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PATTERNED GROUND NEAR DUNDAS (THULE AIR FORCE BASE), GREENLAND

BY

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WITH 2 FIGURES IN THE TEXT AND 3 PLATES

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CONTENTS

Abstract.

Near Dundas in northwest Greenland is an area of 150 square miles (380 square km.) known as Nunatarssuaq. Drift covers most of the region and shows various forms of patterned ground that have developed by repeated thawing and intense freezing.

Stone-rimmed polygons form the prevailing pattern on nearly level till surfaces. These grade into elongate or stretched polygons and stone stripes on sloping ground. On many of the steeper slopes, stone-banked solifluction lobes have developed. All these forms reflect the prevailing stony character of the drift.

In outwash deposits, only a large-scale fracture pattern is common, and limited areas of water-sorted drift (outwash) can by this characteristic be identified readily from a helicopter. No frost-sorted stone borders have developed around outwash polygons.

The primary patterns in both till and outwash show a hexagonal motif and are believed to have developed by contraction resulting from extreme low temperatures. The subsequent frost-sorting process which has given rise to the stone borders is not definitely known. The chief factors governing development of patterned ground in the drift are believed to be: 1, slope; 2, composition of the material; 3, moisture content; 4, drainage; and 5, depth of thaw.

INTRODUCTION

Patterned ground is a term introduced by WASHBURN (1950) to include all types of frost-generated features that give a figured appearance to the ground surface, particularly in regions where the ground remains perennially frozen. Some of the names commonly used for these features are frost polygons, stone-rimmed polygons, stone nets, and stone stripes. These terms are mainly descriptive, and gradational features are common. Strict uniformity of usage by different authors who have used these terms has not been possible. The many forms of patterned ground, some quite devoid of stones, are characteristic of much of the arctic region, and traces of them are known in many formerly glaciated areas in lower latitudes. In the vicinity of Dundas the drift is notably stony, a condition that has greatly influenced the development of patterned ground in that area. The present report deals chiefly with the more common types of features occurring in the glacial deposits in the region known as Nunatarssuaq, an area of about 380 km^2. near Dundas.

Field work was done mostly by foot traverse from base camps and from points along the roadways. Helicopter service gave access to the more remote parts of the region, and detailed observation was thereby possible throughout the Nunatarssuaq. Areal photographs used in this report were taken from helicopters by COLTON.

Topography of the Nunatarssuaq is of notably coarse texture and characteristic of strongly glaciated, high-plateau country. Fiords indent the coastline to distances of several miles and grade into a coarse network of fiord-like valleys that apparently continue beneath the margin of the inland ice. Most of the valley sides are precipitous, rising 325 m or more to broad benchlands whose elevations range mostly from 325 to 600 m. From theses benchlands, long and relatively uninterrupted slopes lead up to rounded summits of hills and ridges at maximum elevations of about 1,650 m.

Lesser or secondary topographic features include marginal moraines and numerous channels cut by marginal meltwaters during the last recession of the glacier. Some of the larger channelways are now gorges which are segments of the major valley network. They were evidently initiated by such meltwater erosion during an earlier interval of deglaciation and subsequently deepened and broadened by glacial erosion. Even the minor channels are remarkably steep sided and difficult to traverse, but their ruggedness is lost in the overall coarseness of the main landscape features.

Numerous erratics occur on all the uplands but the thickness of drift in the region is variable. In some of the more conspicuous end-moraine zones, local relief indicates that the drift is at least a few tens of feet thick; but on the steeper slopes and on some hilltops the surface material consists almost entirely of frost-shattered blocks derived from the bedrock immediately underneath.

On many of the steeper slopes, where the drift (chiefly till) is sufficiently thick, solifluction has developed lobate forms commonly 30 m wide and a few hundred feet long. Actual dimensions of most solifluction lobes or units are difficult to determine because they merge into other forms such as stone stripes and other types of elongate polygons. All distinct lobe fronts and sides consist of boulders evidently segregated from the drift during the process of lobe development. Stone-rimmed polygons are the most common form on slopes of less than 2 degrees, but all gradations among varieties of well-formed polygons and the boulder-fronted solifluction lobes occur on slopes of intermediate steepness.

