MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
Bd. 165 · Nr. 5

MASS-WASTING IN THE TASERSIAQ AREA, WEST GREENLAND

BY

K. R. EVERETT

WITH 11 FIGURES AND 2 TABLES
IN THE TEXT

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
1967

Abstract

The ice-free lake Tasersiaq area, marginal to the Sukkertoppen Iskappe is underlain by jointed granite and gneiss which have only a thin covering of ground moraine.

With local exceptions, patterned ground is not well developed. Solifluction lobes occur on both valley slopes, but solifluction sheets are restricted to the gentler northeast-facing slope. Many sheets and lobes show an imbricate arrangement of boulders at their frontal margins. These features appear to be of rather recent age. Slump features which show imbrication of boulders on their frontal margins are common, both as recent and "fossil" forms.

Micro-mudflows and debris slides are the most active features of the area in terms of volume of material moved. The amount of soil displaced at any one time by a single flow ranges between a few hundred cubic centimeters and several cubic meters. There is evidence of large mudflow activity in the past, but no recent activity was observed.

Water, both under pressure and on the surface, and wind are important contributors to mass-wasting in the Tasersiaq area.

Qualitative and quantitative observations of mass-wasting in the valley suggest that the processes are operating at a rate two to three times faster on the northeast-facing slope than on the opposing valley slope.

CONTENTS

INTRODUCTION

The Tasersiaq area is a portion of the foreland of the Sukkertoppen Iskappe, bounded by latitudes 66°40′ and 66°15′ north and longitudes 51°10′ and 51°30′ west. It is in the Sukkertoppen Kommune, approximately 90 kilometers south-southwest of Søndrestrøm Air Force Base.

The investigations and results presented here are part of a two-year study of the soils, mass-wasting, and patterned ground of the area adjacent to the Sukkertoppen Iskappe.

The area was visited in 1936 and in 1938 by the West Greenland expeditions of the University of Oxford, and in 1962–63–64 by the Institute of Polar Studies First, Second and Third Sukkertoppen expeditons.

In 1963 and 1964 investigations were made in the ice-free area (Fig. 1) from the Sarfartôq Gletscher, south-southeast to "Lake Quantum" on the southwest side of Tasersiaq, and from "Right Angle Point" to "Hidden Lake" on the northeast side of Tasersiaq. The total area investigated was approximately 100 sq. kilometers. A preliminary unpublished report was prepared for the granting agency (Everett, 1964).

Acknowledgements

The research was supported by funds of the U. S. Army Natick Laboratories under contracts DA19–129–AMC–134 (N), and DA19–129–AMC–301 (N), and the Ohio State University Mershon Fund.

I would like to express my appreciation to Colonel JAMES Y. R. ROTH and the personnel under his command at Søndrestrøm Air Force Base for courtesies extended to me and other members of the Sukkertoppen field party. I wish also to acknowledge the able assistance of Mr. HENRY BRECHER in surveying and data reduction. I am grateful to Dr. A. L. WASHBURN, Yale University, Dr. ANDERS RAPP, Uppsala University, and Dr. RICHARD P. GOLDTHWAIT, Ohio State University for their critical review of this report.

K. R. Everett.

Institute of Polar Studies
The Ohio State University
Columbus 10, Ohio.

PHYSICAL GEOGRAPHY

Bedrock Geology

The bedrock geology of the area covered in this report has not been investigated in detail. TREVES, (in LOEWE *et al.* 1962, P. 31–36) made a reconnaissance of the bedrock geology in the Tasersiaq valley in the summer of 1962, and a detailed study in the east half of the valley in 1963. Because of the control which the bedrock exercises on the geomorphology, its general character and structure will be outlined.

The bedrock is composed of steeply to vertically dipping Precambrian(?) gneisses with variable amounts of included schist. The oldest gneiss in the "Gneiss Gorge" area (extreme east end of Tasersiaq) is a grey biotite or hornblende gneiss. In places it is a strongly contorted migmatite containing inclusions and schlieren of biotite schist, hornblende schist and amphibolite (TREVES, in LOEWE *et al.*, 1962). This description also applies to the rocks that make up the precipitous ridge which parallels Tasersiaq on the northeast. Tasersiaq represents a structural discontinuity between the grey paragneiss (TREVES, in LOEWE *et al.*, 1962) and a similar grey paragneiss which makes up, at least in part, the dipslope hills on the southwest. The grey gneiss is extensively intruded by red granite and/or granite gneiss. The gneiss grades(?) across a structural depression into red granite and granite gneiss with minor inclusions of grey paragneiss. This last rock type is coincident with the more rugged topography up to the Sukkertoppen Iskappe.

The gneisses on both sides of Tasersiaq are intruded by large ultrabasic dikes of considerable lateral extent. Red feldspathic dikes are common and intrude the paragneisses on the southwest side of Tasersiaq.

In many areas the original bedding is preserved and dips range between 20° and 65° to the northeast. At least one prominent set of joints characterizes extensive areas of this igneous-metamorphic complex, one set trending northeast-southwest and the other northwest-southeast. To a large degree, this joint set controls the major drainage network of the area.

Surficial Geology

Details of the surficial geology of the Tasersiaq area are treated by CROWL and GOLDTHWAIT (1963) and will be discussed here in general terms as background. Broadly classified, the surficial deposits are: 1) ground moraine or till and end moraine, related to Wisconsin or earlier glaciation; 2) outwash and kame-terraces, representative of several minor glacial advances or stillstands; 3) recent end moraines and outwash close to and related to present glaciers.

Almost the entire ice-free area adjacent to the Sukkertoppen Iskappe is blanketed by bouldery ground moraine and till (Fig. 1), except where it has been removed from steeper slopes by mass-wasting and running water. The slopes, particularly on the southwest side of Tasersiaq, are complicated by a series of discontinuous kame-terraces to 100 meters or more above the present lake level. Similar terraces occur on the opposing slope, but are less well preserved and do not occur as high up on the slope, because either they were never deposited or they have been removed by solifluction subsequent to ice retreat. Many of these terraces have a thin veneer of ground moraine and display rock-rampart fronts.

At this end of Tasersiaq, extensive areas of the valley bottom to an elevation of 19 meters above present spring lake level, are occupied by deposits of pitted outwash. These deposits are related to a late-phase ice tongue in the Tasersiaq valley. The deposits are horizontally bedded or display a gentle dip toward the valley margins. Most are sparsely covered with vegetation and have a wind-stripped surface of lag gravel.

Moraines and outwash associated with present day glaciers cover only a small percentage of the ice-free area (Fig. 1). The moraines are ice-cored and topographically impressive. However, they are of little importance with respect to mass-wasting or patterned ground. Outwash associated with the present glaciers does display weakly developed ground patterns.

Topography

The foreland area just east of the Sukkertoppen Iskappe is characterized by long asymmetrical valleys bounded by precipitous escarpments on the north and northeast side and dip-slope hills on the south and southwest side. Most are occupied by underfit or beaded streams. Highland elevations range from about 500 meters near Søndrestrøm Air Force Base to about 1100 meters near the Sukkertoppen Iskappe.

