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PERIGLACIAL PHENOMENA ON THE VARANGER PENINSULA (NORWAY)

Abstract

The northernmost part of Scandinavia, the Varanger peninsula, belongs to the Subarctic zone. It is possible to observe there the occurrence of both active and inactive periglacial phenomena at the same height above sea level. The area is picked out as being transitional between the active periglacial zone of the Arctic, and the fossilised periglacial zone of Central Europe. In comparison with Spitsbergen, Varanger only exhibits half the active, high Arctic periglacial processes.

INTRODUCTION

The Varanger peninsula is the northernmost part of Norway, and is the largest peninsula in the country, taking in an area of about 5700 square kilometres. The peninsula is bounded to the West by Tanafjord and by the valley of the river of the same name to the South by Varangerfjord, and to the North and East by the Barents Sea. Several relatively wide but short fiords break the north-eastern coastline of the peninsula, the largest being Båtsfjord and Syltefjord, both about 15 km in length. The axes of these fiords run approximately SW—NE, in accord with the dominant trends of the tectonic structures in the area. The 4 km long Trollfjord is also characteristic of the area, dissecting the western coast of the peninsula, and forming a small but geologically interesting arm of Tanafjord. Trollfjord is a glacial valley but was as it were predestined by a clear tectonic line running WNW—ESE known as the Trollfjord—Komagelv dislocation (A. Siedlecka, S. Siedlecki, 1967).

The interior of the Varanger peninsula is occupied by an extensive plateau, which is relatively undifferentiated in morphological terms. Gentle elevations on the planation surfaces reach heights of the order of 250—550 m. The highest hills run in a belt to the south of the Trollfjord—Komagelv dislocation line, broken by tectonic factors and erosion. The highest points here are Stangenestind (724 m), Hanglecerro (618 m), and Skipskjölen (637 m). In the western and north-western parts of the peninsula the morphology of the terrain is conditioned to a considerable extent by tectonic structures. The evident folding of the strata and their fault dislocations have determined the formation of valleys and upland tracts, reflecting the tectonic pattern. The varied resistance of the intensively

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folded strata to erosion processes emphasises this, with a frequent inversion of morphology in relation to geological structure. Valleys are often although not always formed along the lines of anticlines, and synclines are associated with elevations (eg: Stangenestind). The larger rivers among which the longest are Komagelva and Sanafjordelva, both about 45 km long, in general make use of extensive glacial valleys, with well developed post-glacial terrace systems. Their tributaries, especially in areas made up of easily eroded materials sometimes have the character of gorges, with typical V-shaped sections.

The vegetation of the Varanger peninsula is scant. It is only in some more sheltered valleys that it is possible to find a type of vegetation more or less similar to that of the taïga or tundra. There are found in these areas birches often *Betula odorosa*, with *Populus tremula*, *Sorbus ancuparia* and *Salix lapponum*, S. *caprea*, *S. reticulata*, *S. herbacea* and others. *Betula nana* is more widespread. In areas where the rocks include carbonates *Dryas octopetala* is common. Not infrequently one finds the characteristic *Rubus chamaemorus*. Among the lichens the most common are *Cladonia rangiferina* and *Cetraria islandica*.

The occurrence on the peninsula of periglacial phenomena, understood as active processes expressed by the form and stucture of the surface, is indicated by the prevalent climatic and morphological conditions, as was observed by H. Svensson (1962, 1963) who analyses aerial photographs of the area. This study revealed numerous sites of mostly fossilised periglacial forms originating in the post-glacial period and the beginning of the Holocene, principally non-sorted fissure polygons (Svensson *et al.*, 1967). H. Svensson (1970, 1977) has also investigated contemporary periglacial phenomena, including palsas in the south-western part of the peninsula where permafrost is occasionally found. The palsas have been analysed in detail by R. Åhman (1977).

