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THE MORPHOLOGY OF THE SLOPES OF OGOTORUK CREEK VALLEY, NORTHWEST ALASKA

Abstract

Data obtained from six large trenches cut into various slope situations indicate that movement on the upper one third of the southeast-facing slope is extremely slow and that this portion of the slope is in a condition of stability. Movement on the lower two thirds of this slope is maintained mainly by solifluction and creep, with some areas of more or less stabilized benches. The benched features on the opposing slope are stabilized forms which originated perhaps thousands of years ago during a climate warmer than present. These features are regarded as having been formed by a process intermediate between earthflow and nonsaturated creep.

INTRODUCTION

Arctic landforms and especially the processes which produce them have been receiving increasing attention over the years. A more thorough understanding of both is facilitated when they can be viewed in three dimensions. It is the purpose of this paper to present the third dimension in the form of cross section mapping of trenches cutting different portions of the opposing slopes of an asymmetrical Arctic Valley.

Hypotheses will be advanced to explain some of the morphology of the slopes as well as the asymmetry of the valley based on an interpretation of structures revealed in the trenches.

Six trenches were cut into the slopes of Ogotoruk Valley, three on the northwest-facing slope and three on the opposing slope. The trenches were placed so that they cut what appeared to be the significant morphologic elements of the slopes. Each trench had one segment parallel to and one normal to the contour, and all but one were cut to permafrost in late August 1961.

Each trench was mapped and a profile described on a one meter interval.

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The orientation of rock fragments was determined with a Brunton compass. Selected profile descriptions appear on the cross sections and mechanical analyses are tabulated at the end of this paper.

PHYSICAL CHARACTER OF THE VALLEY

The Ogotoruk Creek Valley is on the northwest coast of Alaska, approximately 195 kilometers north of the Arctic Circle (Fig. 1).

The southwest-trending segment of Ogotoruk Creek lies in an asymmetrical valley carved in highly deformed Mesozoic and upper Paleozoic rocks. Salivik Ridge and the upper third of its southeast-facing slope are underlain by dark grey bioclastic limestones and light grey dolomites of the upper and middle Mississippian Lisborne Group. These rocks have been thrust from northwest to southeast over greenish-grey argillite, chert and black shale of the Permian Siksikpuk formation, and the black and grey shales and limestones of the Triassic Shublik formation, which together underlie the lower slopes of Salivik Ridge.

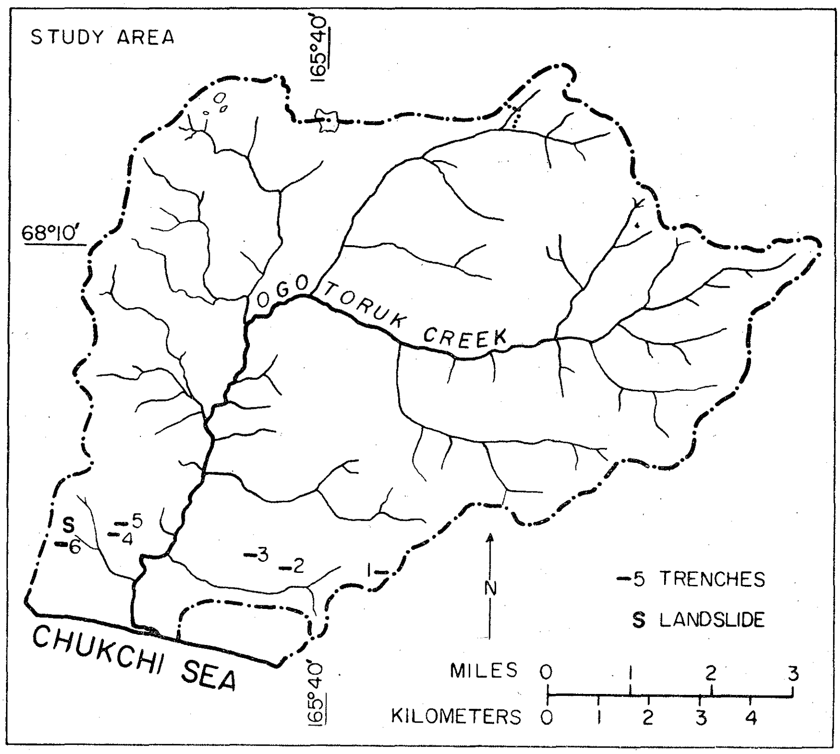

Fig. 1. Location map of area and trenches, Ogotoruk Creek, Alaska

The portion of the slope supported by the Lisborne formation displays stone stripes and talus. The vegetation is sparse and xeric. The lower slopes are marked by earth hummocks, turf-banked terraces, and sorted and nonsorted circles. The slope is wet and covered with several species of *Carex*. Permafrost generally lies within 0.5 meter of the surface.

The valley bottom and the long smooth pediment surface leading to the southeast ridge are underlain by deformed, and weakly metamorphosed mudstones and sandstones of the Jurassic-Cretaceous Ogotoruk formation. The pediment is occupied by extensive areas of *Eriophorum vaginatum* tussocks and nonsorted mud circles. Depth to permafrost averages slightly over 0.5 meter.

Along the upper edge of the northwest-facing pediment, the Televirak formation supports the benched slope leading to a flat crested ridge. The Televirak formation consists of metamorphosed, and highly deformed, sub-feldspathic, lithic greywacke and mudstone. The slope is characterized by a mosaic of xeric and hydrophylus plants. The crest supports only scattered xeric plants on the surface of lag gravel. The permafrost surface averages over one meter deep on the slopes and 1.5 meters on the crests during August.

A complete discussion of the Geology, Botany and Patterned Ground is given by Kachadoorian, R. *et al.*, Johnson, A. *et al.*, and Everett, K. (1966).

NORTHWEST-FACING SLOPE

TRENCH I

Trench I was cut into the flat upland surface of a northwest-facing hill slope (Fig. 1). In general, an Arctic Brown soil which averages 13 cm in thickness, and contains abundant greywacke skeletal material overlies a grey mineral soil. The mineral soil is a silt loam with a large quantity of disseminated medium and coarse rock fragments. Below the mineral soil is a zone of medium and coarse rock fragments with some admixed grey mineral soil. The contact between these zones is distinct but wavy. Beneath the last described interval is a zone of coarse rock fragments, which differ from the overlying zone in coarseness, lack of admixed mineral soil, and the presence of silty coatings. In general this zone is rather „clean", i.e., with a large amount of unfilled space. It rests on what appeared to be in place bedrock. The bedrock was highly fractured, but vertical bedding planes and horizontal joints were discernible (Pl. 1). Silty coatings were developed in the joints and fracture planes, but to a lesser extent than in the zone immediately above.

In such a hill-top position the fine material is moved either by deflation or by water down through the soil profile, accumulating as clayey and silty coatings and fillings in the rubble zone immediately above the bedrock, and in the fractured bedrock itself. The downward migration of fines is stopped at the permafrost table, which, when this trench was cut in August 1961, was 1.4 meters. It is not difficult to imagine that within a short time all of the voids above the solid bedrock would become filled with silt and clay. This, however, is not the case. Removal of fine material must take place within the profile, and perhaps laterally as well, by waters descending along the joints and through the „clean" zone above the bedrock. There appears to be little movement on the hill crest other than frost heaving and the translocation of fines vertically and horizontally within the profile.

It was mentioned above that upon completion in August 1961, Trench I bottomed rather evenly on or slightly into bedrock. When the trench was re-examined in November of the same year, rather deep holes (0.5 to 1.0 meter) had developed in the bottom and were widening by slumping. This process continued in 1962 and 1963, indicating that although bedrock structure is preserved, the fractured pieces of „bedrock" are held suspended in a matrix of ice.

TRENCH II

Trench II cuts through several benches or terraces (Pl. 2) on the lower slope of the hill. The treads of the benches have slopes between 0° to 1°, and incline hillward. The risers have an average slope of 25°. Individual benches may extend over 100 meters along the contour and are broadly lobate in plan.