The most pronounced topographic features of the area are Søndre Strømfjord and Avangnardleq fjord. The latter displays some of the most impressive scenery of the area, particularly on the south side where

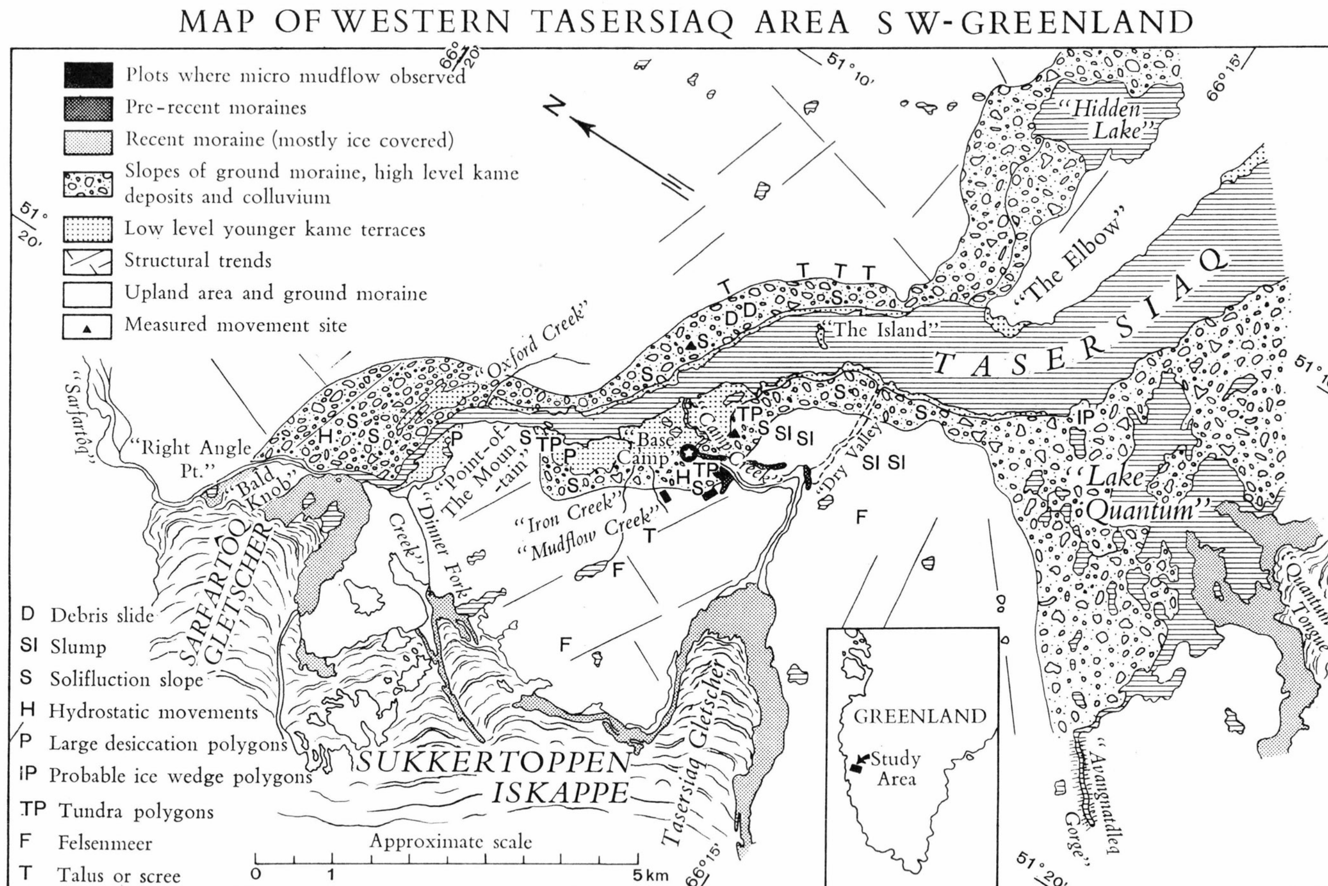

Fig. 1. Location map covering the western end of Tasersiaq, and showing significant geologic and geomophic features.

outlet glaciers of the Inland ice pass around imposing half-domed peaks. Both fjords follow the northeast-southwest joint set. "Bowdoin Bay" and western Tasersiaq follow the northwest-southeast joint set and empty into Søndre Strømfjord. Tasersiaq is approximately 60 kilometers long. Ten kilometers northwest of the 1963–64 base camp (Fig. 1), the lake empties through a narrow gorge, the sides of which rise vertically nearly 300 meters. At this point the outlet is called the Sarfartôq river.

Repeated Pleistocene glaciations have sent tongues of ice down the major drainage lines, and the inland ice has completely covered the area at least once and probably several times. Changes wrought by the ice are not as pronounced as might be expected. The glaciers worked on a landscape with a well-established drainage pattern, a pattern most likely determined by streams, perhaps long before the Pleistocene. Glaciations have modified the landscape in detail, i.e., widened and perhaps deepened some valleys, oversteepened the escarpments, and in the lower reaches of Tasersiaq have sculptured gneissic outliers into roches moutonnées. Sculpturing was observed on the crest area, but was much less fresh in appearance and not as well developed. Kame deposition on the dip-slope hills to the southwest of Tasersiaq has imparted a benched appearance to the slope profile and in one case, just south of the "Base Camp", deposition of an end moraine has caused a 90° turn in "Camp Creek" and the abandonment of its former valley, ("Dry Valley").

The uplands appear to be little modified by glaciation. Till cover is thin or absent. These surfaces have undergone scour by a thinner, slower moving ice sheet. The thin patchy till cover, the relatively stable felsenmeer and the poorly developed and weathered sculptured forms of the uplands indicate a thin cover of ice which predates one, and perhaps several advances down the Tasersiaq valley. These later, perhaps post classical Wisconsin Valley advances, resculptured the roches moutonnées in the valley and deposited most of the constructional forms in the valley bottom and on the slopes. The till line, i.e., the upper limit of fresh appearing till indicates that at the maximum of these later advances the ice was about 150 meters thick near "The Elbow". (See Fig. 1). As far as the gross topography is concerned, the last significant ice advance was possibly 9000 years B. P., Crowl and Goldthwait (1963). Evidence from the area of "Hidden Lake" suggests that post-glacial erosion has just now cut its way through the valley fill material deposited during glaciation, and is once again working on a bedrock surface. Deepening of the bedrock valley by postglacial streams probably has not amounted to more than 0.5 meter at most, except in large outlets such as the gorge north from Tasersiaq.

Climate

Until the summer of 1963, no detailed climatological program had been carried out at Tasersiaq. Climatic records available from Sukkertoppen and from Søndrestrøm Air Force Base span many years, but because these recording stations are respectively on the coast and inland near sea level, they are not useful in the area marginal to the Sukkertoppen Iskappe.

Table I presents weekly maximum and minimum air temperature, relative humidity, and precipitation for the summer months of 1964 and partial data for 1963 at "Base Camp" Station. Kosiba and Loewe (1963) discuss the climate of Tasersiaq in detail.

In general the climate can be characterized as having a cold, wet spring and fall and a cool, dry summer, which may last up to four weeks. The warmest temperatures seem generally to occur in the first two weeks of August.

Table I. *Climatic Data, for "Base Camp" Station*

	Week	Temperature °C Max.	Temperature °C Min.	Relative Humidity Highest	Relative Humidity Lowest	Precipitation (mm)
1963						
July	1– 8	13.8	0.8	...	...	...
	9–15	15.5	1.1	...	...	...
	16–22	12.8	0.0	...	...	...
	23–29	14.4	–0.6	...	...	...
	30– 5	14.4	2.2	...	...	...
Aug.	6–12	18.3	4.4	...	...	...
	13–19	17.2	2.8	...	...	...
	20–26	13.9	1.1	...	...	...
	27–31	6.6	–1.7	...	...	...
Total						47.0
1964						
June	8–14	12.8	–2.2	...	...	...
	15–21	11.1	–4.7	100	37	2.8
	22–28	4.9	–2.7	100	50	6.9
	29– 5	12.1	0.6	92	36	Tr
July	6–12	11.3	–2.1	100	48	7.9
	13–19	9.9	–2.2	100	48	8.4
	20–26	9.4	–1.7	100	49	23.4
	27– 2	11.6	–1.2	100	41	8.4
Aug.	3– 9	10.8	0.8	100	45	.3
	10–16	10.3	4.3	93	46	0.0
	17–23	8.2	–1.2	100	45	.8
	24–31	9.3	–2.9	100	42	0.0
Total						58.9

Wind speeds over 9 meters/sec. are common. In 1963 the highest recorded velocity was 19 meters/sec., while in late June of 1964 a peak velocity of 30 meters/sec. was recorded. The prevailing winds are in the quadrant from East to South, while the strongest are from the South and Southeast. Wind direction and speed are controlled by gravity winds, pressure gradients and topographic channelling (Kosiba 1964).

