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MISCELLANEOUS CONTRIBUTIONS ON THE VEGETATION OF THE MESTERS VIG DISTRICT NORTHEAST GREENLAND

BY

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WITH 61 FIGURES AND 7 TABLES
IN THE TEXT

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CONTENTS

ABSTRACT

The first paper in this series deals with the vegetation of kames and emerged delta remnants that cover a large area about the mouth of Tunnelelv, reaching altitudes of about 110 m on the lower mountain slopes. Following a general discussion of the site factors of ground coverage by vascular plants, moisture, and physical disturbance, the vegetation is described in two specific localities. One of these involves the evolution of turf hummock systems in a small valley, and the other emphasizes the effects of wind deflation and deposition. Finally the flora of the kames and delta remnants is analyzed in terms of its tolerance of variation on the factor gradients mentioned above. An appendix contains observations on the effects of wind in two localities on the shore of the fjord.

The second paper describes the vegetation of a large earthflow in the hills back of Nyhavn. This flow exhibited a fresh break-away scarp and a disturbed area of accumulation below it resulting from an episode that appeared to have occurred within the preceding two years. Comparison was made with scars of earlier flows in the immediate vicinity. The behavior of the small vascular flora of the site (17 spp.) on gradients of coverage, moisture, and physical disturbance is discussed briefly, with no attempt to analyze it in detail.

The effects of slushflow upon vegetation are discussed in the third paper, which is based primarily upon observations in two localities: in the lower valley of a small mountain stream called Lejrelv, and in a similar situation at an altitude of about 230 m on the lower northeast slope of Hesteskoen. Slushflows in both of these areas occurred in the spring of 1958, and in both places botanical observations were made before and after the episodes. The flora is analyzed for differences in species compositions and in the tolerance proportions among its species $1^1/_2$ months, 2 years, and 6 years after the 1958 flows. An attempt is made to date earlier flows by the ages and times of physical injury shown by specimens of *Salix arctica* and *Betula nana* collected from the Lejrelv gully and its adjacent slushflow fan. It is suggested tentatively that the flows have occurred approximately at 10-year intervals since about 1900.

The fourth paper is devoted to palsen-like structures found in 1964 in the Tunnelelv valley about 2 km northeast of the base of Gorms Spids. They are in an area of well-developed turf hummocks, and appear as large peat mounds up to 10×8 m in ground plan and $1^1/_2$ m high. Some have their upper surfaces covered with turf hummocks of living moss and vascular plants, while on others the moss is dead and dry, causing the surface to be shrunken to saucer form. Several species of more xerophytic plants, not characteristic of the neighboring turf hummocks, are found on these dried surfaces. It is proposed that the large mounds are formed by intense frost action in the soils beneath, which are saturated throughout the summer. However, no excavations for evidence of this were made.

The fifth paper discusses the vascular plants of lake and sea shores in the Mesters Vig district. Both of these are poorly developed in the district, some small ponds and lakes and many sea shores being completely sterile. Information is reported from about 12 ponds and lakes and from several sea shores ranging from boulder beaches to sand and mud flats. It is suggested that the scarcity of the flora is due to the shortness and uncertainty of the available growing season and, in some lakes, to major fluctuations in water levels.

Calcicoly among Mesters Vig vascular plants, discussed in the sixth paper, is considered to be of minor importance due to limited development of habitats conducive to it. Basic elements in the soil are present very locally, due to occasional limestone pebbles, cobbles or boulders in the till and outwash, or to shells in the marine silts and clayey silts near the shore of the fjord. Comparison is made between the flora of the Mesters Vig district and reportedly calcicolous floras in neighboring parts of the fjord region.

The seventh paper deals with the vegetation of artificially disturbed habitats. It rests primarily on observations in the neighborhood of the Mesters Vig airfield and at "Camp Tahoe" which was the base for the expedition; but it also includes miscellaneous data from many other localities. No introduced plants were seen in the district, but 44 species from the native flora were found in ruderal habitats. Most of those found are from the vegetation types that were affected by the man-made disturbances, and it is suggested that more ruderal species would appear if other types were disturbed. The ruderal flora is analyzed in terms of its tolerance ratings on gradients of coverage, moisture and physical disturbance. The results suggest that the ruderal species are selected from their respective vegetation types by their special tolerances of nonfrost disturbance. It is impossible with present data to separate in some cases the effects of fertilization from those of physical disturbance. Other cases suggest that ruderal habitats are provided primarily by physical disturbance.

Fig. 1. Emerged delta remnants at mouth of Tunnelelv. View southwest from hills back of Nyhavn, 15 Aug. 1964. River and road to mine are at extreme left. Gravel flat at base of remnants is the northwest distributary of the river.

THE VEGETATION OF KAMES AND EMERGED DELTA REMNANTS

Introduction

A conspicuous feature of the Mesters Vig landscape is formed by a series of kames and emerged delta remnants in the ancient distributary system of Tunnelelv (Figs. 1, 2, 3). It comprises an area upwards of 6000 hectares. The lowermost of the emerged deltas, below about 25 m, margin the present gravel flats along the three outlets of the river, appearing as low, flat-topped terraces. These terraces have a veneer of silty sands over their gravels, thus differing as plant habitats from the higher ones. They have already been discussed elsewhere, and will not be included here (see WASHBURN, 1965, p. 30–37; RAUP, 1971, p. 39-49).

Although the delta remnants were visited on many occasions during the field seasons of 1956–64, most of the detailed data on vegetation were gathered on 1 Aug., 1957; 14–15 July, 1958; 30 July and 7 Aug.,

Fig. 2. Emerged delta remnants at mouth of Tunnelelv. View southeast from trap knob, MS 180, 4 Aug. 1957.

1964. The remnants and kames east of Tunnelelv were visited on 28–29 Aug., 1964. The maps and transects discussed below were made in 1957 and 1958. Data on soils were gathered in company with Dr. UGOLINI in the summer of 1964 (UGOLINI, 1966 A, B).

Topography and soils

WASHBURN has described this area as follows (1965, p. 30–31): "On each side of Tunnelelv a maze of kames and massive delta deposits with ice-contact faces indicate stagnation of the last ice. The emerged delta remnants extend to altitudes a little above 100 m, and the highest ones are pitted with kettles. The highest marine shells and undoubted marine strandline observed in the district are at altitude 76 m on the east side of Danevirke, and the radiocarbon age of these and other shells proves that the Mesters Vig district was open to the sea by about 9000–8500 B.P. if not earlier, and that by this time deglaciation was well under way. Following deglaciation massive fans were built in some of the areas vacated by the ice." "The marine limit is not precisely fixed . . . Delta treads in the vicinity of 100 m are common and, because of their prevalence and similar altitude in a number of different topographic situations,

Fig. 3. Kame topography at head of emerged delta remnants just east of Tunnelelv. Note dry lake bed at left. 29 July, 1964.

suggest that the marine limit is near this altitude. A well-exposed contact between foreset beds and overlying fluvial gravel in a remnant below the highest delta surface west of Tunnelelv is at an altitude of about 85 m. However, pending further data, an origin in glacier-dammed lakes cannot be excluded for these high deltas."

The kames and emerged deltas, although they contain varied plant habitats, are composed primarily of sand and gravel. This makes them very well drained and gives them a relatively deep permafrost table (exceeding 2 m). Thus their surface soils are subject to extreme desiccation in summer. Soils that retain some moisture through all or part of the summer are highly localized in shallow depressions on the delta benches, or along occasional small streams fed by late-lying snowdrifts, or around small kettlehole lakes among the kames and highest deltas.

Some moisture reaches stream beds in the upper deltas and kames from ground ice in the delta beds and in till farther upslope.

The kames are steep-sided knolls or ridges (Fig. 3). The delta remnants have nearly flat to very gently rolling surfaces with steep marginal slopes (Fig. 4). The slopes exposed to dry northwesterly winds from the fjord are commonly modified by these winds, which carry sand up from the steep slopes and distribute it over the adjacent benches. Small active dunes are occasionally found. The treads are partially dissected by steep-sided gullies. It is probable that these have been greatly modified by wind. Most of them open to the northwest, the direction from which most of the effective winds come (Figs. 7, 9). In several places they appeared to be altered currently by this process.

The entire area is covered by deep snow in winter, though in some years parts of the higher windward slopes blow clear for short periods. But most of the work done by the wind is almost certainly done during summer desiccation.

UGOLINI found soils with Arctic Brown profiles in many places on the emerged delta remnants (UGOLINI, 1966 A). Commonly they were ancient profiles, veneered with more recent deposits of sand ranging from a few centimeters to a meter in thickness. In places they were modified by cracks through which humus penetrated. The length of time necessary for the development of Arctic Brown profiles in the Mesters Vig district is unknown. However, the fact that intensive disturbance by geomorphic processes seems to destroy them or prevent their formation suggests that their presence is indicative of relative soil stability. From this it is probable that many kames and the bench surfaces of the delta remnants have not been disturbed at depth for a fairly long time, except by cracking. The latter probably has been due to desiccation, and its pattern is sometimes visible even under dense heath. UGOLINI's findings indicate also that the process of wind deflation and deposition has continued for a rather long time. Apparently there has been ample time for the sorting out of the flora which inhabits the area.

Site factors

For purposes of discussion and analysis three habitat complexes among the kames and emerged delta remnants may be roughly defined on the basis of moisture supplies. The driest sites are on the tops and upper slopes of the kame knolls, the convex or level surfaces of the benches (Fig. 7), windward slopes and the upper lee slopes of the steep bench margins. Broad stony stream channels formerly occupied by glacial out-flow are dry, lack fines, and are essentially sterile of vascular plants. Sites with the most moisture are in a few active stream beds (Fig. 4), on the small alluvial deposits along their margins, and on lake shores. Intermediate moisture sites are in the occasional shallow depressions in bench surfaces, or on the lower parts of lee slopes partially protected from the wind. Also intermediate are the patches of heath tundra scattered over the benches and kame slopes (Figs. 3, 14). Mesophytic moss mats have formed in and under the larger of these patches, affording insulation and increasing the retention of what little moisture is available.

Coverage of the ground by vascular plants

Ground coverage by vascular plants on the delta benches and on upper slopes of kame deposits varies from zero to about 70 %. Most of these surfaces had scattered plants and an average cover of about 10 % (range 0–25 %). Lichens were abundant except in areas of blowing sand. They were mainly crustose, with a few small foliose and fruticose species which were not conspicuous. Patches of *Cassiope* or *Vaccinium* heath (mainly the former) formed islands of denser cover. Somewhat greater density was found also in shallow, saucer-like depressions and on lower lee slopes. These areas had an average cover density of about 40 % (range 5–70 %). Wet mossy meadows and turf hummocks averaged about 65 % cover (range 50–90 %). The average for all sites in the kame-delta area was between 25 and 30 %. Thus, although there was wide variation, coverage in the area as a whole was relatively low. The greatest contrasts were made by the heaths occurring in rather sharply defined patches of relatively high density.

The moisture supply

The excessive drainage and summer desiccation of the sands and gravels have already been stressed. Delta benches and upper kame slopes have surficial moisture from snow for a short time in spring, but they soon dry out. Dwarfed *Vaccinium* on the tops of the "110-m" deltas were rooted in soils that were almost powder-dry when excavated about mid-July, 1958. At the same time there was appreciable soil moisture in the root zone of soils in shallow depressions on the benches and on lower lee slopes. There was water in a few small lake basins in the vicinity, and in small streams flowing from relict snow and thawing ground (see Figs. 3, 4). The stream shown in Fig. 4 disappeared in gravel a few meters beyond the edge of the map (Fig. 5). Even the larger gullies at the delta margins were dry or merely moist at the bottom.

Not only is there wide fluctuation in seasonal moisture, but also in the annual supply. In 1957 and 1958 there were lingering snowdrifts on lee slopes as late as mid-July and early August, and all the lakes were full or nearly so. 1960 was a heavy snow year, and most of the delta remnants remained covered until late June. Much snow remained on lee slopes and in hollows throughout the summer, supplying moisture to many surfaces that were dry in the summers of 1957–58. The summer of 1964 was long, warm and relatively dry. The soils in the area generally dried early, and remained dry through the growing season. Some snow in the latter half of August was too late in the season to affect most plants. The water disappeared from most of the lakes (Figs. 3, 50), streams were non-existent or reduced to small rills, sand was blowing vigorously, and the shallow depressions in the benches were dry and cracked.

The moisture supply, therefore, is highly variable seasonally and from year to year. It probably is most variable in habitats that in most years retain some moisture into the summer only to lose it by mid- or late summer. Sites in which the ephemeral moisture from snow melt disappears very quickly in spring have more uniformly dry conditions. Similar contrasts were found on grus slopes and hilltops among the trap knobs (RAUP, 1969 B, p. 160–179). The greatest variability probably is on the shores of small lakes and in beds of small streams, where there is a great deal of water in some seasons and some years, but little or none in others.

Frost disturbance in the soil

Frost heaving in these soils probably is nowhere very intense, for in most years there is not enough moisture in spring or at autumn freeze-up to produce it. It is most likely to occur in sites that in most years retain moisture through the summer, such as lake shores, stream beds, and at the base of some scarps. Frost heaving is less likely to appear in shallow depressions on the delta benches or on lee slopes. It probably occurs occasionally even on the driest sites when there is a short wet summer such as that of 1960.

Nonfrost disturbance of the soil

The most active disturbing agent in the old deltas and kames appears to be wind (Figs. 9, 10, 11, 12). Its effects are immediately obvious in areas of deflation and deposition on steep windward slopes and adjacent benches. Even the most stable-appearing gravel "pavements" on the benches and windward slopes of the "110-m" deltas lose fines in high winds. A small area of soil partially bound by a few vascular plants and organic crust on one of these surfaces was being undercut by wind, leaving a small bank about 20 cm high on the windward edge of it.

Erosion by water was seen mainly in the beds of the well-defined streams such as those in Figs. 4, 5. Lake shores were affected to a lesser extent. The streams have in places removed the fines from the surface gravel of their beds, and have formed local deposits of sandy alluvium. Some of these deposits are the sites of wet moss-sedge meadows and turf hummocks (Figs. 4, 5, 6).

The vegetation

Introduction

Sixty-five species of vascular plants were found growing in the area covered by the present study. Table 1 is a composite of lists made for each of the three habitat complexes mentioned above. The driest sites contained 39 species, the wettest 34, and the intermediate moisture sites 36. About 65 % of all the species were from those regarded as generally common or abundant in the Mesters Vig district, 32 % were occasional or locally common, and only 3 % were rare or locally occasional. Reference to Table 1 shows that 18 species (28 %) were found in all of the habitat complexes, 8 (12 %) were found in two complexes, and 39 (60 %) were in one each.

Compared to areas discussed elsewhere in the present series of papers (Raup, 1969B, 1971) the flora of the kames and deltas is relatively small. At ES 7 and 8 there were 88 species in a little over 2 hectares of ground and at ES 17 59 species were found within a space of about 500 square meters. The number of species in an area is clearly related to the relative extent of habitat differentiation in the area. Although there is a great deal of apparent differentiation in the kame-delta area, it is highly localized and in the aggregate covers only a small portion of the space. It is over-shadowed in its effects by the prevailing desiccation. Even the areas of more moist soil have seasonal and annual uncertainties in their water supplies. Thus the habitat differentiation of the area as a whole seems more apparent than real, and its lack is probably a major factor in limiting the vascular flora. It is probable also that this factor has been significant in restricting the rare or occasional plants to a very small number, for even partially specialized habitats are small and scattered.

The large percentage of the flora found in only one of the moisture-based habitat variants suggests, on the other hand, that some sorting has occurred. The analysis given below will indicate the way in which some of this may have been accomplished.

The vegetation was studied in detail in two small areas about one kilometer northwest of the main channel of Tunnelelv, and about the same distance from the southern border of the gravel flats that form the western distributary of the river. Sketch maps of these areas (Figs. 5, 8) were made in late August, 1957 from field notes, ground photo-

Table 1. *Vascular plants found on kames and emerged delta remnants bordering the mouth of Tunnelelv.*

	Dry sand & gravel on kame knolls, convex or level surfaces of benches, windward slopes, & upper lee slopes of steep bench margins	Shallow depressions in bench surfaces, lower parts of lee slopes, & in heath tundra on benches	Active stream beds, lake shores, & small alluvial deposits along streams
Equisetum arvense		+	+
Equisetum variegatum		+	+
Festuca brachyphylla	+		
Festuca rubra ssp. *cryophila*		+	
Poa arctica	+		
Poa alpina	+	+	+
Poa glauca	+		
Trisetum spicatum	+	+	+
Calamagrostis purpurascens	+		
Hierochloë alpina	+		
Eriophorum triste		+	+
Carex nardina	+		
Carex scirpoidea	+	+	+
Carex rupestris	+	+	
Carex Lachenalii			+
Carex bicolor			+
Carex Bigelowii		+	+
Carex supina ssp. *spaniocarpa*	+		
Carex glacialis	+		
Carex misandra	+		
Carex capillaris			+
Carex saxatilis			+
Juncus biglumis			+
Luzula arctica	+		
Luzula spicata		+	
Luzula confusa	+	+	+
Tofieldia pusilla		+	+
Salix herbacea		+	
Salix arctica	+	+	+
Oxyria digyna	+	+	+
Polygonum viviparum	+	+	+
Cerastium alpinum	+	+	+
Minuartia rubella	+		
Minuartia biflora	+	+	+

(continued)

Table 1 (continued)

	Dry sand & gravel on kame knolls, convex or level surfaces of benches, windward slopes, & upper lee slopes of steep bench margins	Shallow depressions in bench surfaces, lower parts of lee slopes, & in heath tundra on benches	Active stream beds, lake shores, & small alluvial deposits along streams
Silene acaulis	+	+	+
Melandrium affine	+		+
Ranunculus nivalis		+	
Ranunculus pygmaeus		+	
Papaver radicatum	+		
Draba nivalis	+		
Draba lactea	+	+	
Draba glabella	+	+	+
Draba cinerea	+		
Cardamine bellidifolia		+	
Arabis alpina			+
Saxifraga oppositifolia	+	+	+
Saxifraga nivalis	+	+	+
Saxifraga aizoides			+
Saxifraga cernua	+		+
Saxifraga caespitosa			+
Potentilla nivea	+		
Potentilla Crantzii		+	
Dryas octopetala	+	+	+
Epilobium latifolium	+	+	+
Pyrola grandiflora		+	
Cassiope tetragona	+	+	+
Arctostaphylos alpina	+		
Vaccinium uliginosum ssp. *microphyllum*	+	+	+
Armeria maritima ssp. *labradorica*	+		
Pedicularis flammea			+
Pedicularis hirsuta	+	+	+
Antennaria canescens		+	
Antennaria Porsildii		+	
Arnica alpina		+	
Taraxacum brachyceras		+	

graphs, and from aerial photographs supplied by the Geodetic Institute of Denmark (Photos 634S — 10949, 10850). The areas contain vegetation typical of most of the kame — emerged delta complex.

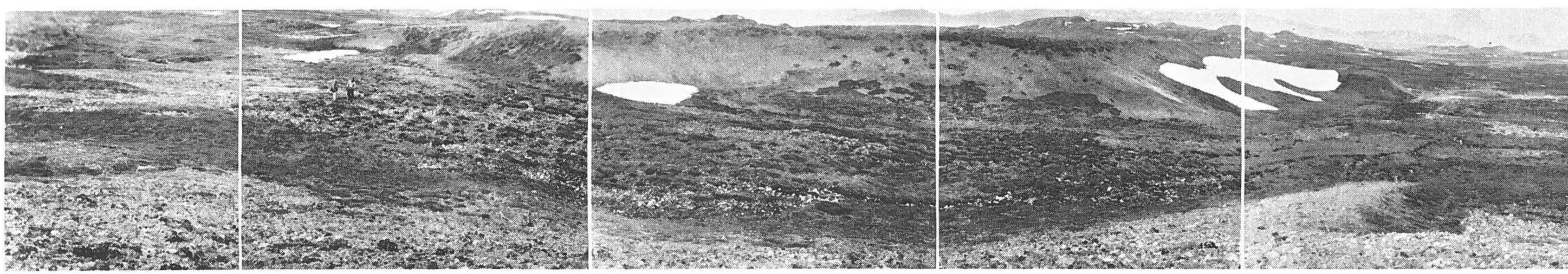

Fig. 4. Scene of vegetation study at first locality, "110-m" delta remnant. Views northwest (left) to northeast (right), 1 Aug. 1957. Photo from top of small knoll (110 m) at left in map, Fig. 5.

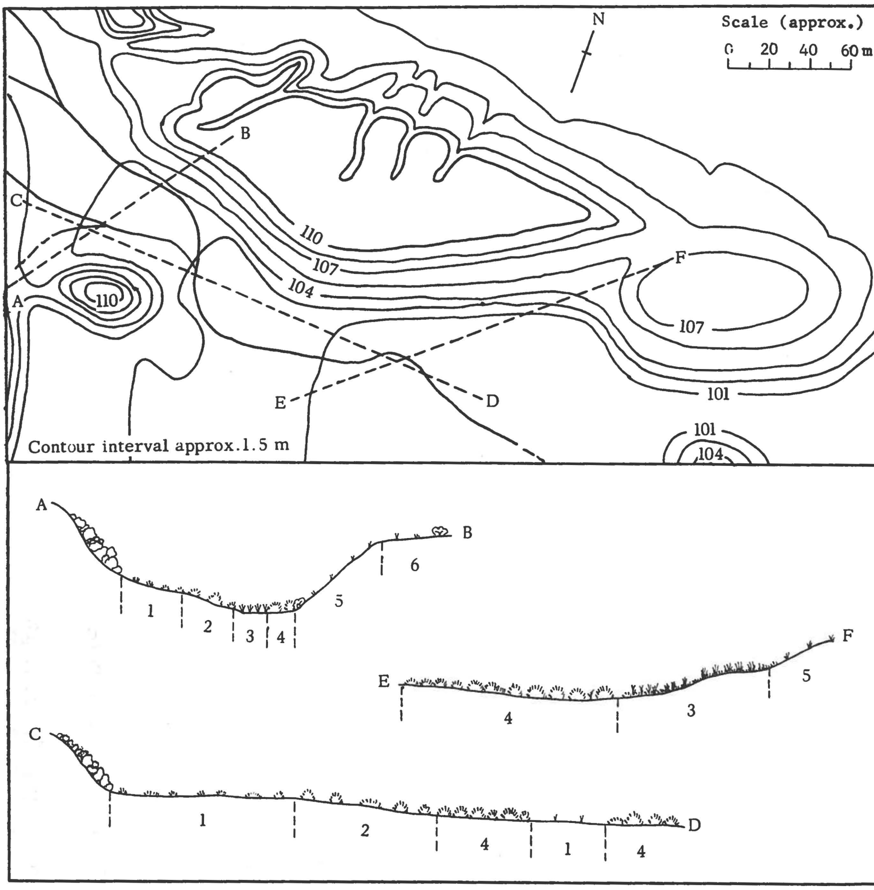

Fig. 5. Sketch map of topography and vegetation, "110-m" emerged delta remnant, about one km west of Tunnelelv; first locality discussed in text (see Fig. 4).

First locality

The map and diagrams in Fig. 5 were made near the upper margin of the kame-delta area, and represent the highest of the delta remnants, which are at about 110 m (see also Figs. 4, 7). Immediately above them, shown on the left side of the map, is a system of large bouldery gelifluction terraces. A small stream flows between the flat-topped remnant and a rounded gravel knoll just south of it. The stream derives its water in part from snowdrifts that linger in its upper valley and in part from thawing of frozen ground in the gelifluction terraces. Eastward from the base of the remnants it flows into the broad stony bottom of an abandoned stream-bed, and is there quickly lost. Transects A–B, C–D and E–F follow the lines indicated on the map. The numbers refer to vegetation types, and individual numbers to the same type in all the transects.

Zone 1. An area of nearly barren gravel at the base of a bouldery gelifluction terrace where the latter merges with the base of a delta remnant knoll. When seen on 1 Aug. 1957, water from the terrace was flowing in a thin sheet over most of the gravel. A few willows (*Salix arctica*) and patches of organic crust were scattered over it, many of the willows dead. There were occasional polsters of living moss. In the lower part of zone 1 there were a few low widely spaced turf hummocks, with most of their willows dead or nearly so, apparently due to desiccation. Though zone 1 is relatively narrow in Transect A–B, it was greatly expanded in C–D. It was developed mainly around the bases of the bouldery gelifluction terraces that bound the southerly side of the stream valley, and had its broadest expanses where seepage water from the terraces was most abundant. It reappeared in the lower part of Transect C–D in the midst of turf hummock vegetation. Here it was on the upper surface of a poorly defined lobate structure, where water was flowing over a broad area of gravel with occasional patches of crust and a few scattered vascular plants.

Zone 2. A zone of widely spaced turf hummocks 15–30 cm high bearing a small vascular flora principally of *Salix arctica* and *Vaccinium uliginosum*. The hummocks are separated by intervals of gravel which is barren or partially covered by organic crusts. Water was running over the gravels at the time of observation. The hummocks showed evidence of deterioration by early-season erosion and subsequent desiccation. Willow roots were exposed around their bases. Zone 2 was narrow at Transect A–B, and did not appear at all in E–F. But in C–D it was several meters broad, part of a considerable expanse of deteriorating hummocks which appears in Fig. 4 (the two figures are standing in it; see also Fig. 6).

Zone 3. This zone is associated with the stream channels, which are interspersed with small areas of wet moss-sedge meadow or hummocky meadow in which the hummocks are small and apparently in early stages of development. The soil is gravel overlain by alluvial sands in which buried humic horizons were seen. The primary vascular species was *Carex Bigelowii*. Secondary species were *Equisetum arvense*, *Carex scipoidea*, *Carex capillaris*, *Carex saxatilis*, *Juncus biglumis*, *Salix arctica*, *Polygonum viviparum*, *Dryas octopetala*, *Cassiope tetragona*, *Vaccinium uliginosum*, *Pedicularis flammea*. The immediate substratum for these plants was a turf 3–5 cm thick over sand. Zone 3 was not present in Transect C–D, but was well developed at the base of the delta remnant in Transect E–F where it occupied what appeared to be the tread and front of a small bench. There it received water from seepage and from a melting snow-

Fig. 6. Deteriorating turf hummocks in small valley among "110-m" delta remnants, shown in Fig. 4 and on map Fig. 5. Zone 2 of vegetation transects. 1 Aug. 1957.

drift that lay in the gully-like depression above it (see Fig. 4). Similar meadows were along the northeast side of the stream above the crossing of Transect A–B. These were watered by melting snowdrifts on lee slopes of the adjacent delta remnants (see Fig. 4).

Zone 4. A zone of maturing turf hummocks (15–30 cm high) separated by narrow channels in the main channel system of the stream, eroded down to the gravel. *Vaccinium uliginosum* was abundant on the hummocks. The zone was narrow on Transect A–B (2–3 m), but greatly expanded along Transects C–D and E–F. The hummocks in these areas were in places crowded, with the channels between scarcely developed. In others, especially on intervals in the braided stream, the interhummock channels were down to the gravel.