A fairly well developed, imperfectly to well drained Arctic Brown soil is developed on the tread. The soil becomes very thin and poorly developed on the riser. Vegetation is sparse and composed predominately of dry-site species.

Profiles of the north wall of the trench (Fig. 2) were made at intervals of one meter, and orientation of rock fragments were determined with a Brunton compass wherever possible.

Three more or less distinct zones were mappable throughout the length of the trench. They are, from the surface down: (1) a soil zone, which locally shows attenuation or alteration of A and B horizons; (2) a zone of loose, fine fragmental material which fills in around a framework of

cm	inches	
0—6	0—2	Dark reddish-brown organic matter with fine sandy loam. Coarse skeleton 50%. Under *Betula* sp.
6—15	2—6	Light yellowish-brown silty clay loam. Weak to moderate, fine, sub-angular blocky structure. Coarse skeleton 50%
15—34	6—13	Olive grey-brown silt loam matrix in interfragment spaces. Coarse skeleton 30—50%
34—124	13—48	Oriented, loose, medium shale fragments. Fine shale fragment matrix
124—134	48—52	Coarse to medium shale fragments. Fine sand and silt matrix. Interval is dry and compact

cm	inches	
0—11	0—4	Medium reddish-brown silt loam (A horizon). Weak, fine, sub-angular blocky structure. Coarse skeleton 60—80%. Under *Leidum* sp. and *Betula* sp.
11—80	4—31	Oriented shale fragments. Olive grey-brown silty clay loam and fine to medium sand matrix
80—88	31—35	Coarse to medium shale fragments. Fine sand and silt matrix. Interval is dry and compact

cm	inches	
0—11	0—4	Olive grey-brown to light reddish-brown sandy to silt loam. Structurless. Under bare ground. Coarse skeleton to 7 cm comprise 50%
11—33	4—13	Olive grey-brown silt loam. Coarse skeleton average 5 cm, 30—50%. Finer fragments 0.5—2 cm
33—120	13—47	Oriented shale fragments with fine, loose shale fragment and sand matrix. Clay skins
120—140	47—55	Coarse to medium shale fragments. Fine sand and silt matrix. Interval is dry and compact

cm	inches	
0—15	0—6	Medium, reddish-brown silty clay loam. Fine weak, sub-angular blocky structure. Medium shale fragment skeleton 20—30%
15—54	6—21	Medium reddish-yellow brown silty clay loam. Moderate fine, sub-angular blocky structure grading to medium, moderate angular blocky. Coarse skeleton 20—30%
54—84	21—33	Olive grey-brown to olive brown silty clay loam. Moderate to well, coarse sub-angular blocky to platy structure. Coarse skeleton 15—20%
84—140	33—55	Oriented coarse to medium shale fragments and sand matrix. Clay skins are thick (1—2 mm) on large fragments
140—146	55—57	Coarse to medium shale fragments. Fine sand and silt matrix. Interval is dry and compact

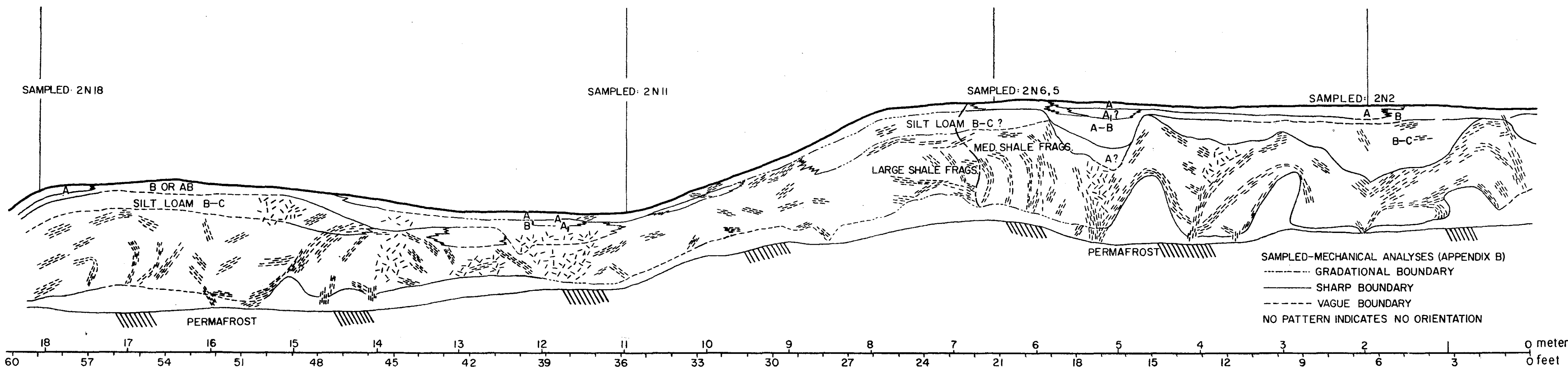

Fig. 2. Section of north wall, trench II

cm	inches	
0—9.2	0—4	Reddish-yellow silty clay loam. Fine to medium shale skeleton 30—50%
9.2—38.1	4—15	Fine shale with scattered medium and coarse fragments; matrix is grey silt loam with very fine shale fragments
38.1—71.1	15—28	Medium shale fragments (2.54 cm) with scattered coarse fragments; matrix of very fine shale fragments; clay skins and some silt fillings

cm	inches	
0— 6.4	0 — 2.5	Light reddish-brown humus and silty loam under mosses
6.4—26.9	2.5—10.5	Reddish-yellow-brown silt loam; abundant roots; gradational with above; weak to moderate fine, nut-like structure near lower contact
26.9—40.6	10.5—16	Coarse to medium shale fragments; fine shale matrix; considerable silt coatings on shale fragments imparting a grey-brown color to the unit
40.6—81.3	16—32	Coarse to medium shale fragments with silt coatings; fine shale matrix
81.3—99.0	36—39	Medium shale fragments; some fine shale matrix; extensive silt fillings up to 1.5 cm in thickness. Entire interval very compact and dry

cm	inches	
0—9.1	0—3.5	Reddish-yellow-brown silty clay loam; fine weak to moderate, nut-like structure grading with depth to weak, subangular blocky; coarse skeleton is less than 10%
9.1—27.9	3.5—11	Differs from above only in that coarse skeleton increases to 50%
27.9—44.6	11—17.5	Medium shale fragments with olive grey-brown silt coatings
44.6—78.7	17.5—31	Black, medium to coarse shale fragments; fine shale and sand matrix; silt coatings on shale fragments
78.7—91.4	31—36	Medium shale fragments with thick silt fillings; dense and dry

cm	inches	
0—9.1	0—3.5	Reddish-brown silt loam under vegetation
9.1—53.3	3.5—21	Reddish-yellow-brown silt loam; upper 25.4 cm displays weak to moderate, fine, nut-like structure, grading to medium, fine nut-like. Skeleton increases to medium shale fragments and structure becomes coarse, subangular blocky to coarse, angular blocky as the lower contact is approached. Dips are random
53.3—71.1	21—28	Black, fine to medium shale fragments; very fine shale fragment and sand matrix
71.1—86.4	28—34	Medium to coarse shale fragments with clay skins. Fine shale fragment and sand matrix

cm	inches	
0—6.5	0—2.5	Fine shale fragments; some finely disseminated organic material
6.5—25.4	2.5—10	Fine shale fragments; olive grey-brown silt matrix. Friable
25.4—48.3	10—19	Reddish yellow and reddish brown silt loam interfingering with medium shale fragments
48.3—58.4	19—23	Reddish brown silty clay loam with fine shale fragments
58.4—73.7	23—29	Fine to medium black shale fragments; shale, sand and silt fillings