A total of 47 mm of precipitation was recorded at the "Base Camp" station in 1963. Of this, 32 mm fell between 26 June and 18 July, and 9 mm between 24 August and 1 September. No precipitation was recorded between 19 July and 2 August.

Precipitation in 1964 totaled 58.9 mm and was somewhat more evenly distributed; however, August totals were lowest. Snow flurries occurred in all months.

Judging from snowbank accumulation, winter snowfall appears to be moderate to light. Strong southerly winds form large drifts on the north- and northwest-facing slopes, many remaining throughout the summer. These strong winds keep the terraces relatively clear of snow.

Patterned Ground

The terminology used here follows that proposed by Washburn (1956). The types of patterned ground and their distribution in the Tasersiaq area are governed primarily by the mechanical composition and slope of the surface deposits.

Nonsorted mud circles and polygons develop best in areas underlain by silty and clayey material and as a consequence are almost absent in the area. Coarse surface material seems to favor the development of sorted polygons and nets, which are common on both sides of the Tasersiaq valley.

Sorted and nonsorted polygons. Sorted polygons are the most widespread and by far the best developed ground pattern in the Tasersiaq valley. These features are abundant on slopes between 5° and 8°, southeast from "Dry Valley" to "Lake Quantum" (Fig. 1), and at scattered positions on the opposing slope.

Polygon diameters range from 2 to 5 meters. The bordering blocks of rock are from a few decimeters to several meters in length, and have their long axis inclined to the horizontal.

There is very little fine material in the borders except at depth. The central areas tend to be convex and covered with vegetation, and they may have one or several large boulders at the surface.

Large well-defined sorted polygons occur on kame-terrace deposits near the Sarfartôq Gletscher (Fig. 1). Individual polygons with diameters as much as 5 meters are common. The borders are narrow, 3 to 4 cm. The surface of the terrace is a lag gravel. The polygonal outlines appear to be desiccation cracks. (Desiccation polygons with diameters of 5 meters are not uncommon in the arid Southwest United States). The cracks are not discernible below 25 cm, and only the upper 1 to 3 cm. contain the larger gravel fragments. The gravel fragments which outline the polygons range from 2 to 5 cm. This size fragment makes up much of the lag-gravel surface of the terrace including the central areas of the polygons. The polygons do not occur everywhere on the terrace, but are confined to several marginal areas where internal drainage is good.

There is considerable evidence that a process like BRYAN's (1940) Gully Gravure is operative on the terrace. The polygonal borders gradually become filled with wind-blown silts and fine sands, in which plants become established. Once established the plants act as a trap for the wind-blown material and the polygonal borders are built up. This sequence has been found in all stages of construction and destruction. The result may be the obliteration of the polygonal outline or the creation of a polygon whose borders are composed not of coarse fragments but of fine sands, while the central area of the polygon still displays a coarse gravelly surface.

Over large areas of the outwash and younger kame-terraces northwest of "Base Camp", only discontinuous raised polygonal borders exist which support grasses and *Campanula rotundifolia*, or polygons with depressed borders of fine sands, which are accentuated by the plant *Silene acaulis*.

Nonsorted polygons are not abundant in the valley. They are confined to the moister, sloping (1° to 3°) margins of the outwash terraces, and to moist depressions between Tasersiaq and "Lake Quantum". Diameters range from less than 1 meter to as much as 4 meters. Such polygons probably contain ice wedges at depth, however, excavation to permafrost did not reveal definite ice wedges.

Sorted and nonsorted nets. Well-developed sorted nets are common on south and southeast-facing slopes on the uplands. The slopes range between 8° and 12°, and are covered with lichen-encrusted boulders. As the slope steepens, the nets become drawn out down-slope, but are still well defined. The central areas composed of a mixture of coarse and fine material support only scattered clumps of grasses and several species of *Carex*. This material is found to spill over into the rock-filled depressions on the sides or over the downslope depressions. The flow or spill-over is thought to be largely a surface phenomenon, perhaps mud-flow aided by rill-wash.

The central areas are slightly convex. The rocks at the margins commonly have their long axes inclined to the horizontal, and are relatively free of smaller fragments to a depth of 5 to 20 cm. Below this depth, finer fragments begin to fill completely the interfragmental space. At a depth of about 40 cm., the marginal and central areas are indistinguishable, either by color or texture.

Nonsorted nets are common on highland areas, which have a thin veneer of ground moraine. They are also common on the high-level kame-terraces.

Polygonal cracks appear in some areas of the tundra in August when seasonal frost has receded 0.3 to 0.5 meters and the ground has become dryer, (see page 13). They are best developed on slopes between 5° and 12°. Individual cracks (sides of polygons) have been measured up to 13 meters with no more than one intersecting crack. Crack openings can measure up to 1 cm. at the surface and extend to a depth of 5 cm. or more. Excavation normal to a number of such cracks has revealed a steep, hillward inclined fault plane. Dislocations of organic-rich or iron stained horizons cut by the fault have been measured to be as much as 8 cm. Relative motion along the fault has been down on the upslope side. There is no evidence that ice wedge formation plays a role either in the development or propagation of these cracks, and they are regarded as produced by desiccation. Deformation associated with the fault plains may be due to a number of factors, among which are differential compaction and creep.

Felsenmeer. Many acres of the uplands on the north and northeast side of the valley are covered with coarse, lichen-encrusted felsenmeer, some of which contains debris islands and crude, irregular stripes. The general aspect of the felsenmeer is one of stability, and such movements that do occur must be small.

MASS-WASTING

Introduction

The results of mass-wasting are observed everywhere in the Tasersiaq area. Here, as in other semi-arid regions, water and gravity are the prime movers in mass-wasting. Although summer precipitation is slight, snowbanks, some of which are perennial, provide large and long-lasting sources of water. Judging by the extensive areas lacking lichen cover, snowbanks of the past were much more extensive than at present. Many of the mass-wasting features suggest that large quantities of water were involved in their formation.

Solifluction

On the slopes surrounding Tasersiaq, solifluction manifests itself in the form of sheets and lobes. Whether a sheet or lobe is produced depends on the configuration of the bedrock, i.e., channelling of material to produce a lobe in bedrock depressions, or movement as a broad sheet where no depressions exist. Lobe fronts are usually a few meters wide and are best developed on slopes between 5° and 15°. Sheets, on the other hand, may have fronts several tens to a hundred meters wide, and are best developed on slopes between 5° and 7°.

Both lobes and sheets are usually multiple, i.e., a succession of lobes or sheets, one atop the other in stair-like fashion. Figure 2 shows the terminus of a solifluction sheet moving over the surface of a delta deposit 3 kilometers northwest of "Base Camp". The front of the sheet is 0.2 to 0.5 meters high and is nearly continuous for several hundred meters. The sheet is composed of ground moraine and inter-mixed sands and gravels from higher kame deposits. The ground moraine is not particularly bouldery in this area, no more than 5 percent of the surface showing boulders.