The periglacial studies presented here are linked to geological studies of the older bedrock, which have been carried out by S. Siedlecki for many years. Special research covering periglacial phenomena was carried out in the summer of 1974 on the initiative and with the assistance of the other author (Jahn), who has been involved in studying periglacial areas on the other side of the Barents Sea, on the Spitsbergen archipelago. It seemed of interest and importance to link the periglacial forms of the Varanger peninsula mostly fossilised, to the mostly contemporary periglacial forms on Spitsbergen. Varanger is a transitional area in both spatial and temporal terms, where only several thousand years ago periglacial processes were fully active, as at present on Spitsbergen. These processes died out slowly, and it is our main intention to present certain regularities of this expiring periglacial cycle.

We would like to stress that our studies have not taken in all the periglacial phenomena on the peninsula: they are shown on the map (fig. 1). Apart from our observations, use has also been made of results obtained by others (Svensson 1962, 1963, 1964, Svensson *et al.* 1967; Boutand and Godard, 1977; Sollid *et al.*, 1973; Åhman, 1977). We feel that this is sufficient for the construction of a first synthesis of periglacial phenomena on the peninsula.

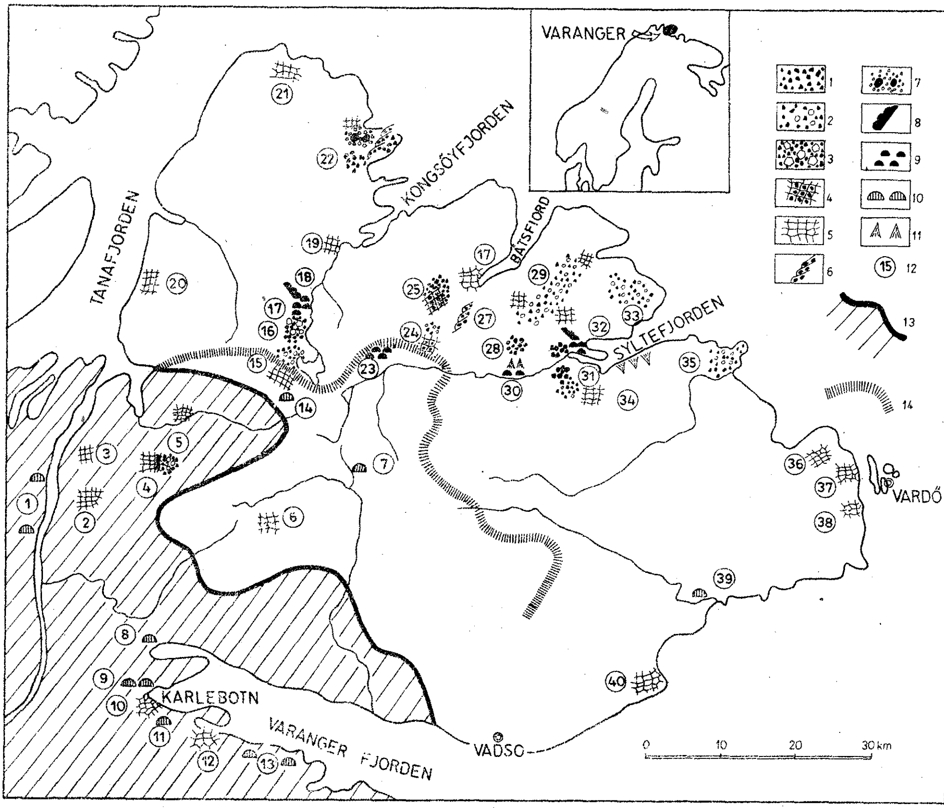


Fig. 1. Map of periglacial phenomena of the Varanger peninsula

1. block and debris fields; 2. block fields with debris and earth islands; 3. sorted polygons; 4. nonsorted polygons (frost crack nets) among block fields; 5. nonsorted polygons on terraces; 6. gelifluction lobes and debris terraces; 7. tundra craters; 8. gelifluction turf terraces; 9. turf and earth hummocks; 10. palsas; 11. scree cones; 12. number of site; 13. area of densely occurring woody vegetation (*Betula, Populus, Salix*); 14. boundary of climatic regions

THE CLIMATE OF THE VARANGER PENINSULA

The climatic features of the Varanger peninsula were analysed on the basis of information provided by R. ÅHMAN (1977). Difficulty is caused by the fact that all the information about the course of climatic events on the peninsula cames from meteorological stations located on the coast; there are none inland. Thus the climatic features of the interior of the peninsula can only be determined by extrapolation, as an approximation to reality (fig. 2).

