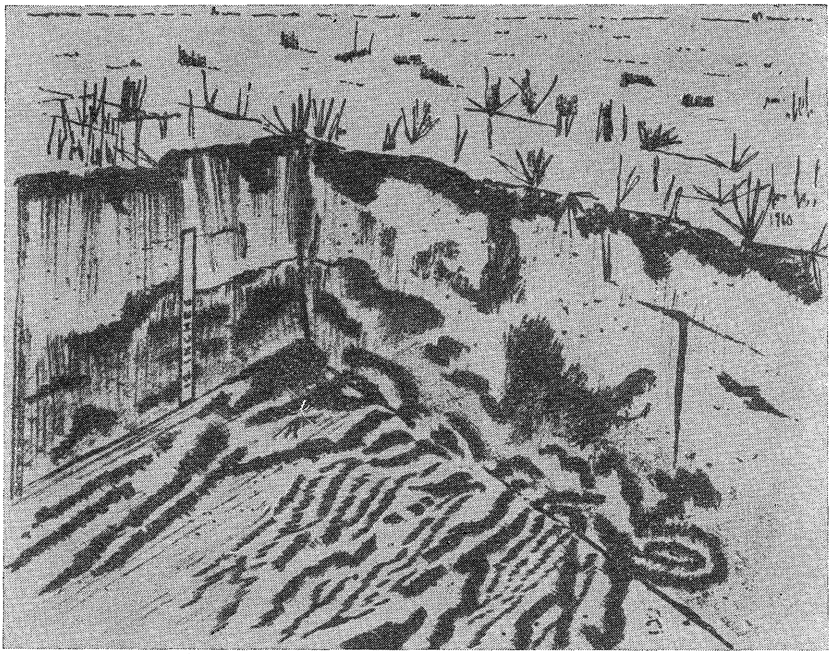

Fig. 1. Arctic tundra soil showing eratically distributed organic matter throughout the profile

Drawing from actual field conditions, Alaska. Original photograph by L. A. Douglas

MELTING OF GROUND ICE

Most tundra and bog-soils areas of the Arctic are underlain by a complex network of ice wedges. In certain localities these wedges may be melted surface water and associated processes, with resulting collapse and mixing of the soil. Fig. 2 shows such an area. The original ground level is represented by the tops of the polygons, while the large channels mark the collapsed and eroded portions of the landscape. These collapsed areas show highly disturbed soil profiles.

SOILS IN THE VICINITY OF THAW LAKES

On broad, flat areas, particularly those of the arctic coastal plain of Alaska and of some terraces and loessial deposits of the foothills, the landscape is dotted with lakes. Some of these have been referred to as thermokarst or frost thaw lakes. They are of special interest because of the unique characteristics of the soil in the peripheral areas. Many flat areas of the Arctic have had a complex geomorphic history from stream sculpture,

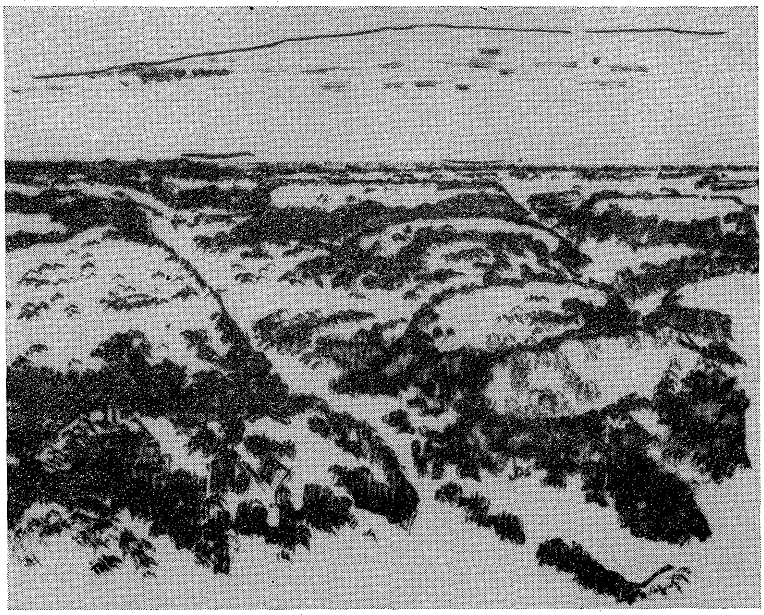

Fig. 2. The ice wedges melted out of this bog soil causing a network of channels to form

The tops of the polygons remain intact. The soils between the polygons have their genetic features virtually destroyed. Drawing from actual field conditions along the Okpilak River, Alaska

thaw lake formation, and related phenomena (Hopkins & Karlstrom 1955; Britton 1957). Once the lakes form they tend to remain in an unsteady state with considerable cutting and filling. Banks adjacent to the lakes are commonly in a steady state of erosion during the summer months. The frozen ground, with its usually large content of ground ice, is susceptible to erosion by waves during the summer months. While one side of a lake may be actively cutting back, other parts may be filling with sediments. Fig. 3 shows a typical cross section of a frost thaw lake in northern Alaska, fig. 3-A marking the original land surface. The soils in fig. 3-A display the usual upland tundra profile features. The area in fig. 3-B, however, shows reworked sediment consisting of a mixture of organic and mineral matter. The soils in fig. 3-B are a heterogenous mixture of mineral and organic matter, usually with water standing on the surface and with few genetic properties. While the character of the soils as shown in fig. 3-B is not ascribable to frost porcesses *per se*, an indirect relationship is indicated.