Figure 3 is a sketch cross-section in the front of the sheet shown in Figure 2. There is a concentration of boulders laid in imbricate fashion at the overriding margin. Inter-boulder voids occur for nearly 0.5 meter into the sheet. The frequency of large boulders decreases as the sheet is penetrated. The intense deformation of the bedded delta deposit and the

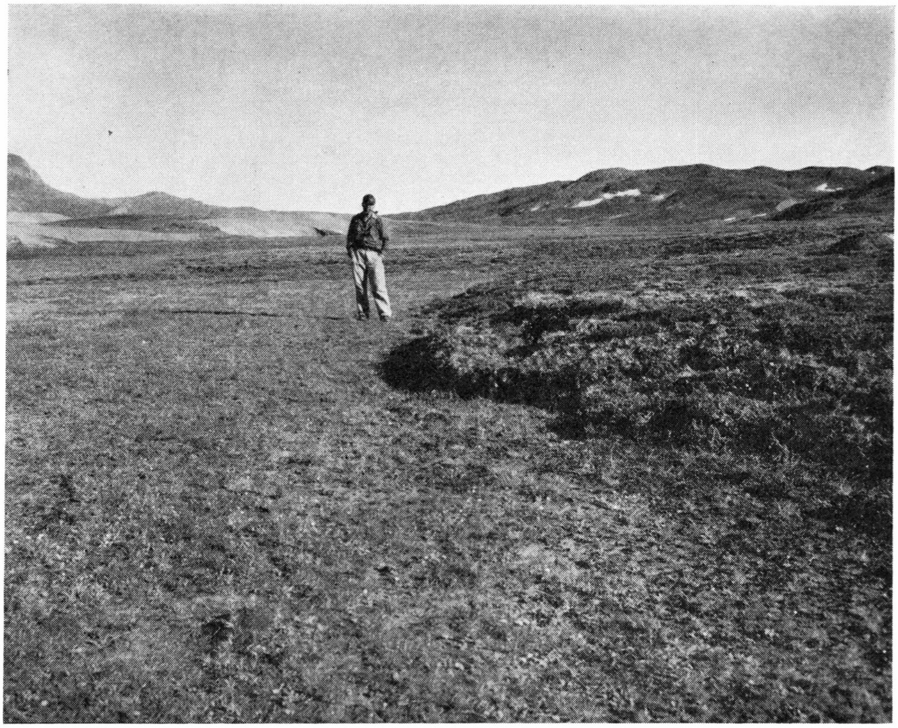

Fig. 2. Solifluction sheet, 3 kilometers northwest of "Base Camp". Sheet is pushing into a deltaic deposit related to a former high level of Tasersiaq. August, 1963.

smeared and stretched character of the organic matter indicate that the sheet has not merely crept over the delta but has actually pushed into and deformed it. Smaller pits dug farther upslope show that the fine and medium sands and silts near the permafrost table, which in August was at a depth of about one meter were very compact and would, with normal digging become "quick" and viscous. The moisture by weight in this material is 18 to 20 percent.

Tests showed the material to be non-plastic, Table II. Further tests showed that in most cases an addition of 2 to 3 percent moisture was sufficient to cause the mineral soil to go from a rather friable, granular form to the viscous state when subjected to slight jarring. Similar phenomena have been noted by SØRENSEN (1935), and JAHN (1946). When the viscous state had been reached, a film of water appeared on the surface. After setting a few minutes, the mineral soil below the surface water film was compact, rather dry and vesicular, similar to wet concrete which has undergone vibration, i.e., compaction has occurred and the water is expelled.

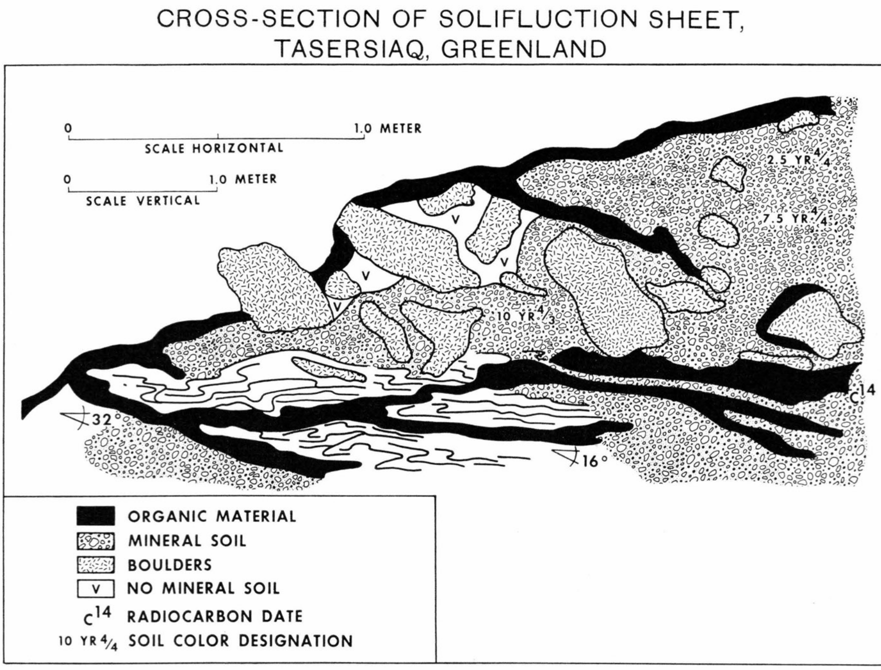

Fig. 3. Cross-section of solifluction sheet pictured in Figure 2.

Field moisture values for the "quick" material were usually well above the critical values obtained for the same material in the laboratory. It is believed that moisture and soil texture play the most important roles in the flow of these soils.

Table II. *Physical data for profile 11, applicable to cross-section*, Fig. 3.

Sample No.	Sand Percent	Silt Percent	Clay	Bulk density	Plasticity Index	Non-flow Moisture %	Flow Moisture %
TAQ 11...... 5–45 cm	61.0	36.6	3.1	1.63	NP	10.25	14.33
TAQ 11...... 45–73 cm	59.4	38.6	2.5	1.75	NP	12.75	15.24
TAQ 11...... 97–112 cm	63.4	35.5	1.8	1.47	NP	15.70	22.50

The near lack of large boulders in the upper 0.5 meter of the sheet, and a boulder concentration at the margin suggest that boulders may have been brought to the edge by a more rapidly moving surface and gradually rolled under, or that they have moved up in imbricate fashion along shear planes. Vertical velocity profiles indicating more rapid surface movement and the presence of shear planes in moving arctic soils have been described by Williams (1957) and Rudberg (1958) among others. In the spring when soil moisture is high, the stability (consistency) of the soil is radically changed near and on the surface, with the result that micro-mudflows (see footnote, page 22) occur (Fig. 7), as well as flowage in the upper 10 to 20 cm. As thawing progresses, sufficient moisture is liberated from the melting of seasonal frost to produce soil instability in progressively deeper layers. In this manner the entire sheet slowly advances. Boulders are emplaced in imbricate fashion by moving up along shear planes and are concentrated along a front controlled by a change in slope gradient. The result is similar to that pictured in Figure 5 though the rate of movement in the formation of the two features differs greatly, (see page 20).

Drying of the surface in many areas results in cracking in a more or less polygonal pattern, although cracks have been noted which now essentially parallel the advancing front of the sheet. Excavation normal to the crack reveals considerable distortion on either side. The cracks open in response to desiccation and lowering of the water table in late summer. Lateral subsurface soil flow may accentuate the cracks and account in part for the associated deformation. The formation of ice wedges may also account for some of the deformation. The development of the cracks also provides zones of relief (shear) along which subsequent lobes may start, the result being multiple solifluction sheets.

On the southeast-facing slope of the Tasersiaq valley, where solifluction lobes dominate, an excavation of one lobe showed essentially the same cross-section as that shown in Figure 4. The frontal rise of the lobe was 1 meter. The percentage of large surface boulders, 10 to 20 percent, is much greater on this slope. Excavation again revealed a concentration of boulders at the lobe margin. Their size and frequency decreased as the cut was extended back. The extreme contortion noted in Figure 3 was not present here because of the absence of bedded sands. The process of lobe formation is considered to be the same as for the sheet.