Zone 5. On the line of Transect A–B the vegetation changed rather abruptly at the base of the steep southerly slope of the delta remnant. There was a narrow zone of *Vaccinium* heath and then nearly barren gravel to the top of the slope. Elsewhere around the base of the remnant the heath extended about a third of the way up the slope. It was dense (cov. 80–90 $^0/_0$) in some places, but interrupted by bare spots. Associated species were *Salix arctica*, *Cassiope tetragona*, *Carex Bigelowii*, *Pedicularis hirsuta*, and *Equisetum arvense*.

Above the heath in places where it extended some distance upslope there were patches with low to intermediate cover (20–30 $^0/_0$). Here the following primary species alternated patch-wise: *Salix herbacea*, *Carex Bigelowii*, *Salix arctica*, *Vaccinium uliginosum*, *Cassiope tetragona*. All other plants were scattered indiscriminately: *Festuca rubra* ssp. *cryophila*, *Trisetum spicatum*, *Luzula spicata*, *Oxyria digyna*, *Cerastium alpinum*, *Minuartia biflora*, *Melandrium affine*, *Draba glabella*, *Cardamine bellidifolia*, *Saxifraga nivalis*, *Antennaria canescens*, *Arnica alpina*.

Sites of this kind were seen only on lee slopes protected from strong northwesterly winds, and somewhat concave to the sky. Lateral to them on the slopes, on surfaces convex to the sky, the soils were drier and in many places moving downslope by dry creep. On such places scattered mats of *Dryas octopetala* replaced the heaths and willow, and the herbaceous flora changed to isolated individuals or clumps of *Poa glauca*, *Carex nardina*, *Carex rupestris*, *Carex supina* ssp. *spaniocarpa*, *Luzula confusa*, *Oxyria digyna*, *Cerastium alpinum*, *Minuartia biflora*, *Draba nivalis*, *Draba cinerea*, *Saxifraga nivalis*, *Epilobium latifolium*. Most of the ground on the convex surfaces was bare, with vascular plant coverages less than 10 $^0/_0$. In a few places the creep was sufficient to undercut the edge of the bench above.

Zone 6. This is the top of the more or less elliptical delta remnant which is the principal topographic feature on the map (Figs. 5, 7). The soil is sandy gravel, most of it barren of any continuous vegetation except a few species of lichens. The open coverages ranged from 0 to about 20 $^0/_0$, but the average was 5–10 $^0/_0$. Very shallow depressions in some cases had organic crusts with well-developed nubbins (see WASHBURN, 1969, p. 85), suggesting a little more moisture than obtains on the flat or convex surfaces. However, most of these when seen were dry and cracked.

Scattered over the top surface were patches of *Cassiope* heath from one to several meters wide. A few of these could be correlated with depressions up to 2 m deep at the heads of gullies opening to the northwest. Others were scattered over flat surfaces apparently indiscriminately. They appeared to occupy soils that were undistinguishable from those

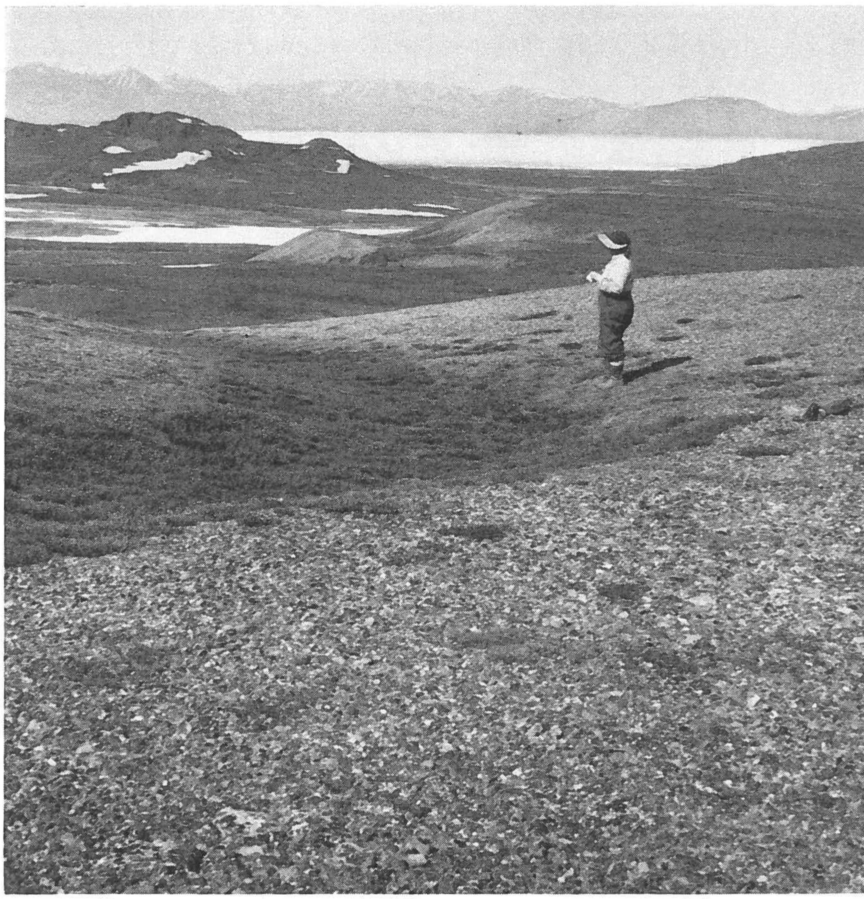

Fig. 7. Top of "110-m" delta remnant. View northeast, 15 July, 1958. Small patches of vegetation on gravel are *Dryas octopetala. Cassiope tetragona* is in headward portion of small gully opening N–NW.

nearby except that the presence of the heaths had given rise to thin organic horizons beneath them. The heath patches showed a great deal of mortality in the *Cassiope*, particularly at the margins. Coverage in patches varied from 50 to 70 $^0/_0$, formed almost entirely by the *Cassiope*, although occasional willows and blueberries were seen.

The flora of the more open areas was highly variable from place to place. At the northern end of Transect A–B it was extremely scanty, consisting of *Carex nardina* and a few widely scattered clumps of *Dryas octopetala* and *Vaccinium uliginosum*. These clumps were partially dead. A general list for the top surface made in 1958 added small mats of *Salix arctica* and widely spaced individuals of *Luzula confusa*, *Papaver radicatum*, *Poa glauca*, *Carex rupestris*, *Cerastium alpinum*, and *Draba cinerea*.

Other spots, examined in early August, 1964, added *Saxifraga nivalis*, *Minuartia rubella*, and *Potentilla nivea.*

The position of *Vaccinium* in this vegetation is difficult to evaluate. In many places it is extremely common, but it is so small, depauperate and inconspicuous that it is often missed. Individual "bushes" are commonly no more than 2–3 cm high, scarcely rising above the stones in the gravel, or above the crusted nubbins where the latter occur. Their capacity to live in such a dry site may be related to the structure of their root systems, which are prolific, fine textured and finely divided. Although the soils were almost as dry as powder, and ran through the fingers when picked up, they were sometimes found to be filled with great masses of roots from the tiny *Vaccinium* plants. With such a root system the species may be able to take up and live on very little soil moisture.

The summits of kame knolls and the tops of high knolls and bluffs among the delta remnants are favorite roosting places for birds. The resultant manuring of the soil makes the vegetation more luxuriant than it is on the surrounding surfaces. Not only are the plants more abundant but they also grow larger, with more stems or branches. The grasses are especially conspicuous. The areas involved are small (2–5 m diameter). The flora of such "bird places" seen in the Mesters Vig district did not differ floristically from their immediate surroundings. Some evidence that such spots have been used by the birds for a long time is in the fact that patches of Arctic Brown soil have developed directly beneath them (UGOLINI, 1966A, p. 16).

Turf hummock systems

The small drainage basin illustrated in Fig. 4 and in the transects appears to contain small replicas of the "turf hummock system" described in an earlier paper (RAUP, 1965B). Each of the snowdrifts in Fig. 4 has a moss-sedge meadow below it. These meadows merge downslope first into hummocky meadows in which the hummocks are small and in process of early proliferation of their mosses. These small hummocks merge into areas of larger, maturing hummocks with more or less dissected intervals between them.

The valley as a whole appears to contain an overall hummock system that may or may not be independent of those that are clearly related to the present snowdrifts. The upper part of the basin has the large area of disintegrating hummocks noted above (Fig. 6). Below this the valley narrows (near Transect A–B), and the stream gradient steepens. The stream is actively dissecting the turf hummocks here, but on the more gentle slope below the water is more widely dispersed, the dissection is less, and the dispersed moisture supplies a relatively large area of mature or maturing hummocks.

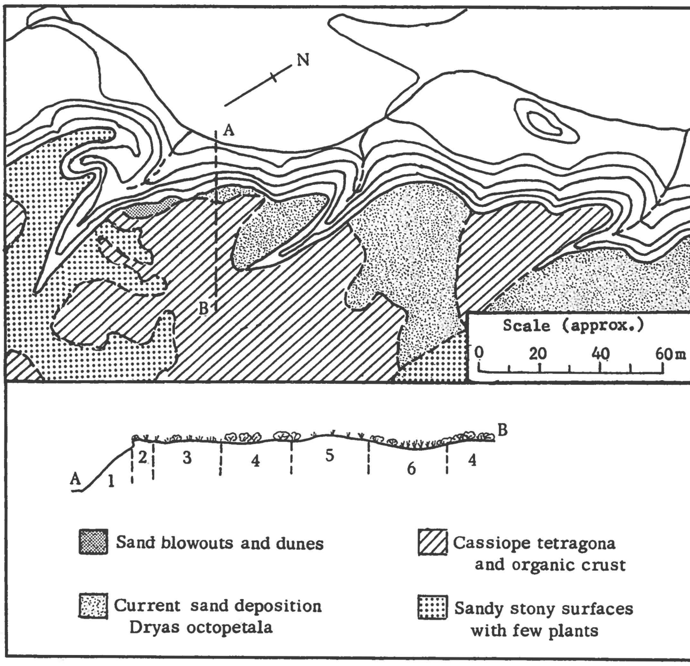

Fig. 8. Sketch map of topography and vegetation, "90-m" emerged delta remnant, about one km west of Tunnelelv; second locality discussed in text.

The presence of the deteriorating hummocks over a large section of the upper valley suggests that not long ago there was a wet moss-sedge meadow over most of the gravel in this part of the basin. To produce such a meadow, of which the present ones may be small remnants, much more summer moisture would be required than now obtains. The larger, more persistent snowdrifts postulated for the earlier years of the present century could have supplied this need (Raup, l.c., p. 96–99).

Less snow, accompanied by longer and perhaps warmer open seasons probably also affected the drier parts of the kame-delta area. Some evidence of this is in the depauperate condition of *Vaccinium* on the tops of the delta remnants, together with the high mortality and broken continuity of the heath. Large expanses of this heath were found (Fig. 13), but they were on the upslope portions of lower delta remnants, where they received snow melt water from the remnants above them.

Second locality

The second phase of the delta remnant study is partially mapped in Fig. 8. It is about $^1/_8$ km northeast of the "110-m" remnants described above, and at an altitude of about 90 m. It differs from the preceding phase in having on its northwest (windward) side a steep bank of loose

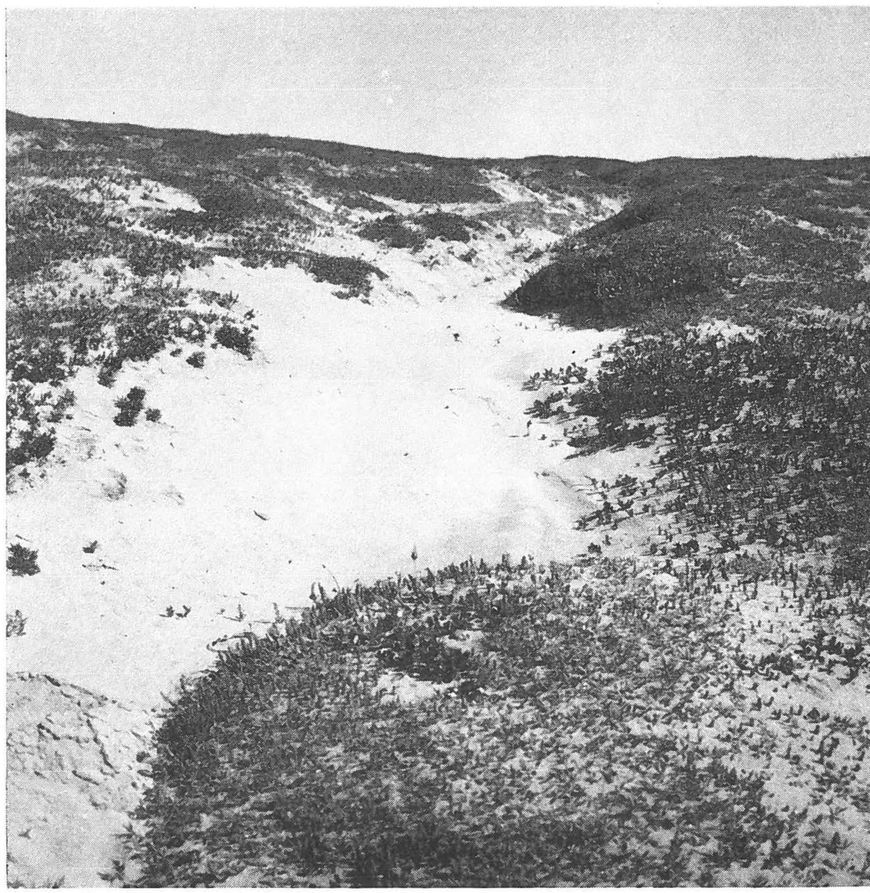

Fig. 9. Deflation and deposition on windward margin of delta remnant shown in map Fig. 8. Incipient gully formed or modified by wind. Plants are *Dryas octopetala*, *Salix arctica*, *Arctostaphylos alpina*, *Epilobium latifolium*. Part of zone 2 of transect in Fig. 8. 14 July, 1958.

sand which is being eroded actively by the wind. The bank is 20–30 m high above the adjacent valley which is here a broad depression opening to the northwest. The sand bank, one of many in the emerged delta area, is subject to the full force of northwest winds blowing down Kong Oscars Fjord. The top of the delta remnant is more or less flat in some places, and in others has broad rounded knolls and depressions. The total relief is for the most part a meter or less. Transect A–B is schematic, showing the general relation of the vegetation to the topography.

Zone 1. The steep bank of sand was essentially sterile of plants. Dry creep was moving sand downslope, while the wind was carrying a great deal of it up and scattering it over the adjacent bench. Both pro-

Fig. 10. Wind deflation and deposition on top of emerged delta remnant east of Tunnelelv, 28 July, 1964.

cesses were undermining whatever vegetation was at the top. Plants found on the steep slope were nearly always rooted in some piece of soil sliding down from the bench surface.

Zone 2. The top of the delta back of the abrupt break in slope at the top of the sand bank can be divided roughly into three kinds of sites. First is a relatively narrow zone (1–10 m wide) just back of the edge characterized by deflation and in some places the formation of small dunes. Second are broad areas of accumulation that are clearly receiving sand at the present time. Third are areas that probably are receiving small amounts, but here it is not readily visible among the stems of the plants. This third type has relatively level places alternating with low, dry sandy knolls and shallow depressions that sometimes have a small amount of moisture in their soils.

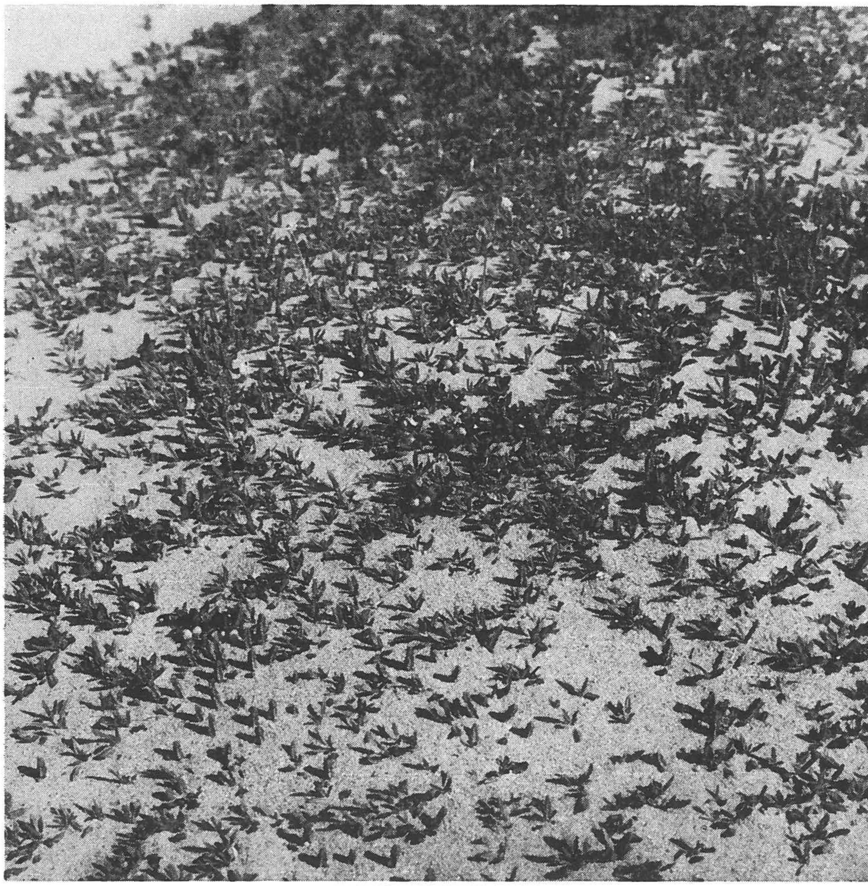

Fig. 11. Heath tundra inundated by wind-blown sand on "90-m" delta remnant, 14 July, 1958. See Fig. 12.

Zone 2 of Transect A–B is the area of deflation and deposition. It is discontinuous along the break in slope. Dense clumps of *Cassiope* apparently can hold the sand for a while, but they eventually die and disintegrate or fall en masse. Where the tundra is thinly populated it is easily blown out. In the immediate vicinity of the transect the vascular plant coverage in zone 2 was less than 5 %, made up of *Carex nardina* and small mats of *Dryas octopetala*. Less than half of the remainder of the ground had lichens and *Polytrichum* moss on it.

Nearby gullies extending back into the bank were being modified by the wind. A few meters south of the transect this was especially evident in a small lateral gully on the easterly side of a "peninsula" of the remnant surface. There was much deflation and deposition on the slopes of these gullies (Fig. 9), with mats of heath being blown out and inundated

Fig. 12. Heath tundra on "90-m" delta remnant, partially covered by sand blown from northwest margin of remnant. Zone 3 of transect in Fig. 8. 14 July, 1958.

alternately. Most abundant of these plants was *Dryas octopetala.* Nearly as common, and appearing alternately, were *Arctostaphylos alpina* and *Cassiope tetragona.* Others were *Salix arctica* and *Epilobium latifolium.*

Toward the eastward margins of the deflation zone coverage is a little greater (10–15 $^0/_0$) and varied by the addition of *Hierochloë alpina, Minuartia rubella, Papaver radicatum* and small clumps of *Cassiope.*

Zone 3. The deposition of sand on the bench surface apparently is discontinuous (see map, Fig. 8), and seems to be coincident with periods of activity on one or another segment of the windward banks. A segment a few meters north of the transect seems to have been active recently, for fresh sand was visible in the vegetation at least 100 m eastward from the deflation zone (Figs. 11, 12). Elsewhere such new sand could not be detected. The recent deposits gradually became thinner from west to east.

Fig. 13. Heath tundra continuous over large area on top of "90-m" delta remnant. Predominantly *Cassiope tetragona*. 14 July, 1958.

Where the new deposits were relatively thick, toward the western edge, *Dryas octopetala* clearly predominated (Fig. 12). It formed wide expanses, made conspicuous by pale green foliage. In many places only the tips of branches and flower stalks projected above the sand. As the new sand thinned eastward the *Dryas* was gradually replaced by *Cassiope* heath, varied by mixtures or nearly pure stands of *Vaccinium*. *Dryas* and *Salix arctica* were only occasional in this heath. Other species scattered through it were *Carex Bigelowii*, *Luzula confusa*, *Polygonum viviparum*, *Silene acaulis*, and *Pyrola grandiflora*. Although fairly large expanses of relatively dense heath (50–80 $^0/_0$ cov. could be found in the vicinity (Figs. 13, 15), its most common distribution was in isolated patches (Fig. 14). Intervening areas had bare soil or organic crusts with a few scattered herbaceous species.

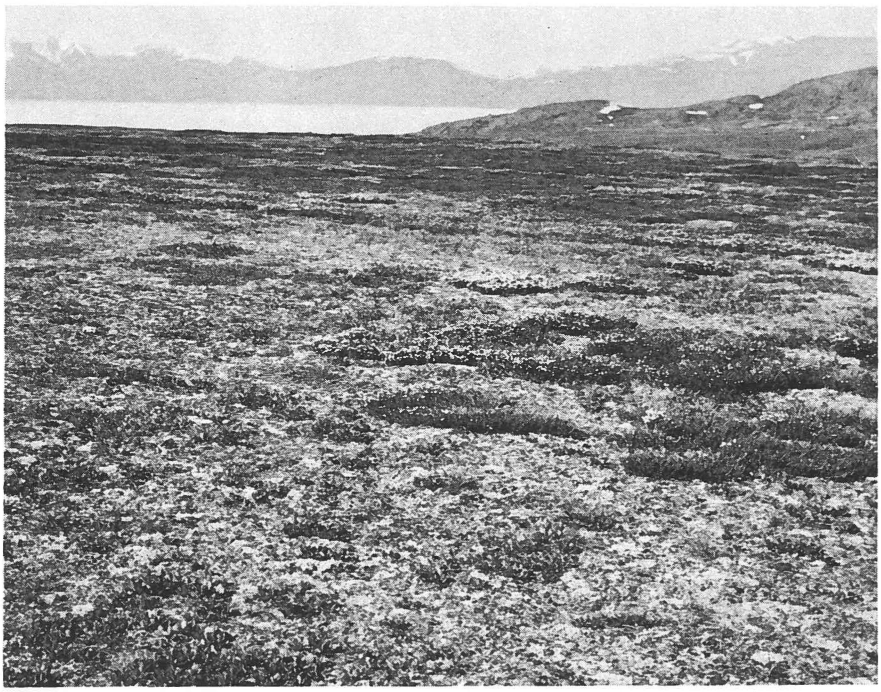

Fig. 14. Heath tundra, mainly *Cassiope tetragona* with patchy distribution on essentially level surface of "90-m" delta remnant. 14 July, 1958.

Zone 4. The vegetation of shallow saucer-like depressions varied from a thin tundra of organic crust and scattered vascular plants to a denser, meadow-like type. Coverage even in the latter reached only about 40 $^0/_0$. The most characteristic species in these "meadows", giving them the appearance of a green sward when seen at a distance, was *Carex Bigelowii*. Associated with it were: *Equisetum arvense*, *Trisetum spicatum*, *Luzula confusa*, *Salix arctica*, *Polygonum viviparum*, *Cerastium alpinum*, *Minuartia biflora*, *Ranunculus nivalis*, *Ranunculus pygmaeus*, *Cardamine bellidifolia*. Marginal to the sedges in the depressions were more organic crusts, and an abundance of *Salix herbacea*. *Cassiope* and *Salix arctica* were occasional in these margins. The soils in the depressions were clearly more moist than those around them. In the dry summer of 1964, however, desiccation was general over the bench surfaces.

Zone 5. Convex surfaces on the top of the delta remnant, forming low rounded knolls, were usually of dry sandy soil. Their vascular plant cover ranged from 0 to about 10 $^0/_0$. Approximately 5 $^0/_0$ of the surface was bare sand. The commonest lichen was *Stereocaulon* sp., and there was a great deal of *Polytrichum* moss. These species with a few other

Fig. 15. Mixed heath tundra of *Cassiope*, *Vaccinium* and *Salix arctica* on top of "90-m" delta remnant. 3 Aug. 1964.

lichens covered most of the ground surface. Vascular plants were scattered as individuals or small groups, the most conspicuous being widely separated mats of *Salix arctica*. The upper parts of the knolls were the most open, and were margined by isolated stands of *Cassiope*. Mortality in the willow mats appeared to be high, and occasional deflation of the sand by wind was seen. Other species of vascular plants were: *Poa arctica*, *Festuca brachyphylla*, *Trisetum spicatum*, *Luzula confusa*, *Cerastium alpinum*, *Minuartia biflora*, *Silene acaulis*, *Papaver radicatum*, *Draba lactea*, *Saxifraga nivalis*, *Dryas octopetala*.

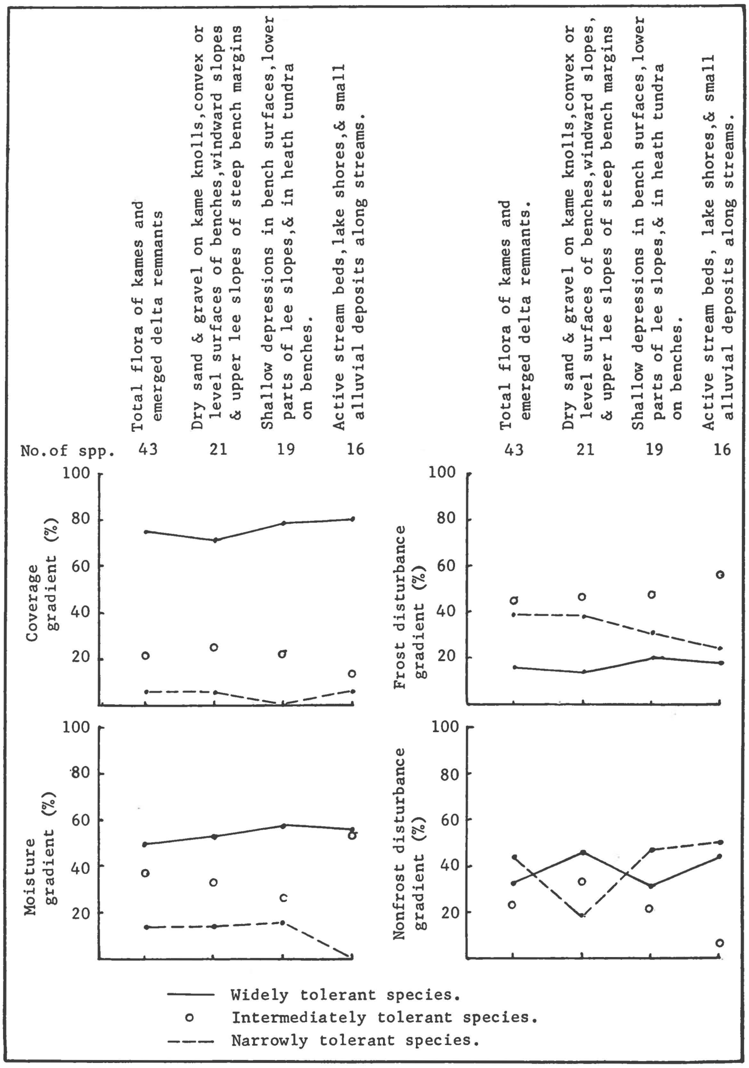

Fig. 16. Distribution of species tolerance on gradients of ground coverage, moisture and physical disturbance in three habitat complexes on kames and emerged delta remnants, compared to its distribution in the whole kame-delta area.