PATTERNED GROUND IN TILL

Stone-rimmed polygons. Stone-rimmed polygons, with their many variations, are the most common type of patterned ground in the Nunatarssuaq and are best developed in level or nearly level areas. In diameter, most polygons range from 4 to 7 m. The stone rims or borders separating adjacent centers occupy about half the ground surface and form a coarse network that shows a general hexagonal motif, though with many irregularities. The stones making up the borders have obviously been segregated from the original till, leaving the finer materials to form the centers. It is this segregation or sorting that has given rise to the term sorted-stone polygon. Boundaries between centers and their stone borders are abrupt.

An excavation across a typical polygon showed that the stone borders continue downward more than $1^1/_4$ m[1]. The stones are tightly wedged together and the largest are at the top. Downward, stone size decreases but average roundness increases. At a depth of about $1^1/_4$ m the average size is approximately 75 mm or less.

[1]) Excavation was abandoned at this depth because of a blizzard.

Boulders make up the bulk of visible stones in the borders, and their tops project somewhat above the elevation of the centers. Tabular stones stand edgewise and elongate stones tend to a vertical position. Thus the coarsest constituents of the drift dominate the landscape and give the observer an erroneous impression of the true average grade-size composition of the drift. This impression of coarseness is further accentuated by the surface concentrate of pebbles on the centers as a result of deflation. Beneath the surfzce, silt and fine sand are abundant although there is virtually no clay. The near-absence of clay reflects the absence of soft or weak rock types in the drift, and also the probable removal of some fine materials by meltwater.

Polygon steps and stone stripes. These features are characteristic of till surfaces in areas of moderate slope (commonly 2 to 6 degrees). Where the till in such areas contained numerous large stones, the polygon centers are strongly developed and the centers well confined. When these centers are first thawed, they contain enough interstitial water to render them semifluid. In this condition their surfaces have become nearly horizontal, giving a stairstep appearance to the slope on which they occur.

Where the stone content of the till was only average in sizes and abundance, most stone borders on the downslope sides of the developing polygons evidently were not strong enough to prevent the center materials from spilling over and partly burying the incipient rim, and tending to merge with the adjoining center downslope. The process of stone segregation transverse to the ground slope was thereby slackened or stopped altogether by the remixing of materials. All stages of apparently arrested rim development were obseved; but in all cases, rim development at the sides, parallel to the slope, has gone on unimpeded. Eventually most of the coarser stones have been moved into these side borders, giving rise to the more or less continuous stone stripes. However, these stone stripes or borders branch and reunite at irregular intervals so that the actual pattern in many areas is an elongate-mesh net, broken in places where a polygon center has merged downslope with two others instead of one. This process gives a looped appearance to these linked zones of finer materials. Also, the striped pattern may extend downslope with curving offsets, giving to the whole a *vermicular* appearance as seen from the air. Commonly the stone borders are about 2 m wide and occupy about half the ground surface.

The effect of slope steepness in developing elongate patterns seems to have been considerably modified in many places by the amount of moisture in the drift. Some striped and vermiculate patterns have developed on 12-degree slopes, but in a few places on much steeper slopes only a slight tendency to elongate-pattern development is shown. The differences seem to be related to perviousness of the till and to probable original ease of subsurface drainage; the more pronounced elongation on a given angle of slope occurred where the subsurface drainage was slower. Also, where an area of apparently pervious and easily drained drift receives considerable drainage from adjacent higher ground, elongate pattern seem to be correspondingly favored.

Median cracks. Elongate polygons and the zones of fine material between adjacent stone stripes characteristically have a prominent lengthwise median crack along which the stones are somewhat larger than those farther from the crack. Some of these cracks may represent incipient stone borders which never developed fully, and in a few places the till along the cracks shows evidence of recent frost heaving. Many of these cracks contain concentrations of sand. In most places the relative coarseness of adjacent stones seems best interpreted as the result of loss of finer constituents either by falling into the crack (which is evidently renewed or expanded slightly each year by frost), or by deflation, or by both. Possibly the cracks result from shrinkage resulting from lowered temperatures following complete freezing of interstitial water during the winter season.