Of particular interest in this cross-section (Fig. 4) are the pendant inclusions of organic matter. Their attitude and progressive stretching out represent surface motion considerably greater than that in the subsurface. They may also represent incipient lobes.

Carbon Dating. Carbon 14 dates were obtained for the two solifluction features in Figures 3 and 4. A date of 1695 ± 140 years B. P. (Isotope No. I–1095) was obtained on frozen peat 2 meters from the frontal margin and at a depth of 1.6 meters, (Fig. 3). A date of 935 ± 120 years B. P. (Isotope No. I–1096) was obtained from unfrozen organic

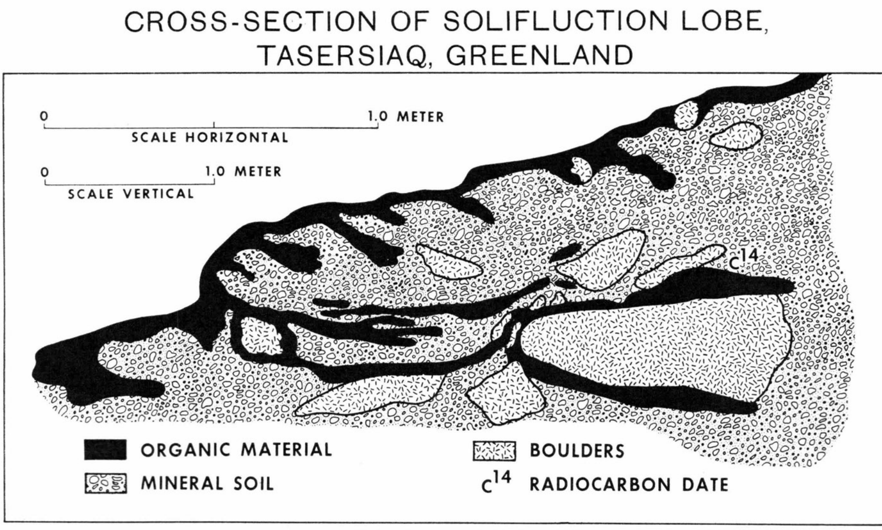

Fig. 4. Cross-section of solifluction lobe, southwest-facing slope of the Tasersiaq valley.

matter 1.7 meters back from the lobe front and 0.93 meter below the surface, (Fig. 4). It was hoped that such dating would give not only relative ages of the features but relative rates of movement as well. This hope was not realized, because based on geological evidence the 1695 B.P. date appears too old. The solifluction sheet from which this date was obtained overrides a deltaic deposit related to a high level of Tasersiaq. This high level is thought to be not much over 100 years old, Crowl and Goldthwait (1963). The date for the drop in the level of Tasersiaq is based on a missionary's letter written in 1879 (*in* Jensen 1879), cited by Crowl and Goldthwait (1963). The letter stated that Eskimos had told of an outburst of the Sarfartôq river which carried four of their boats away, and that this river was blocked from time to time by a glacier. Crowl and Goldthwait conclude that this outburst was the release of the ice-dammed Tasersiaq. The level of the lake dropped at least 84 years ago. Perhaps the strongest argument against accepting either the 1695 or 935 dates at face value is that suggested by Burns (personal communication). He suggests that organic material in even the shallow A horizons may range over several thousand years from top to bottom of the horizon because of the slow decomposition rates in arctic environments. Because of the contortion and mixing which accompanies solifluction, any date obtained on organic material so buried would be a composite date which reflects neither the age nor the rate of movement.

Speculation on the basis of a single date is risky at best and in view of the considerations outlined above, none will be attempted. This does not rule out use of these dates and others like them once systematic sampling and dating has been done both vertically and horizontally in the soil. Such a program is necessary to determine the effect of solifluction on dating.

Slump

Slump debris with imbricate structure is depicted in Figure 5. These deposits occur on the steeper (15° to 25°) till covered northeast-facing slopes. Snow drifts accumulate on these slopes and during spring and summer the till becomes saturated by snow melt and slumping occurs. The frontal margin of the slumps can range between 1 and 2 meters and display an imbricate arrangement of the larger blocks. Many of these blocks dip 35° and 37° into the slope. In all observed slumps the inter-block spaces were void, a condition imparted at the time of slumping.

The hollow or depression up slope of the slump becomes an accumulation site for snow. Melting of the nivation snow banks thus formed provides ample water which moves fine material over and between the large blocks. See Ekblaw (1918) for a discussion of snowbank accumulation and solifluction in Northern Greenland. Nivation sapping and running water tend to keep the interboulder spaces on the margin open.

The slump deposits display certain similarities to solifluction lobes, particularly the imbricate arrangement of rocks at the frontal margin and the void space between them. They differ from solifluction lobes or sheets as described in this paper in that they result from rapid movement.

Many boulder-rampart terraces, that are now heavily encrusted with lichens and support a wet meadow on the tread, are interpreted as "fossil" slumps. It is assumed that slumping was particularly active immediately after deglaciation and many of the "fossil" slumps may date to that period.

Some of the more recently formed slumps may undergo some movement by solifluction, but no doubt retain the imbricate boulder front.

I consider that once formed the slumps represent an essentially stable element in the slope morphology. The boulder front (as suggested by Rapp, personal communication) acts like a dam.

Mudflow

Mudflow is an important agent of mass-wasting in almost all climatic regions. It is, however, best developed in arid and semiarid areas where it may be the most important factor in mass-wasting. Washburn (1947, p. 86) states, "Mudflow is not usually associated with Arctic regions. Yet it occurs in them and locally at least may be of considerable importance". Rapp, (1960) has treated arctic mudflows in the Kärkevagge area in considerable detail.

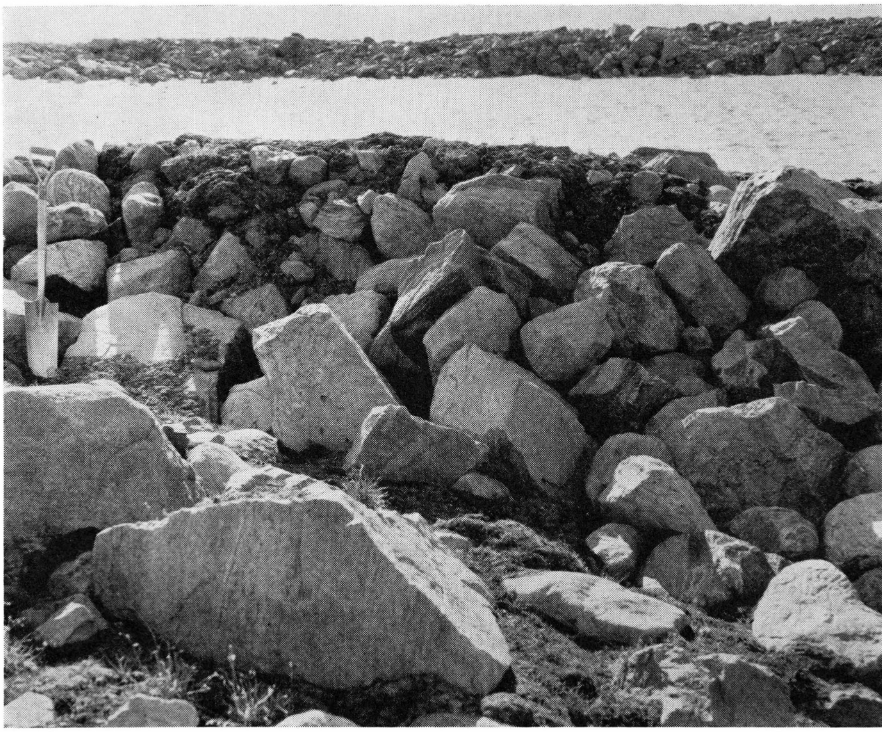

Fig. 5. Slump debris showing imbricate arrangement of blocks along the front. Nivation snowbank behind. Note open space between blocks and the decrease in size of the overlying material.