Behavior of the species on gradients of ground coverage, moisture and physical disturbance

In the following analysis the three habitat complexes described above, and used in Tab. 1 to define floristic units, are compared in terms of the distribution of their species with respect to tolerance of variation on some environmental gradients. The whole vascular flora of the kame-delta area is also used in the comparison. The method of analysis is similar to that employed in earlier papers of the present series. Only definitive species are admitted to the graphs in Fig. 16; *i.e.* those that are not widely or narrowly tolerant of variation on all the gradients.

The coverage gradient

Vascular plant coverage in the kames and emerged deltas was extremely variable, ranging from zero to over 80 %. Even the densest vegetation, such as the *Cassiope* heath, was broken by frequent intervals of 10–20 % coverages. The heath itself varied from 50 % to 80–90 %. The high percentages of wide tolerance of cover variation shown in Fig. 16 reflect not only the situation in the kame-delta area, but also the prevailing structure of the vegetation in the Mesters Vig district as a whole (RAUP, 1969A, p. 39–49).

The moisture gradient

The prevalence of summer desiccation produces relatively large seasonal and annual variations in moisture supply. The generally high proportions of species widely tolerant of moisture variation reflect this. Analysis of the flora of the whole area as a "norm" shows that departures from its behavior in the three habitat complexes are not great (about 10 % in wide tolerance and 16 % in narrow). This suggests that the whole range of moisture variation in the area is not sufficient to effect much sorting of species. However, the curves for tolerance proportions on the moisture gradient trend in the directions expected from observation of habitats. The widest variation, as previously noted, probably is in the sites having the most moisture in the summer (wet meadows and turf hummocks). In these sites the percentage of wide tolerance is relatively high and no definitive narrowly tolerant species were seen. A relatively lower percentage of wide tolerance and a higher proportion of narrow were in the sites that had least variation because they became dry very early in spring and remained so. The intermediate moisture sites did not differ much from the driest in tolerance proportions, suggesting that summer desiccation was about equally effective in the selection of species even though it was somewhat delayed.

The frost disturbance gradient

With little soil moisture available in the autumn, and not much frost action as a result, species sensitive to frost heaving (narrowly tolerant) should be able to grow in the kame-delta area with relative impunity. The curves in Fig. 16 for the frost disturbance gradient suggest that this was the case. In all of the sites, including the area as a whole, narrowly tolerant outnumbered widely tolerant species. The trends of the curves, reversing those on the moisture gradient, are also consistent with expectation. Sites that occasionally remained moist through the summer in wet years probably were heaved to some extent, and should have, as they do, a little lower proportion of narrowly tolerant species, and a little higher percentage of widely tolerant. Neither of these trends, however, has been sufficient to reverse the proportions, probably due to the dominant effects of desiccation.

The nonfrost disturbance gradient

Only on this gradient, dominated by wind disturbance of the dry soils, was there clear contrast between habitat complexes. (For a discussion of the nonfrost disturbance factor see Raup, 1969 A, p. 59–62; 1969 B, p. 199–203). On the benches, kames, windward and upper lee slopes there were more than twice as many definitive species widely tolerant as narrowly tolerant of nonfrost disturbance. The curves in Fig. 16 show reversals of these proportions in the more moist soils of depressions, lower lee slopes, heath tundra, wet meadows and turf hummocks, where narrow tolerance was more prevalent than wide. A proportionately lower percentage of wide tolerance in intermediate moisture sites than in higher moisture, suggests that in the latter, largely found along streams and lakes, erosion by water may have had some influence. Comparison with the analysis of the flora as a whole suggests that the floras of the damp to wet sites were closer to the "norm" than that of the driest sites. It also suggests that in all of the wetter sites, though narrowly tolerant species superceded widely tolerant, the difference was not very great (6–15 $^0/_0$). It is probable that the nonfrost disturbances have been effective in selecting a relatively large number of species resistant to them throughout the area, though not so effective as to eliminate a little larger proportion of the sensitive species. Nonfrost disturbances have accomplished the latter only in sites especially subject to wind action.

Appendix: Supplementary notes on wind action in the Mesters Vig district

Deflation and deposition by wind were discussed briefly above in the vegetational studies of emerged delta remnants (p. 23–33, figs. 9–12). They were also noted in the discussion of ES 16 which is near the top of MS 112m (Raup, 1969 B). The following are supplementary observations on wind action in two localities containing beach sand. One of these is in the vicinity of Fangsthus, a small house on the fjord side of a narrow neck of land separating Noret from the open fjord (see map, pl. 1, in Washburn 1965). The other is near the northwest shore of Noret, where the latter

Fig. 17. View northwest from base of Labben overlooking the sand and mud flats of the central distributary of Tunnelelv. Sand in left foreground has been blown over the low trap ridge to form a small beach on the northwest shore of Noret which is just outside the photo at lower left. The north side of this ridge is polished by the blown sand (see Fig. 19). 10 July, 1958.

is separated from the broad sand flats to the northward by a low trap ridge (Fig. 17).

The shore near Fangsthus consists of a gently sloping sand beach several meters wide, subdivided by a low ridge of sand and pebbles. This ridge is above ordinary high tides, but is affected by occasional storm waves. The beach and ridge are cluttered with flotsam: windrows of dried algae, driftwood, parts of boats, barrels, etc. The stony-sandy ridge was dry when seen on 17 July, 1958, with the sand being blown about by the wind. The adjacent tundra was on a gentle slope, with intersecting soil cracks parallel and normal to the shore line.

Fig. 18. Sand dunes developed around proliferated plants of *Salix arctica* and *Dryas octopetala* on the windward side of trap ridge (MS 69), at northwest base of Labben. 10 July, 1958.

The lower beach was entirely sterile of vascular plants, in this respect similar to most other fjord beaches in the Mesters Vig district. The low stony-sandy ridge, however, had a scattered flora of some 18 species, among which *Silene acaulis*, *Luzula confusa* and *Salix arctica* were most common. Others are as follows: *Poa arctica*, *Phippsia algida*, *Carex nardina*, *Carex Bigelowii*, *Juncus biglumis*, *Salix herbacea*, *Cerastium alpinum*, *Sagina intermedia*, *Minuartia biflora*, *Papaver radicatum*, *Draba lactea*, *Draba subcapitata*, *Cardamine bellidifolia*, *Saxifraga oppositifolia*, *Saxifraga nivalis*. There were occasional moss polsters, but lichens were very few and restricted to crustose species on stones. The nearby tundra was mainly covered with organic crust vegetation broken here and there by scattered mats of *Salix arctica*, *Dryas octopetala*, and *Cassiope tetragona*.

Fig. 19. North (windward) side of low trap ridge shown in foreground of Fig. 17. Sunlight is reflected from rock surfaces polished by windblown sand from sea beaches to right of picture. 4 Aug. 1964.

A few of the species, such as *Juncus biglumis* and *Salix herbacea*, were seen only in shallow depressions where the sand was slightly moist. Most of the plants, however, were being alternately buried and exposed by blowing sand. Some formed the nuclei of miniature dunes, notably *Poa arctica* and *Draba subcapitata*.

The small bay called Noret is separated from the tidal flats north of it by a low trap ridge that extends, with one small gap, from Langdyssen to the base of MS 69 m on Labben (Fig. 17) This ridge system also separates the northeastern and southeastern distributaries of Tunnelelv. The flats north and northeast of the ridges comprise 3–4 sq. km, and are open to the dry northwesterly winds from the fjord. These winds have blown sand from the tidal flat and piled it against the northerly base of MS 69 m and the low connecting ridge

Fig. 20. Lichens on sand-polished trap shown in Fig. 19. Note destructive effects of sand-blast on lichen thalli. 11 July, 1960.

mentioned above. Some of the sand has been blown over this low glaciated ridge and has formed a small beach at the northwest corner of Noret. This sand has polished the northerly face of the trap (Fig. 19). Small dunes up to 60 cm high have been formed on the windward slopes facing north and northwest (Fig. 18).

Most of the active sand is nearly barren. The principal dune-forming plants are *Salix arctica* and *Dryas octopetala*, the latter associated mainly with the larger dunes. These plants form dense mats which accumulate sand, and the branching stems proliferate upward as the dunes grow. Dissection of one of the larger dunes showed that it was filled with these stems and with dead willow leaves remarkably well preserved. Other species seen on the dunes are *Carex nardina*, *Polygonum viviparum*, *Silene acaulis*, *Saxifraga oppositifolia*, *Epilobium latifolium*. Very few plants were seen on the interdunal sands. *Epilobium latifolium* was found on these sands as well as on the dunes.

The sand-blasted surfaces of the trap ridge are made conspicuous by reflected sunlight (Fig. 19). Examined at close range, however, they proved to have lichen "patterns" on them (Fig. 20). Many of the patterns, formed by the radial growth of the lichen thalli, were 1–3 dm broad. In some cases the outer parts of the thalli were present while the central portions were gone. In other places only the etched surface of the rock indicated the lichen outline, the plant itself having been eroded away by the blown sand. Very few young thalli were seen on the surfaces that were most directly in the path of the sand.

The abundance and size of the old lichen thalli suggest that they were able to become established and grow for many years without being damaged by sand-blast. This period of expansion appears to have been followed by increased erosion which continues nearly or quite to the present. The general desiccation of the landscape in the Mesters Vig district during the last 60–75 years, for which evidence is found elsewhere, may account for the increase of sandblast activity shown by the deterioration of the lichens.

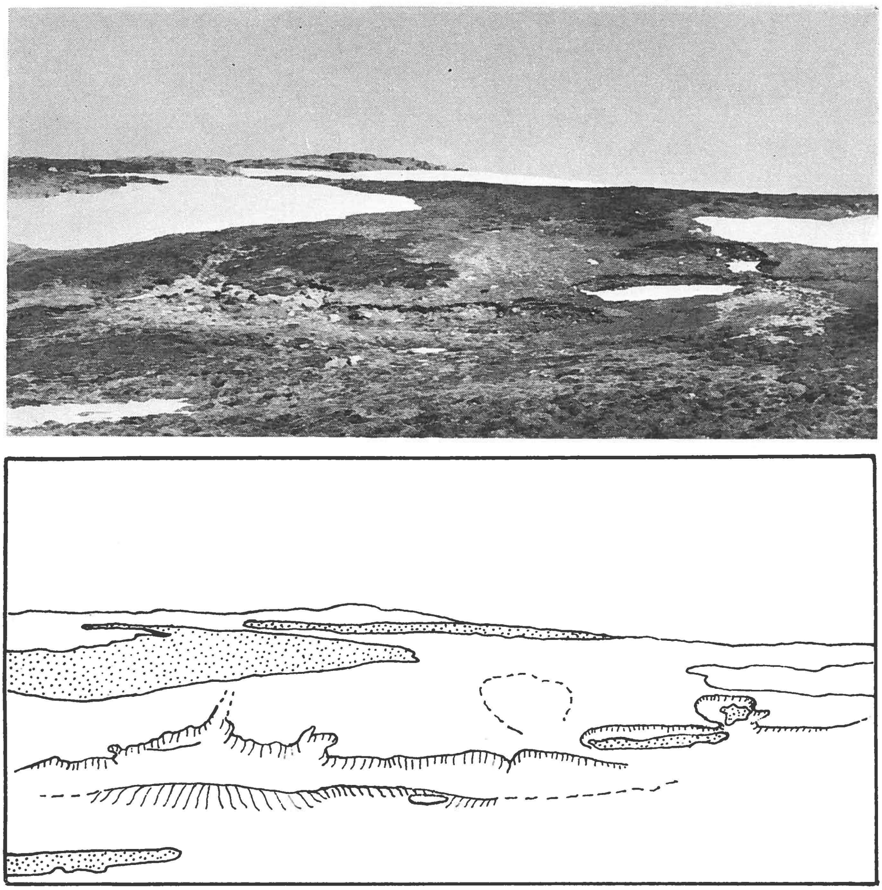

Fig. 21. Earthflow on valley slope just north of trap knob MS 112 m, hills back of Nyhavn. View north. 16 July, 1960.

THE EFFECTS OF EARTHFLOW UPON THE VEGETATION

Introduction

Earthflow, as the term is used here, involves more-or-less sudden movement downslope of large masses of earth leaving a break-away scarp. The process as observed at Mesters Vig usually has resulted in disruption of the flowed material and its accumulation at varying distances below arcuate scarps.

Most if not all of the earthflow features seen were in relatively fine textured glacial till or in emerged marine deposits of clayey silt. They are common throughout the district on slopes underlain by these materials.

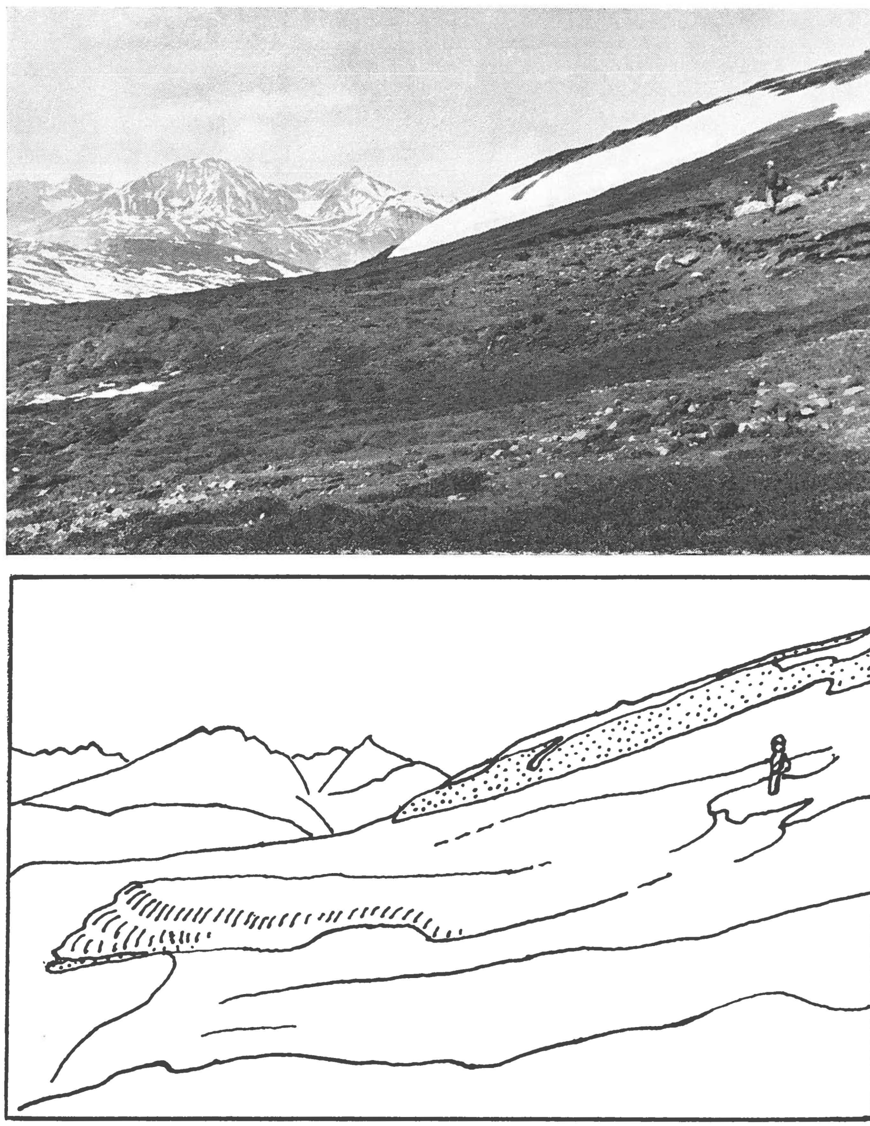

Fig. 22. Earthflow on valley slope just north of trap knob MS 112 m, hills back of Nyhavn. View west. 16 July, 1960.

Freshly formed ones were observed on only a few occasions, but scars of characteristic form were abundant. After the features were formed, gelifluction and creep tended to smooth the contours, but the essential forms remained clearly identifiable. The individual episodes by which earthflow occurs appear to depend upon especially abundant supplies of melt water in localized areas of thawed ground.

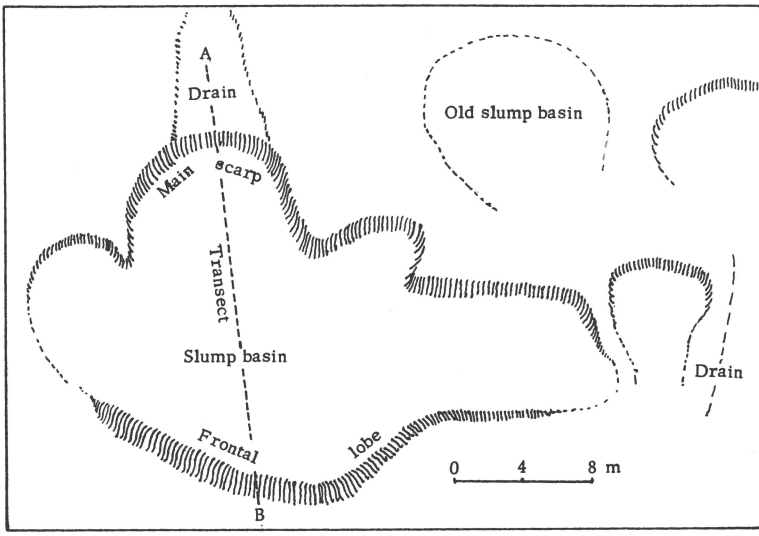

Fig. 23. Sketch map of earthflow on valley slope just north of trap knob MS 112 m, hills back of Nyhavn (see Figs. 21, 22).

A single case of earthflow was studied in considerable detail (Figs. 21, 22). It was located on a lower south-facing slope in the hills back of Nyhavn, at an altitude of about 90 m, in a valley just north of trap knob MS 112 m. This valley was visited in the field seasons of 1958 and 1960. In 1958 the feature was not seen, although WASHBURN remembered seeing some cracks on the slope that may have been incipient flows. On the date of the study, 16 July, 1960, there were one large and several adjacent smaller flows, all of them appearing fresh. In at least two of these (see Fig. 21) were remnant snowdrifts from the winter of 1959–60, suggesting that the flow studied did not occur in the spring of 1960. Thus it is assumed to have occurred in 1959.

Topography, soils and water supply

The area involved in the flow was approximately 1000 square meters (see map, Fig. 23). The slope at the main scarps was about 22°, while just below the frontal lobe it was about 10°. Below the flow area the slope continued gentle and merged with the valley floor. The rounded hill above the area rose to about 140 m. The main scarp at the transect A–B (see Fig. 27) was about 1.5 m high. Elsewhere it ranged from this down to a few centimeters. Below the main scarp was an area called the slump basin. The upper part of this basin was more-or-less concave to the sky, while the lower part, subtended by the frontal lobe, was convex. The frontal slope of the lobe at the transect was about 55°, but elsewhere it varied from 20° to nearly vertical. The average slope of the slump basin was about 5°.

Flows lateral to the main one were smaller and more shallow, though the same forms were evident. On parts of the slope marginal to these smaller flows were still lesser ones represented by systems of arcuate cracks. Variously healed scars of earlier flows were common in the neighborhood. In these the scarps were still evident as steeper slopes in arcuate patterns around the upper sides of basins which in many places were still subtended by low frontal lobes (Fig. 30).

The upper part of the slump basin had large areas of bare soil, as did also the scarp. Boulders, cobbles and pebbles were scattered over them, some obviously still slumping out of the face of the scarp (Fig. 25). Also there were scattered masses of surface soil with their vegetation still intact and growing. The lower parts of the basin had their vegetation still present but variously modified (see below).

Water supply to the flow area was almost entirely from melting snow and thawing ground on the slope above. Remnant snowdrifts were present on this slope in mid-July when the study was made, and it is probable that their location was repetitive (Figs. 21, 22). There were several very light rains recorded at the Mesters Vig weather station in 1959 (1–4 mm) and one of about 13 mm in the first week of August. Summer precipitation in 1958 was slight (total of 6.4 mm in June, July and August). It is not known whether the rains in 1959, particularly the 13 mm early in August, were effective in triggering the flow (for data on precipitation see WASHBURN, 1965, Tab. 1, Fig. 3).

The vegetation

The flora of the study area was sparse, consisting of 17 species of vascular plants (Table 2).

Table 2. *List of vascular species found growing on recent earthflow in hills back of Nyhavn, 16 July, 1960.*

Poa arctica	*Polygonum viviparum*
Trisetum spicatum	*Silene acaulis*
Hierochloë alpina	*Draba glabella*
Carex rupestris	*Potentilla Crantzii*
Carex scirpoidea	*Cassiope tetragona*
Carex Bigelowii	*Vaccinium uliginosum* ssp. *microphyllum*
Luzula spicata	*Antennaria Porsildii*
Luzula confusa	*Taraxacum brachyceras*
Salix arctica	

Figure 24 is a diagrammatic sketch of the topography and vegetation along the transect A–B, Fig. 23. For purposes of description it is divided

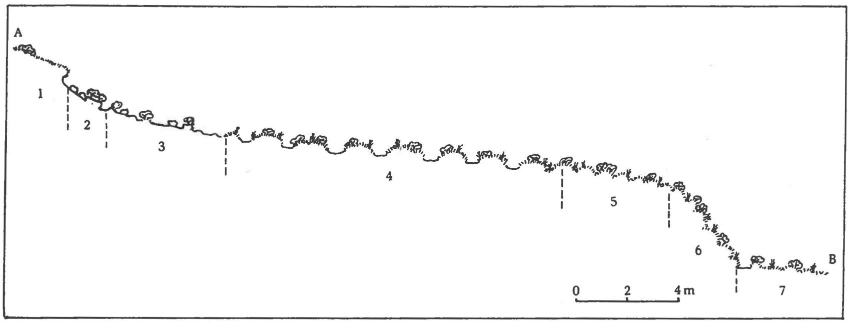

Fig. 24. Transect of topography and vegetation of earthflow in hills back of Nyhavn, along line A–B in Fig. 23. 16 July, 1960.

Fig. 25. Main scarp and upper part of slump basin in earthflow, hills back of Nyhavn, 16 July 1960. Zones 1, 2, and part of 3 in transect shown in Fig. 24. View north-west. Scale is 17-cm rule.

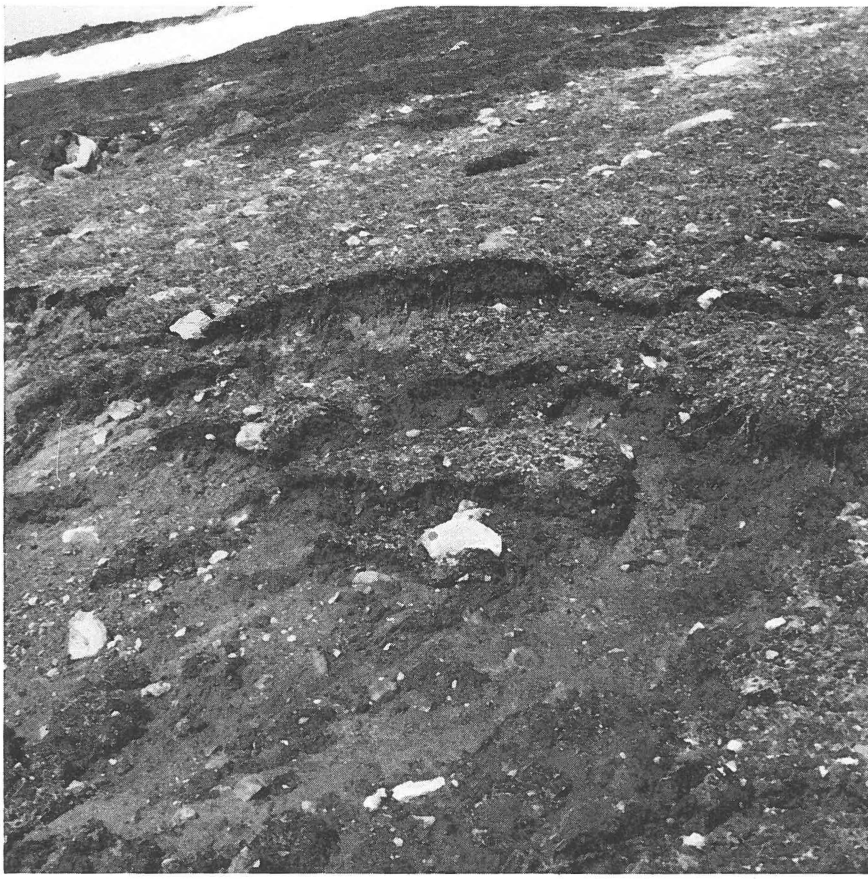

Fig. 26. A series of small scarps near eastern end of main scarp; earthflow in hills back of Nyhavn, 16 July, 1960. In foreground zone 2 of transect in Fig. 24.

into seven zones, whose distribution along the transect is approximately as shown. The proportions of the segments change laterally across the slump basin, though their character remains essentially the same.

On the slope above the scarp (zone 1) much of the ground surface was covered with black organic crust in which there were scattered patches of *Salix arctica*, *Cassiope tetragona* and *Vaccinium uliginosum*, singly or in mixture. Otherwide the flora appeared as isolated individuals or small groups of *Poa arctica*, *Trisetum spicatum*, *Hierochloë alpina*, *Carex rupestris*, *Luzula confusa*, *Polygonum viviparum*, and *Antennaria Porsildii*.

The main scarp (zone 2) was nearly vertical in some places, and in others a sloping tumble of boulders, cobbles and finer materials (Fig. 25).

Fig. 27. Zone 4 of transect shown in Fig. 24. Note masses of vegetation separated by bare soil. Earthflow in hills back of Nyhavn, 16 July, 1960. Scale is 17-cm rule. Zones 1–3 in background.

It was being undercut here and there by creep of the soils beneath a root zone which was partially held by the vegetation. The scarp surface was barren of vegetation except for fallen fragments from the slope cover described above.

The uppermost part of the slump basin (zone 3) consisted of hummocky, stony rubble, muddy at the time of observation (Fig. 27). It had no vegetation other than had ridden down from above on lumps of soil. Some of these lumps were up to a meter in diameter, with living mats of *Vaccinium* on them.