Central stone pits. A few polygons of nearly equidimensional form have a depressed group of stones–a stone pit–at their centers. Except for the depression below the surface of the surrounding finer material, their appearance is like that of the stone borders.

POLYGON STRUCTURE

Reference has already been made to the internal composition of a polygon as revealed by excavation. Figure 2 illustrates a second trench which crosses two adjacent and partly joined polygon centers and their stone borders. Between the centers is an imperfectly developed segment of a border that apparently did not develop completely because of the tendency of the two centers to unite. In the well-developed borders the coarsest materials, large cobbles and small boulders, occur at the top; but in the imperfect central segment the coarsest are at the bottom. Each polygon center, which consist of sandy silt with numerous dispersed pebbles and small cobbles, has a sand-filled median crack. Depth of thaw in the centers was scarcely 0.66 m at the time of trenching (29 June), but was somewhat deeper in the stone borders because of water draining from upslope. The thawed portions of the centers were water-saturated.

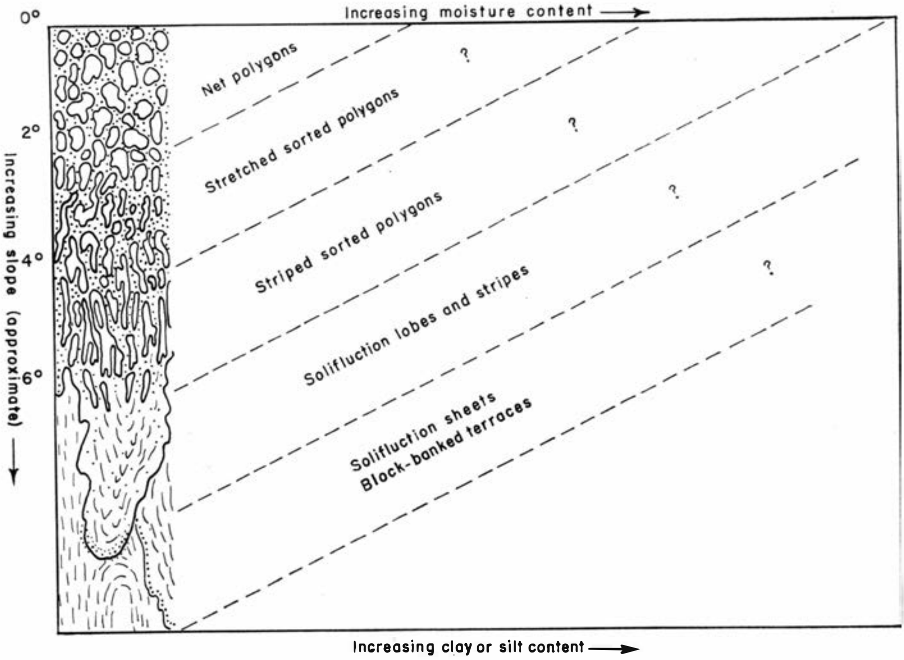

Fig. 1 – Diagram showing the relationship of sorted polygonal forms and solifluction lobes to moisture content, slope, and clay or silt content.