Large mudflows, involving hundreds or thousands of tons of debris have occurred in the Tasersiaq area in the past. A well-developed example of a large mudflow is on the southwest-facing slope of the Tasersiaq valley north of "The Island", (Fig. 1). The flow moved down a 20° slope and spilled into the lake. Now only prominent gully embankments remain.

There are indications of mudflow on the northeast-facing slope near the head of "Mudflow Creek". The evidence is primarily gully embankment and scattered patches of debris along the valley sides. Breached high level kame-terraces and fan deposits suggest mudflow activity on other areas of this slope. The flows may be quite old, dating perhaps to the last ice recession from the valley. There is no evidence of recent large mudflow activity.

Fig. 6. Typical north-northeast-facing slope. Slope angle ranges between 8° and 10°. Slopes of this character are prone to micro-mudflow. See Figure 8. July, 1963.

Micro-Mudflow[1]

Micro-mudflow, particularly on the northeast-facing slopes, is of great importance in mass-wasting in the Sukkertoppen area. Figure 7 pictures a micro-mudflow which occurred during the summer of 1963. The slope in Figure 6 has many lobate terraces which range in length from 0.5 to 6 meters and from a few tenths to several meters in width.

[1]) The term micro-mudflow is used to designate small, rapidly moving flows of unconsolidated, saturated material down moderate to steep, sparsely vegetated slopes. The size of these flows range from a few decimeters to several meters in length and width. The volume of material moved ranges from a few hundred cubic centimeters to a cubic meter. An abundant but intermittent water supply is needed. The water may come from rains and/or melting snow.

The resulting flows are usually confined to channels. The edge of the flow is lobate and steep, rising several centimeters to a decimeter or more. The flows may be multiple, arranged in stair-like fashion. It is usually the upper-most flow that is active.

Micro-mudflow differs from conventional large mudflow by virtue of its size, and from solifluction because it is channeled, has levees, moves rapidly enough to be perceptible and does not require underlying permafrost.

Fig. 7. Micro-mudflow on the slope shown in fig. 6. Amount of material involved in flow is 0.96 M^3. August, 1963.

The terraces are usually compound, i.e., they have a succession of lobate terraces upslope. The successive frontal lobes usually support some vegetation, and rise several centimeters above the inclined slope of the terrace immediately downslope. Often both the lobate edge and the terrace slope show wrinkles suggestive of surface flowage, also noted by WILLIAMS (1957).

Where the terraces are best developed, the slopes are usually dry in middle and late summer because they are freed of snow in early spring.

In August 1963 there was considerable evidence of recent mudflow activity on these slopes. The flows occurred between the first week in July and late August, probably during or immediately after the heavy rain of 6 July. On this date 13.5 mm. fell, roughly 40 percent of the total recorded between 23 June and 1 September. No flows as large as that pictured in Figure 7 occurred in 1964.

The terraces apparently become thoroughly saturated to the point of flowage. In some cases the frontal rim of the lobe was breached, releasing the unstable, saturated mass behind. In other instances the frontal lobe simply flowed over the next succeeding terrace with only minor breaching of the lobe. The larger flows moved blocks as large as 20 cm., 1 to 3 meters downslope, and finer, sandy material two to three times that distance.

Figure 8 represents the distribution of terraces and mudflows over two 2500 M^2 [1]) areas on a northeast-facing slope and the positions of 5 flows active in 1963–64. The total amount of material displaced in these flows was 2.1 M^3).

Small flows involving from a few hundred to several thousand cubic centimeters of material occur on many areas along the north and northeast-facing slopes. Most are associated with snowbanks. In a swale adjacent to "Mudflow Creek" (Fig. 1) four recently active flows were observed in an area of 3000 M^2. Each flow had extruded sands over last year's vegetation. The total amount of material displaced was 1500 $cm.^3$. Excavations revealed that all four flows had been inactive for many years prior to 1964, as organic material buried by previous activity was decomposed, but still identifiable. Highly decomposed organic material was found 60 cm. up slope and beneath the terrace. The appearance of the successively buried organic material suggests many periods of activity separated by periods of inactivity for the terrace. A willow (*Salix arctica*), on an inactive terrace immediately upslope from the ones just described was dated by tree rings and found to be 65 years old. This terrace, however, given the right conditions of moisture could become active once more. Other tree ring dates indicating periods of major inactivity of the substrate are shown in Figure 8.

A small flow was observed in motion on June 24, 1964 (Fig. 9). The material had become saturated by the melting of a small patch of the previous night's drifted snow. The general slope of the area was 15°, however the flow maintained a slope of 26° and moved at a rate of .25 cm/minute for approximately 15 minutes. The flow was composed of fine sands, the surface had a thin film of water, with small bubbles. The material (dug into while in motion) was dense and vesicular and had a moisture content of 9 percent. This moisture content is close to that found in other moving flows and for the "quick" material shown on Page 17. The bubbles on the water film may indicate air has been forced from the mass and that the vesicular character of the soil may have been imported by entrapped air.

[1]) The volume of material displaced was computed by measuring the width of a flow near its toe, midpoint, and head, and the length of the flow parallel to its long axis. Thickness was measured at nine or more points on cross-sections along the measured lengths. A parallelepiped was formed using the average thickness (height) and its volume calculated. Debris slide volumes were obtained in approximately the same way with the exception that an ellipsoid was assumed rather than a parallelepiped. Thin, patchy sands distributed down slope were not included in the calculated volumes, thus the figures given in the text must be regarded as minimum volumes.