The more heavily vegetated parts of the slump basin were in two segments. In the first of these (zone 4) the vegetation was a rather dense

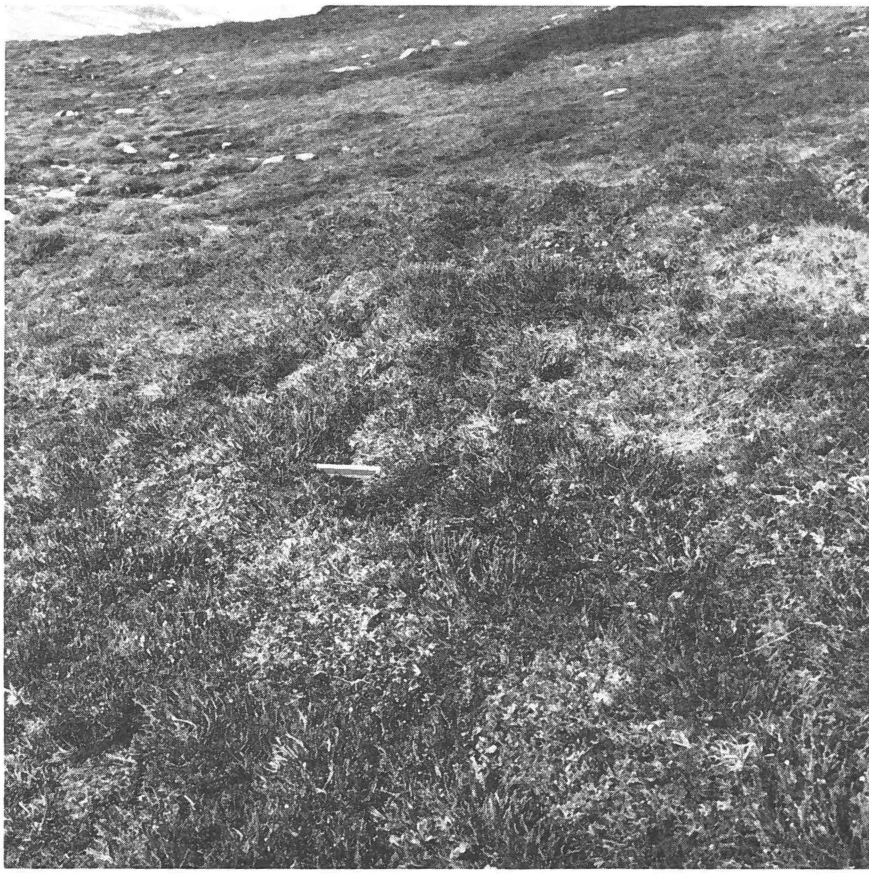

Fig. 28. Zone 5 of transect shown in Fig. 24. Note tundra ridges apparently pushed together. Scale is 17-cm rule.

heath tundra on a relatively thick mat of mesophytic mosses: *Poa arctica*, *Trisetum spicatum*, *Carex scirpoidea*, *Carex Bigelowii*, *Salix arctica*, *Polygonum viviparum*, *Silene acaulis*, *Draba glabella*, *Potentilla Crantzii*, *Cassiope tetragona*, *Vaccinium uliginosum*. This mossy heath tundra was broken by a series of shallow trench-like depressions more-or-less parallel to each other or anastomosing, and transverse to the line of the transect. Thus the vegetation appeared in low convex ridges separated by strips of bare soil 10–30 cm wide or more (Fig. 27).

The vegetation next below this (zone 5) was essentially the same in form and composition, but here it formed a dense cover without barren intervals. Transverse ridges were evident (Fig. 28), apparently resulting from accordion-like folding caused by pressures from upslope. This process

Fig. 29. Frontal lobe of earthflow in hills back of Nyhavn, 16 July, 1960. Scale is 17-cm rule. Zones 6 and 7 of transect shown in Fig. 24. Note tundra-covered ridges overriding one another on front.

was greatly accentuated on the lobe front (zone 6) where overriding thin lobes were tightly pressed together and stacked one above another to form, in places, nearly vertical surfaces (Fig. 29). There was no change in the heath tundra vegetation except for the addition of a few plants of *Luzula spicata* and *Taraxacum brachyceras.*

Immediately below the lobe front (zone 7) was a hummocky heath tundra in which the turf hummocks were relatively mature and separated by interhummock intervals covered with organic crusts and scattered vascular plants (see foreground in Fig. 21). This tundra merged with that of the valley floor, on which were intervals of sedge meadow.

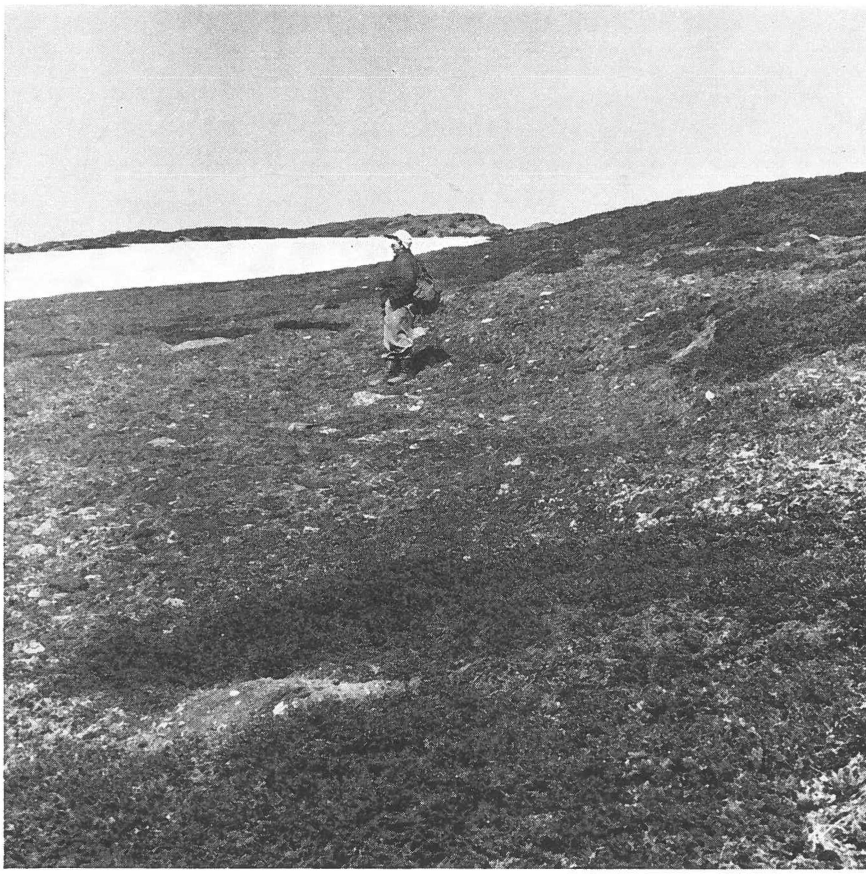

Fig. 30. Old earthflow scar just east of recent flow (see map, Fig. 23), 16 July, 1960. Figure stands in slump basin at foot of former main scarp.

Behavior of the flora on gradients of coverage, moisture and physical disturbance

Eight of the 17 species seen in the flow area were found to be widely tolerant on gradients of coverage, moisture and physical disturbance, leaving 9 that were considered definitive. About 78 % of the latter were widely tolerant of variation in coverage, 22 % intermediate, and none that were narrowly tolerant. About 56 % were widely tolerant of moisture variation, while the remaining 44 % were equally divided between intermediately and narrowly tolerant. None of the definitive species were widely tolerant of frost disturbance, 56 % were intermediate, and 44 % were narrowly tolerant. The 9 species were equally divided on the non-frost gradient among widely, intermediately and narrowly tolerant.

These scanty data yield a few tentative suggestions with respect to the adjustment of the flora to disturbance by earthflow. It is probable that the vegetation is essentially that of the pre-flow surface, merely modified by recent destruction or displacement. However, if earthflow has been common on this slope as the old scars suggest, the flora may reflect it. Probably the area has always been rather moist, though it is on a south-facing slope and no doubt subject to a certain amount of summer desiccation, particularly in the upper portion (represented by zones 1–3 of the transect). The presence of five definitive species widely tolerant of moisture variation, and of two narrowly tolerant species suggests this moderately variable moisture supply. The absence of definitive species widely tolerant of frost heaving, and the fact that nearly half of them were narrowly tolerant suggest that the frost action has not been a major limiting factor.

Summer desiccation of the surficial soils in the upper part of the area would tend to reduce autumn frost heave, though data on the extent of this desiccation are not available. The lower part of the area, represented by zones 4–7 of the transect, appears to have been nearly all covered by moss-heath tundra, in which most of the species were rooted in turf. Plants rooted thus are known to be relatively free of frost heave injury.

Experience has shown that most upland tundra sites subject primarily to disturbance by frost heave and gelifluction have relatively high proportions of species narrowly tolerant of nonfrost disturbance (Raup, 1969 B, p. 199–202). Usually the narrowly tolerant plants outnumber the widely and intermediately tolerant. The presence of equal proportions of wide and narrow tolerance in the earthflow site therefore suggests more adjustment to nonfrost disturbance by the flow process than occurs where this process is not prominent.

Summary

Judging by the vegetation of zones 4 and 5 in the slump basin, and by that growing on fragments of soil in zones 2 and 3, it is probable that the original cover of the flow area was transitional from that of the dry upper slopes of the hill to the hummocky tundra of the valley floor. The scarp appears to mark the upper part of the transition, where patches of heath were large and the intervening areas of crust and thin tundra greatly reduced. Most of this vegetation was destroyed. It probably occupied the part of the slope represented by zones 2 and 3.

The slumping process seems to have been much less destructive in zone 4, where the massive movement of the soil, probably in depth, merely "spread" the active layer at the expense of its thickness. The surficial effect was the series of tundra-clad ridges separated by bare soil. The vegetation mat here was sufficiently bound together by its root and stem systems to retain its identity although it was partially torn apart.

Presumably the effects seen in zone 4 were due to lessening moisture supply to the soil. In zones 2 and 3 the soil must have been completely saturated at the time of the flow, and essentially fluid. In zone 4 there was still enough for flow, but being farther from the source of moisture the flow was much reduced. Still father downslope, in zone 5, the soil seems to have been plastic but its appearance seems to have been caused by stoppage of its free flow behind a stabilizing front. This seems to have lessened its up and downslope dimensions, and to have bulged its surface slightly. The vegetation mat here was crushed into wrinkles. The extent of the movement in zones 5 and 6 is unknown, for there was no opportunity to trench the frontal slope and find out whether there had been overriding of the vegetation in zone 7, and if so how much.

The primary effect of earthflow upon the vegetation appears to be destructive. Changes in whatever remains relatively intact after the event probably are due to alterations of drainage. The soils just above the scarps are much more subject to seasonal desiccation than previously because of excessive drainage through the scarp, and their plants would have to be more tolerant of it. The same would be true, though to lesser extent, of soils on the upper part of the frontal lobes. Observations indicated that the first cover in the areas completely denuded was organic crust. This was gradually colonized by the scattered tundra herbs noted in zone 1, above (see Fig. 24). Frontal lobes below old scars were relatively dry habitats, with vegetation similar to that of the dry lateral banks of large gelifluction lobes (see discussion of ES 17 in RAUP, 1969B, p. 129, Fig. 45), and to that of large stabilized lobes on lower mountain slopes.

Next to frost action earthflow probably is the process most effectively restrictive to plants on diamicton soils in the Mesters Vig district. Although as noted above its occurrence in any one year is infrequent, its aggregate effect over a period of years becomes massive. This is in part because of the complete destruction resulting from it, and because of the slow process of recolonization.

THE EFFECTS OF SLUSHFLOW UPON VEGETATION

Introduction

Slushflow has been defined as mudflow-like flowage of water-saturated snow along stream courses (WASHBURN & GOLDTHWAIT, 1958). In the Mesters Vig district it occurs when rapidly thawing snow in spring produces more melt water in mountain-slope basins than can drain through the snow. The slush may push openings through snow-filled channels at relatively low velocities and not carry much load. However, if the slush is dammed the snow is likely to break through suddenly and rush down to valley floors in seconds or minutes. When this happens the slush may pick up and transport heavy loads of rock debris. When the flow reaches lower footslopes or valley floors it quickly loses its velocity and drops its load in large fans.

Fans of bouldery gravel to which this process has contributed are characteristic features of lower mountain slopes in the Mesters Vig district (Fig. 31). Morainic material mantles these slopes to varying altitudes, up to about 700 m, in many places forming terrace-like features. Streams and slushflows from collecting basins above the morainic deposits have cut deep gullies in the latter, through which the slushflows are channeled. The fans are formed just below the mouths of the gullies. Large slushflows of this kind are described below.

Flows similar in kind but of small size were seen elsewhere on the mountain sides. An example was on the north slope of Domkirken a short distance above the southerly base of Gorms Spids, at an altitude of about 500 m. Here a small stream from the mountain above flows through a gully 3–5 m deep. The stream is deflected rather sharply northeastward for a short distance around the base of Gorms Spids, and then makes another sharp bend before continuing down the mountainside. Occasionally slush is dammed above the first bend, and when released it cannot be confined in the channel where the latter makes the sharp turns. Consequently it spews over the banks, strewing debris over a hectare or more of the neighboring slopes. In some places the surface is of cobbly gravel, with little or no vegetation. In others heath tundra is partially inundated

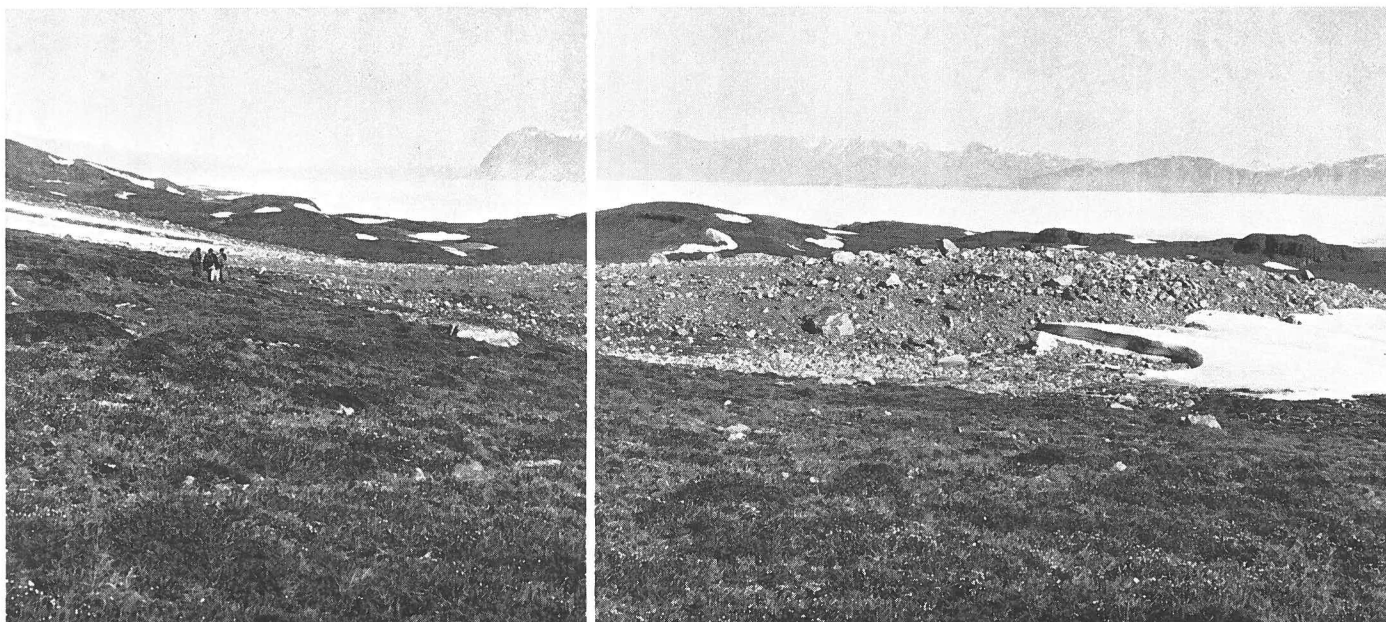

Fig. 31. Slushflow fan on lower northeast slope of Hesteskoen, about 1 km north of "Camp Tahoe". View north, 14 July, 1958.

Fig. 32. Slushflow fan in valley of Tunnelelv just below Nordisk Mineselskab mine. Lejrelv at left flowing around north margin of fan. View northeast from mouth of Lejrelv gully, 18 July, 1958.

by scattered patches of sand and gravel. It is probable that this process is locally common in the district, and that it has modified the tundra vegetation, in the aggregate, to a very considerable extent.

Sources of data

Data for the following discussion came mainly from two large slushflow fans on the lower slopes of Hesteskoen, and the gullies associated with them. One was on the northeast slope about 1 km north of "Camp Tahoe", at an altitude of about 230 m (Fig. 31). The other was at the base of the southeasterly slope of the mountain, in the valley of Tunnelelv just below the mine operated by Nordisk Mineselskab (Blyklippen on map in WASHBURN, 1965, pl. 1) (Fig. 32). The fan here, at approx.

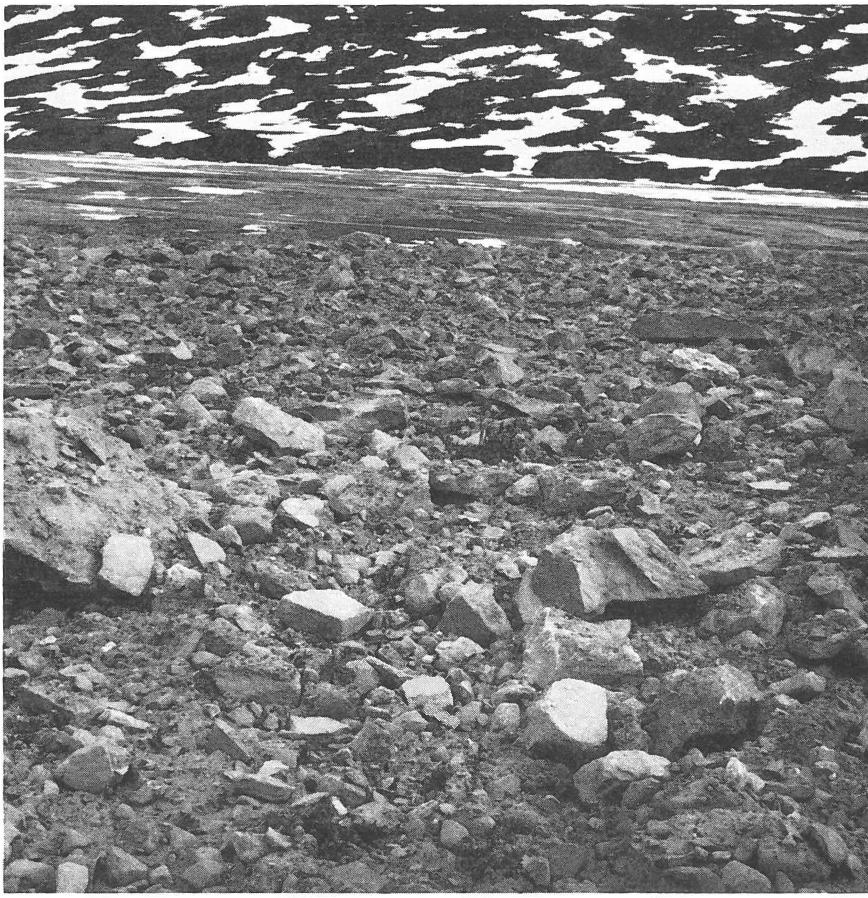

Fig. 33. Surface of Lejrelv slushflow fan, 14 July, 1960, two years after slushflow of 2 June, 1958. Note scanty flora and gravel perched on large boulders.

230 m, was formed by debris from a small stream (Lejrelv) that rises in a drainage basin reaching to the summit of the mountain. Neither of these fans was activated by slushflows during the period of observation (1956–1964) except in the spring of 1958 when both of them were. The flow in Lejrelv was witnessed by a laborer at the mine, and occurred on 2 June.

Notes on the vegetation of the "Camp Tahoe" fan were made on 7 July, 1957, 14 July, 1960 and 17 July, 1964. The Lejrelv fan was studied on 18 July, 1958, about $1^1/_2$ months after it had been active, and again on 13 July, 1960.

Description of the sites

The fans are composed of heterogeneous masses of sand, gravel and boulders, the latter commonly 1–2 m in diameter. The eye-witness account

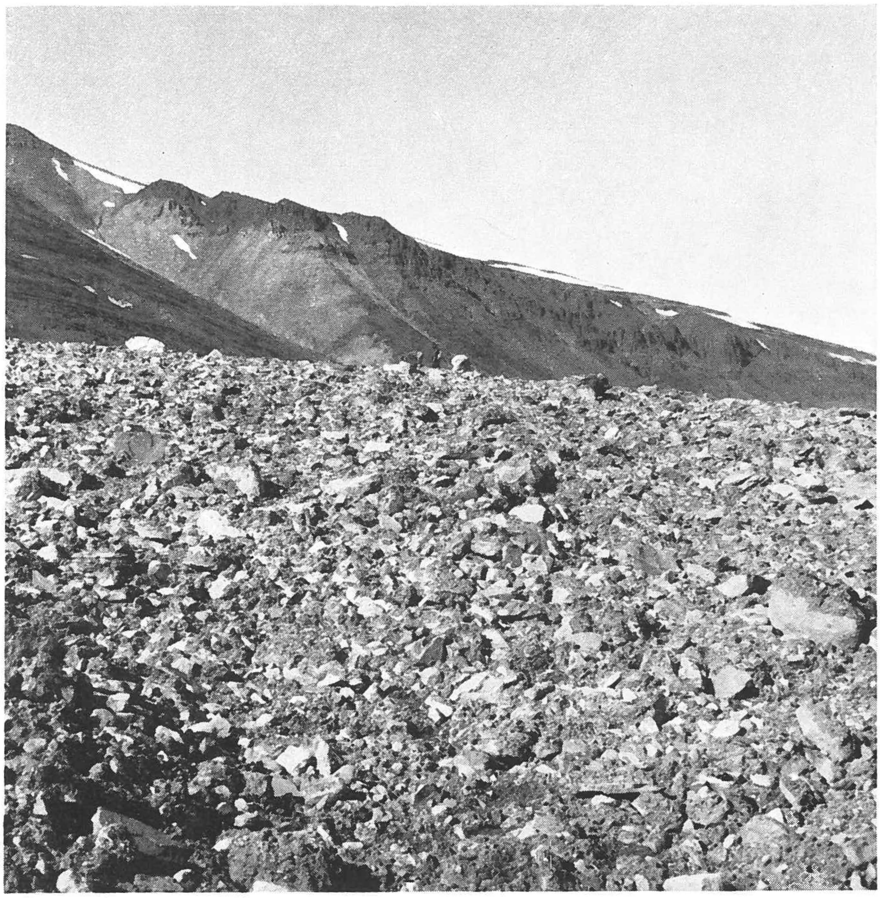

Fig. 34. Fresh deposit of sand and gravel, less than two months old, on slushflow fan north of "Camp Tahoe", 14 July, 1958. View northwest toward mouth of gully. Note figures for scale.

at Lejrelv tells of water, slush and rock debris flying through the air out of the mouth of the gully and being "sprayed" over the surface of the fan. Large boulders commonly had gravel lying on their tops (Fig. 33). In the flow of 1958 the Lejrelv fan received upwards of half a meter of fresh debris on its upper portions and less than 10 cm toward the outer edges. When examined on 18 July, 1958, it still had masses of snow and ice that had been veneered with gravel and were slowly melting out. This resulted in slumping of the debris to form a differential relief of 1–2 m. This fan was about $^3/_4$ km wide. A road built over it to service the mine (Fig. 32) was destroyed by the 1958 episode. Freshly deposited gravel and sand were found on the upper part of the "Camp Tahoe" fan in the summer of 1958, though it was not there in 1957. It was only a few centimeters thick, and apparently laid down by a relatively small flow in the spring of 1958 (Fig. 34).

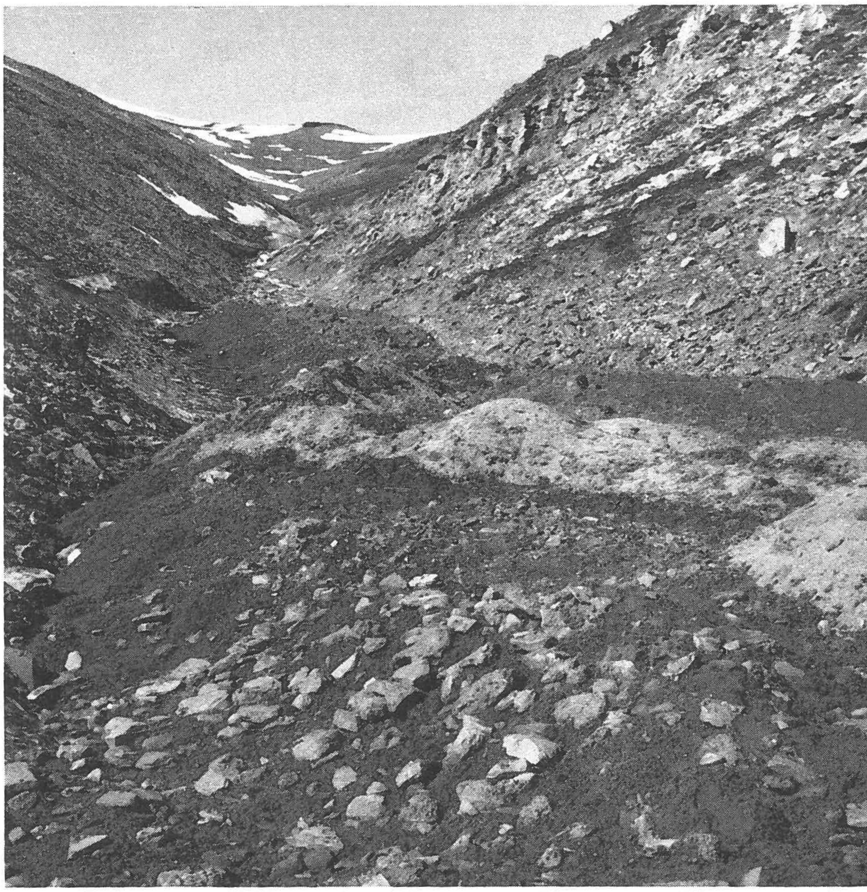

Fig. 35. Lejrelv gully, view west, upstream, $1^1/_2$ months after scouring by 1958 slushflow. Moraine-like debris in fore- and middle ground, overlying relict ice. 18 July, 1958.

The Lejrelv gully was vigorously scoured by the slush and its debris (Fig. 35). Stones were found scattered on the sideslopes of the Lejrelv channel to heights of 20 m above the bed of the stream (WASHBURN & GOLDTHWAIT, l.c.). Much of the tundra vegetation was removed entirely. Where firmly rooted woody plants were not torn out completely they were damaged by tearing, having the bark partially scraped off their stems, and losing buds. Spreading willows and dwarf birches commonly had their upstream stems torn off and the remainder extended in the direction of slushflow (Figs. 36, 37).

When the Lejrelv gully was examined in mid-July there were several masses of ice that had been left in the V-shaped bottom. They were covered with miniature morainelike deposits of debris left by the slushflow as the latter dropped the last of its load (Fig. 35). The small stream,

Fig. 36. *Salix arctica* scraped and partially torn out by 1958 slushflow north of "Camp Tahoe". 14 July, 1960. Scale is 17 cm long.

easily stepped across at this stage, was running through tunnels in the ice masses. At the lower end of the gully the stream turned northward and flowed around the margin of its fan, eventually reaching Tunnelelv.