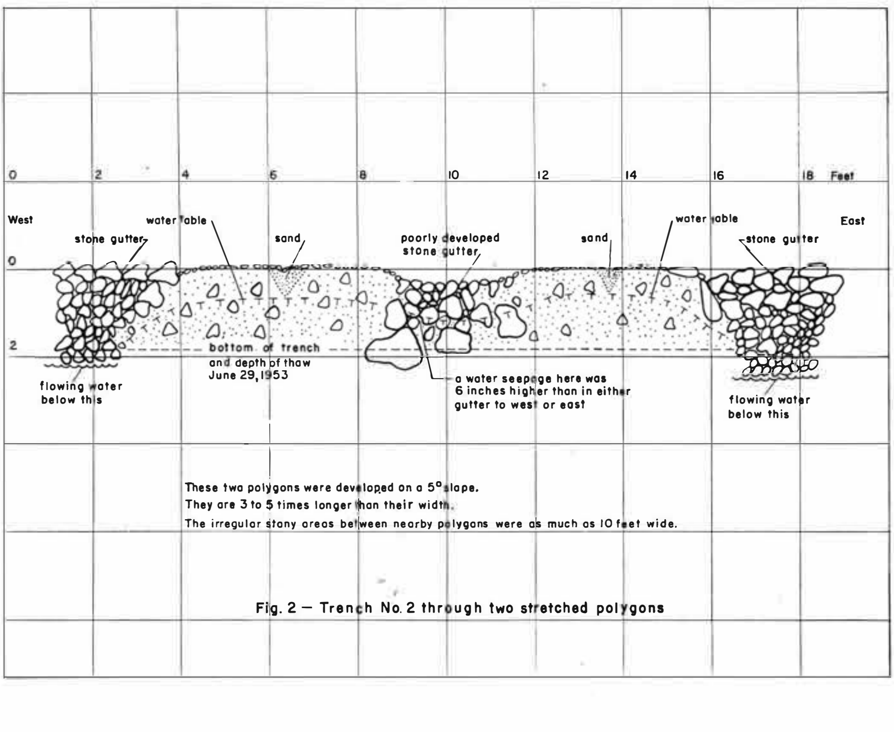

Fig. 2 – Trench No. 2 through two stretched polygons

SECONDARY POLYGONS. OR POLYGON SEQUENCE

In many places the common type of stone-bordered polygon center, 3 to 5 m in diameter, is subdivided into smaller polygons approximately 1 m in diameter around which minor, yet distinct, stone borders have developed. These lesser polygons must have formed after the larger ones had reached their present condition, or the smaller would have been disarranged by any continuation of the process of segregation by which the larger borders originated.

From favorable vantage points, as from a helicopter, the larger polygons themselves can, in certain areas, be seen as units in a super pattern of extra wide stone borders (pl. 1a and pl. 3), though this super pattern can seldom be noticed in walking over such an area. Characteristically the borders of the lesser units terminate against those of the greater ones. Where a super pattern exists, it was apparently first to become outlined, closely followed by the common polygons of intermediate size. The smallest, or third-order forms were developed last. In a few areas, recent or continued frost disturbance is in evidence along these third-order margins.

PATTERNED GROUND IN OUTWASH

Outwash deposits. Outwash deposits range in texture from gravelly sand to bouldery concentrates, the latter as floor deposits along some of the larger well-defined channels. The largest deposits occur on the flatter areas but some are found in gaps along higher divides, and small, irregular patches can be seen from a helicopter widely distributed over the uplands. Thickness of the deposits was not determined, but evidently varies much from place to place. Those on the uplands probably do not exceed a few feet in depth.

Characteristics. Two outstanding differences distinguish polygon patterns in outwash from those in till. One is their large size, or the coarseness of the pattern; and the other is the general absence of segregated stone borders. (See pl. 1b). As in the till polygons, those in outwash tend toward hexagonal outlines marked by slightly depressed stripes, mostly less than 1 m wide, which evidently have formed from an initial set of shrinkage cracks into which the adjacent stones have settled. Distances between intersecting cracks,–that is, lengths of polygon sides,– range mostly from 20 to 30 m. Some of these borders intersect at or near right angles giving locally a square or rectangular pattern. However, slight offsets are generally observed at these intersections, showing that the offset cracks developed later than the uninterrupted one.

A variation from the usual pattern in outwash was observed in a coarse-textured deposits on a slight slope beside a small lake in the western part of Nunatarssuaq. Large boulders occur along the border cracks, and gravel ridges have been upheaved along both sides to a height of about 0.66 m. The bottoms of the cracks are $1^1/_4$ to 2 m below the tops of the ridges. Some of the polygons are divided into smaller ones, especially where the outwash grades laterally into till in which only the common forms of sorted borders could be discerned. The ridges are believed to have formed by lateral pressure from ice wedges that developed in the original cracks. Elevation of the land surface is only slightly above that of the lake, and the base of the outwash is probably somewhat below lake level.