From examination of these data it may be seen that the peninsula can be divided into two climatic regions, the boundary between which runs in an arc from the middle of Tanafjord to the entrance to Varangerfjord. In the main part this boundary coincides with the line marking the highest elevations on the peninsula, and corresponds to the important tectonic line, the Trollfjord—Komagelv Fault zone. The NE region (I on the map) is characterised by a higher mean

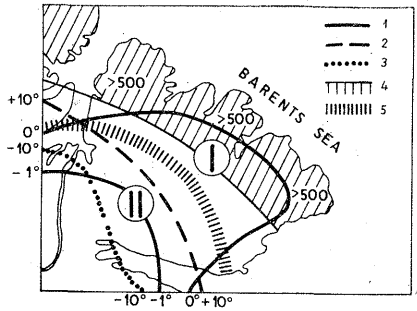


Fig. 2. Climate of the Varanger peninsula, based on the data provided by H. ÅHMAN (1977) in the period 1960—1974

1. mean annual temperature; 2. mean summer temperature; 3. mean winter temperature; 4. mean annual precipitation higher than 500 mm; 5. boundary of climatic regions; I and II - climatic regions

annual temperature (0° to +1 °C), a mild winter (mean —4° to —8 °C), and a cool summer, with mean temperatures below +10 °C. Precipitation is greater, with an annual total of more than 500 mm. The SW region (II on the map) has a mean annual temperature below 0 °C, a winter temperature of the order of —10 °C, and summer temperatures on the average above +10 °C. Precipitation is less than in the North, with an annual total of about 400 mm. The northeastern part of the peninsula thus has a more oceanic climate while the south-west has a more continental climate.

These climatic differences are distinctly visible in the external features of the land surface. In the northeast, the surface is mostly composed of bare rock or debris. Grassy areas are impoverished, and occasionally stunted birches (*Betula nana*) and willows (*Salix* sp.) are found. There is no continuous permafrost. The southwestern area, with its continental climate is covered with grass and its valleys contain woods, mainly copses composed of *Betula tortuosa*. Farther south there are *Pinus silvestris* and *Picea obovata*, together with stunted *Betula* and *Salix* trees.

The characteristics of the climate are evident in the vegetation. On this basis I. HUSTICH (1960) held that almost the whole peninsula should belong to the subarctic zone, and only a narrow belt on the northern coast to the arctic zone. It seems to us, however, that the whole peninsula belongs to the subarctic zone, and that it should be divided into the above two climatic regions. This would be in accord with the views of A. A. GRIGORIEV (1946) who differentiated the Subarctic between the near-arctic Subarctic and the near-boreal Subarctic. On the Varanger peninsula, these differing climatic zones are separated by the main ridge, and thus belong to different morphological regions.

It will be one of our main tasks to examine whether these regions also differ in their types of periglacial phenomena.

THE GEOLOGY OF THE PENINSULA

From the geological point of view the Varanger peninsula is of great interest. It is here that four significantly differing geological regions approach and even touch each other. They are (Fig. 3):

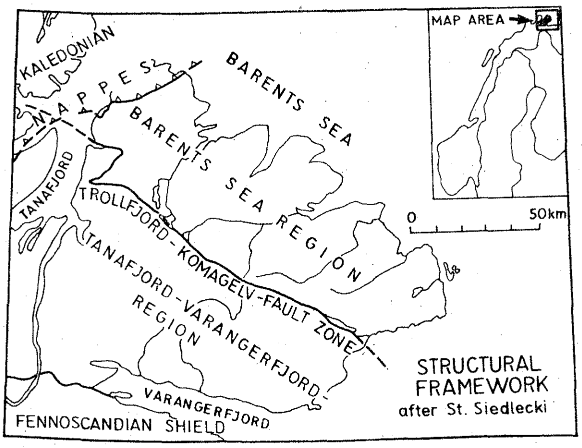


Fig. 3. Geological structural framework according to S. Siedlecki

1. The Fennoscandian shield, built of Precambrian cristalline rocks, which is the oldest structural unit in the area. Its northern edge forms the southern edge of Varangerfjord. To the west of the fjord, more or less along its axis, the edge of the shield, is gradually covered by sedimentary formations of the Youngest Precambrian, and Cambrian.