Moisture supply in the surface soils was abundant immediately after the 1958 flows, from masses of snow and ice scattered over and through them. It is probable that this moisture persisted through much of the summer of that year. Subsequently there was no source of moisture except spring snow-melt and occasional, light rains. In July of 1960 and 1964 the soils were very dry. The same was true on the "Camp Tahoe" fan when it was seen in the summers of 1956 and 1957. Physical disturbance by frost action was minimal. There was not enough moisture left in the sands and gravels by autumn to make frost heaving significant. The violent disturbances (Fig. 38) caused by erosion and transport during

Fig. 37. *Betula nana* partially excavated and injured by 1958 slushflow north of "Camp Tahoe". 14 July, 1960. Scale is 17 cm long.

the single slushflow episodes were, on the other hand, highly effective in producing new habitats and in selecting the plants to occupy them.

Judging by the above conditions, the species found on the fans could be expected to be widely tolerant of variation in the moisture supply, and at the same time well adjusted to disturbance by nonfrost processes. They ought to show preponderant sensitivity to frost disturbance.

Behavior and distribution of vascular plants

Twenty-three species of vascular plants were found growing on the slushflow fans. They were sorted into categories in part on the basis of their local distribution over the fans, and in part on elapsed time since the last flow (Table 3). Most of the plants were widely distributed though

Fig. 38. Disturbed soil and vegetation at lower end of Lejrelv gully, $1^1/_2$ months after 1958 slushflow. 18 July, 1958.

extremely scattered. The lower slopes of the fans appeared to have been relatively inactive for longer times than the upper parts which had received more recent deposits. Their vegetation was more abundant, with larger mats of *Salix*. No lichens or mosses were seen on the fresh deposits, though a few appeared on rocks and soil exposed for more than 2 years.

Table 3 contains seven species that appeared immediately after the 1958 slushflows and were seen on all fan surfaces up to ages beyond the 6 years of observation: *Poa alpina*, *Poa glauca*, *Salix arctica*, *Oxyria digyna*, *Cerastium alpinum*, *Draba glabella*, *Epilobium latifolium*.

All except one of these are widely tolerant of variation on all the factor gradients studied. The exception is *Poa glauca* which is widely tolerant on all the gradients except moisture, where it is intermediate.

Table 3. *Species found on slushflows on the lower slopes of Hesteskoen, 1957–1964.*

	Surfaces disturbed by 1958 slushflows			On lower marginal slopes of fans, not disturbed in 1958
	$1^1/_2$ months after 1958 slushflows	2 years after 1958 slushflows	6 years after 1958 slushflows	
Equisetum variegatum				+
Festuca brachyphylla	+			+
Festuca rubra ssp. *cryophila*		+		+
Poa alpina	+	+	+	+
Poa glauca	+	+	+	+
Trisetum spicatum		+	+	+
Carex nardina			+	+
Salix arctica	+	+	+	+
Oxyria digyna	+	+	+	+
Polygonum viviparum		+	+	+
Cerastium alpinum	+	+	+	+
Minuartia rubella	+			+
Silene acaulis			+	+
Melandrium affine	+			+
Draba lactea				+
Draba glabella	+	+	+	+
Arabis alpina		+	+	+
Saxifraga nivalis				+
Saxifraga oppositifolia		+	+	+
Saxifraga aizoides	+			+
Saxifraga cernua	+		+	+
Dryas octopetala				+
Epilobium latifolium	+	+	+	+

Five more species were present 2 years after the 1958 disturbance: *Festuca rubra* ssp. *cryophila*, *Trisetum spicatum*, *Polygonum viviparum*, *Arabis alpina*, *Saxifraga oppositifolia.* Two of these are widely tolerant on all the gradients, two others were wide on all but the frost disturbance gradient (which probably was not limiting on this site), and the fifth, *Festuca rubra*, was rated as narrowly tolerant on the frost and nonfrost gradients. There is evidence from several sites that this rating was incorrect, and that the species is more tolerant than earlier observations indicated.

Two additional species were found 6 years after the disturbance of 1958: *Carex nardina* and *Silene acaulis.* Both were rated widely tolerant on all the gradients. Surfaces undisturbed for a longer time (at least more than 6 years) had only four species not found on the younger sites:

Equisetum variegatum, *Draba lactea*, *Saxifraga nivalis*, *Dryas octopetala*. All but one of these were rated widely tolerant on all gradients. The exception, *Equisetum variegatum*, was considered narrowly tolerant of nonfrost disturbance, and intermediate on the moisture gradient.

How much of the progression in numbers of species was due to new germinations on the fans is not known. However, because most of the plants, when seen, had well-developed root and stem systems, it can be postulated that most if not all of them grew from transported mature or maturing plants which did not all sprout up at the same time. Those that came up almost immediately after the 1958 slushflows must have been so transported, and it is probable that the additions after 2 and 6 years had not had time to reach their maturity from seed. Their tolerance ratings suggest that nearly all of them had the requisite capacity to live under the conditions of the gravel fans.

There remains the question of four species that appeared on fresh deposits immediately after the 1958 disturbances but were not seen in 1960 or 1964. All of them were found on surfaces older than 6 years: *Festuca brachyphylla*, *Minuartia rubella*, *Melandrium affine*, *Saxifraga aizoides*. All of the first three, which are the definitive species in this group, have shown intermediate or narrow tolerance on one or another of the moisture and disturbance gradients. It is possible that they were injured by carriage to such an extent that though they immediately put out new growth they were unable to persist. The last species in the group has been rated as widely tolerant on all the gradients, and although it was found, as its ratings indicate, in a wide variety of sites, it has preferences for somewhat moist soils. After injury by transport it may not have been able to stand the extreme desiccation of the fan gravels.

Ten of the 23 species found on the fans were widely tolerant on all the gradients used for analysis. Thus the numbers of definitive species in the floras of the younger surfaces are too small for very significant comparisons. Nonetheless these floras have been analyzed in terms of their species tolerances to show suggested trends (Fig. 39).

The comparatively high percentages of wide tolerance on the two-and-six-year old surfaces, on the gradients of coverage, moisture and nonfrost disturbance, is at once apparent. They contrast with a greater mixture of wide and lesser tolerances on the fresh 1958 surfaces and on those older than 6 years. This contrast is consistent with the supposition expressed above that four of the 12 species which first appeared on the fresh deposits were not as well adjusted to their new site as the others that appeared at that time. It may be that they could reappear only on the more stable and less dry parts of the fans. The relatively high pro-

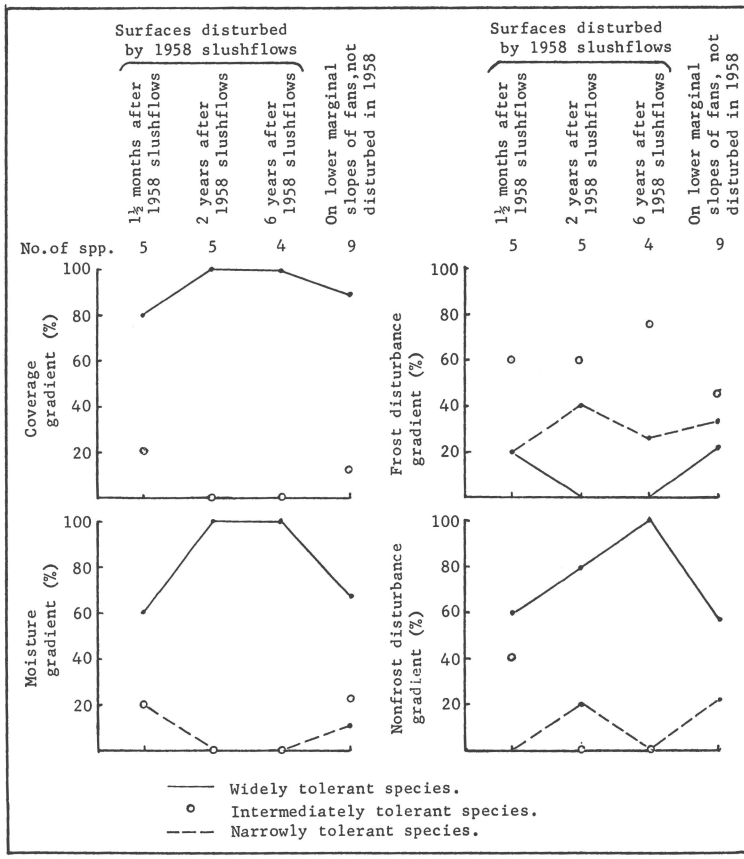

Fig. 39. Distribution of species tolerance on gradients of ground coverage, moisture and physical disturbance on slushflow fans.

portions of species narrowly tolerant of frost disturbance is consistent with the absence or very low incidence of frost action in the dry sands and gravels.

On the frequency of slushflows

Introduction

It was thought that some evidence of past slushflow disturbances, and possibly their dates, might be gained from the roots and stems of woody plants that were directly involved in the activity of the flows. Similar studies of willows had yielded useful information on the nature and history of turf hummocks (RAUP, 1965 B). Therefore specimens were collected and later sectioned in the laboratory so that their growth rings could be examined and counted. The same methods of study were used that were employed in the turf hummock investigation. Reference may be made to the author's discussion (l.c.) of the difficulties and hazards in the use of woody plant materials in this way.

The first collection was made by WASHBURN within a day or two after new debris had been deposited on the Lejrelv fan in early June, 1958. He picked out of the debris miscellaneous detached woody roots and stems that had come out of the gully and been spread widely over the fan.

It is probably safe to say that most of this material came from relatively low altitudes, and from the sides of the gully itself, rather than from the slopes of the drainage basin higher up. In the latter areas the water and slush would not have had the velocity and force to dislodge the plants.

This collection was placed in a covered box and was not examined further until about mid-July, when it was taken out and sorted. By this time it had dried out considerably, but the specimens that had represented living plants at the time of the slushflow were still flexible. In many cases the current year's shoots and buds were still present and intact. In the sorting an effort was made to keep only specimens that had been alive at the time of the deposits, and those that were root-stem combinations; or if they were detached pieces of roots or stems they were kept only if they appeared to be "whole", so that their ages would be determined by sectioning near the base. Needless to say, very few specimens in the latter category were saved. In all, 25 were gleaned from this early collection (nos. 55–79, incl.).

Further collections were made on July 18 from the gully through which the slushflow came down. Numbers 1–8, incl., are from the lower slope of the south side of the gully near its mouth, not far above the head of the fan (Fig. 38). The soil here was greatly disturbed by the scouring action of the slushflow, with much of the vegetation entirely torn away. The specimens all came from living *Salix arctica*, much battered and twisted, but still attached in their original positions. Specimen nos. 9–34, incl., were found in the debris that covered the relict ice masses previously described as occurring along the stream farther up the gully. All these specimens were detached stems or roots, but all had obviously been alive when picked up by the slushflow. The same rules were used in selecting them that were used for the specimens from the fan. It is unlikely that any of them came from farther away than the gully slopes upstream. Two additional specimens (nos. 35 and 36) from the gully slopes are included, both of them from a disturbed surface on the north side. This is a steep slope, and the two plants were growing about 5–6 m above the bottom of the gully. Another pair of specimens (nos. 53 and 54) are added because the dates of their origin and development probably could be correlated with the material from Lejrelv. They came from fresh debris deposited in the spring of 1958 on the large fan north of "Camp Tahoe".

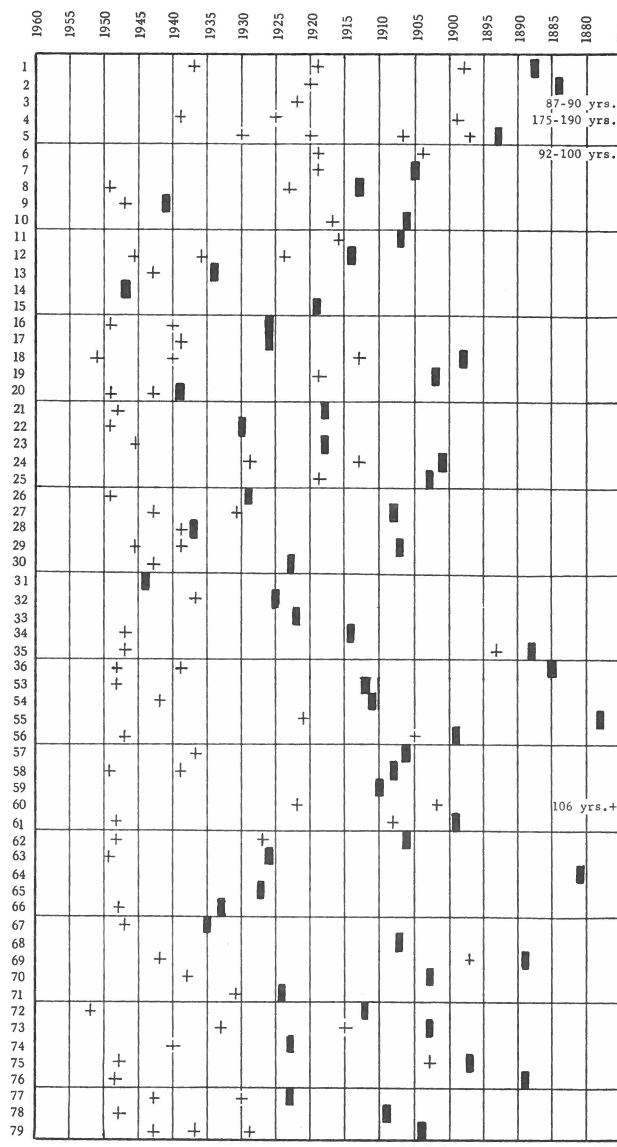

Fig. 40. Chart showing dates of origin of 63 specimens of arctic willow and dwarf birch collected from slushflows on the lower slopes of Hesteskoen in July, 1958 (solid blocks), and dates of suppressions in their growth rates (plus signs).

Analysis of the data

Figure 40 is a chart showing the approximate dates of origin of each of the specimens used in the study, and the dates at which suppressions occurred. Figure 41 A (solid line) gives the numbers of these plants which were living in any given year since 1876 or earlier. In 1923, for example,

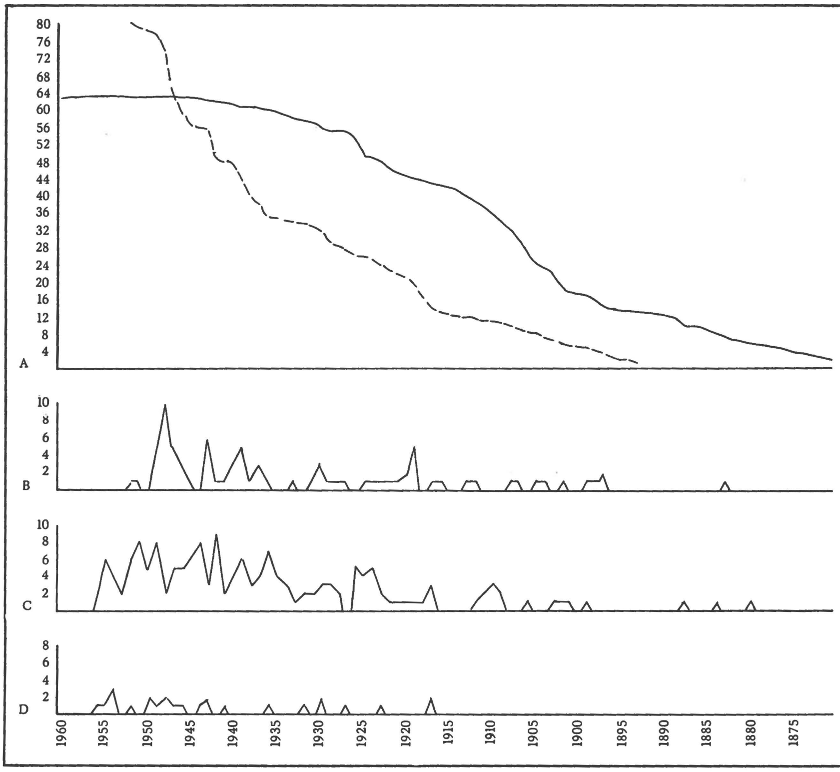

Fig. 41. Charts of population growth and incidence of suppressions in 63 specimens of arctic willow and dwarf birch collected in 1958 from slushflows on the lower slopes of Hesteskoen, compared to data on suppressions from 68 willows on the dry Labben slopes, and from 31 willows in wet moss-sedge meadow on Labben: A (solid line) — cumulative population growth of 63 slushflow plants; A (dashed line) — suppressions in these 63 plants added cumulatively; B — sums of suppressions in the slushflow plants added by years; C — sums of suppressions in the 68 willows from dry Labben slopes, added by years; D — sums of suppressions in the 31 willows from wet moss-sedge meadow on Labben, added by years.

about 48 of them were living somewhere in the path of the slushflow, and in 1930 about 56 of them. The steepest part of the curve lies between 1900 and 1930, indicating that most of the plants originated in that period. Origins after 1947 were non-existent in the collections.

Figure 41 B was made by counting the number of suppressions in each year and charting the result on a time scale similar to that used in Fig. 40. The concentration of suppressions centering around 1948 is striking, and may be coupled with the absence of specimens originating after 1947. The suppressions suggest that the plants were badly injured about this time. Their subsequent growth was insignificant, and all but one of them (No. 8) failed to survive the 1958 slushflow. Lesser peaks in the curve appear about 1943, 1939, 1930, and 1917–18. Again, these are not all precise dates, but it is suggestive that 1958, '48, '39, '30 and 1918 are approximately decadal in frequency. The peak for 1917–18 is of special interest because it is based in considerable measure upon suppressions in specimens 1–8, which came from the disturbed soil at the mouth of the gully and were still attached. Although this group shows a few suppressions in the later periods, it has a concentration of them only in the one around 1917–18. In contrast, only a few of the other plants show any effects of this earlier suppression.

Another way of relating suppressions to population growth is to chart them cumulatively at a scale commensurate with the population chart. Figure 41 A shows the coincidence of rapid population growth with relatively low incidence of suppressions prior to 1915–'20. As the latter then gradually became more frequent, until about 1936, population growth was gradually falling off. With the steep rise of suppressions after 1936, population growth was notably retarded, leveling off about 1947.

These data are admittedly scanty, and only suggested interpretations can be made from them. They propose that, on the average, slushflows have occurred in the Mesters Vig district about once in 10 years since about 1917–18. A peak in the curve about 1943, however, suggests that flows may have come, on occasion, in intervening years.

Comparison of plant growth behavior in slushflows and on the Labben slopes

Comparative studies of growth patterns in willows (*Salix arctica*) on the Labben slopes indicated that differences in the patterns were highly localized (RAUP, 1965 B, p. 87). Two willows growing a meter apart or less, commonly had quite different histories of suppression and growth. Further evidence for areal variation in growth behavior appears when patterns from the slushflows are compared to those from Labben.

Figure 41 A–D compares the distributions of suppressions in 63 specimens of arctic willow and dwarf birch from the slushers, 68 specimens of *Salix* from the dry clayey silts on the Labben slopes, and 31 specimens of willow from the wet upper part of a turf hummock sequence on Labben (RAUP, l.c., p. 89–92, Figs. 37–39). All of these collections showed build-ups in the incidence of growth suppressions beginning in the late 1800's or early 1900's. Judging by the curves for cumulative suppressions (Fig. 41 and RAUP l.c., Figs. 36 and 39), the build-ups were in three stages, but their timing differed notably. On the dry Labben slopes there seems to have been a gradual increase from about 1880 to 1909–10. A similar period of slow increase of suppressions for the slushflow plants began about 1895–96 and ended about 1917–18. Suppressions in the wet moss-sedge meadow of the hummock sequence did not begin until about 1916, after which there was a slow increase for about 20 years. The populations were growing rapidly during these intervals, affording ample numbers of plants to record larger numbers of suppressions had the latter occurred.

The second stage appears as a somewhat more rapid rise in the curves for cumulative suppressions. On the dry Labben slopes this lasted to about 1923, but among the slushflow plants it ran from about 1917–18 to about 1936–37. In the wet moss of the hummock sequence it extended from about 1936 to 1960 when the willows were collected. In these periods of more rapid accumulation of suppressions the populations continued to increase, though not so rapidly as during the preceding periods.

The third stage is marked by rapidly steepened curves for accumulated suppressions. It began on the dry Labben slopes about 1923, and in the slushflows about 1937. On the former it continued to 1958 when the willows were collected. In the slushflows the peak in the number of suppressions came about 1948 (Fig. 41 B).

Not only do the stages in the cumulative curves show differences in timing, but also the details given in the sums of suppressions by years (Fig. 41 B–D). The peak of suppressions about 1918 in the slushflows has no counterpart at either of the sites on the Labben slope, nor has the high peak that occurred about 1948. A minor peak on the dry Labben slopes about 1910 is not matched by anything on the slushflow curve, and a fairly notable peak on the former about 1925 was coincident with a single suppression recorded on the latter. The highest peak noted on the Labben slopes, about 1942 (9 suppressions), was coincident with only a single suppression on the slushflows.

The general lack of coincidence in the timing of the growth suppressions argues that the injuries causing them were due to localized and varied factors rather than to more widely effective seasonal changes in weather and climate. However, in view of the overall three-stage structure of the cumulative suppression curves, and the fact that all their major changes are contained in the period between the present and the late 1800's, it is suggested that all of these changes probably were due to some general controlling factor.

Data from the Labben slope willows as well as from other sources have suggested that there has been a progressive warming of the climate during the past 60–75 years, accompanied by retreat of perennial snowdrifts and desiccation in large areas of soil (WASHBURN, 1965; RAUP, l.c.). Because the overall structure of curves for the slushflows is the same as those on the Labben slopes, although they differ in detail as to time and intensity of disturbance, one is constrained to attempt a reconstruction of events and causes analogous to the turf hummock sequence.

A suggested sequence in the development of slushflows in the Mesters Vig district

It is necessary to postulate a period of time during which most of the plants in the Lejrelv gully could have had their origin and early successful growth. The population growth curve in Fig. 41 A suggests that this was, for most of them, prior to 1930. If the "slushflow theory" of disturbance to their existence is valid, the flows must not have been active in scouring out the gully during this period. The data suggest that the flows then built up to a peak of violence in the late 1940's which may be still on the increase or may be passed. It is presumed that the gully predated this sequence. If not, the plants that have recorded the sequence, and were not carried away until 1958, could not have been growing in place to undergo the suppressions.

The earlier episodes in the build-up of slushflow intensity which seems to have come after 1930, in view of the general warming trend during the last 60–75 years, would have been lesser in magnitude, and effective at lower altitudes than the more recent ones. The slushflows would have originated in the lower parts of the mountain drainage basins, and probably were not able to ream out gullies deeply filled with snow and ice. These flows probably would have affected the mineral soils, and the plants growing on them, only at low levels at or near the mouths of the gullies. The suppressions that occurred about 1917–18 may have been due to an early disturbance of this kind. They were recorded mainly by plants that had survived the 1958 flow at the mouth of the Lejrelv gully. Slushflows after about 1930, fed by deeper thaws at higher altitudes, scoured the gullies with progressive intensity, causing increasing damage to the plants.

THE VEGETATION OF PALSEN-LIKE STRUCTURES

Location and description of the site

Palsen-like structures were found during the summer of 1964 in the Tunnelelv valley about 2 km northeast of the base of Gorms Spids and about 1 km east of the river. They are in a partially ponded section of a braided channel system which is formed by Rungsted Elv and a smaller stream just west of it, both of the latter draining the northwest slope of Domkirken. Between this area and Tunnelelv is morainic topography described in another paper. The site is swampy, with pools of water having marginal vegetation of moss-sedge meadow. There are fields of turf hummocks up to 50 cm high, in which are scattered palsen like structures 1–1.5 m high and appearing like aggregate turf hummocks. The whole area is floored with boulders, cobbles and gravel, and is roughly 100×50 m in extent.

The turf hummocks (Fig. 42) range from 20 cm to 1.5 m in diameter. In several places stones appear to have been heaved up through them, and several hummocks are cracked all the way across, with deep sharply defined fissures extending to the base. Roots that cross these fissures are stretched or broken. Some of the hummocks appear to be heaved up bodily so that fissures are developed around the base. In one case a transverse fissure had exposed a mass of soil that seemed to have been pushed upward so that it expanded the fissure (Fig. 43). This fissure was 20–30 cm wide across most of the hummock surface, and the water table was within 2–3 cm of the base of the hummock. The hummock was about 1 m in diameter and about 40 cm high.

Toward the lower (N) end of the hummock area there were a few places where groups of contiguous hummocks appeared to be raised above the general level (Fig. 44). The largest of these was about 10 m×8 m and 1–1.5 m high, with its long axis parallel to the trend of the valley. It was irregular in contour, but in general had a hummocky surface. Smaller ones measured about 3 m in diameter and 1 m high, 1.5×6 m and 1 m high. These appeared to be palsen or palsen-like structures resembling those described in Iceland (Thorarinsson, 1951) and northern Eurasia

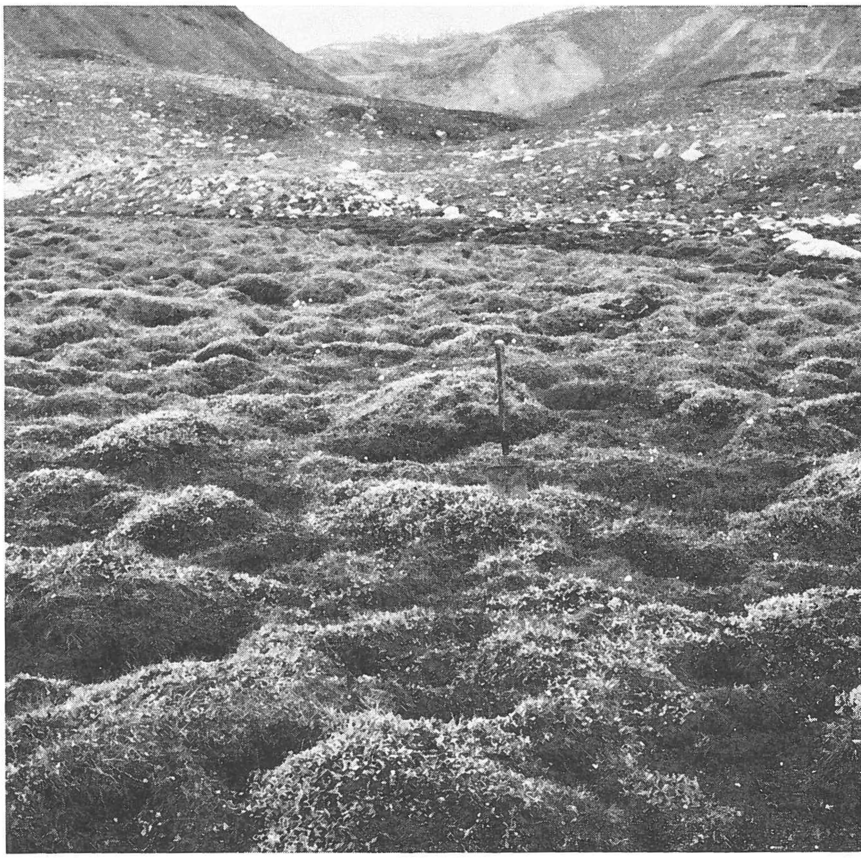

Fig. 42. Turf hummocks in area of palsen-like structures about 2 km northeast of Gorms Spids. Handle of shovel is 50 cm long. 25 Aug., 1964.

(see TROLL, 1944, for discussion and references). Lack of time prevented their dissection after they were found late in the summer of 1964, and the writer has only conjecture on how they were formed.