Another and more common type of variation in outwash areas is the occurrence of single isolated patches of finer materials, generally about $1^1/^2$ m in diameter, in the midst of a bouldery field devoid of any other evidence of size segregation. Whether these centers represent an initial phase of polygon development, or whether an end phase in which all coarse material has been brought to the surface, was not determined conclusively. Their occurrence is generally in broad sags or on topographically low and nearly level ground.

In general, the coarse pattern is developed best in what seems to be the thickest outwash, and where good subsurface drainage is probable. Gradational forms are invariably found where subsurface drainage is (and presumably was) retarded. In a few areas where a thin veneer of outwash sand and gravel overlies till, the prevailing till pattern has developed.

PATTERNED GROUND IN YOUNG DRIFT

A marginal zone of varying width bordering the inland ice has been overridden by the glacier in the recent past, and the resulting drift shows different stages of polygon development, depending on thickness and character of the drift, and on duration of exposure. In one place near the north end of Nunatarssuaq a group of four(?) marginal moraines form a probable recessional series. (See WHITE, 1956, p. 24). The youngest drift contains numerous striated stones and shows only a beginning stage of frost heaving and stone-border segregation. There is almost no vegetation. On the next older moraine, cobbles and boulders show an early stage of weathering, striated stones are less numerous than on the youngest drift, and polygon development is more advanced. On the third moraine only a few stones retain striated surfaces, polygon development is nearly complete, and vegetation is well established. The fourth and oldest moraine of the series is aligned topographically with the others but no striated stones remain and polygon development is complete.

In places where drift of this readvance is thin, development of the pre-existing polygon pattern (common till type) has continued, or has been renewed, through the veneer of younger drift. In similar fashion, older patterns have developed through thin coverings of marine-beach sand and other sediments in certain areas along the fiords.

Plate 2a shows the relative development of patterns in till and near-contemporaneous outwash of the younger drift. The typical coarse pattern is apparently complete on the outwash area, but polygon develment on the till is still inconspicuous. However, ground observation shows good incipient till-type polygons, with certain marginal segments more conspicuous than others. These more conspicuous borders are believed to be parts of a super pattern and have presumably been in process of development longest. In dimensions, this super pattern is comparable with that which is characteristic of the adjacent outwash and both probably began development at about the same time, but no secondary patterns have developed in the outwash.

SOLIFLUCTION LOBES

On the steeper hillsides the till has flowed in lobate masses, some of which are 30 m. wide, several hundred meters long, and from $^2/_3$ to 3 m. high. Virtually all have developed a strong concentration of stones along their margins, especially at their fronts. (See pl. 2b). These flows are believed to have formed at times when the till was water-saturated, and the stone borders must have developed during the process of flowage. In most places at present these stone embankments are apparently adequate to give at least temporary stability to the lobes, as shown by the fact that the numerous lichen-covered boulders on their surfaces give no indication of recent disturbance. However, slight movement may occur frequently, and the possibility of further extensive movement exists.

To secure data on any movements that may occur on two selected solifluction lobes, a long-range project was set up. On, and adjacent to, the lobes, a number of boulders were mapped by means of telescopic alidade and steel-tape measurements from each boulder to those nearest it, thus forming a network of accurately located points on and adjacent to the lobes. Any movement of a lobe will disarrange the network, and the nature and amount of such movement can be determined by subsequent measurements and remapping. It is hoped that the measurements can be checked at suitable intervals during the next few years.

ORIGIN OF POLYGONAL PATTERNS

Discussion thus far has dealt chiefly with three main factors believed to be significant in the development of patterned ground in the Dundas region: 1) nature of drift materials (whether till or outwash), which determines interstitial-water capacity; 2) conditions of subsurface drainage (whether the materials are well or poorly drained); and 3) angle of slope. The interrelations believed to exist among these factors are represented graphically in figure 1.