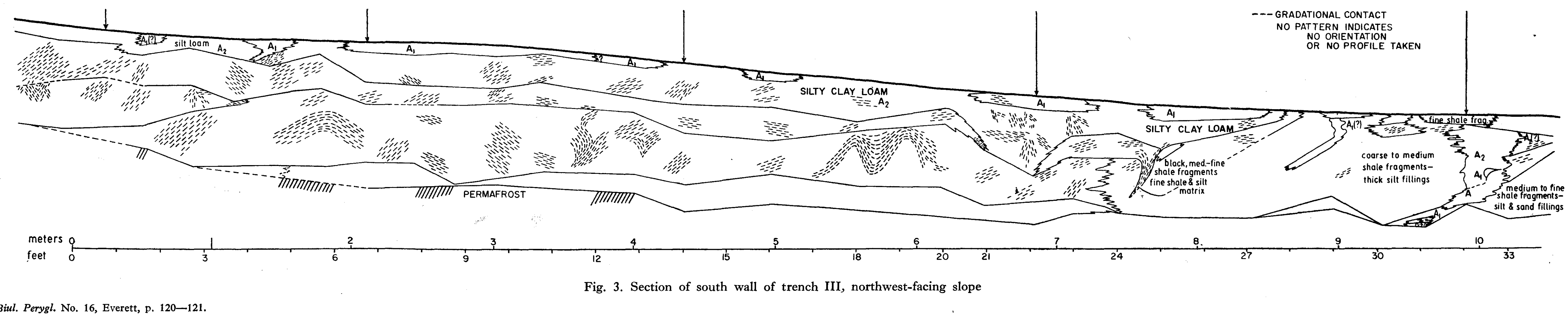

Fig. 3. Section of south wall of trench III, northwest-facing slope

larger, oriented fragments; (3) a compact zone consisting of large, non-oriented fragments held securely by interstitial fine fragments and silt and clay, which represents the present permafrost table. The thickness of this zone indicates that the permafrost table fluctuates from year to year.

The three zones are recognizable not only in Trench II but also in Trenches III and IV. It is not possible to draw sharp boundaries between the three zones because of the interference of other mappable zones of small lateral extent which show definite color and texture.

The most striking characteristic of the benches in cross-section is the high degree of deformation displayed principally in Zone 2. This deformation seems to be the key to an understanding of their formation. It becomes apparent upon examination of Figure 2 that forces of large magnitude were required to effect the internal deformation of the benches. The viscous, extensive flow of solifluction does not produce such intense deformation (compare Fig. 2 with Fig. 5).

Washburn (1947) considers stone streams on Victoria Island to be a product of non-saturated creep. Certain characteristics of these features attributed to non-saturated creep find counterparts in the bench features of Ogotoruk Creek, specifically the imbricate structure and coarsening of fragments near the terminus of the bench (see Fig. 2). However, relationship between features of such different size and so widely separated geographically does not establish consanguinity. Hunt and Washburn (1960) describe terraces in Death Valley that also have certain resemblances in form to those described here, though they are much smaller. The Ogotoruk benches have morphologic similarities to slump features observed in West Greenland (Everett, 1967) and to smaller benches studied on Prince Patrick and Ellef Ringnes Islands (Everett, in preparation). The internal structure of these latter benches is however more suggestive of slow movement.

The forces involved in the formation of the benches at Ogotoruk Creek were large and are believed to involve shear couples. These shearing forces were distributed with a decreasing intensity (neglecting the soil for the moment) from top to bottom of the profile. There are many areas in the section which illustrate local shear, for example, between meters 0 and 1[1] and 6 and 7 (Fig. 2).

Eakin (1916) in describing terraced or benched hill slopes in the Yukon-Koyukuk river area, Alaska, suggested they were formed by a special

[1] Meter 0 and 1 refers to the profile interval directly above the corresponding numbers on the meter scale.

kind of solifluction: „. . . the author has suggested the term „altiplanation" to designate a special phase of solifluction that, under certain conditions, expresses itself in terrace-like forms and flattened summits and passes that are essentially accumulations of loose rock materials." The terraces described by Eakin are similar to those of Ogotoruk Creek. Taber (1943) considers such features as the result of soil movement due chiefly to creep.

Shear resulting from unidirectional movement does not account for all of the structure visible in Figure 2. This is particularly true at the position of the deep, multiple horizon profile at Meter 5. It has been suggested that the convergent orientation of fragments near the base of the profile is the result of ice wedge formation, and subsequent collapse after the wedge melted. Dylik and Dylikowa (1960, p. 103) depict structures at Królewski Dwór, Poland, in Pleistocene fluvioglacial deposits which appear to be similar to that shown at Meter 5 (Fig. 2), and consider them to represent positions of former ice wedges.

TRENCH III

Trench III at the base of the slope is cut through an area of raised-center stone nets, transitional between nonsorted mud circles of the *Eriophorum*-tussock pediment area, and the benched slopes just described. The slope ranges from 6° near the base of the hill, Meter 1 (Fig. 3), to 3° at Meter 7. The solum horizons of the Arctic Brown soil range from 5 to 25 cm. in thickness. They are interrupted locally by raised-center stone nets. Figure 3 is a detailed section of this Trench. Three general zones were mapped and have been described for Trench II, p. 120—1. The second zone has been subdivided in Trench III into two zones primarily on the basis of color (which may have nothing to do with deformation). Deformation is clearly defined by plotting the orientation of rock fragments. The most intense deformation which takes the form of folds and thrusts is largely confined to a zone of medium to coarse shale fragments with varying amounts of fine shale fragments and sand matrix. Again differential shear under considerable compressive force is indicated, note particularly the profiles at Meter 0 and Meter 4 (Fig. 3). The zones as mapped lose their distinctive character and hence their mappability from about Meter 6 on. Noteworthy from Meter 6 downslope is the amount of A horizon soil material associated with the shear at all depths in the section. It is also noted that differential shear and intense deformation is much reduced from Meter 7 on. The amount of mineral soil increases, and coarse skeletal material is surrounded by silt loam. The dense zone just above the permafrost table is still present locally.

The mechanics of movement change abruptly as the slope becomes more gentle (2° to 3°) (Fig. 3). The section indicates that compression and shear due to gravity weakened with decreasing slope and that the type of movement changed from the relatively rapid quasi-earthflow which formed the benches to something approaching saturated viscous creep, i.e. solifluction.

CREST FLATTENING AND BENCHED MICRORELIEF: (HYPOTHESIS)

The melting of interstitial ice and subsequent caving of the bottom of Trench I (Pl. 1) suggest a mechanism by which flattening of the crests and the production of benched microrelief could have taken place.

If at some time in the past the permafrost table stood higher than at present under a hill with a convex crest carved in fractured bedrock, and was gradually lowered in response to a warming climate, the results would be: (1) to melt the ice lenses separating rock fragments and thereby lower the crest; (2) to lower the crest would result in leveling the crest; (3) to create large volumes of unstable material on the crest and slopes. This material presumably would be accompanied by a considerable volume of water, though not necessarily saturated. Such unstable debris is prone to sliding and slumping, which would result in the formation of broadly lobate benches; (4) to raise the permafrost table beneath the newly formed benches by upfreezing as a result of burial and give incresaed stability to them.

Eventually a time would be reached for a particular climate when ridge tops would become flattened, the slopes extended valleyward with an accompanying reduction in slope angle and displaying a benched microrelief. The bench form as it now exists in Ogotoruk Valley represents a stable landscape element and has been so for a long period of time.

The pronounced contortion, and in some cases fracturing of the shale fragments exhibited in Trenches II and III lend support to the idea that the benches were formed rather quickly by sliding of material released through compaction of the summit and recession of the permafrost table on the slopes.

Some of the material released through sliding on the slope moved a short distance out onto a pediment surface. As is shown in Figure 3, the forces involved in the sliding weakened once the mass had reached the pediment and most signs of contortion and shear disappear a short distance after the break in slope is passed.