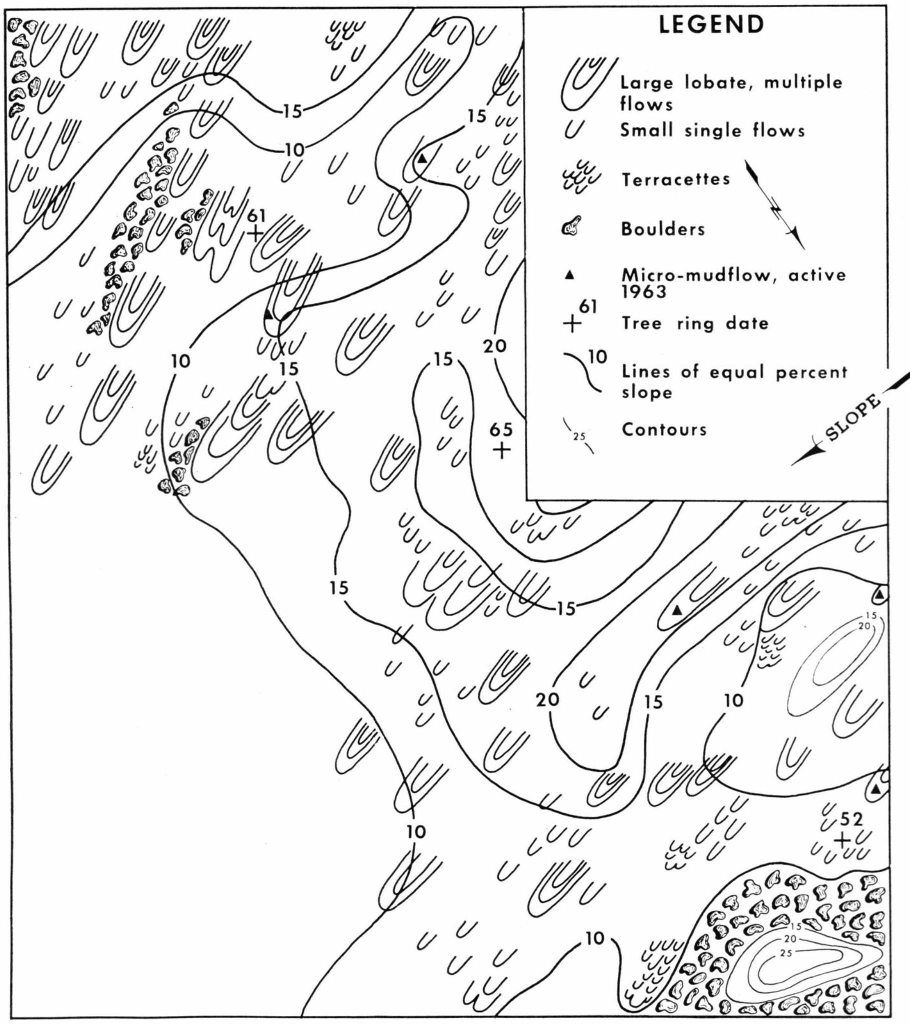

Fig. 8. Plot of major micro-mudflows and terraces on two 2500 M³ plots on a northeast-facing slope of "Camp Creek". See Index Map for location and figures 5 and 6 for surface detail. The map does not attempt to show all surface features, only the recently active mudflows and distribution of prominent, potentially active mudflows as well as some terracettes and boulder lines. The map was constructed by brunton and tape traverse. Corners and midpoints of plots were marked with painted cairns. Up and downslope brunton and pace traverses were made every five meters. Percent slope was taken on five meter centers.

Flow results from saturation of a terrace by snowbank melt and/or in combination with heavy rains. The flow can take the form of a viscous creep of 1 to 3 cm. over several days or as a rapid release of material through a breach in the frontal margin. When snow banks are melting, running water is a common adjunct to the process of micro-mudflow

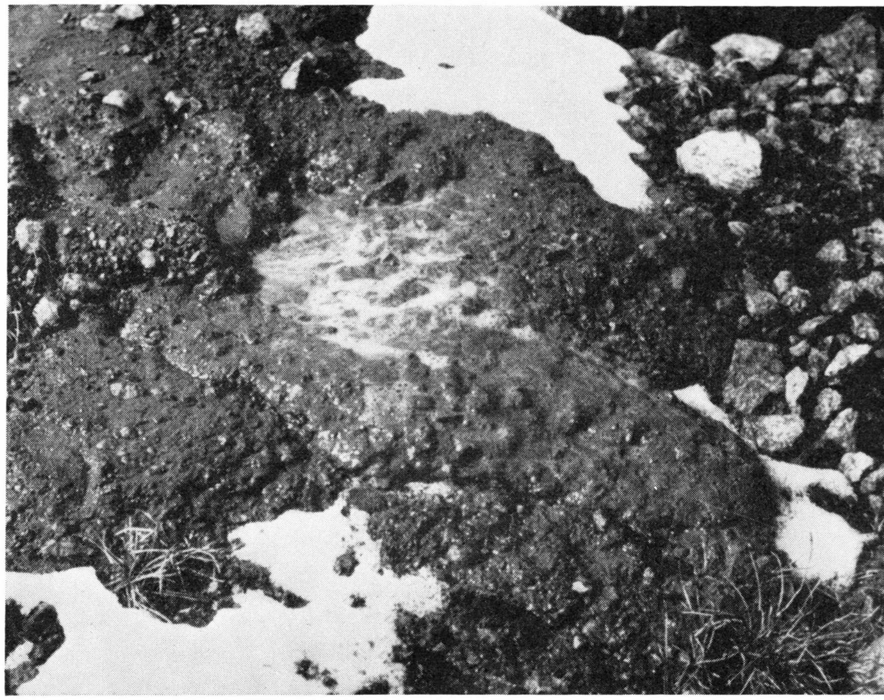

Fig. 9. Small micro-mudflow in motion. Note froth and isolated bubbles on surface and lobate front. July, 1964.

(but not a necessary one), and serves to spread the finer material down slope. Micro-mudflow and terrace formation over any particular area at any time is largely dependent upon fortuitous circumstances of runoff, rain fall and snow accumulation.

Debris slides. The term debris slide is used here with the realization that in some instances the material may have been saturated. Debris slides were noted only on the drier, steeper (10° to 25°) southwest-facing slope. Two occurred in 1963, one on a slope of 31° and the other on a slope of 30°. The first slide involved 117 M^3, the other, 8 M^3. Traces of old slides are common on the slope. Micro-mudflow was not observed on this slope in 1963 or 1964 although it probably occurred to a very limited extent.

Rockfall

Rockfall and the resulting scree accumulation are impressively developed on southwest-facing slopes, principally on the northwest side of Tasersiaq. The oversteepened upper slopes, coupled with the jointed character of the gneissic bedrock, provide optimum conditions for rockfall. The scree slopes, without exception, show a gradation from fine fragments near the top of the slope to large blocks, several meters in diameter, near the toe. At a break in slope, from 27° to 15° the straight, inclined scree gives way to parallel or sub-parallel rock streams, which, as the slope decreases, give way to block-bordered polygons.

New additions to the scree do not appear to be large and the material added is confined to the upper part. This material is fresh and broken as opposed to the bulk of the lichen-encrusted scree. There are numerous debris islands scattered throughout the scree where local shallowing of the slope occurs, many have deep, well drained alluvial soils, Holowaychuk and Everett (in preparation). As a whole the scree shows a high degree of stability, particularly the lower two thirds of the slope. The finer material near the head tends to be rather unstable, unless held by soil and grass.

Slopes recently freed of perennial snow banks are just now being affected by frost desintegration and are producing a talus by rockfall. The talus is composed of large angular blocks and displays only weakly any gradation in size up slope. Rock fans are developed in several areas at the end of deep, narrow, open joints.

Rock and snow avalanches (dirty avalanches), Rapp (1960), are not a factor at present in the development of scree or talus at Tasersiaq.

Rockfall is an important mass-wasting process on the upper south and southwest-facing slopes, and in the initial production of slope form. It gives way with decreasing slope, and perhaps with time, to solifluction and creep.

Wind Erosion

It is not possible to estimate the influence of wind erosion in the total denudational picture in the Tasersiaq area. Its effects are most apparent on the lower outwash and kame-terraces along the lake. Here wind stripping has in some cases cut 20 cm. into the surface, producing low scarps, several tens to a hundred meters long, normal to the prevailing southwest wind. Windward of the scarps a lag gravel has formed and many of the rocks are faceted and polished. Blow-outs and small dunes are common to the lee of the scarps.

Wind, with its tools of dust and snow grains and aided by chemical desintegration has prevented growth or stripped away lichens from many rocks on the uplands, and left them with a granular, disintegrated windward face. In some cases a weak cavernous weathering can be observed. Kosiba (1937) has described scour pits in the bedrock of the Nordre Strømfjord area of western Greenland, which he believes due to the action of wind and sand grains. Small, poorly developed scour pits were noted at Tasersiaq and were likely developed by wind action.

Fig. 10. Hydrostatic welling of sands. Fine material is deposited several meters downslope. As melt progresses the wells further downslope become active and those above are abandoned. Thickness of sand layer is 1 to 2 cm. July, 1964.

Water

Running water is an effective erosive agent where it acts on recent debris slides and micro-mudflows, redistributing the finer material down slope. Of equal importance are the hydrostatic effects of water. On many areas of the slopes, particularly below nivation snow banks water can be seen bubbling up through the soil and carrying coarse and fine sands down slope (Fig. 10). In one case a large boulder was observed to have been lifted several decimeters above the surface and a mass of mineral soil extruded from beneath it (Fig. 11).

Early in the spring, melt water streams from snow banks carry large quantities of fine sands and silts downslope, distributing them in a thin veneer over the vegetation.

The erosive action of running water is most common and best displayed on the north and northeast-facing slopes. Although no calculations were made on the volume of material moved, it must be substantial, perhaps several cubic meters on some slopes.