Development of the polygon patterns is believed to involve two successive processes. First is the initial outlining of the pattern by a system of border fractures; and second, movement of stones to or toward these fractures. In the first process, development of a coarse or large-scale network is followed by subdivision of the large polygons if sufficient interstitial water is present. This subdivision is characteristic of the till but is rare in outwash. The second process, stone segregation, does not go on in typical outwash deposits.

The tendency toward hexagonal outlines is evidently a common factor in all types of polygons observed, and indicates development under tensional stress. This conclusion suggests either dessication or cooling as the cause of the shrinkage. Small-scale hexagonal polygons, notably mud cracks, develop by dessication; however, this hypothesis seems quite inadequate to account for the large-scale patterns in material deficient in clay. Regularity of pattern and initial large size of pattern units in both till and outwash imply a common medium of fracture control and also a common cause. Firm and uniform coherence of the diverse drift materials must have prevailed at the time of fracturing. Therefore the preferred hypothesis is that of solid freezing of water-saturated ground, followed by further lowering of temperature and consequent shrinkage. As in other types of columnar structure, three cracks radiating from any given point on a shrinkage-stressed surface are the minimum number that can relieve the stress in all directions. With reasonably uniform distribution of such central points, the hexagonal pattern of fractures develops, analogous to the columnar jointing common in tabular igneous-rock masses. The initial cracks formed could easily receive enough windblown sand to localize them as the process was repeated during successive seasons. Ground ice also could fill such cracks, and by repeated shrinkage, filling, and expansion on warming could exert lateral thrust adequate to bulge up the materials adjacent to the cracks, as was noted at one place mentioned earlier. This interpretation is in accord with those of Leffingwell (1915) for patterned ground in northern Alaska, and of Richmond (1949) for the same in Wyoming.

The way or ways by which stones become segregated into the borders and stripes is not clear, but the cryostatic hypothesis of WASHBURN (1956, p. 842) may find application here. As freezing of the saturated till progresses laterally inward from a border crack, the proximal surfaces of stones would become firmly held while the surrounding matrix would be forced backward, because of the expansion due to freezing, toward the polygon center.

Absence of sorted borders around outwash polygons implies that stone segregation does not go on unless there is abundant interstitial water, and materials fine enough to afford capillary action. However, further speculation regarding the sorting process should await additional data.

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Færdig fra trykkeriet den 20. maj 1960.

PLATES

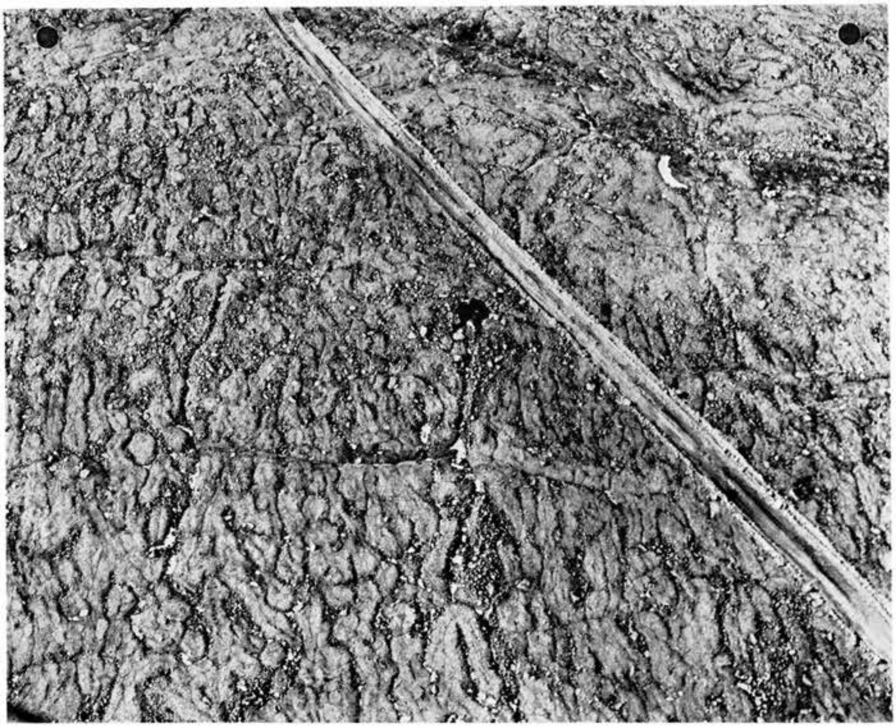
Plate 1.