Secondary structures such as those believed related to ice wedge development may have formed shortly after the formation of the benches and indicate either a post-bench development warm period or increasing aridity.

It should be noted here that not all crests in the general area of Cape Thompson are flat; as a matter of fact, they are the exception rather than the rule. Inland and northwest of the village of Kivalena, the hills display sharply convex crests. The hills of the DeLong Mountains just to the north of Ogotoruk Creek show not only convex crests but also many sharp crests. These hills are composed largely of Mississippian limestone and dolomite which is not as intensely deformed or fractured as the Jurassic-Cretaceous formations which make up the even-crested hills southeast of Ogotoruk Creek. The formation of the benched microrelief depends equally upon a climatic change within a permafrost region and highly fractured bedrock substrate.

SOUTHEAST-FACING SLOPE

TRENCH IV

Trench IV cuts a sparsely plant covered southeast-facing slope on a belt of Permian shale and sandstone. Figure 4 is a detailed section of the north wall of this trench.

In general, the structures observable in Trench IV are similar to those in Trench II. However, certain specific differences exist. The zone of maximum deformation rises to the surface and crops out at about Meter 9, which corresponds to a break in slope. This break in slope may be analogous to the break between riser and tread on the benches as in Trench II. However, in the vicinity of Trench IV the tread and riser sequence so typical of the opposing slope is much subdued and not readily apparent. From Meter 0 to Meter 5 in Trench IV there is a continuous though rather thin A horizon and a thick B horizon, overlying a zone of oriented fragments. From Meter 5 to Meter 9 the A horizon is less continuous, the B horizon thins rapidly and is cut out at Meter 9. The zone of oriented fragments thickens and is subdivided (Fig. 4) on the basis of color and the amount of mineral soil matrix. The dense compact zone, Zone 3, Page 121, appears at Meter 2.5.

The small thrusts or sheared areas between Meters 3 and 7 are notable for the A horizon material associated with them. Downslope from Meter 9 distinct zones of oriented fragments and the dense basal zone begin to lose their identity which is reflected in Figure 4 by the multiplicity of zones. Significantly the zone of oriented fragments is no longer confined to areas