The larger of the palsen-like structures appeared to be "deteriorating". In most of the upper surfaces the moss was dead and grayish-brown in color though still alive on the lower margins of the structures. Some moss was also alive on the remains of a few hummocks on the upper surfaces where they appeared as small bedraggled "islands" in the mat of dead moss (Fig. 45). The latter was cracked in some places, apparently by desiccation, and shrinkage had depressed the surface to a saucer-like form. A smaller structure, 4–5 m in diameter, 1 m high, was covered with rather small sharply defined turf hummocks 30–40 cm in diameter and 10–20 cm high. The intense desiccation seen on the larger structures was present here only in a few narrow inter-hummock areas. Evidence that

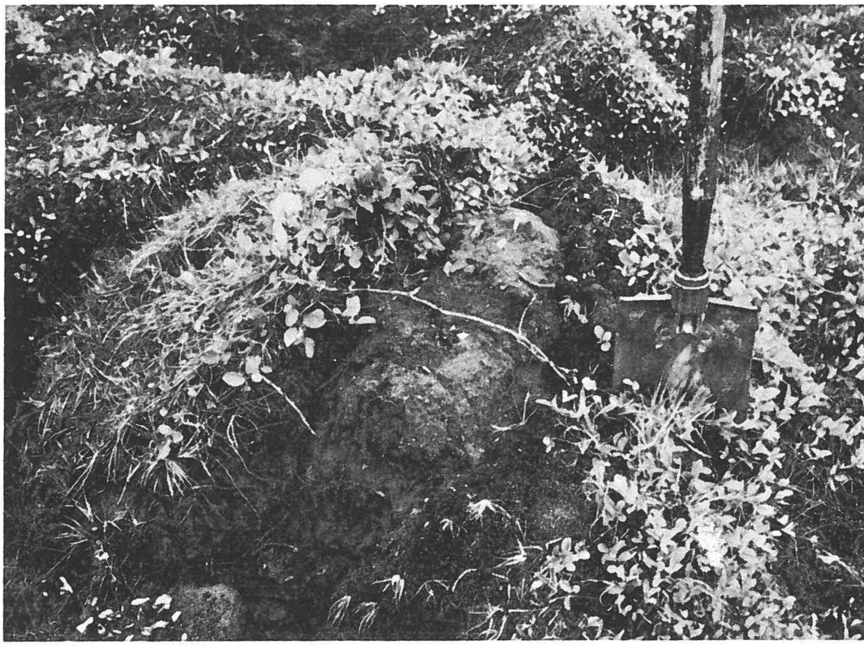

Fig. 43. Turf hummock apparently split open by heaving of earth core. Area of palsen-like structures about 2 km northeast of Gorms Spids, 25 Aug., 1964.

Fig. 44. Palsen-like structures in valley about 2 km northeast of Gorms Spids. The upper surface of the larger one at the left is shown in Fig. 45. View north, 25 Aug., 1964.

Fig. 45. Upper surface of palsen-like structure shown at left in Fig. 44. Note central depression floored with dry, semidecayed mosses. 25 Aug., 1964.

the structures may be subject to disintegration by major cracking was seen in an elongated one 5–6 m long and 1–1.5 m wide (Fig. 46). It was about a meter high and had nearly vertical sides, with the crests slightly overhanging in places. The whole structure had an arcuate ground plan, and on the inside of the curve, distant about 75 cm, was a somewhat lower and much smaller piece that appeared to have broken off the larger one.

Vegetation

Aquatic mosses grow profusely in pools and small ponds throughout the area, while more mesophytic species form the hummocks. At pool margins *Carex rariflora* is predominant, though *Eriophorum Scheuchzeri*, *Carex Lachenalii* and *Equisetum variegatum* are common to abundant.

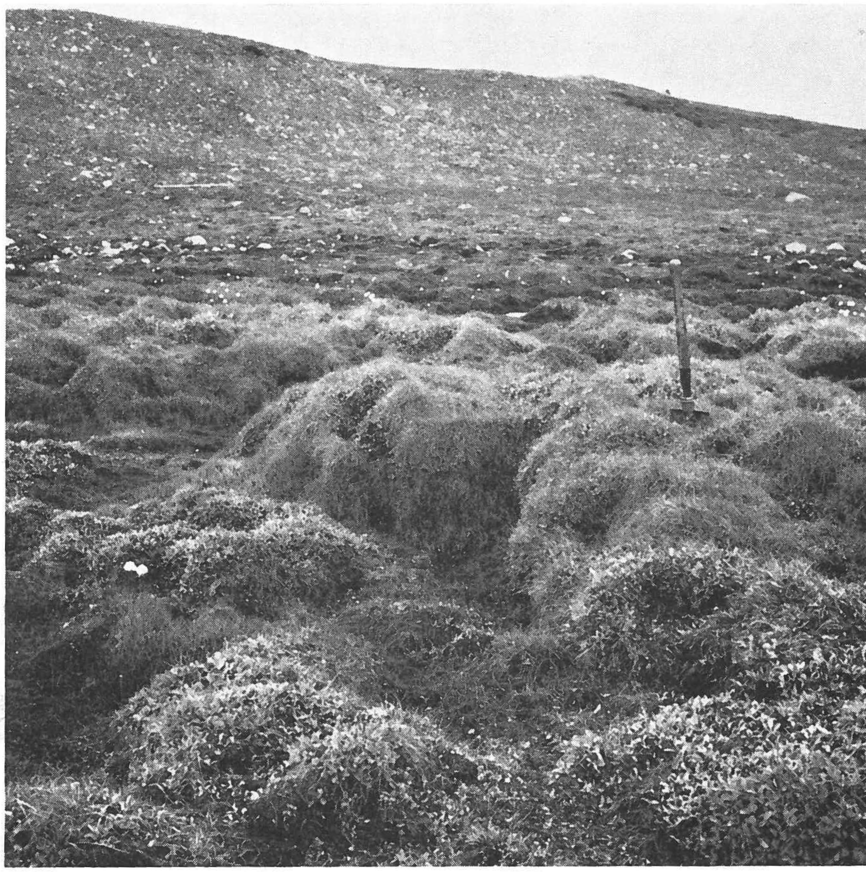

Fig. 46. Palsen-like structure in valley about 2 km northeast of Gorms Spids. Note arcuate ground plan with scarp-like slope on concave side (left of shovel), and hummock mass to left of it which appears to have broken off from the main structure. 25 Aug., 1964.

On the lower turf hummocks (up to 50 cm high) the primary species are *Salix arctica*, *Carex Bigelowii* and *Carex rariflora*. The last two seem to alternate, though on a few hummocks they are mixed. The larger of these hummocks have mostly *Salix* and *Carex Bigelowii*, while the smaller ones, particularly toward the pool margins, have nearly pure stands of *Carex rariflora*. The living moss is nearly continuous in the interhummock areas, with only small intervals of organic crust or dead moss. *Eriophorum Scheuchzeri*, *Carex Lachenalii* and *Salix arctica* are common in these areas, and *Equisetum variegatum* is occasional.

The palsen-like structures have the same hummock vegetation noted above, with much the same variations except on the desiccated surfaces of the larger structures. The following species were found scattered in the dead mosses of these surfaces: *Poa alpina*, *Carex* sp., *Polygonum viviparum*, *Cerastium alpinum*, *Minuartia biflora*, *Sagina intermedia*, *Draba alpina*, *Draba lactea*, *Draba glabella*, *Arabis alpina*, *Saxifraga cernua.*

Discussion

Evidence of intensive frost heaving was seen in the raised stones and the conspicuous cracking and heaving of the turf hummocks. An abundance of water in the mineral substratum, lasting throughout the season even in a dry summer such as that of 1964, provides for intensive heaving at autumn freeze-up. Probably, therefore, the development of the palsen-like features also was due to frost action, probably with the formation of large ice lenses. Or perhaps the larger structures were raised by a pingo-like mechanism. The upper surfaces of the larger ones, with their dead, shrunken mosses, suggest the recent warming and desiccation noted in other parts of the Mesters Vig district. Palsen (rusts) in Iceland have been considered by THORARINSSON (l.c.) to be deteriorating due to recent thawing of permafrost.

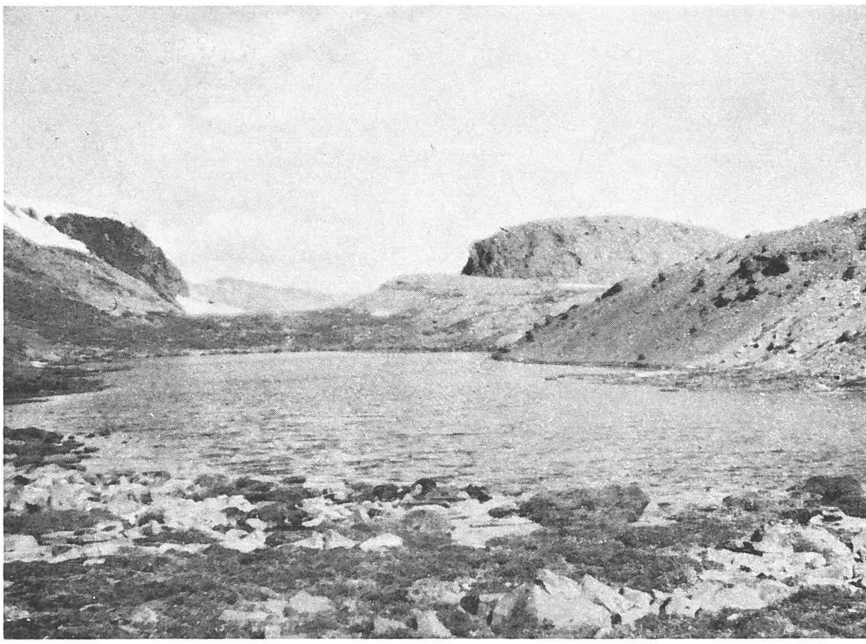

Fig. 47. Lake in the hills back of Nyhavn near MS 165. Alt. about 120 m. Shores of gravel, cobbles and boulders, without vascular plants. View north, 26 July, 1957.

THE VASCULAR PLANTS OF LAKES AND SEA SHORES

Lake shore vegetation

Sørensen described in the fjord region two ecosystems concerned primarily with fresh water vascular plants and vegetation that might be related to lake shores: "Pools and Tarns — Fresh Water Vegetation" (1937, p. 132), and "Water-Soaked Ground — Swamps" (1937, p. 131). The second of these he noted as occurring in "depressions and flat ground completely saturated or literally inundated with water . . .". Nowhere in this description did he associate the vegetation which he called "swamp", with a lake shore, though he probably so intended at least in part. In his descriptions of "Pools and Tarns" he limited himself to species actually growing in standing water and behaving more or less as hydrophytes. He remarked on the subordinate importance of lacustrine plants in the vegetation, and could list only eight in the whole fjord region: *Potamogeton filiformis*, **Eriophorum Scheuchzeri*, *Pleuropogon Sabinei*, *Alopecurus alpinus*, **Ranunculus trichophyllus* var. *eradicatus*, **Ranunculus hyperboreus*, *Callitriche verna*, **Hippuris vulgaris*.

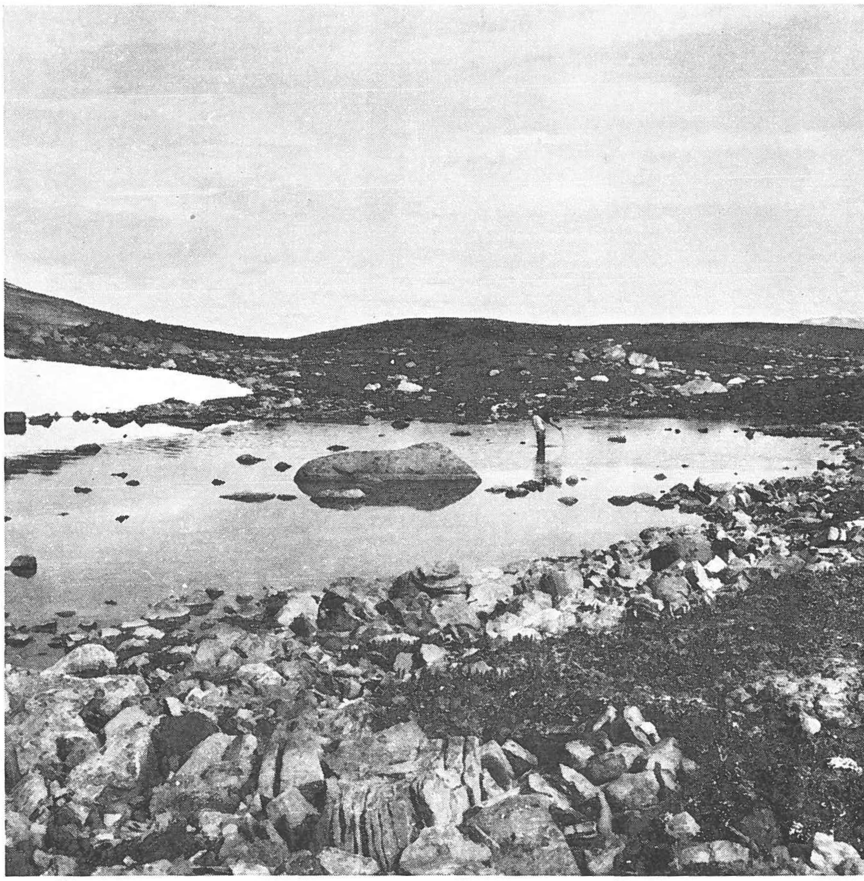

Fig. 48. Small lake near northeast base of Gorms Spids. Shores without vascular plants. Alt. about 250 m. View northeast, 9 Aug., 1958.

It is an observed fact that not only is aquatic vegetation poorly developed in the Mesters Vig district, but also the vegetation of lake shores (Figs. 47, 48). Only four of the eight hydrophytic species listed by SØRENSEN were seen in the district (marked * above). Some 12 small lakes were examined in the course of the field work, and they were all notably poor in or sterile of aquatic plants and of species characteristic of freshwater shores. Only one lake was seen in which there was appreciable floating aquatic vegetation (*Ranunculus trichophyllus* var. *eradicatus*). In this lake there was a thin and scattered growth of *Eriophorum Scheuchzeri* in the shallow water at the margin, but nothing else. In another lake was a small patch of *Hippuris vulgaris* and a little *Ranunculus hyperboreus*, again with occasional sparse growths of *Eriophorum* at the borders. One small body of water was found in which there was a marginal moss mat containing a rather dense mixture of *Carex rariflora*, *Juncus*

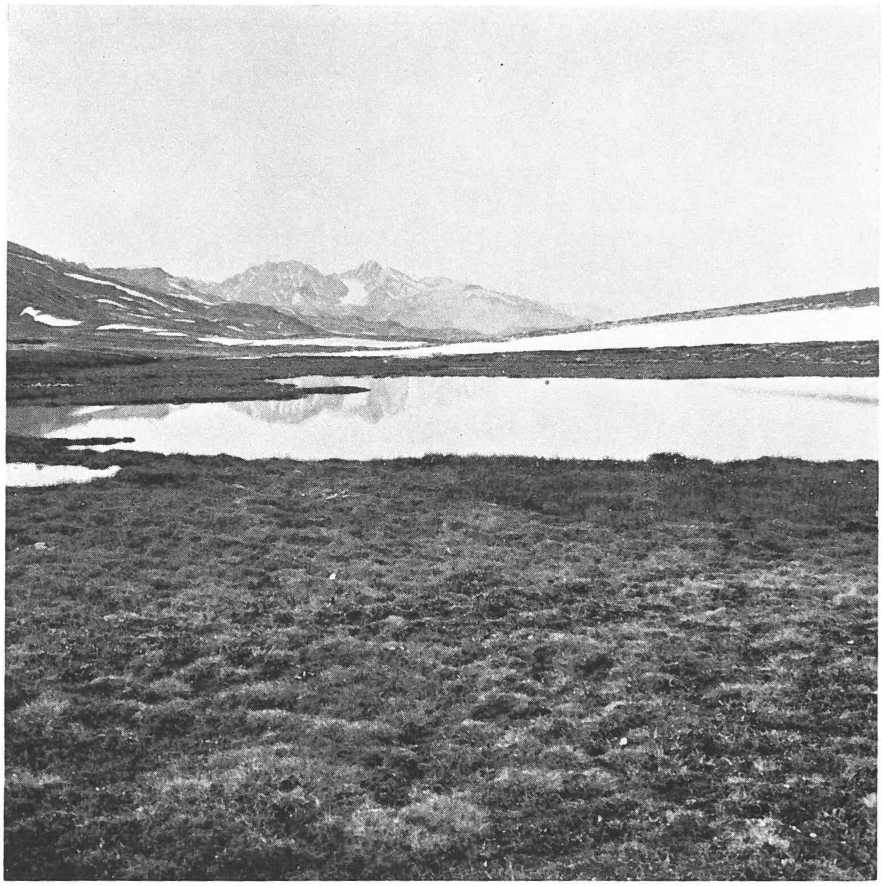

Fig. 49. Moss-sedge meadow on shore of small lake at southeast end of Danevirke. Alt. about 130 m. View north, 25 July, 1958.

triglumis, *Triglochin palustris*, *Carex Lachenalii*, *Kobresia simpliciuscula*, *Carex Bigelowii*, *Carex atrofusca*, and *Carex capillaris*. Two others had thin marginal mats of moss, on one of which were alternating growths of *Carex Lachenalii*, *Bigelowii*, and *saxatilis*, while the other had open mixed stands of *Eriophorum Scheuchzeri* and *Carex rariflora* (Fig. 49). The shores of the other lakes visited either had no distinctive marginal vegetation at all, or had only scattered plants of *Eriophorum* or *Carex Lachenalii*.

Reference is made elsewhere in the present series of papers to the heavy and continuous winter snow accumulation in the Mesters Vig district (Raup, 1965 B). In some years the snow is gone by early June, but in others a great deal remains until early July. The spring seasons of 1957 and 1960 were illustrations of this. In 1960 most of the ground surface was still under snow and basal ice until after 1 July. Thus it

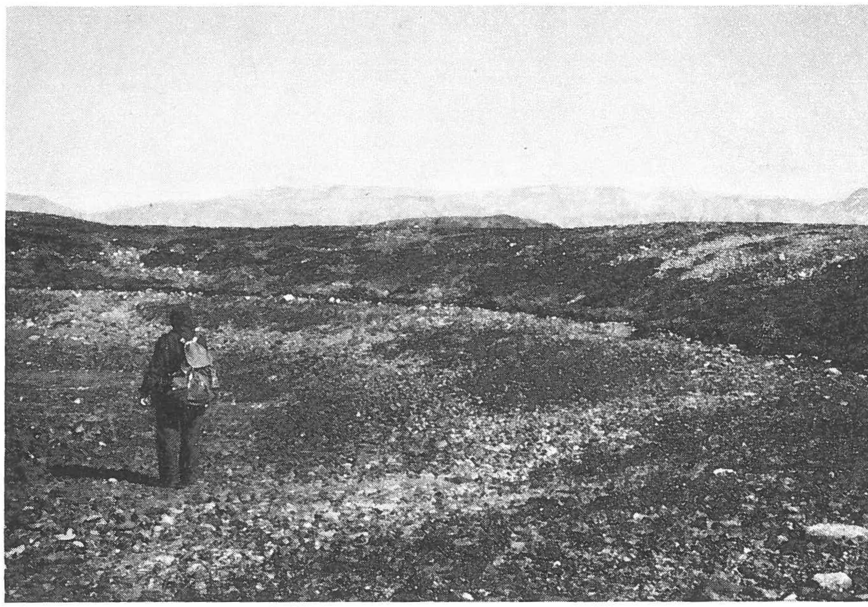

Fig. 50. Dry lake bed in 110 m emerged delta remnants about 1 km west of Tunnelelv. View northeast 27 July, 1964. Water level in most years was at well-defined shore line at base of gravel slope.

seems clear that in the Mesters Vig district there are many years in which the open season in freshwater lakes is very short. It is not impossible that this time factor is limiting, and may account for some of the poor development of aquatic and shore elements in the flora and vegetation.

A few observations made in 1957 and 1958 at lakes in kame topography associated with 110 m delta remnants about 1 km west of Tunnelelv suggested that the water levels had some range of fluctuation and were high at the times of observation. Such species as *Epilobium latifolium* were growing off-shore in water 10 or more cm deep. They were abundant but sterile.

In the summer of 1964 the land surface of the Mesters Vig district was unusually dry by mid-July. Many large snowdrifts commonly thought of as "perennial" had melted away. The lakes mentioned above were entirely dry except for slight dampness in their centers (Fig. 50). The bottoms are stony, saucer-like depressions about 1 m deep, somewhat more sandy in the centers, and with small gravelly spits projecting from the shores. A certain amount of sorting has occurred among the coarse and fine materials to form nets. A zone of vegetation about three m wide below the shore lines of the lakes was definable. The most conspicuous species was *Epilobium latifolium*, which was abundant but sterile. *Equi-*

setum variegatum was common and locally abundant. Eight other species were scattered as occasional individuals or small groups throughout the zone: *Carex Lachenalii*, *Luzula confusa*, *Cerastium alpinum*, *Minuartia biflora*, *Melandrium affine*, *Draba glabella*, *Saxifraga oppositifolia*, *Saxifraga cernua*.

All of the small lakes seen in prior years were not visited in 1964, but those that were examined (about half) were found dry or with greatly lowered water levels. The marginal zone of a dry lake bed in a kame area just east of Tunnelelv, similar to the situation described above, yielded the following additional species, all scattered: *Poa alpina*, *Trisetum spicatum*, *Oxyria digyna*, *Arabis alpina*, *Saxifraga nivalis*, *Saxifraga aizoides*, *Saxifraga caespitosa*. Small residual pools in nearby lakes produced *Carex bicolor* and *Carex saxatilis*. Considering the 17 species growing in the absence of standing water or shore moisture, 14 are regarded as widely tolerant in their behavior on the moisture gradient in the Mesters Vig district generally. The remaining three are rated as intermediately tolerant on this gradient. In fact both *Carex bicolor* and *Carex saxatilis* are also rated as having intermediate tolerance.

These findings indicate that the water level fluctuations suggested by the initial observations, when they occur, may become destructive. If this is the case it provides a further cause for the small representation of fresh water aquatic plants and lake shore vegetation in the Mesters Vig district.

With further research long-term trends in changes of lake level may become discernable. The principal water supply to the lakes must come from melting snow and thawing ground, and its amount is determined locally by the effect of the general temperature climate upon the local supply sources. There is much evidence that the warming trend in the general climate that occurred during the late 19th and the early decades of the 20th century (Washburn, 1965, p. 23–24) produced a progressive desiccation of the land surface (Raup, 1965 B, p. 96–99). The effects of the process upon purely surficial moisture distribution are complex but most of them can be seen. Much of the water for the lakes comes from subsurface origins that are not readily defined.

Plants of the sea shores

Gelting (1934, p. 247) and Sørensen (1937, pp. 112–15, 136) together listed only 5 species of vascular plants in the fjord region that they regarded as strictly halophilous, always associated with the tidal zone on the sea beaches. These are: *Puccinellia phryganodes*, *Carex ursina*, *Carex glareosa*, *Honckenya peploides*, and *Stellaria humifusa*. In addition they listed 14 species as "more or less" halophilous, found in or very near

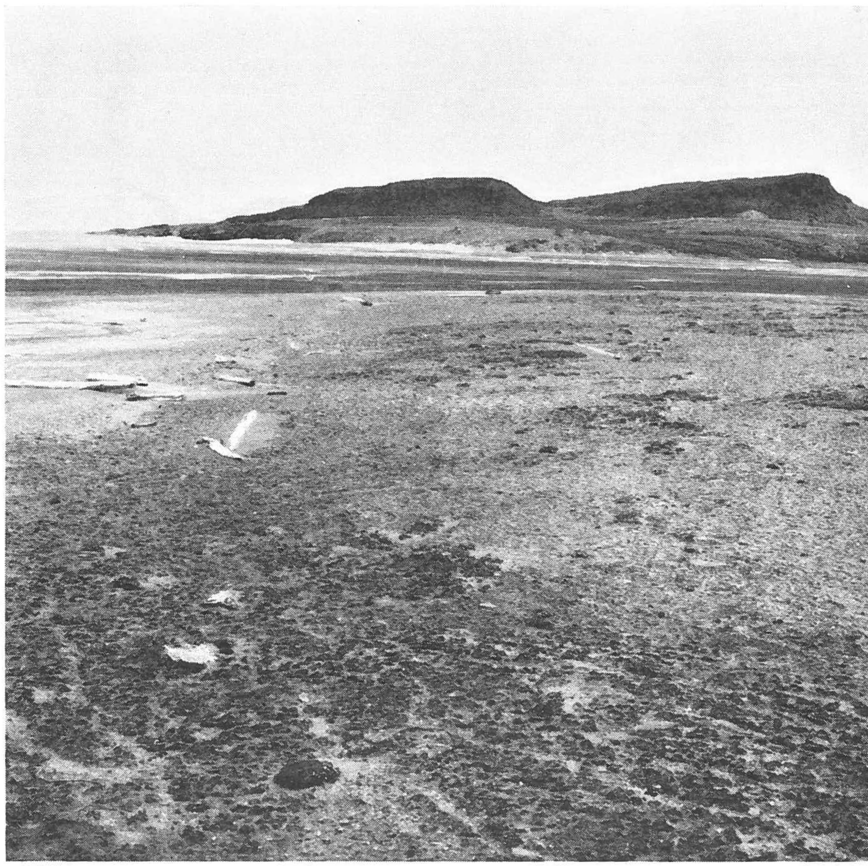

Fig. 51. Shore of fjord between Nyhavn and Labben. High tide indicated by driftwood. Above this are scattered organic crusts and a few vascular plants. Below high tide the beach is sterile. View east, 22 July, 1958.

the tidal zone, or at least within a short distance of the sea coast. They are as follows (Tab. 4; *Found at Mesters Vig):

Table 4. *Halophilous vascular plants found on the northeast coast of Greenland.*

**Triglochin palustris*	**Carex maritima*
**Puccinellia angustata*	**Sagina intermedia*
**Puccinellia coarctata*	**Cochlearea officinalis*
Puccinellia vaginata	ssp. *groenlandica*
**Phippsia algida*	**Saxifraga rivularis*
**Poa Hartzii*	**Armeria maritima*
Carex stans	ssp. *labradorica*
**Carex subspathacea*	**Matricaria ambigua*

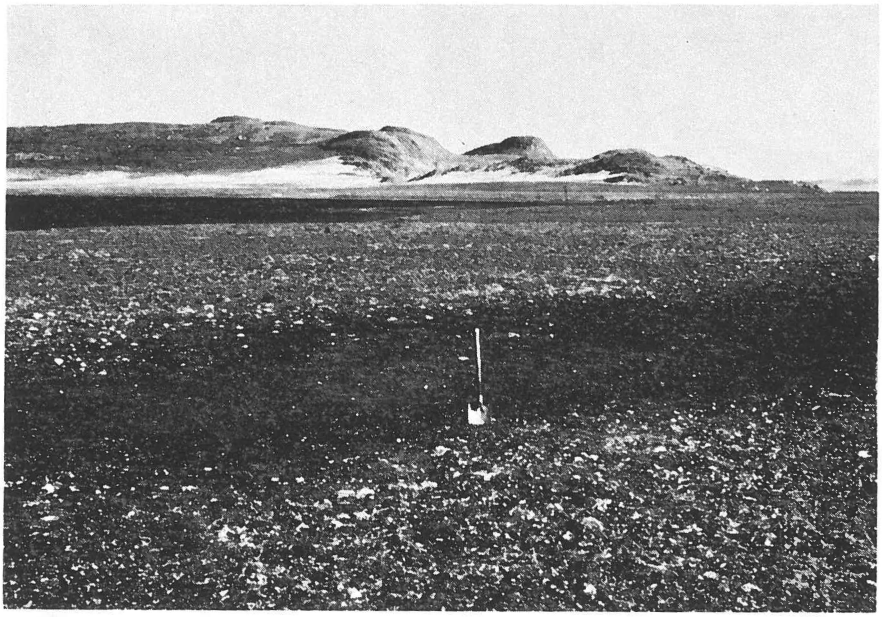

Fig. 52. Organic crust and scattered vascular plants on flats between Nyhavn and Labben. View southeast, 12 Aug., 1964.