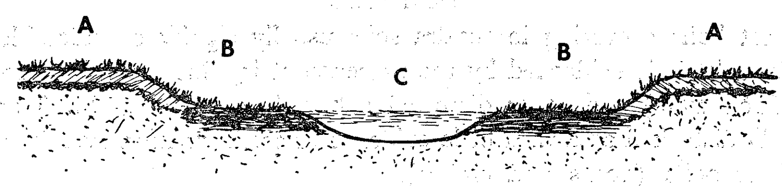

Fig. 3. Diagram of a thaw lake in the Arctic Foothills of Alaska

The original land surface is indicated by „A", the collapsed and reworked material by „B" and the present lake by „C". Soil formed under „A" is Upland Tundra while under „B" it is a very poorly drained arctic soil with few genetic features

POLYGONS

Continued growth of ice wedges results in a change in shape and configuration of polygons (Black 1954). As ice wedges grow, not only do lateral pressures cause changes in micro-relief, but the organic matter is buried and intermixed with the mineral matter in a very complex pattern. Excavations into the main portion of the polygon or the surrounding trough clearly show the complex nature of the soil morphology (Britton 1957; Douglas & Tedrow 1960). Organic and mineral material exist in a highly intermixed pattern. Some topographic positions show more polygonization than do others. In general, the highly developed polygons are present in the flatter areas. Where the terrain is broad and flat, such as that of coastal plain areas and river terraces, many areas of low-center polygons are found. Pl. 1 shows an oblique aerial view of such a complex low-center polygon area. Since these areas are quite flat and the low-centered polygons have no drainage outlets, bog-like conditions prevail.

STONE RINGS AND STONE STRIPES

In the mountainous country of the Arctic, stone rings, garlands, stone polygons, soil stripes, and related forms of patterned ground are very common. These structures, although commonly associated with well-drained land, may be found under a wide range of drainage conditions. Soil profiles in these patterned ground areas are of special interest because of their erratic morphology. Quite often virtually no continuity is found in the soil — either vertically or horizontally. Pl. 2 shows a stone ring, the center part of which consists of a core of silt, sand, and clay. Surrounding the core of fines is a concentration of fine gravel that has a fresh appearance. The outer portions consist of lichen-covered cobbles. Considerable reworking of the bare mineral soil in the center of the stone ring is indicated.

FROST BOILS

Frost boils occurring in tundra soils usually signify considerable reworking. This is evidenced by the presence of involutions (Hopkins & Sigafoos 1951) and other distorted sub-surface features. Pl. 3 shows a highly disturbed area with little evidence of soil formation even between the frost boils (non-sorted circles).

Unfortunately, few measurements of soil movement have been made in arctic regions. Williams' (1960) report on quantitative studies of frost action are of great value in this connection. In 1953 C. M. Matthews placed a series of sand-size garnet cores in two frost boils in northern Alaska. A probe about the size of a pencil was used and the holes were extended down to the frost table. One of the frost boils was carefully excavated in 1955 and no evidence of displacement of the garnet chips was found. When the second was excavated in 1957, the two cores near the periphery of the frost boil showed no displacement, but those near the center showed considerable translocation in the upper 3 inches. Garnet chips were displaced as much as 2 inches from their original position, and they were found not only between structural aggregates but within the aggregates as well.

That many of the erratic features of arctic soils can be related to frost processes appears to be fairly well established. Solifluction, congeliturbation, frost collapse, ice-wedge growth, and other cryopedologic processes modify and alter soils as well as other features of the arctic landscape. The growing belief that a much warmer climate once prevailed and that seasonal thaw was deeper than at present suggests that some of the morphologic features unique to arctic soils are merely relics of earlier times. A number of the qualitative processes are better understood now than they were 20 years ago, and some quantitative data are now available. Many problems, however, remain to be solved.

One may not get a realistic picture of the areal distribution of the various frost features. Excluding both high- and low-center ice-wedge polygons, the percentage of arctic land surface occupied by well-defined patterned ground in the non-mountainous Arctic is really not very great.

How fast do frost processes operate in the Arctic? Did involutions or buried peat require ten or ten thousand years to develop? Or did such frost features develop quickly some time in the past and then go into a stabilized condition? These are some of the problems that need to be answered. Use of the term "frost-churned" or "frost-stirred" soil may confuse the reader who lacks arctic experience. He may get the false impression that most frost displacement in arctic soils is a seasonal or continuous process.

Some genetic features are present in arctic soils. Brown & Tedrow (1958) and Douglas & Tedrow (1960) pointed out some of the pedogenic processes operating in the arctic regions. All of the acquired morphologic features of arctic soils are not obliterated. The appearance of the upper mineral horizon of the gley soils differs from that of the horizons deeper in the profile. Structure, color, pH, and organic matter content show change with depth, indicating that certain pedogenic processes are operating in the arctic regions and that frost processes do not always completely mask or destroy the acquired morphology.

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Photo by F. C. Erickson

Pl. 1. Oblique aerial view of low center polygons with standing water

The bog-like soils show very erratic features. Polygons measure 20—40 feet across

Pl. 2. A sorted circle in the high country of the Brooks Range

Notice that in the center there is a concentration of fines surrounded by fine gravel. The outer margin consists of lichen-covered cobbles. There is virtually no soil development on structures of this type

Photo from the Arctic Foothills, Alaska

Pl. 3. Frost boils formed on bentonite shales

There is no indication of the formation of soil horizon in the area shown above — instead raw, earthy material is present up to the surface