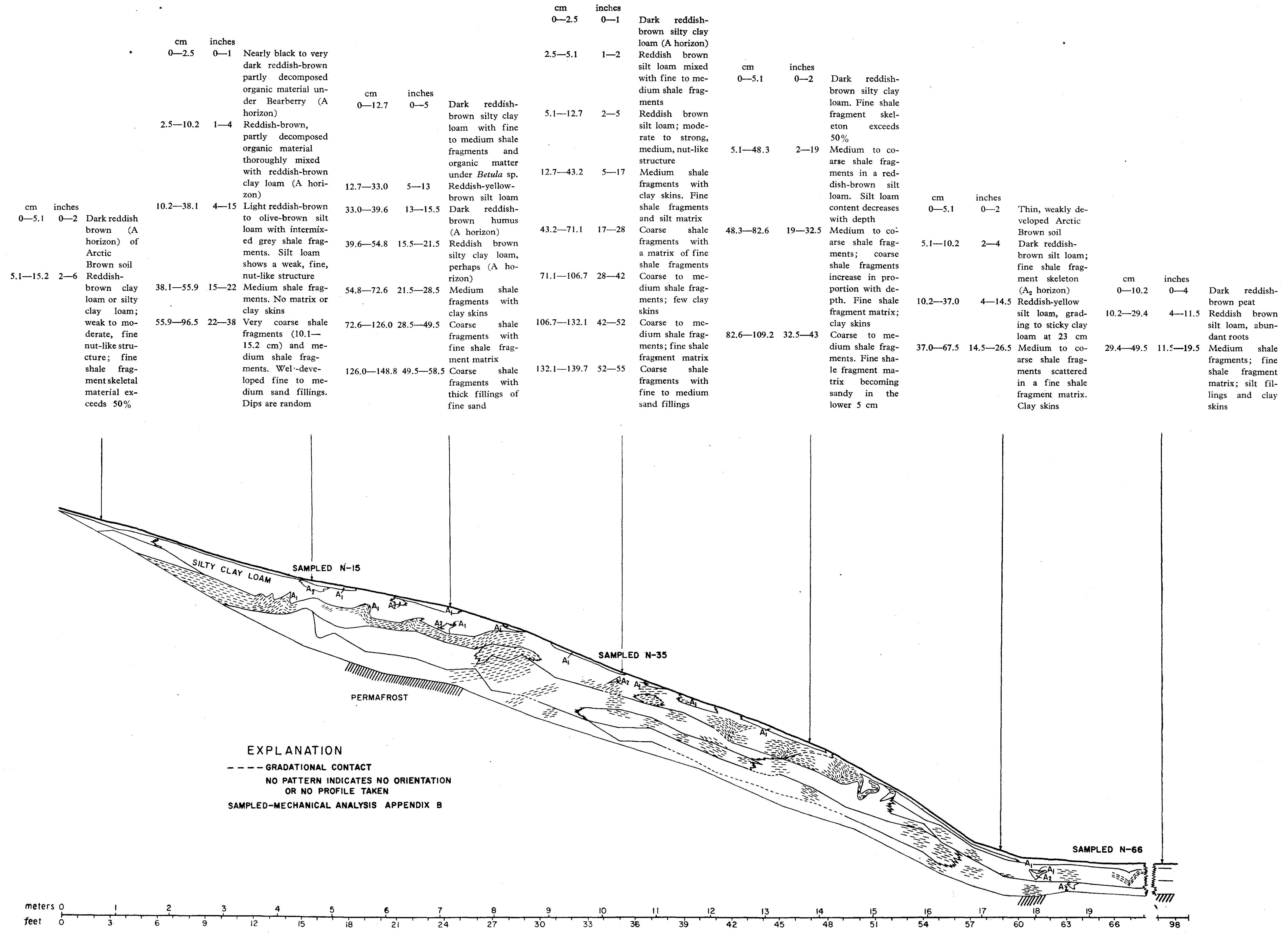

Fig. 4. Section of north wall of trench IV, southeast-facing slope

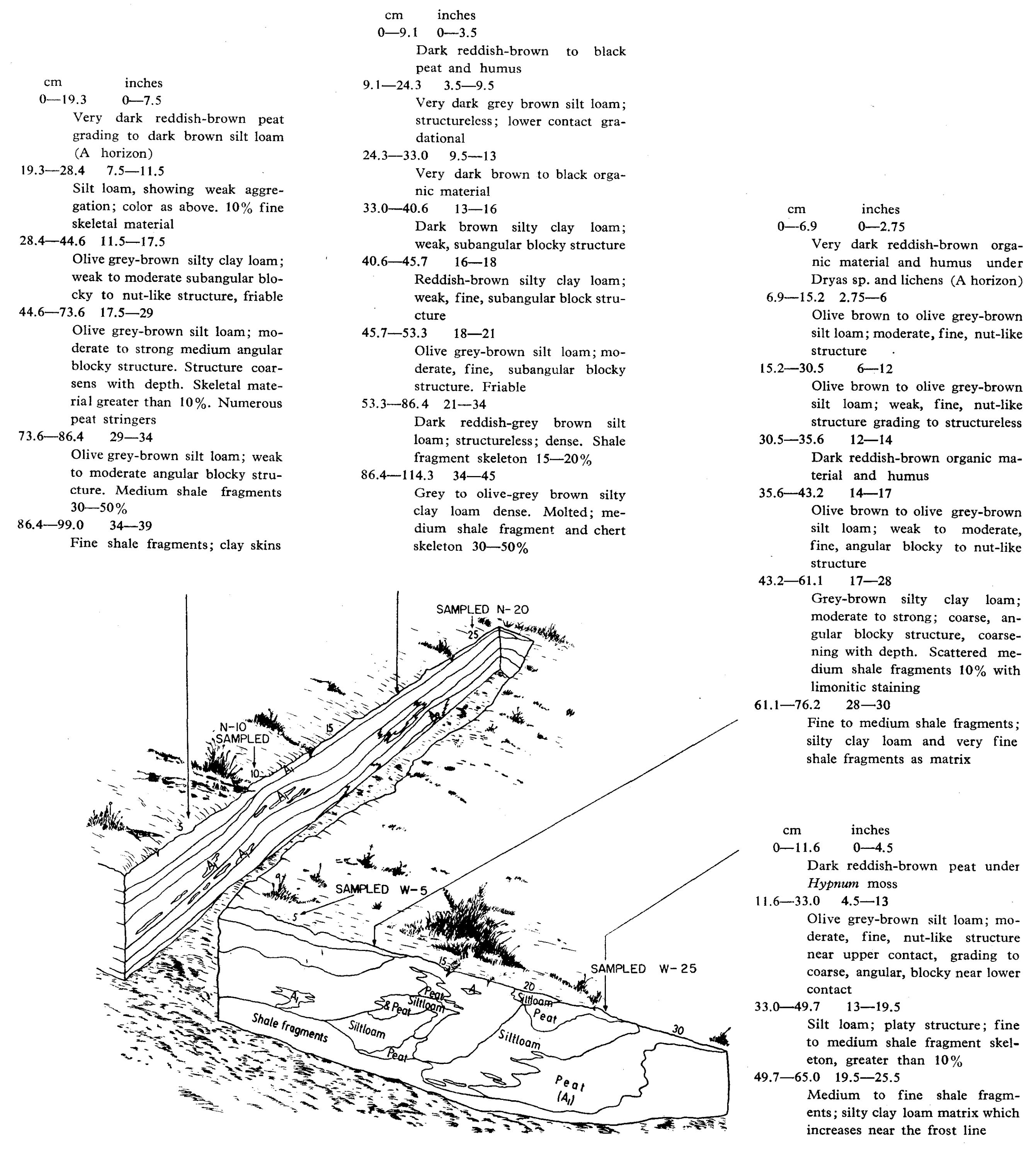

Fig. 5. Sections of north wall and west wall of trench II, southwest-facing slope

with little except fine shale fragment matrix, but extends nearly from top to bottom of the profile. Buried A material is less abundant than between Meters 0 and 9, but it is still present.

A major break in slope occurs at Meter 14 associated with intense deformation and the disappearance of the soil zone. At Meter 17 the slope is reduced from 22° to 3—5°, and the soil type changes from an Arctic Brown, shallow phase, to a very weak Arctic Brown. Between Meters 17 and 18 buried and underformed A horizon material is present throughout the profile. It is also notable that there is very little deformation in this interval. Between Meter 19 and Meter 30 the profile is simple and shows no deformation, probably because the shearing forces were expended before this point.

The deformation shown in the section indicates rather intense shear under the force of gravity. It appears from an examination of Figure 4 that at least several phases of movement and deformation are recorded, viz, the buried A material associated with thrust features in the 3 to 7 meter interval, and the multiple buried A horizon layers at Meter 17. The lack of intense deformation on the upper part of the pediment as it abuts the initial break in slope is a major difference between Trench IV, Trench II and Trench III. Shearing movements in the slope seem to be abruptly translated to creep or solifluction at the break in slope which is very likely active at the present time. Pl. 3 is a view of Meters 6 which 7 on the south wall of Trench IV illustrating intense deformation in what appears to be two phases.

TRENCH V

Trench V, near midslope, cuts an area under an *Eriophorum angustifolium—Carex* sp. association. Structural evidence of movement, though abundant, is difficult to map. This is the result of a lack of discernible boundaries, particularly in the downslope segment of the trench. Boundaries are, however, more distinct in the Trench segment parallel to the contour. A generalized profile consists of a weakly developed Arctic Brown soil having a depth of 24 to 25 cm, overlying 41 to 51 cm of olive brown to olive grey brown silt loam which contains stringers of peat. This is in sharp contrast to the underlying zone of small to medium shale fragments whose interfragmental spaces are filled with fine shale fragments and sand. This zone extends vertically only 5 to 10 cm above the permafrost table. In marked contrast to Trenches II, III and IV, no distinct zones of movement are apparent in Trench V, and the folds and thrusts so characteristic of the other Trenches are absent. It appears from the profile (Fig. 5) that movement occurs as progressive and discontinuous overriding of the surface of a saturated shale. The form of some of the peat segments suggests continued slow deformation throughout the profile. The indurated shale fragments are oriented with their long axis downslope and appear to act as a base for the movement of the overlying finer materials. The fragments are probably involved in movement.

Movement by creep or solifluction is common on this slope particularly where soil moisture is high.

TRENCH VI

Trench VI cuts a steep talus (24 to 27°) on the upper third of the southeast-facing slope of Saligvik Ridge (Fig. 1). The slope for the most part supports isolated areas of xeric vegetation. Such areas are usually distributed between stone stripes. In these localities a rather deep Arctic Brown soil is developed (Pl. 4), and rests on non-oriented fragments of all size ranges. Mappable zones of significant lateral ex.ent did not exist and no composite profile was attempted. Vertical profiles were described every 4 to 8 meters over a Trench distance of 100 meters downslope, and 30 meters parallel to the slope. Mechanical analyses for selected profiles of this Trench appear in Table I. The following profile description will serve to illustrate the general relations found in Trench VI:

Meter 6, South wall, *June 17, 1962*
Slope angle 24°, bedrock, dolomite.

0—13 cm	Dark reddish-brown silty clay loam (Arctic Brown); structureless. Roots not abundant. Rock fragments (10 to 28 cm) near and at the surface. Skeleton 50 to 70%; boundary gradational and wavy.
13—21	Medium to light reddish-brown silty clay loam grading to very fine sandy loam with depth. Rock fragments abundant and average 5 cm. Considerable void space between skeletal fragments near 21 cm.
21—32	Similar to 13—21 cm interval. Amount of fragmental material in 1—2 cm range increases over the above interval.
32—49	Large rock fragments average 10 cm. One to two centimeter size material fills interfragmental spaces. Upper boundary is well defined, lower boundary is indistinct. Considerable development of calcium carbonate crusts on lower side of rocks.

49—60 Interval as above. Rock fragments average 7 cm, some to 20 cm. Few fine fragments. Ice acts as a matrix.

Throughout Trench VI calcium carbonate encrustations are common and well developed on the underside of rock fragments in areas where mineral soil and fine fragments do not fill in between larger fragments. Such encrustations are interpreted as: (1) representing both downward movement in the soil profile and downslope migration of waters bearing $CaCO_3$; (2) representing considerable stability of the slope. Baulig (1950) regards such calcium carbonate encrustations on limestone boulders as a common phenomena, even in humid climates. It does not necessarily prove immobility but only slow displacement.

Movement on the slope does not appear to be rapid. The deep soil profile in Pl. 4 between stone stripes, the fact that only rarely are lichens found on the underside of surface rocks, and the encrustations of $CaCO_3$ on the underside of rocks within the profile, all suggest considerable stability. There is opportunity for the movement of fines by melt water from nivation snowbanks which can be heard running under the surface. The internal friction of the material above the permafrost is probably sufficient to prevent any movement. However, the material which underlies the talus and is held in a matrix of ice may move slowly as the ice is plastically deformed under the influence of gravity, thus the entire mass moves slowly. It remains to be shown what proportion of ice to rock is necessary to overcome the internal friction of such a system, in a field situation.

Scree slopes are also common on the northwest-facing slopes of Ogotoruk Creek but appear quite different from the talus slope just described. The difference is in the nature of the bedrock, which on the northwest-facing slopes is shale and thin-bedded greywacke. Observations on such slopes indicate substantial surface movement. In addition to displacements of large fragments in avalanche fashion, micro-slides involving a few to several hundred small rock fragments (3 to 5 cm) occur. There is a definite zonation within the scree. In general, a shallow profile reveals the following: (1) a layer of large fragments at the surface, having a thickness of not more than two individual fragments, (2) a zone of smaller fragments which may or may not have some interstadial mineral soil, underlain by (3) a zone of gravel-sized material and fines. Beneath the last zone the very coarse fragments (10 to 25 cm) typical of the surface were encountered again.