Plate 1a.

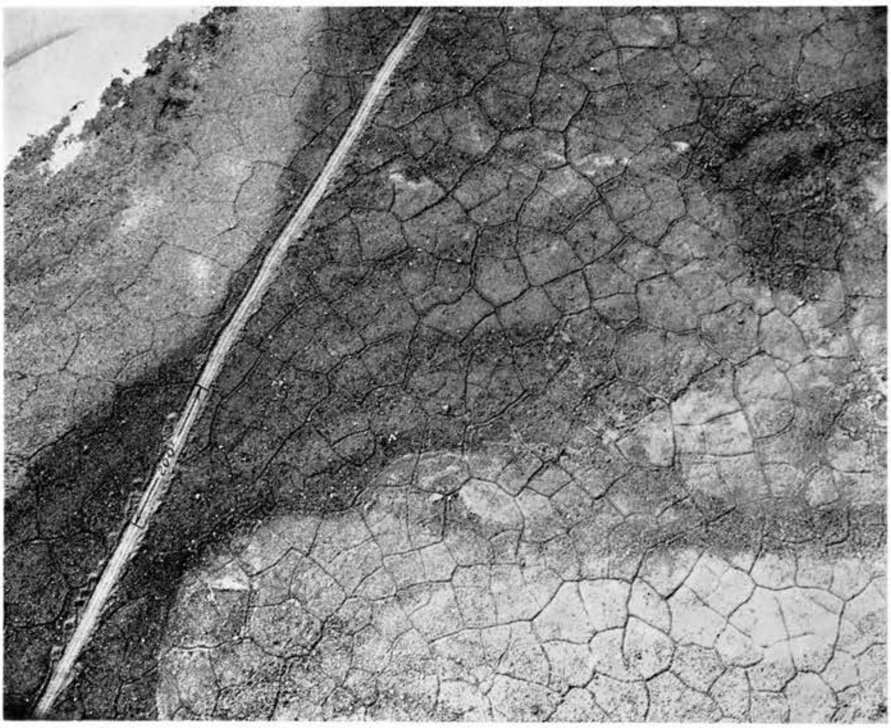
Sorted polygons and frost-crack furrows along a road. The parent material is till. Note the median lines in the sorted polygons. The road is approximately 22 feet wide. Photograph taken August 17, 1953.

Plate 1b.

Patterned ground in outwash. Nearly verticel photograph of polygons formed by the intersection of frost-crack furrows. The road is about 7 m. wide. The darker stripes across the area are channels in which coarser gravel was deposited by ice-marginal streams. Note that some of the frost-crack furrows are double. Note that some sorted polygons have apparently developed along the frost-crack furrows. The bleached effect in the upper left hand corner of the photograph indicates that lichens have not grown on the rocks as they have in the darker areas. Snow lingers longest during the spring in the bleached area which adjoins a perennial snowbank showing in part in the extreme upper left corner of the photograph. Photograph taken July 6, 1953.



1 a.



1 b.

Plate 2.

Plate 2a.

Recently formed frost-crack furrows at the head of an outwash plain containing a kettle hole. Note that furrows are not well developed in the till in the upper part of the picture even though the ages of the two deposits are nearly the same.

Plate 2b.

Solifluction lobe 30 m. wide, 3 m. high, and 90 m. long. Note the concentration of boulders in front of the nose of the lobe. Note the area of obstruction where the soil is forced to flow around and nearly over a concentration of boulders such as is present in front of the lobe. The slope of the surface of the lobe is 1 : 9 or 12.3 percent of grade or 7 degrees.

2 a.

2 b.

Plate 3.

Frost-crack furrows along which sorted polygons have developed. Apparently there is an outwash deposit in this area which contains a moderate amount of fines. Note the different shape and distribution of polygons in the deposits of different composition.