Streams

The amount of material carried by streams either as bed load or suspended load varies greatly from year to year depending on the intensity

Fig. 11. Large boulders lifted hydrostatically. Slope angle ranges from 4° to 6°. The boulder on the right has been lifted. Such movements must take place early in the Spring. Most drainage is underground between large boulders. July, 1964.

of melt. Turbidity measurements of several perennial streams in 1964 indicated very little material was in suspension, Koob (1964, personal communication). Glacial outlet streams of course have high turbidities due to large quantities of rock flower. They are, however, well below Tasersiaq. Calculations of suspended material in Tasersiaq were made by passing a liter of water through a .45 μ filter. Suspended material amounted to 140.0 mg/liter, which when computed for a 1 meter wide cross-section of the lake gave a figure of 400 metric tons (Fig. 1). "Camp Creek" is the only contributor in the west end of the valley.

MEASURED MOVEMENTS

Three networks of stakes were set out at three sites in 1963. Two sites were selected on the northeast-facing slope, one below a late-lying nivation snowbank and the other below an early melting snowbank. The third site was placed on the dry southwest-facing slope where snow cover disappears early in the spring.

Each site consisted of twelve stakes, which were surveyed three times from June 26th to August 23rd, 1963. Calculated displacements of many of the stakes were considered much too large, when compared with results obtained by others in similar environments, Williams (1957), Smith (1960), Washburn (1960), and Everett (1962). Because of logistic difficulties encountered in 1964 there was no opportunity to resurvey the stakes and for this reason measurements are not presented here.

The 1963 measurements suggest that the direction of movement is controlled by slope form and the position of bedrock outcrops. Further, that movements by creep and/or solifluction were greatest below the late-lying snowbank and on other areas at or near saturation. The smallest movements occurred on the drier southwest-facing slope.

All types of mass-wasting considered, it seems that denudation is proceeding at a faster rate on the northeast-facing slope than on the opposing slope by a factor of 2 and perhaps as high as 3.

SUMMARY

The ice-free Tasersiaq area, marginal to the Sukkertoppen Iskappe, is underlain by jointed granite and gneiss which have a thin veneer of ground moraine. Kame-terraces of several generations occupy the valley bottom and occur at different elevations on both the southwest- and northeast-facing slopes.

With local exceptions, patterned ground is not well developed in the area because of the coarse grained texture of the moraine material. Solifluction lobes occur on both slopes, but solifluction sheets are essentially restricted to the gentler northeast-facing slope. Many sheets and lobes show an imbricate arrangement of boulders at their frontal margins. These features appear to be of rather recent age, and to have developed as a result of critical soil moisture and texture relationships inherited from the till and kame deposits which mantle the slopes.

Slump features which show imbrication of boulders on their frontal margins are common, both as recent and "fossil" forms. Micro-mudflows and debris slides are perhaps the most active features of the area in terms of volume of material moved downslope. The amount of soil displaced at any one time by a single flow ranges between a few thousand cubic centimeters and 2 cubic meters. There is considerable evidence that mudflows were active in the past, but no recent activity was observed.

Wind and water (both running and under pressure) are important elements in the pattern of mass-wasting in the Tasersiaq area.

Measured rates of movement by creep and/or solifluction in the area, though not wholly successful suggest that displacements are strongly influenced by the position of late-lying snowbanks. The direction of movement is controlled to a large extent by the configuration of the slope.

Both qualitative and quantitative observations of mass-wasting in the Tasersiaq valley suggest that the process is operating at a rate two to three times faster on the northeast-facing slope than on the opposing valley slope. The northeast-facing slope is the wetter slope because of the formation of large, long lasting snowbanks, the Piedmont snowbanks of EKBLAW, and consequently the more active slope. Snowbank accumulation on this slope is conditioned by the fact that it is a dip slope athwart the prevailing wind direction.

REFERENCES

BRYAN, K., 1940: Gully Gravure, a Method of Slope Retreat: Jour. Geomorphology, Vol. 3, p. 89–106.

CROWL, G. H. and GOLDTHWAIT, R. P., 1963: The Glacial Geology of Western Lake Tasersiaq, Greenland: in Sukkertoppen Ice Studies, Institute of Polar Studies, Unpublished Preliminary Report 1701–1, p. 2–4.

EKBLAW, WALTER ELMER, 1918: The importance of nivation as an erosive factor and of soil flow as a transporting agency, in northern Greenland: National Academy of Sciences of the U.S.A., Proceedings vol. 4, p. 288–93.

EVERETT, K. R., 1962: Slope Movement, Neotoma Valley, Southern Ohio, Institute of Polar Studies, Report No. 6, p. 59.

— 1964: Preliminary report on mass-wasting in the western Tasersiaqarea, southwest Greenland: p. 21–47 in R. P. GOLDTHWAIT, Tasersiaq area-Sukkertoppen Ice Cap studies, Ohio State University Research Foundation, Report 1702–2, unpublished, 67 p

— 1966: Slope Movement and Related Phenomena: Chapter 12, in Environment of Cape Thompson Region, Alaska, eds. N. J. Willmovsky and J. N. Wolfe. U.S. Atomic Energy Commission Report PNE–481, p. 172–220.

HOLOWAYCHUK, N. and EVERETT, K. R. (in prep.): Soils of the Tasersiaq Area, Greenland.

JAHN, A., 1946: Bodania nad Strukturą i Temperaturą Gleb w Grenlandi Zachodniej – (Research on the Structure and Temperature of the Soils in Western Greenland): Akademija Umiejetnosci Krakow, Classe Des Sciences Mathématiques et Naturelles Bulletin, International Series A 1940–46, p 50–59.

KOSIBA, A. 1937: Grenlandia: S. A. Książnica-Atlas. Lwów-Warszawa, Poland. 178 p.

— and LOEWE, F. 1964: Meteorological Observation in the Tasersiaq Area, Southwest Greenland, During Summer, 1963: Institute of Polar Studies, Report No. 11, 19 p.

LOEWE, FRITZ, et al., 1962: Reconnaissance of Sukkertoppen Ice Cap and Adjacent Tasersiaq Area, Southwest Greenland: Institute of Polar Studies, Report No. 4, 36 p.

RAPP, ANDERS, 1960: Recent Development of Mountain Slopes in Kärkevagge and Surroundings, Northern Scandinavia: Geografiska Annaler, Vol. XLII, No. 2–3, p. 73–200.

RUDBERG, STEN., 1958: Some Observations Concerning Mass Movement on Slopes in Sweden: Meddelanden Från Uppsala Universitets Geografiska Institution, Series A, No. 126, p. 114–125.

— 1960: Periglacial Geomorphology and Mass Movements in Sweden: Biuletyn Peryglacjalny, No. 11, p. 165–350.

SØRENSEN, T., 1935: Bodenformen und Pflanzendecke in Nordostgrönland: Meddelelser om Grønland, Vol. 93, No. 4, p. 1–70.

SMITH, J., 1960: Cryoturbation Data from South Georgia: Biuletyn Peryglacjalny, No. 8, p. 73–79.

WASHBURN, A. L., 1947: Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions, Arctic Canada: Geol. Soc. America, Memoir 22, 142 p.

— 1956: Classification of Patterned Ground and Review of Suggested Origins: Bull. Geol. Soc. America. Vol. 67, p. 823–866.

— 1960: Instrumentation for Mass-Wasting and Patterned Ground Studies in Northeast Greenland: Biuletyn Peryglacjalny, No. 3, p. 59–64.

WILLIAMS, P. J., 1957: The direct Recording of Solifluction Movements: American Jour. Science, Vol. 255, p. 705–714.

— 1959: Solifluction and Patterned Ground in Rondane: The Rondane Survey, Publication No. 6, p. 6.

Færdig fra trykkeriet den 30. januar 1967.