Since the entire surface layer of such slopes is very unstable as evidenced by the almost complete lack of vegetation, a slight vibration can cause fragments up to several centimeters to slide and roll downslope. These fragments are stopped by larger more stable rocks, or by scattered patches of vegetation. Smaller fragments and gravel follow in the wake of the larger rocks, exposing poorly developed mineral soil. The mineral soil thus laid bare is susceptible to rain-wash and deflation. The final form of such a slide is a small lobate terrace. Distance of movement ranges from several decimeters to a metre or more.

VALLEY FORM

The form of the main valley of Ogotoruk Creek is the result of a combination of factors, which have operated to different degrees and at different times.

The valley axis trends roughly northwest-southeast, with the steeper slope facing south and southeast. The opposing slope, though steepened near the crest is flanked by a broad pediment.

Currey (1963) has suggested that the smaller tributary valleys of the Ogotoruk drainage owe their asymmetry (north bank steeper) to their exposure to the prevailing wind and consequent snow bank accumulation. In the case of these valleys this is probably a legitimate argument, however, it is not sufficient to account for the asymmetry of the master valley.

Bedrock structure and resistance to erosion must be considered as the main factors contributing to the asymmetry of the Ogotoruk Creek valley. The broad pediment flanking the northwest-facing slope is assumed to have been developed as Ogotoruk Creek migrated to the north across contorted and fractured Jurassic-Cretaceous greywacke to the more easily eroded mudstones and shales of the Triassic Siksikpuk formation.

As stream migration occurred, a broad well developed pediment was left in its wake and subsequently buried by loess, which is undoubtedly still accumulating. Because of the continuous deformation from the benched microrelief of the slopes above the pediment to its extension into the materials which bury the upslope end of the pediment, the benches may have been formed contemporaneous with or somewhat after the pediment. As a consequence of the hypothesis for crestal flattening and formation of the benched microrelief (p. 119) the pediments are regarded as old, stabilized and now inactive elements of the landscape.

Ogotoruk Creek which is now eroding throughout most of its length in the relatively softer Triassic sediments, behaves as if it were working down a dip slope. The steeper south and southeast-facing slope is the active slope, shedding debris by landslide and creep (including solifluction) at a rate 2—3 times the opposing slope (Everett, 1966). Two factors are operative in maintaining the steepness of this slope. One involves the rather resistant, dolomitic Lisbourn limestone which has been thrust to the southeast over less resistant shales, mudstones and limestones. The limestone „cap" contributes to a steep, rather stable, talus covered upper slope. The second factor involves the ability of Ogotoruk Creek to remove the material fed to it from the lower slopes. This material is fed across a narrow, ill-defined pediment (this is the case at least in the lower reaches, where the asymmetry is most pronounced). During periods of high water such as occurred in September 1961, Ogotoruk Creek was able to move its coarse bed load and erode, in some areas, 3 metres into its north bank. It is believed that the combination of these two factors is sufficient to keep this slope steep and active.

Based upon exposure, the permafrost table should be lower on the southeast-facing slope than on the opposing slope, which is the reverse of fact. This may be explained in part by the somewhat higher rainfall and greater snow accumulation on this slope. The greater moisture on this slope coupled with the rather continuous peat cover keeps the permafrost table elevated. A high permafrost table on an already steep slope should tend to maintain steepness.

The effect of Corioles force as an effective agent in the steepening of the southeast-facing slope can be given only passing consideration. The Corioles parameter for this latitude (68°N) is 1.3457×10^{-4} sec^{-1}. This force would be ineffective except at times when the axial flow of Ogotoruk Creek is at a maximum.

SUMMARY AND CONCLUSIONS

Information obtained from trenches cut into the northwest-facing slope suggests that the benched microrelief of that slope was developed as the result of quasi-earthflow in which large shearing and compressional forces were developed. It is postulated that the quasi-earthflow came about under a climate warmer than present which depressed the permafrost table. Depression of the permafrost table resulted in collapse of the fractured bedrock of the crest and as a consequence flattening the crest. In this process some material moved down the slope forming a benched microrelief. Other benches formed as a result of landsliding in the thick unstable debris of the slope.

Such processes probably occurred on the opposing slope as well, but their results have largely been destroyed by subsequent movements which continue today. Present movements on this, the southeast-facing slope, are by landslide, creep and solifluction. Some benched microrelief is visible on this slope and several periods of movement are indicated. From measurements of movement rates on the opposing slopes, it has been calculated that the rate of denudation on the southeast-facing slope is 2—3 times that of the opposing slope.

The asymmetrical form of the main valley of Ogotoruk Creek is the result of bedrock structure and resistance to erosion. Ogotoruk Creek appears to have shifted its course to the northwest from the more resistant Triassic shales, leaving behind a broad pediment surface and isolating the northwest-facing slope from further strong erosion.

The opposing slope maintains its steepness because of a „cap" of resistant dolomitic limestone which forms a steep, stable talus on the upper slopes. Ogotoruk Creek appears to be able to remove all of the material fed to it from the active lower slopes and is undercutting these slopes during flood stage.

Slope exposure has not played a significant role in either the development of microrelief or the general valley form. Corioles force is considered too weak to be significant in the development of the valley asymmetry except possibly when Ogotoruk Creek is in flood.

At the present time the Ogotoruk Creek valley is characterized by a broad northwest-facing pediment surface which culminates in a shallow benched slope. These features were formed many thousands of years ago and represent stable elements of the landscape. The pediment is possibly aggrading at a slow rate by loess deposition. The opposing slope is being cut into by Ogotoruk Creek and is an active landscape element.

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Size distribution in mm (percent)