When these lists were made *Puccinellia angustata*, as it was interpreted on the Northeast Greenland coast, was an aggregate species containing both *P. coarctata* and *P. vaginata* (cf. Sørensen, 1953).

Two of the five strictly halophilous species were not seen at Mesters Vig, one of them common and highly characteristic of sand beaches (*Honckenya peploides*, *Carex glareosa*). On the other hand, 12 of the 14 partially halophilous plants were found there.

The sea strand vegetation in the Mesters Vig district is extremely scanty. There are many kilometers of stony, sandy or silty shores, even in protected bays, on which there are no vascular plants at all (Fig. 51). The strand flora, when found, usually consists of scattered individual plants or small patches here and there. Its best development in the district was seen near the western outlet of Tunnelelv. This branch of the river flows through a broad mud flat before entering the fjord. Although the total range of the tide is small, it advances far inland over this flat.

The surface above ordinary high tide level is covered mainly with brown to black organic crusts with their usual scattering of vascular plants (Figs. 52, 53). *Sagina intermedia* is especially abundant near the upper edge of the high tide zone. This zone, as far as it is marked by vegetation, is here 20–30 m wide, and appears to occupy an extremely

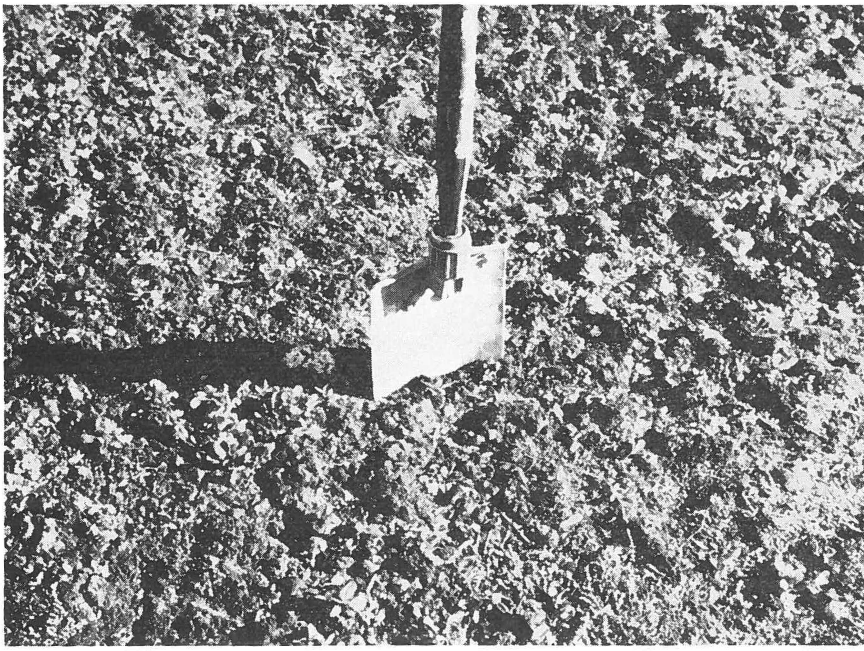

Fig. 53. Organic crust and nubbins, with scattered vascular plants on flats between Nyhavn and Labben. Locality same as in Fig. 52. 12 Aug., 1964.

small vertical range, probably not more than 10 cm. It is characterized by *Carex ursina* and *Carex subspathacea*, occurring singly or in mixtures, sparsely, or abundant enough to turn the surface faintly green. Scattered among them, and in places locally common, are *Stellaria humifusa* and *Puccinellia phryganodes*. Below the narrow high tide zone is a wide expanse of mud flats and sand beaches bearing no vascular plants. On shelving shores several hundred meters of these beaches may be exposed offshore at low tide, in some places showing beds of kelp (Fig. 54). On rare occasions isolated individual plants of *Cochlearia officinalis* ssp. *groenlandica*, or *Puccinellia coarctata* appear on the mud flats, always involving the suspicion that they have been transported there.

All the plants of the seashore must undergo a certain amount of physical disturbance due to wind, wave and ice action. They must also withstand burial in mud and sand. However, it is probable that a more important limiting factor is the short growing season available to them in many parts of the fjord region. The length of this season is geographically variable within the region due to the configuration of land and currents, and variable over time due to changing climate and weather. Dr. LAUGE KOCH (1945, p. 61) summarized the opening dates for Kong Oscars Fjord in the years 1929–1939 as follows. Minor areas in the interior

Fig. 54. Shore of the fjord at low tide on the eastern side of Labben, below ES 1, 11, 12. Marine algae exposed at right, with stranded blocks of ice. Sand and gravel beaches entirely sterile of plants. Raised beaches at left with lichens on cobbles and boulders. View north, 20 Aug., 1964.

of the fjord become free of winter ice in the last days of June. Narrow fjord ramifications open during the first week of July. The winter ice usually leaves the main part of the fjord, and the latter becomes open to the sea, during the second or third week in July. In especially favorable years all the winter ice may be gone by mid-July, but in unfavorable years it may persist to mid-August or longer. After its disappearance it may be replaced by pack ice blown in from the sea by easterly winds. New ice begins to form in sheltered bays early in September, and the fjord is commonly frozen over by late September.

In the years of our observations the winter ice remained in the fjord off Mesters Vig until 22 July in 1956, 28 July in 1960, and into the second week of August, 1964. In the period 1929–1939 Koch reported pack ice blown into Kong Oscars Fjord three times (29 Aug.–2 Sept., 1934; 28 Aug., 1935; 26–30 Aug., 1938), all of them to or beyond Mesters Vig. Minimum temperature data extracted from the records of the Danish weather station at the Mesters Vig airfield, located just above the shore of the fjord (Washburn, 1965, p. 46–50) show that temperatures below 0° C were experienced at this level in every August during the 8 year period from 1954–1961. They were also recorded in all Julys during the period 1953–1960.

These observations suggest that the marine shores in the Mesters Vig district present an exceedingly rigorous habitat for vascular plants. Not only is it physically unstable, but it has a hazardous growing season with respect to both length and freezing temperatures. Other areas in the fjord region, described by SØRENSEN and GELTING, are obviously not so rigorous and have a somewhat larger flora.

CALCICOLOUS VASCULAR PLANTS IN THE MESTERS VIG DISTRICT

Both SØRENSEN (1933, p. 167–70) and GELTING (1934, p. 226–28) designated certain species in their respective parts of the fjord region as being especially favored by soils rich in lime. A combined list derived from both sources and slightly amended is as follows (Tab. 5; *Found at Mesters Vig):

Table 5. *Vascular plants considered to be especially favored by soils rich in lime in Northeast Greenland.*

**Equisetum variegatum*	**Minuartia Rossii*
**Triglochin palustris*	*Cerastium Regelii*
Potamogeton filiformis	**Braya purpurascens*
Roegneria borealis var. *hyperarctica*	*Braya Thorild-Wulfii*
Deschampsia brevifolia	*Braya humilis*
Deschampsia pumila	*Braya linearis*
Pleuropogon Sabinei?	*Braya intermedia*
Dupontia psilosantha	*Draba Bellii*
**Eriophorum callitrix*	**Eutrema Edwardsii*
**Kobresia simpliciuscula*	**Lesquerella arctica*
**Carex nardina*	*Potentilla rubella*
**Carex parallela*	*Potentilla pulchella*
**Carex scirpoidea*	*Potentilla rubricaulis*
**Carex atrofusca*	*Potentilla stipularis* var. *groenlandica*
**Carex misandra*	**Dryas octopetala*
**Carex bicolor*	*Dryas integrifolia*
**Carex microglochin*	*Dryas punctata*
**Carex capillaris*	**Saxifraga aizoides*
**Carex glacialis*	*Saxifraga flagellaris* ssp. *platysepala*
**Carex saxatilis*	*Saxifraga Hirculus*
Juncus arcticus	**Saxifraga Nathorstii*
**Juncus castaneus*	**Hippuris vulgaris*
**Juncus triglumis*	*Epilobium arcticum*
**Tofieldia pusilla*	**Pedicularis flammea*
Rumex acetosella	*Polemonium boreale*
	**Erigeron compositus*

Approximately half (27) of the 51 species in this list were found in the Mesters Vig district, suggesting that calciphytic vegetation might be rather well represented there. This is not borne out, however, by the behavior of the species found. About one third of them (10) were noted as rare or only occasional in the district. Another third (9) were occasional, or common in very small areas. Two were considered common and six were regarded as abundant. Several species considered as occasional or only locally common at Mesters Vig appear to be, from descriptions by earlier students, considerably more frequent in areas richer in lime. Such species are *Carex atrofusca*, *Kobresia simpliciuscula*, *Juncus triglumis*, *Juncus castaneus*, *Braya purpurascens*, *Lesquerella arctica*, *Saxifraga aizoides*, *Saxifraga Nathorstii*.

The calciphiles noted as common at Mesters Vig are *Carex capillaris* and *Pedicularis flammea*. Those rated as reaching abundance are *Equisetum variegatum*, *Carex misandra*, *Carex nardina*, *Carex scirpoidea*, *Carex saxatilis*, and *Dryas octopetala*. All of these but one (*Carex capillaris*) were listed by SØRENSEN, who described them as being "perceptibly favoured on limy soil with a strong basic reaction . . . (basophilous species)." They were not, however, among the plants that he regarded as strongly calcicolous, for which he reserved another symbol in his list. Only two of those noted as abundant at Mesters Vig are in GELTING's list of calciphiles: *Carex misandra* and *Carex saxatilis*. Under *Carex misandra* in his catalog of the flora Gelting made no mention of calcicoly. *Carex saxatilis* does not appear in his list of calciphiles, but in the catalog (p. 172) he stated that it was "in some degree" calcicolous. In the case of *Carex nardina* (p. 166–68) he differed sharply with other authors regarding the calcicoly of the species, saying that although in Scandinavia it was recognized as a calciphile, in East Greenland it grew on all kinds of soil. In his rather intensive studies of *Dryas octopetala*, not only in his work on the flora (1934, p. 97–100), but also in his investigation of ptarmigan foods (1937, p. 30–32), he made no mention of calcicoly in this plant, which seems to grow equally well in all kinds of soil materials.

The above notes suggest that there is some question as to the significance of the abundance of these common species as an indicator of strongly calciphytic habitats at Mesters Vig. It is notable also that only two of the species mentioned by SØRENSEN as being strongly calcicolous were found at Mesters Vig: *Kobresia simpliciuscula* and *Carex glacialis*. These were found only occasionally, or the first was common in a few very localized areas.

All these data, taken together, suggest that habitats favoring calcicolous plants are, in fact, rather poorly represented at Mesters Vig. Outcrops of limestone are rare in the district, and apparently restricted to some of the higher strata in the mountains. The only ready sources of lime are from occasional erratics in the till, a few pebbles brought down from the mountains by glacial streams, or in the shell-bearing marine silts that cover large areas of lowland immediately adjacent to the shores of the fjord (see Washburn, 1965, p. 25–31).

If this general conclusion is tenable, then the apparently limited development of habitats particularly favorable to pronounced calciphiles is reflected in the relatively small development of these plants at Mesters Vig, and probably also in the absence of many of them.

RUDERAL PLANTS
IN THE MESTERS VIG DISTRICT

Introduction

Ruderal habitats in the Mesters Vig district are here defined as those that are disturbed by human agency. They are around habitations where the soil is disturbed or the normal tundra vegetation is partly or entirely removed, or they are in roadways and landing fields where bulldozers and scrapers have been used and where day-to-day traffic passes. The Mesters Vig area was essentially undisturbed by these causes until about 1951 when the mine at Blyklippen was established, with attendant roads, buildings, harbor installations, airfield and weather station.

The following notes on the behavior of ruderal species were made principally in two areas: the neighborhood of the airfield and its buildings, and around the expedition's base at "Camp Tahoe". Additional information came from observations at shore and harbor installations, at Blyklippen, and along connecting roads. Field notes were made in the summers of 1956–58, 1960 and 1964. Many of the data discussed here have been published, in fragmented form, in a general account of the vascular flora (Raup, 1965A).

Investigations of vegetational relations to geomorphic processes described elsewhere in the present series have suggested that the plants selected for certain natural habitats reflect the presence and intensity of these processes. It is therefore thought useful to analyze the ruderal flora for its reactions to the site factor gradients used here for "natural" vegetation, particularly to see whether physical disturbance, as well as fertilization by nitrogenous and other wastes, may have significance for its behavior.

Description of the study sites

The Mesters Vig airfield and vicinity

The Mesters Vig airfield is on gravel outwash in the central and southern sectors of the distributary system of Tunnelelv. Attendant buildings are on a low gravelly terrace along the southern distributary near the shore of Noret, a small bay of the fjord into which this branch of the river flows. The buildings include dwellings, offices, workshops and storage facilities, used by 15 to 40 people. The numbers are greatest in summer, but the station is used throughout the year. One or two teams of sledgedogs usually are kept on the site. The airfield and weather station were established in 1951–52.

Notes on ruderal plants were made in the general vicinity of the airfield, and more specifically around the buildings. Both physical disturbance and fertilization probably have influenced the ruderal flora in the vicinity of the buildings. Isolation and assessment of their effects is not possible with present information.

"Camp Tahoe" and vicinity

The site of "Camp Tahoe" is at an altitude of about 220 m on the easterly slope of Hesteskoen along a temporary road constructed about 1951. This road serviced the mine at Blyklippen for a short time, but was soon abandoned for a better one about a kilometer south of it and nearer Tunnelelv. It is little more than a "track" through the tundra, smoothed by the removal of large boulders and cobbles, and crowned for improved drainage in a few places by bulldozers. The soils at "Camp Tahoe" are gravelly-sandy loams, on a gentle easterly slope that becomes steeper just below. A small mountain stream flows easterly in a shallow gully about 100 m north of the road.

The site of the camp remained essentially undisturbed until its first occupation by WASHBURN's field party in the summer of 1955 (Figs. 55, 56). At that time a small portable house was erected near the stream and facing east, and caches for equipment and supplies were established on the ground immediately upslope from it. Very little excavation or movement of soil resulted from these operations, for the house was placed upon a few piles sunk to near permafrost, and the caches were laid on planks that rested on undisturbed tundra. Some small tent floors were made just west of the house by removal of stones and vegetation and leveling of the surface soil.

The camp was used in all the summers from 1955 to 1964, incl., in most cases continuously throughout the season. On 4 or 5 occasions the field parties arrived before the spring thaw and did not leave until September or early October. Numbers of persons in these parties varied from 2 to 9, frequently increased by visiting individuals or groups. All of the area was tramped over frequently, but certain places were used more intensively than others. As would be expected, surfaces immediately adjacent to the house, tents and caches were most disturbed. The surfaces at the front of the house, and between it and the stream were the most

Fig. 55. Site of "Camp Tahoe" at time of establishment in summer of 1955. House site is just beyond the caches. Note fairly dense cover of *Cassiope-Salix* heath to right of caches. View northeast; photo A. L. WASHBURN.

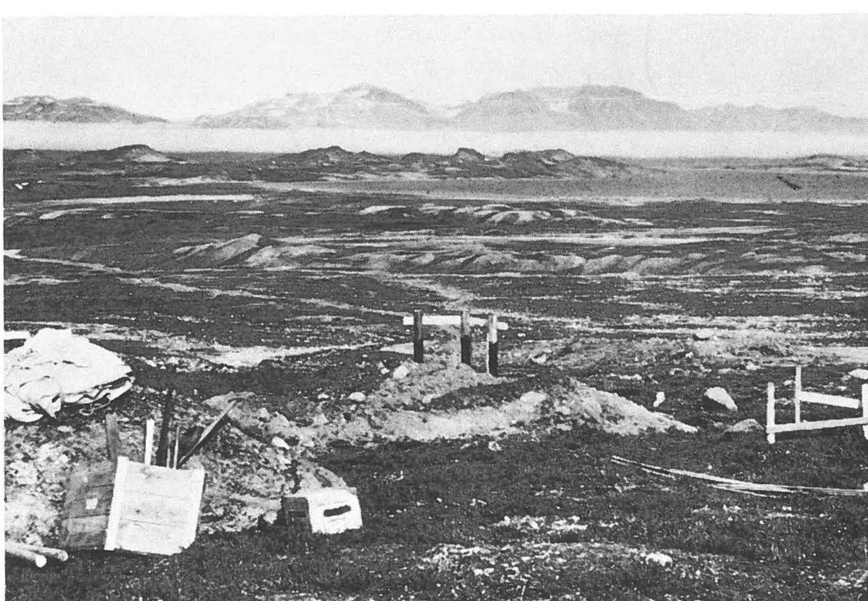

Fig. 56. House site during establishment of "Camp Tahoe", summer, 1955. Note *Cassiope* heath in right foreground. View northeast; photo A. L. WASHBURN.

intensively trampled. Next were two access paths from the road, one a walk to the front of the house and the other a vehicle track to the caches. The walk was partially paved with flat stones. Across the road from the house were a latrine and a parking area for vehicles.

The total area covered by the studies at "Camp Tahoe" was about 1500 sq. m. For comparative purposes the flora of the surrounding "undisturbed" tundra was also noted. Because of the close floristic relationships between adjacent ruderal and nonruderal vegetation it was thought useful to assign frequencies of occurrence that could be compared. This was done by ocular estimate, using four main categories: abundant (A), common (C), occasional (O), and rare (R). Intermediate frequencies (C–A, O–C, R–O) were used for species common and locally abundant, occasional and locally common, etc.

Due to a shorter time of occupance at "Camp Tahoe", fewer people there than at the airfield, and a fairly well defined spatial segregation of most of their activities, it is thought possible to segregate most of the effects of fertilization from those of physical disturbance. Most of the trash accumulation went into a pit about 50 m down a steep slope below the house, but liquid refuse was commonly thrown downslope a few meters from the front door. The only vegetation that showed clear evidence of fertilization was on this slope, where a rank growth of grasses developed, mainly of *Trisetum spicatum*. A small garden (about 5 sq. m) was established in front of the house. No exotic species were introduced, but many native tundra plants were assembled. The garden was occasionally watered and fertilized.

Vegetation

Vegetation prior to human occupance

No data are available on the vegetation of the airfield site prior to 1951. However, relatively undisturbed vegetation in the immediate vicinity suggests that much of it was "thin tundra" composed of organic crust, lichens, and scattered vascular plants, mainly herbaceous. There are wide expanses of this type on the low terraces bordering the Tunnelelv distributaries (Figs. 52, 53). The soils are gravels and sands with a thin veneer of fine sand and silt, often cracked to form small polygons. The vegetation appears to be a "younger" version of that described on the 17- and 25-meter emerged delta remnants just west of the airfield (Raup, 1971, p. 39–49, Figs. 15–22), but has much less *Cassiope* heath in it. Also the cracking is less prominent, and the growth of foliose and fruticose lichens on the crust and in the cracks is less and more scattered. There are remnants of such vegetation at the level of the airfield adjacent to the above-mentioned higher terraces, and at the eastern end of the airfield.

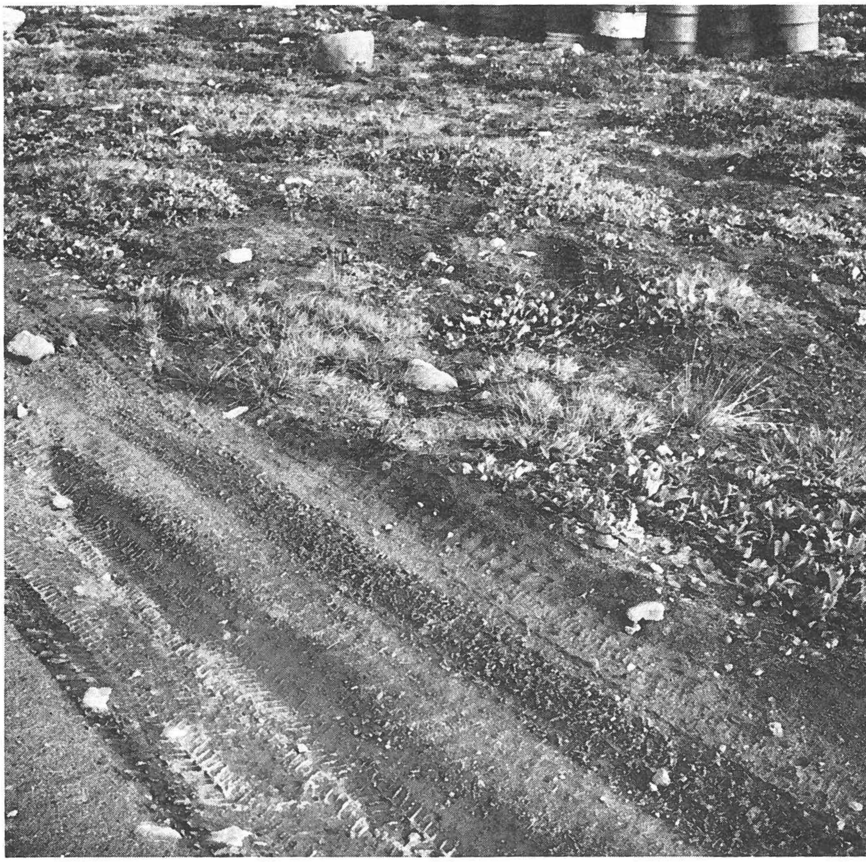

Fig. 57. Roadside vegetation at "Camp Tahoe", 14 Aug., 1964. Principal species are *Salix arctica*, *Carex scirpoidea*, *Carex Bigelowii*, *Trisetum spicatum*.

An expanse 2–3 sq. km in extent surrounds the small pond called Rypesø south of the eastern end of the airfield.

Another element in the original flora of the airfield locality probably consisted of species characteristic of "dry sites" (see RAUP, 1971, p. 9–14, tab. 1). Examples among the ruderal plants listed for this locality in Tab. 6 are *Minuartia rubella*, *Papaver radicatum*, *Draba glabella*, *Arnica alpina*. All of these occur in the scattered flora of nearby gravel terraces and emerged delta remnants. *Phippsia algida* and *Matricaria ambigua* probably belong with this group, though they are more characteristic of wet, fine-textured soils that become extremely dry in summer.

Judging by the terrain and the neighboring tundra the vegetation of the "Camp Tahoe" site prior to 1955 was a mixed heath interrupted by many boulders and cobbles and by patches of organic crust. It was composed primarily of *Cassiope tetragona*, *Vaccinium uliginosum* and *Salix* *arctica* with occasional patches of *Betula nana.* The flora of immediately adjacent heath is listed in Tab. 6. In some places this heath forms an 80–90 % cover, but it has intervals of cracked organic crust in which the cover is 30–50 %. Also there are a few patches in which the primary species are *Carex Bigelowii* and/or *Carex scirpoidea.*

The roadside flora in the immediate vicinity of "Camp Tahoe" differs very little from that in the nonfertilized disturbed areas around the house (Fig. 57). Roadside floras in the district as a whole differ greatly from place to place, and are most closely related to the adjacent tundra. Between "Camp Tahoe" and Blyklippen the road traverses, in part, a slope on relatively stable loam soils. *Taraxacum brachyceras*, *Potentilla Crantzii*, and *Arnica alpina* are common on this slope and growing profusely at the roadside, but they were not seen in the immediate vicinity of the house or in the nearby tundra there.

The ruderal vegetation

No introduced vascular plants were found in the Mesters Vig district. Thus the flora of ruderal habitats is made up of native species which have thus far survived the changes since human disturbance began in the early 1950's, or have come in from surrounding undisturbed vegetation. Many of them have not only survived, but have grown vigorously and

Table 6. *Species found growing as ruderals in the Mesters Vig district.*

A – abundant C – common O – occasional R – rare	Estimated general frequency in Mesters Vig district	Species found in vicinity of Mesters Vig airfield			Species found in ruderal areas and adjacent heath tundra vic. of "Camp Tahoe"			
		Estimated frequency in ruderal areas	Frequency greatest in ruderal areas	Frequency greatest in estimate for district	Estimated frequency in adjacent heath	Estimated frequency in ruderal areas	Frequency greatest in ruderal areas	Frequency greatest in adjacent heath
Lycopodium Selago	C				O	R		+
Festuca brachyphylla	C				O	O		
Poa pratensis ssp. *alpigena*	O-C	C	+					
Poa arctica	C–A	A	+		C-A	O		+
Poa glauca	C-A				O	O		
Trisetum spicatum	C-A	A	+			A	+	
Phippsia algida	O-C	C	+					
Carex nardina	A	C		+	O	O		
Carex scirpoidea	A				C-A	A	+	
Carex rupestris	O-C	O	+		O	O		
Carex Bigelowii	A				C-A	C-A		
Carex glacialis	O				O	O		

(continued)

Table 6 (continued)

A - abundant B - common C - occasional R - rare	Estimated general frequency in Mesters Vig district	Species found in vicinity of Mesters Vig airfield			Species found in ruderal areas and adjacent heath tundra vic. of "Camp Tahoe"			
		Estimated frequency in ruderal areas	Frequency greatest in ruderal areas	Frequency greatest in estimate for district	Estimated frequency in adjacent heath	Estimated frequency in ruderal areas	Frequency greatest in ruderal areas	Frequency greatest in adjacent heath
Carex misandra	C-A	A	+		O			
Juncus biglumis	C-A	O		+				
Luzula spicata	O-C	C	+		O	R		+
Luzula confusa	C-A	C-A						
Tofieldia pusilla	O-C				O	R		+
Salix arctica	A	A			A	A		
Betula nana	C				C-A	O		+
Oxyria digyna	A	A			R	C-A	+	
Polygonum viviparum	A	A			C	O-C		+
Cerastium alpinum	A	A			O	A	+	
Sagina intermedia	C-A	C		+				
Minuartia rubella	C	C						
Minuartia biflora	O-C	C	+		C	C		
Silene acaulis	A	A			C	C		
Melandrium affine	C	A	+		R	C	+	
Papaver radicatum	C	A	+					
Draba nivalis	O-C	R		+	R	R		
Draba lactea	C-A	C		+	O	C	+	
Draba glabella	C	C-A	+		O	A	+	
Saxifraga oppositifolia	A	C		+	C	O		+
Saxifraga nivalis	O-C	C	+		R			
Saxifraga cernua	C-A	A	+		C	A	+	
Sibbaldia procumbens	O-C	C	+		O	C	+	
Potentilla Crantzii	C	C			O	C	+	
Dryas octopetala	A	C		+	C-A	C		+
Epilobium latifolium	A	C		+	O	O		
Cassiope tetragona	A	C		+	A	C		+
Vaccinium uliginosum ssp. *microphyllum*	A	C		+	A	C		+
Pedicularis hirsuta	C	O		+	C			
Matricaria ambigua	O	O						
Arnica alpina	C	R		+	O	R		+
Taraxacum brachyceras	O-C	C	+		O	C	+	

spread profusely in these habitats, apparently more so than in ground not thus disturbed (Figs. 58, 59).