Sample No.	Depth in cm.	30 mm.	12 mm.	4 mm.	2 mm.	Total sample weight in grams	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Total sands	Total silt	Clay 2	Clay 0.2	Total clay
2N-0	0—7	0.0	32.8	12.2	11.9	236.2	22.2	9.6	3.3	5.5	6.7	47.3	37.2			15.5
	7—33	0.0	37.6	10.9	6.0	344.1	9.4	5.1	2.1	3.8	6.1	26.5	58.5			15.0
	94—134	0.0	18.4	19.3	6.7	293.8	11.9	10.0	5.7	11.8	9.5	48.9	45.7			5.4
2N-2	0—15	0.0	25.2	25.3	13.9	320.8	26.3	12.3	4.1	6.4	6.5	55.6	31.7			12.7
	15—54	0.0	43.6	5.2	5.2	297.4	9.1	8.2	3.3	6.0	7.4	34.0	49.9			16.1
	54—84	0.0	12.6	14.7	6.2	197.2	8.2	5.1	1.8	3.2	6.3	24.6	52.9			22.5
	84—140	8.2	44.0	30.8	8.2	896.2	46.7	15.3	3.1	2.6	2.7	70.4	20.0			9.6
	140—146	0.0	28.5	17.4	12.6	381.2	22.0	11.8	4.5	7.1	6.3	51.7	37.5			10.5
2N-65	0—11	0.0	25.5	22.5	8.9	406.9	22.8	12.5	4.6	7.4	7.0	54.3	37.3			8.4
	11—33	0.0	33.5	26.0	9.3	518.6	16.2	11.9	5.2	9.1	7.6	50.0	41.8			8.2
	33—73	0.0	35.1	36.6	11.5	453.0	33.8	19.2	6.1	7.4	4.3	70.8	21.8			7.4
	100—140	0.0	26.1	31.7	14.5	436.0	35.4	15.4	4.5	6.8	5.6	67.7	23.6			8.7
2N-11	0—11	0.0	47.7	17.3	7.3	355.2	20.5	10.3	3.2	5.0	6.7	45.7	40.1			14.2
	11—31	0.0	49.3	19.4	7.8	445.8	21.9	15.5	6.3	8.8	7.0	59.2	29.2			11.6
	31—51	0.0	59.5	28.1	6.2	551.0	44.3	16.6	4.0	4.4	3.1	72.4	18.5			9.1
	80—88	29.7	20.0	21.8	7.8	482.6	26.8	13.7	5.3	7.0	5.3	58.1	35.7			6.2
2N-18	34—124	0.0	46.5	27.4	12.3	479.9	50.6	20.8	4.7	4.0	1.1	81.2	12.0			6.8
	124—134	6.6	50.6	17.5	5.5	1040.1	20.6	14.9	7.9	14.9	9.4	67.7	24.9			7.4
3N-6	0—7	0.0	43.0	28.5	10.4	272.2	23.2	7.0	2.8	5.4	6.3	44.7	40.4			14.9
	7—19	0.0	15.7	9.4	6.6	147.5	6.5	4.7	1.9	4.0	6.4	23.5	47.1			29.4
	19—33	0.0	21.5	25.2	17.0	257.2	25.0	10.3	4.8	3.4	4.1	47.6	25.5			26.9
	33—63	0.0	23.2	37.6	15.0	390.1	9.6	8.0	4.3	9.0	9.0	39.9	50.4			9.7
	63—87	0.0	16.9	22.6	7.2	311.7	33.0	8.1	2.4	6.1	11.6	61.2	30.3			8.5
4N-15	2.5—10	0.0		32.2	67.8	43.1	6.4	31.5	16.8	5.0	8.9	68.6	19.6	10.4	1.4	
	10—38	23.1		30.1	46.0	66.3	4.1	22.2	12.2	3.2	4.9	46.6	30.1	22.5	0.8	
	38—59	20.0		59.3	20.7	488.1	2.0	37.7	17.9	3.7	3.7	85.0	9.0	5.1	0.9	
	59—76	0.0		70.5	29.5	237.2	4.9	34.9	20.3	6.6	8.5	75.2	18.1	5.7	1.0	
	76—114	60.9		34.6	4.8	1121.5	4.3	34.9	28.5	7.8	8.3	83.3	12.1	3.5	0.6	
	114—135	47.4		45.0	7.8	223.9	11.6	11.1	10.9	7.2	18.7	59.5	34.6	4.9	1.0	
4N-35	2.5—5	38.8		51.0	10.3	440.6	3.2	41.0	13.8	3.4	4.1	65.5	19.1	14.2	1.2	
	5—12	13.3		63.8	22.9	57.1	5.4	18.2	9.3	3.0	4.9	40.9	31.5	25.9	1.7	
	12—43	37.7		51.3	10.9	916.2	2.0	51.5	15.3	3.5	3.6	75.0	13.0	9.5	0.6	
	43—71	27.4		59.0	13.5	760.1	2.9	52.5	19.9	5.0	5.4	85.7	9.5	4.5	0.3	
	71—107	Missing														
	107—132	72.5		28.8	4.5	519.0	12.4	20.5	21.6	10.1	19.3	83.9	13.3	2.6	0.2	
	132—140	56.5		35.6	7.8	337.9	12.3	17.9	19.3	9.9	17.4	76.8	21.4	1.6	0.2	
4N-66	0—10	Organic														
	10—38	0.0		62.6	37.4	73.0	6.8	25.8	14.9	5.1	7.7	60.3	26.1	12.4	1.2	
	38—51	36.0		52.0	12.0	561.7	3.1	45.5	19.5	5.2	5.6	78.9	15.9	4.8	0.4	
5W-5	0—20	Organic														
	20—28	0.0		36.6	63.4	4.7	19.9	3.0	2.9	1.9	7.0	34.7	53.3	9.5	2.5	
	28—43	0.0		67.9	32.1	12.5	12.0	2.0	1.9	1.3	6.4	23.6	53.2	20.9	2.3	
	43—74	0.0		73.7	26.2	14.1	11.8	4.4	2.9	2.1	8.3	29.5	49.5	18.0	3.0	
	74—86	0.0		70.0	29.9	31.8	12.5	6.5	4.1	2.3	8.4	33.8	42.8	20.2	3.2	
	86—99	0.0		65.1	35.0	154.7	5.3	48.7	13.7	3.9	6.2	77.8	15.0	6.3	0.9	
5W-25	0—13	Organic														
	13—33	0.0		39.2	61.0	6.2						25.7	51.4	19.9	3.0	
	33—51	0.0		68.4	31.6	25.4						29.6	48.0	19.0	3.4	
	51—53	Organic														
	53—61	73.6		17.5	8.8	297.3						80.6	13.3	5.2	0.9	
5N-10	0—8	Organic														
	8—15	20.0		61.1	18.8	38.9	11.9	5.5	3.6	1.9	7.4	30.3	52.3	15.6	1.8	
	15—41	0.0		52.0	48.1	5.2	18.3	2.8	2.6	1.6	6.7	32.0	57.6	8.6	1.8	
	41—71	14.3		65.1	20.6	55.8	11.9	5.5	5.1	3.1	10.4	36.0	45.5	15.4	3.1	
	71—76	0.0		70.7	29.3	294.5	8.7	10.9	6.7	2.7	7.9	36.9	48.3	13.5	1.3	
5N-20	0—10	Organic														
	10—25	0.0		52.6	47.3	3.6	20.8	2.8	2.4	1.5	6.5	34.0	57.9	7.2	0.9	
	25—36	0.0		0.0	100.0	0.1	14.0	0.6	0.8	0.6	5.2	31.2	63.2	13.4	2.2	
	36—41	Organic														
	41—46	0.0		41.1	58.8	5.6	20.7	2.7	2.2	1.2	5.8	32.6	60.7	6.3	0.4	
	46—53	0.0		33.3	66.3	4.2	21.1	2.5	2.1	1.5	6.7	24.9	55.6	17.0	2.5	
	53—86	0.0		73.4	26.6	56.7	10.8	14.3	10.2	4.2	10.2	49.7	44.0	13.8	2.5	
	86—114	0.0		72.0	28.0	38.5	11.2	6.7	6.0	3.3	9.9	37.1	58.8	18.9	2.8	
6S-0	0—5.5	0.0	36.2	23.0	8.1	402.0	19.3	7.7	3.5	9.7	15.9	56.1	41.7			2.2
	5.5—10.5	0.0				487.2	8.6	4.0	1.9	6.9	15.6	37.0	52.1			10.9
	10.5—22	27.0	36.3	19.7	4.7	625.6	13.4	6.6	2.8	7.7	15.0	45.5	42.7			11.8
	22—35	58.5	38.0	1.9	0.3	2235.4	20.4	8.1	2.9	7.2	15.2	53.8	38.0			8.2
	35—70	27.4	71.1	1.1	0.3	2574.3	14.0	7.6	2.0	8.4	16.9	48.9	42.7			8.4
6S-6	0—21	0.0	41.2	18.1	5.0	483.5	5.6	4.7	2.6	8.9	22.5	44.3	55.2			0.5
	21—28	18.4	44.3	7.5	3.1	431.9	5.0	1.4	2.9	4.5	14.8	28.6	61.1			10.3
	28—38	33.6	39.2	8.8	3.2	600.2	5.4	3.3	1.4	3.8	12.5	26.4	59.6			14.0
	38—89	5.8	83.6	8.3	0.4	2475.5	8.7	4.6	2.0	4.9	11.0	31.2	54.8			14.0
6S-17	0—10	0.0	50.6	17.9	3.6	696.1	8.2	3.7	1.7	6.2	15.0	34.8	62.1			3.1
	10—21	0.0	40.4	24.0	4.4	502.6	6.3	4.4	2.5	7.4	15.2	35.8	62.0			2.2
	21—48	23.4	56.0	9.2	2.3	970.6	17.8	3.9	0.3	7.5	16.7	41.2	56.0			2.8
6W-0	0—15	0.0	43.0	17.4	4.8	373.9	7.1	4.5	3.3	9.4	18.4	42.7	55.9			1.4
	15—25	21.3	65.9	3.7	1.0	901.9	8.7	3.7	1.7	5.2	13.9	33.2	60.8			6.0
	25—55	Missing														
	55—90	0.0	39.5	59.1	1.0	1233.5	15.8	9.2	2.6	5.4	8.6	41.6	49.8			8.6
6W-8	109—129	0.0	23.0	47.9	17.7	580.6	52.6	8.1	1.9	4.3	6.9	73.8	21.1			5.1
	139—159	0.0	14.8	40.1	23.1	616.2	47.2	9.6	1.9	4.6	9.4	72.7	22.6			4.7
6W-12	0—26	0.0	27.7	26.0	8.8	315.4	15.5	6.0	3.0	8.6	17.4	50.5	48.2			1.3
	26—50	18.4	44.8	15.2	3.3	808.4	5.5	3.2	1.6	5.2	14.1	29.6	57.0			13.4
	131—141	0.0	36.8	57.7	4.4	1818.7	49.0	5.6	1.4	3.4	5.2	64.6	27.7			7.7
	156—176	0.0	26.3	58.3	10.7	518.8	38.1	7.5	2.4	5.2	7.5	60.7	31.5			7.8
	206—216	0.0				1267.9	34.8	8.2	2.5	6.0	11.3	62.8	31.0			6.1

References

Baulig, H. 1950 — Essais de Géomorphologie. Paris Soc. Ed. Belles Lettres; 160 p.

Currey, D. R. 1964 — A Preliminary Study of Valley Asymmetry in the Ogotoruk Creek area, Northwestern Alaska. *Arctic*, vol. 17, No. 2; p. 84—98.

Dylik, J., & Dylikowa, A. 1960 — Compte-Rendu des Excursions du 19 au 30 September 1958. *Biuletyn Peryglacjalny*, No. 8; p. 81—141.

Eakin, H. M. 1916 — The Yukon-Koyukuk Region, Alaska. *U. S. Geol. Survey, Bull.* 667; 54 p.

Everett, K. R. 1966 — Slope Movement and Related Phenomena; in: The Environment of Cape Thompson, Alaska. United States Atomic Energy Commission, PNE-481; p. 175—220.

Everett, K. R. 1967 — Mass-wasting in the Lake Tasersiag Area, Southwest Greenland. *Meddelelser om Grønland*, vol. 165, No. 5.

Hunt, C. B., & Washburn, A. L. 1960 — Salt Features that Simulate Ground Patterns Formed in Cold Climates. *U. S. Geol. Survey, Prof. Paper* 400-B; p. B403.

Johnson, A. 1960 — Preliminary Studies of the Influence of Frost Action and Related Phenomena on the Vegetation of the Ogotoruk Creek Valley: Progress Report, Project Chariot, Phase III; 60 p.

Kachadoorian, R., & Campbell, R. H., *et al.* 1966 — Geologic Investigations in Support of Project Chariot in the Vicinity of Cape Thompson. in: The Environment of Cape Thompson, Alaska. United States Atomic Energy Commission, PNE-481; p. 57—84.

Taber, S. 1943 — Perennially frozen ground in Alaska: its origin and history. *Geol. Soc. America, Bull.*, vol. 54; p. 1433—1548.

Washburn, A. L. 1947 — Reconnaissance geology of Portions of Victoria Island and Adjacent Regions, Arctic Canada. *Geol. Soc. America, Memoir* 22; 142 p.

Pl. 1. View of east wall of trench I

Note rubble zones above bedrock have considerable open space; decimeter pole rests on permafrost. September, 1961

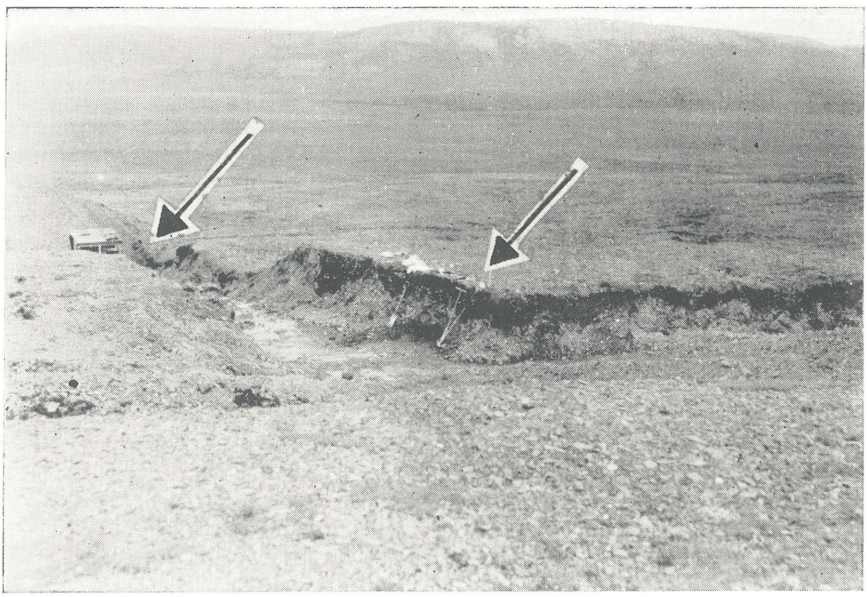


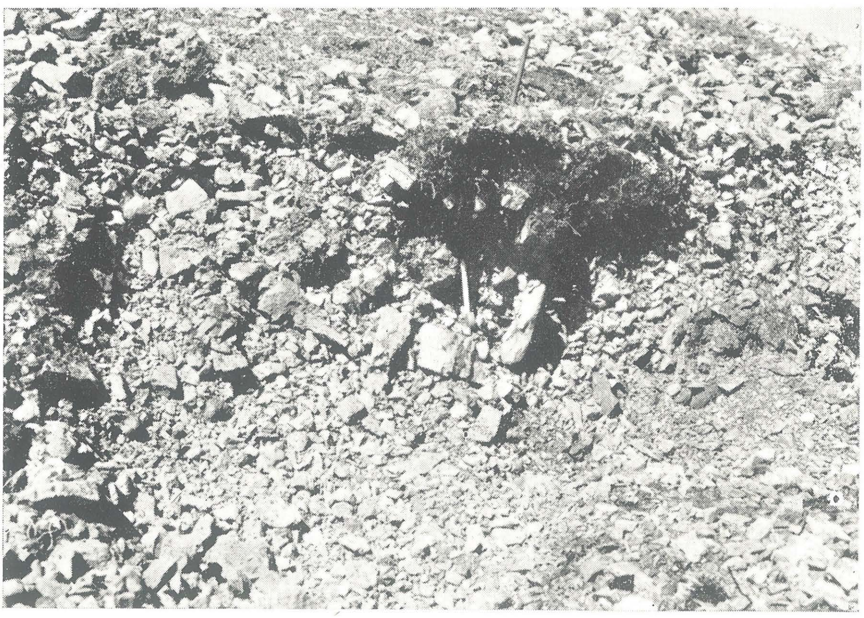
Photo. by N. Holowaychuk, August, 1961

Pl. 2. View of trench II showing west and north wall

Dark material near top of trench is mineral soil, light material is medium to coarse shale fragments. Arrows mark section in fig. 2

Pl. 3. Detail of meter 6—7, south wall of trench IV

Note extreme deformation near the surface and imbricate structure and angularity of fragments. Two periods of deformation seem to be indicated. 1962



Pl. 4. Meter 4, west wall of trench VI

Note thick (20 cm) section of Arctic Brown soil. No soil is developed on either side under stone stripes. Slope angle 22°. 1962