Table 6 contains a list of the 44 ruderal species seen in the Mesters Vig district. Information presented is in three elements. First are estim-

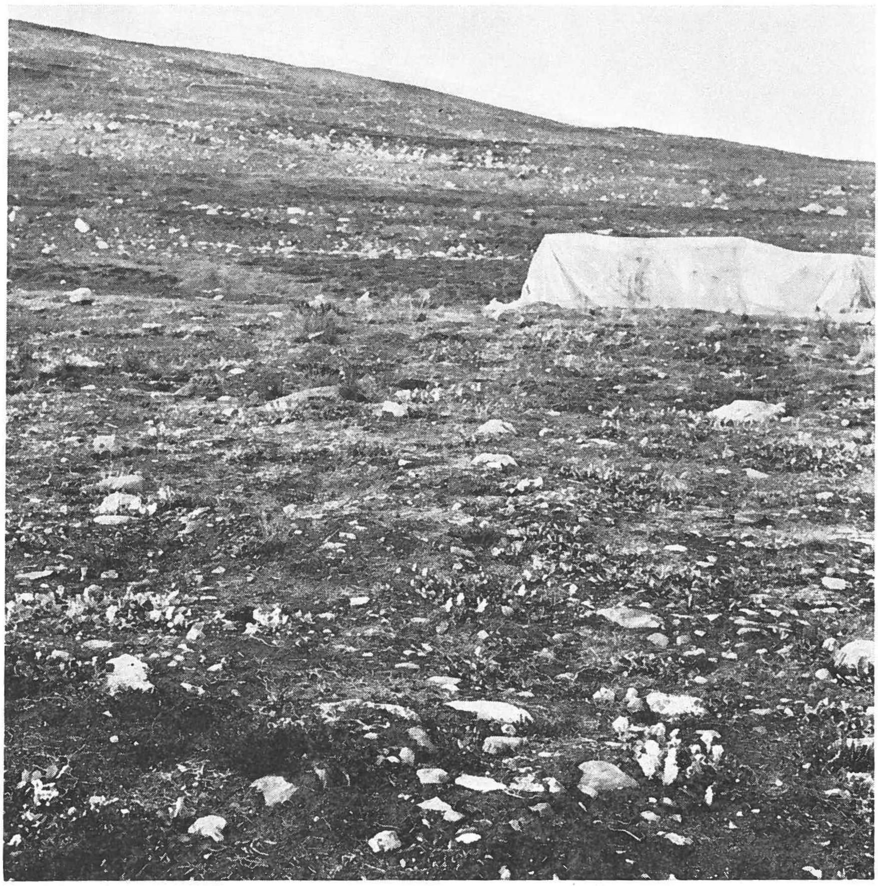

Fig. 58. Ruderal vegetation on much-trampled surface between road and house at "Camp Tahoe". The area shown is approximately that seen at the right of the caches in Fig. 55. Note reduction of *Cassiope*. 14 Aug., 1964.

ates of the general frequency of these species in the district as a whole (RAUP, 1965A; 1969A, Tab. 1). Second are notes on the behavior of 36 of them that were seen mainly at the Mesters Vig airfield and around its buildings. These notes are in three columns: estimates of frequency in the disturbed areas, species more frequent in the disturbed areas than in the district as a whole, and species less frequent than in the district. Third are notes on the occurrence of 33 species in the vicinity of "Camp Tahoe", including those along the road between there and Blyklippen. The first column in this element shows estimates of frequency in the adjacent heath tundra, while the second column contains frequency estimates for the same species in the disturbed areas. The third column notes the species that are more frequent in the disturbed areas than in

Fig. 59. Detail in much-trampled area shown in Fig. 58. Note luxuriant growth of *Trisetum spicatum* and persistence of *Salix arctica*. 14 Aug., 1964.

nearby heath, and the fourth column lists the species more frequent in the heath than in the disturbed areas.

Of the 36 species of vascular plants noted as ruderals in the Mesters Vig airfield area 26 (72 $^0/_0$) are also found in the neighboring organic crust vegetation. Of the remaining 10, 6 (17 $^0/_0$) appear to have come from dry sites (gravel terraces, talus, etc.) and 4 (11 $^0/_0$) from heath tundra. It is uncertain whether these 10 species came from a distance or are relicts from small local populations of their respective types. All of the ruderals seen at "Camp Tahoe" and vicinity were also found in the adjacent heath tundra. The approximate extent to which these ruderal floras represent their respective types is as follows (Tab. 7).

Table 7. *Approximate extent to which the Mesters Vig ruderal floras represent their respective types of vegetation.*

	No. of spp. in the type	Ruderal spp. no.	%
Organic crust vegetation	64	26	41
Dry site vegetation	60	6	10
Heath tundra	55	33	60

Mortality in the trampled area near the house at "Camp Tahoe" is obvious, but is variable as to species. Among the woody plants *Cassiope* shows the highest mortality, with *Vaccinium* next, and *Dryas* or *Betula* in third place (Figs. 58, 59). A few species present in the surrounding tundra were not seen in the disturbed areas and may have been eliminated: *Carex misandra*, *Saxifraga nivalis*, *Empetrum hermaphroditum*, *Pedicularis lapponica*, *Pedicularis flammea*, and *Pedicularis hirsuta*. Other species, though present in the trampled soil, were less frequent there than in the adjacent tundra: *Lycopodium Selago*, *Poa arctica*, *Luzula spicata*, *Tofieldia pusilla*, *Polygonum viviparum*, *Saxifraga oppositifolia*, *Arnica alpina*. It is possible that all of these species are more susceptible to injury on the kind of site represented at "Camp Tahoe" than in other situations. It will be noted that some of them have reacted differently at the airfield site or along roadsides other than those at "Camp Tahoe".

Eleven species in the "Camp Tahoe" area showed approximately the same frequence in the trampled parts and in the adjacent tundra: *Festuca brachyphylla*, *Poa glauca*, *Carex nardina*, *Carex rupestris*, *Carex Bigelowii*, *Carex glacialis*, *Salix arctica*, *Minuartia biflora*, *Silene acaulis*, *Draba nivalis*, *Epilobium latifolium*. Twenty-two species were either more or less frequent in the disturbed soils than in the neighboring tundra (see Tab. 6).

The general structure of the vegetation in the trampled areas at "Camp Tahoe" had been only partially altered by the disturbance. The heath patches were still apparent, as were the intervening organic crusts. Although much of the *Cassiope* was dead, *Salix* was about as abundant as in the adjacent tundra, and *Dryas* appeared to have increased to some extent. Patches of *Carex Bigelowii* and *Carex scirpoidea* were also persisting. One of these was traversed by the path from the front of the house to the road, and appeared to be thriving in spite of the heavy summer traffic over it (Fig. 60).

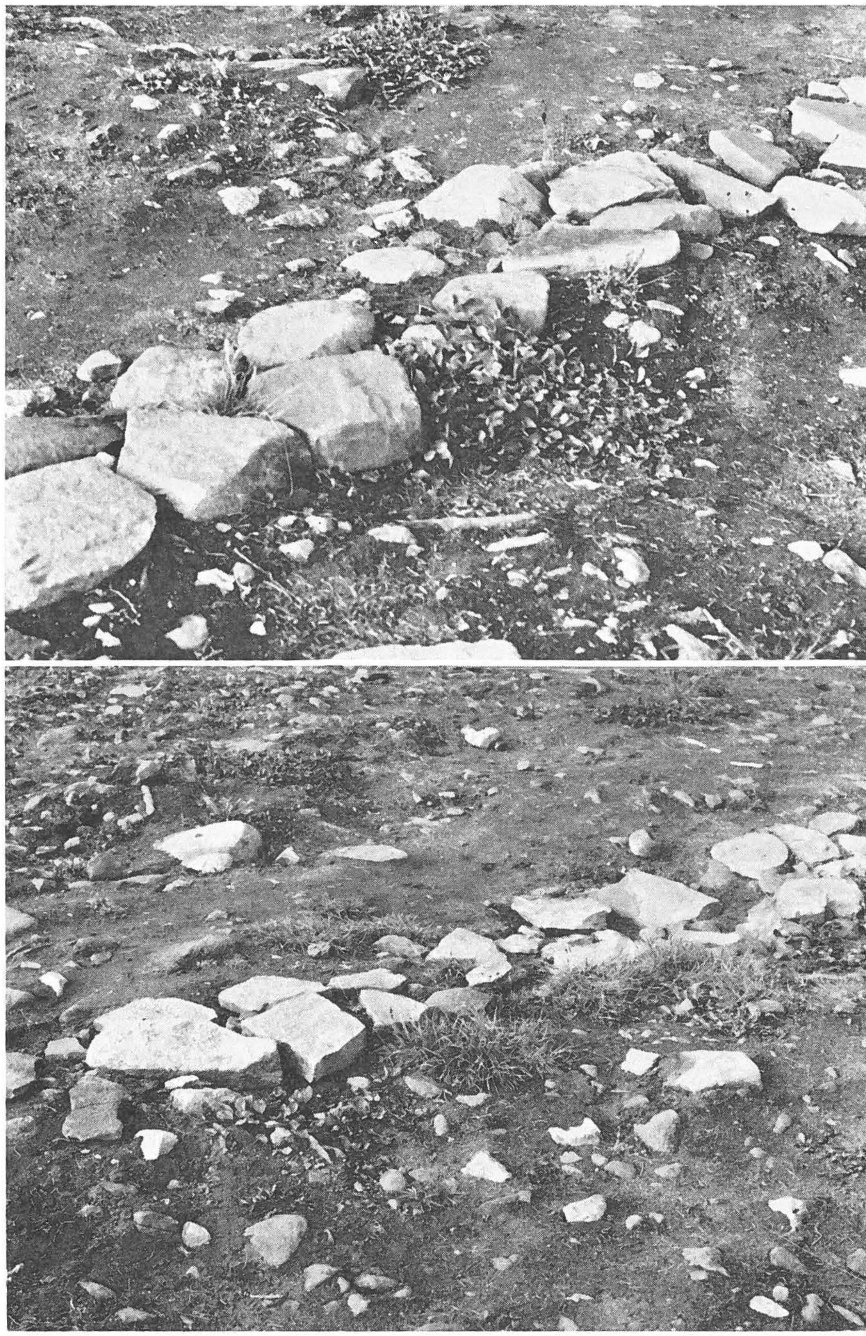

Fig. 60. Stone path from road to house at "Camp Tahoe", 14 Aug., 1964. Note vigorous growth of *Salix arctica* among stones and on much-trampled surfaces in some places, and *Carex scirpoidea* or *Carex Bigelowii* in others.

Habitat factors in ruderal areas

Coverage of the ground by vascular plants

Coverage of the ground by vascular plants in ruderal habitats varied from zero to dense vegetation covering 80–90 % of the surface. Areas frequently walked or driven over were nearly or quite barren, as were some roadsides that were disturbed by maintenance implements at frequent intervals. The densest cover was near habitations where physical disturbance was supplemented with organic wastes. Between these extremes there was a full range of variations, but viewing the habitats in general, low to medium coverages were most prevalent (0–50 %).

Moisture supply

The initial location of human habitations and most travel routes on soils that are dry or merely moist tends to eliminate the wet habitats from the moisture gradient experienced by the ruderal plants. Further, the manipulation and use of the ruderal sites tends to make them drier than they would be under natural conditions. Heath vegetation on moist soils may be partially or entirely eliminated, together with the mosses and humus beneath it. Thus the insulating effect of the heath disappears, and at the same time the soil is exposed to the desiccating effects of wind and sun. Sand and gravel slopes and terraces, already relatively dry, are rendered more so by the grading and artificial drainage of roadways and house sites, or by the elimination of whatever vegetation is present. Thus ruderal habitats tend to have wide seasonal variation in moisture supply, from moist in spring to dry in mid- or late summer.

Physical disturbance by frost action

It is probable that disturbance of the soil by frost action is minimal in most of the ruderal habitats. No precise data were available to prove this, but judging by the behavior of targets in the experimental sites it is to be expected. Observations at these sites indicate that frost action is relatively insignificant in soils that hold little or no moisture at the time of autumn freeze-up. Possible exceptions are clayey loams that are very wet for a short period after snow-melt and may then be affected by a small number of freeze-thaw cycles. However, these soils were rarely seen in the ruderal habitats, for they are mire-like in spring and have been rather carefully avoided in laying out hose sites and roads. The general desiccation of soils in ruderal habitats, even where they would retain moisture under natural vegetation, probably leaves them so dry in autumn that very little frost action is possible.

Physical disturbance by nonfrost processes

The ruderal habitats are by definition physically disturbed, ranging from those that are merely walked over repeatedly to those that are furrowed or entirely displaced by heavy vehicles or road-making machines. The disturbance may result in the physical injury or removal of the natural vegetation, compaction of the soil, or loosening of the soil structure and the destruction of whatever "profile" it may have had under natural conditions.

Nutritional factors

The arctic plants, as those in temperate zone vegetation, are stimulated to unusual growth by the addition of nitrogen to their soils. This is clearly seen in "bird places" in the tundra, near animal burrows, and in places where muskoxen habitually congregate. It is probable that the behavior of ruderal plants around human habitations is affected in the same way by nitrogenous and other wastes. In the following studies it is difficult to tell how much of the behavior of the Mesters Vig plants was due to such fertilization and how much to purely physical disturbance of the sites. No data were gathered on nutritional gradients or on plant reactions to their variations. Consequently only suggestions may be made on the relative importance of the two kinds of factors.

Behavior of ruderal species on gradients of coverage, moisture and physical disturbance

Introduction

The ratings of species with respect to their behavior on gradients of coverage, moisture and physical disturbance, used elsewhere in the present series of papers (RAUP, 1969A, B; 1971), were based almost entirely upon species' behavior in "natural" habitats, undisturbed by human agencies. It will be useful to apply the ratings to habitats affected by the latter, as a further check on the validity of the ratings, and to see whether the ruderal flora reflects any of the habitat differences caused by artificial disturbance.

Figure 61 shows analyses of the ruderal flora on the various gradients, arranged for behavioral comparisons of all of the species with those most frequent in disturbed areas, and with those most frequent in "natural" habitats. The general behavior pattern for the whole vascular

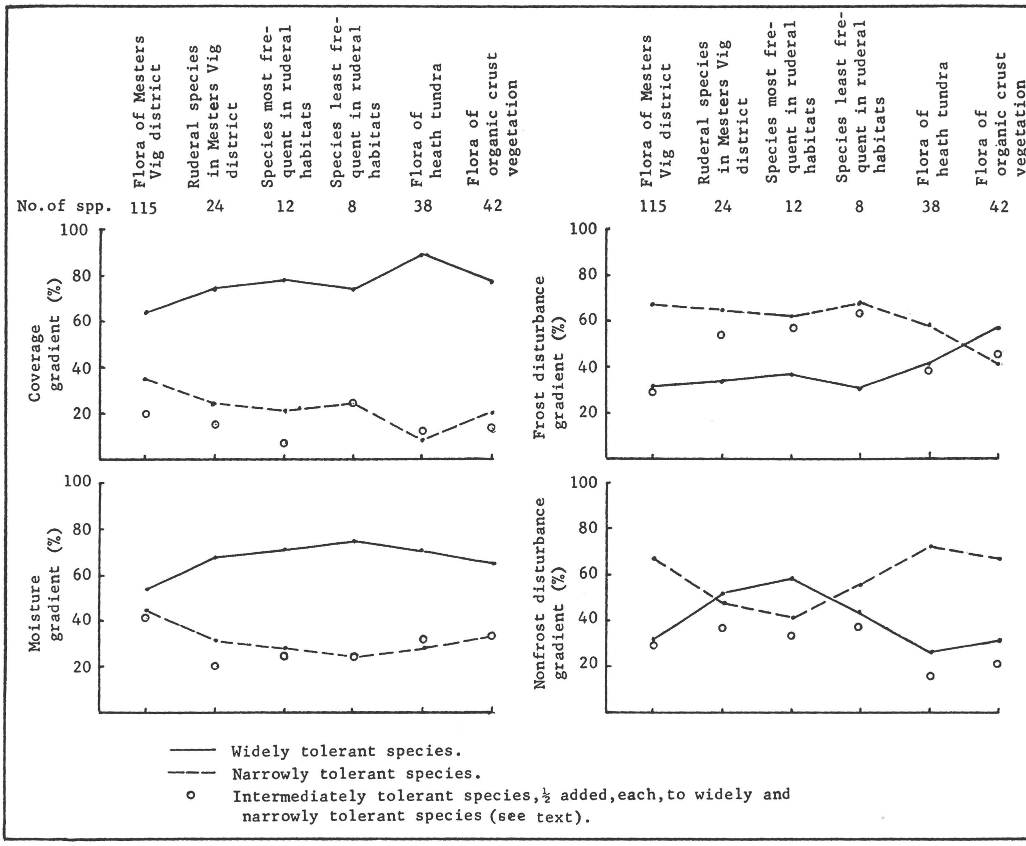

Fig. 61. Distribution of species tolerance on gradients of ground coverage, moisture, and physical disturbance in ruderal habitats, compared to distributions in the total Mesters Vig vascular flora in heath tundra and in organic crust vegetation.

flora of the district is included as a "norm", to suggest the extent of variation seen in the disturbed habitats. Also included are analyses of the floras of heath tundra and organic crust vegetation, both derived from studies of these types in sites not disturbed by human agency. They were selected for comparison because they appear to have been the original vegetation in the two areas from which most of the data on ruderal plants were gathered. All of the species in Tab. 6 are used in the analysis, with no division between those in the airfield habitats and those around "Camp Tahoe". Thus the data for comparison of the frequency groups are derived from an amalgam from these two areas.

As in earlier papers, only definitive species are used in the analysis. Of the 44 species in Tab. 6, 19 are widely tolerant and 1 is narrowly tolerant on all the gradients, leaving 24 to be used for comparison. Of

20 species more frequent in ruderal than nonruderal sites, 7 are widely and 1 narrowly tolerant on all gradients. Of 18 species that are less frequent in the ruderal sites, 10 are widely and none narrowly tolerant on all gradients. Thus the definitive species in these two frequency groups number 12 and 8, respectively. To emphasize trends rather than specific differences, half the intermediately tolerant species are added, each, to the widely and narrowly tolerant, thus making mirror images of the curves in Fig. 61.

The coverage gradient

Experience with this gradient at most sites has shown that the species are not very sensitive to site differences. Probably this is due to generally wide tolerance of coverage variation in a large percentage of the flora. However, Fig. 61 suggests that the ruderal habitats have a larger proportion of widely tolerant species, and fewer narrowly tolerant, than the flora as a whole. This is to be expected from the wide variation in coverage known to occur in ruderal habitats.

The moisture gradient

It was noted above that seasonal moisture variation in the ruderal habitats is wide, probably wider than in the same sites prior to human disturbance. This is probably most notable in the organic crust habitats where vascular plant coverage usually is low. In Fig. 61 the proportions of widely tolerant species in the ruderal habitats are much greater than in the vegetation as a whole, and a little greater than in the organic crust vegetation that has not been disturbed by people. These differences suggest that, in general, species with lesser tolerances of moisture variation tend to be eliminated from these habitats, both ruderal and nonruderal. There is also a suggestion that more are eliminated from ruderal than from nonruderal sites, at least in organic crust habitats.

The frost disturbance gradient

The heath tundra and organic crust vegetations have notably different species tolerance distributions on the frost disturbance gradient in nonruderal situations. In heath tundra narrowly tolerant species exceed the widely tolerant by about 16 %. In organic crust vegetation the reverse is the case, and widely tolerant species predominate by about the same proportion. In Fig. 61 the general level of narrow tolerance exceeds the wide in ruderal sites formerly inhabited by both of these types, and is about the same in both. Frost action is known to be moderate in heath tundra, and this is reflected in the relatively low percentage of wide tolerance on this gradient. But in organic crust frost heaving is relatively intense and wide tolerance of it predominates. Summer dessiccation in ruderal habitats is suggested as an effective cause for lowered frost action intensity, which in turn may be reflected in the generally low proportions of wide tolerance in the ruderal crust habitats shown in Fig. 61.

The nonfrost disturbance gradient

Species narrowly tolerant on this gradient exceed those with wide tolerance in both heath tundra and organic crust vegetation (RAUP, 1969B). In the ruderal habitats based on these types (Fig. 61) the reverse obtains, and wide tolerance predominates. An exception is among the ruderal species that are more frequent in nonruderal than in ruderal habitats. The difference in frequency here suggests that these species are, on the average, not as well adjusted to nonfrost disturbance as those that reach greater frequency in ruderal habitats. This may be indicated by the higher proportion of narrowly tolerant species among them. It is also significant that narrowly tolerant species greatly exceed widely tolerant in the flora as a whole, which emphasizes the reversal of proportions in the ruderal habitats.

Summary

The following suggestions may be derived from the preceding data on the ruderal behavior of vascular plants in the Mesters Vig district.

(1) Ruderal plants in any given locality are derived primarily from the vegetation on the site at the outset of human disturbance, or from similar vegetation adjacent to the site.

(2) It is probable that (1) is, at least in part, a function of the time elapsed since human disturbance began, and/or the intensity of the disturbance. The airfield area, subjected to intensive disturbance after 1951, had 72 $^0/_0$ of its flora from the major vegetation type on which it was established, while the "Camp Tahoe" locality, with much less disturbance after 1955, drew 100 $^0/_0$ of its flora from the local tundra.

(3) A corollary to (2) is that human disturbance in other types of vegetation would bring more species into the list of those that behave as ruderals. In the localities studied 40 to 60 $^0/_0$ of the floras of their respective types were ruderal. A speculative extrapolation from this suggests that a similar proportion of the total vascular flora of the district might be expected as ruderals at one place or another.

(4) Estimated frequencies of the ruderal species in ruderal and nonruderal habitats suggest a three-fold division into those that are more and those that are less frequent in ruderal than nonruderal sites, and

those that show about the same frequency in both. From this it can be assumed that some of the tundra plants are more sensitive to human disturbance than others, and that some are not only permissive of it but actually thrive on it.

(5) Studies at experimental sites in the Mesters Vig district support the suggestion that significant effects of human occupance upon the plant habitats are reduction of plant cover, compaction and desiccation of the soils, reduction of frost action, and greatly increased physical disturbance of the soil due to nonfrost activity.

(6) Nitrogenous wastes, where they occur, greatly stimulate the growth of ruderal plants; but in the time periods involved here they do not appear to have affected the floristic content of the ruderal habitats. Related natural habitats such as "bird places" and areas frequented by muskoxen suggest that even with longer time spans the flora remains the same as that of the immediate surroundings though it is stimulated to prolific growth.

(7) The distribution of tolerance proportions among the ruderal plants suggests that it is related to the factor gradients of physical disturbance, and in part to that of moisture. If this is true the ruderal species appear to be selected from their natural habitats, at least in part, according to their tolerances of variation on these gradients. The extent to which they are selected by nutrient variations is not clear. Complete separation of the nutrient from other factors was not possible in the areas studied, but an approach to it was seen at "Camp Tahoe". There most of the nitrogenous wastes were localized, leaving a large area in which physical disturbance was predominant. The ruderal floras of the two areas were essentially the same, and the differences were mainly in vigor and profusion of growth.

LITERATURE CITED

GELTING, PAUL, 1934, Studies on the vascular plants of East Greenland between Franz Joseph Fjord and Dove Bay (Lat. 73°15′–76°20′ N): *Meddr Grønland*, **101**, 2, 340 p., 47 figs., 4 pl.

— 1937, Studies of the food of the East Greenland ptarmigan, especially in its relation to vegetation and snow-cover: *Meddr Grønland*, **116**, 3, 196 p., 46 figs., 1 pl.

KOCH, LAUGE, 1945, The East Greenland ice: *Meddr Grønland*, **130**, 3, 373 p., 140 figs., 1 pl.

RAUP, H. M., 1965 A, The flowering plants and ferns of the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **166**, 2, 119 p., 1 pl.

— 1965 B, The structure and development of turf hummocks in the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **166**, 3, 112 p., 40 figs., 1 pl.

— 1969 A, The relation of the vascular flora to some factors of site in the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **176**, 5, 80 p., 15 figs., 3 tab.

— 1969 B, Observations on the relation of vegetation to mass-wasting processes in the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **176**, 6, 216 p., 75 figs., 10 tab.

— 1971, The vegetational relations of weathering, frost action, and patterned ground processes in the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **194**, 1, 92 p., 47 figs., 11 tab.

SØRENSEN, THORV., 1933, The vascular plants of East Greenland from 71°00′–73°30′ N. Lat.: *Meddr Grønland*, **101**, 3, 177 p., 7 figs., 20 pl.

— 1937, Remarks on the flora and vegetation of Northeast Greenland, 74°30′–79° N. Lat., *in* SEIDENFADEN and SØRENSEN, The vascular plants of Northeast Greenland, etc.: *Meddr Grønland*, **101**, 4, p. 108–140.

— 1953, A revision of the Greenland species of Puccinellia Parl., with contributions to our knowledge of the arctic Puccinellia flora in general: *Medd Grønland*, **136**, 3, 179 p., 144 figs., 13 pl.

THORARINSSON, SIGURDUR, 1951, Notes on patterned ground in Iceland: *Geogr. Annaler*, no. 3–4, p. 144–156.

TROLL, C., 1944, Strukturboden, Solifluktion and Frostklimate der Erde: Geol. Rundschau, bd. 34, p. 545–694. English translation by H. E. WRIGHT, JR., publ. as Transl. 43, *U.S. Army S.I.P.R.E.*, 1958.

UGOLINI, F. C., 1966, Soils of the Mesters Vig district, Northeast Greenland, 1, The Arctic Brown and related soils: *Meddr Grønland*, **176**, 1, 22 p., 5 figs., 1 pl.

WASHBURN, A. L., 1965, Geomorphic and vegetational studies in the Mesters Vig district, Northeast Greenland, General introduction: *Meddr Grønland*, **166**, 1, 60 p., 8 figs., 5 pl., 5 tab.

— 1969, Weathering, frost action, and patterned ground in the Mesters Vig district, Northeast Greenland: *Meddr Grønland*, **176**, 4, 299 p., 118 figs., 91 pl., 29 tab.

— and GOLDTHWAIT, R. P., 1958, Slushflows: *Geol. Soc. Amer. Bull.*, **69**, p. 1657–8 (abstract).

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