2. Scandinavian Caledonians, the northernmost units of which are known as the Kalak overthrust complex. The rocks occurring here were initially sediments (sandstones, claystones, conglomerates) which have to a greater or lesser extent been subject to metamorphosis, and transformed into quartzites, crystalline, slates, and metaconglomerates.

3 and 4. Two regions geologically different are known as the Tana and Varangerfjord region, and the Barents Sea region.

The above regions are separated by the dislocation line, known (A. Siedlecka and S. Siedlecki, 1967) as the Trollfjord—Komagelv dislocation or fault. The course of the dislocation, very complicated in detail, has a general WNW—ESE trend, that is almost exactly at right-angles to the dominating trend in the Caledonian structures.

Despite differences in the stratigraphical and tectonic characters of both regions, they have similar features if one considers the types of rocks occurring, and it is this which is of decisive importance for periglacial phenomena. Both regions are dominated by sedimentary rocks which have either not been metamorphosed, or only to a slight extent. They include various kinds of sandstones, often arkose, or quartzites occurring alternately with clay and silt series. In addition conglomerates are to be found, specially in the initial phase of larger sedimentary cycles. A minor but characteristic feature of both regions is the occurrence of carbonate formations (dolomites and limestones), normally interbedded with clay deposits.

Characteristic glacial and fluvioglacial sediments (tillites, sandstones, clays) connected with the late Precambrian glaciation, the „Varangian Ice Age" are a very interesting and important element of the geology of the Varanger peninsula for stratigraphy and palaeogeography. They are, however, only known in the Tana and Varangerfjord region. In the Barents Sea region on the other hand dolerite dykes are often to be found, a rarity in the Tana—Varangerfjord region. These intrusions are of no significance in the study of periglacial phenomena.

The sedimentary formations of the Tana and Varangerfjord region reach a thickness of the order of 4500 m. They directly overlie the crystalline base of the shield, and their genesis is interpreted as being linked with a shallow water sedimentary environment principally marine, although in some cases continental.

In tectonic terms these sediments are only slightly contorted and in the tectonic description of the Varanger peninsula are described as autochthonous or parautochthonous.

BLOCK AND DEBRIS FIELDS

The occurrence of block fields on the Varanger peninsula is dependent upon geological factors. They are formed on exposures of harder rocks, quartzites and sandstones (Pl. 1). Since these rocks make up the highest ridges in the area, the watershed running diagonally across the whole peninsula, these phenomena are found on these ridges at a height of about 500 m (sites 15, 16, 29). The block fields are composed of boulders with diameters ranging from 0,25 m to more than 1 m, without fines. They can be distinguished on aerial photographs by their light colour. If a ridge or slope is covered by debris, consisting of elements of smaller diameters, then we may speak of a debris field. These debris fields cover slopes built of weaker rocks, like slates. Lobes of debris descend a long way down the slopes, occasionally reaching valley floors.

The block fields were formed by the mechanical collapse of the rock after the retreat of the ice sheets. H. Svensson (1970) has suggested that this happened in the Younger Dryas, which is confirmed by Norwegian research (Sollid *et al.*, 1973). Traces of ice sheet activity were observed by the present authors over the whole area of the peninsula, principally moraines and striation marks. It does not seem probable that even the highest parts of the peninsula, exceeding 600 m in height, were nunataks during glacial maxima. The block fields were formed as suggested by R. Dahl (1966) and L. Strömqvist (1973) in the Post-glacial period under periglacial climatic conditions. None of the summit, quartzite block fields known to us show any sign of current activity. The boulders are covered with lichen, the fields are dry, well washed, and are not subject to movement due to gravity. This conclusion does not concern slope block fields, which will be discussed below.

The block fields often have their own relief, as was noted by H. SVENSSON (1970). Furrows are evident on their surfaces, laid out in the form of polygons. This kind of tetragon was described by H. SVENSSON on the basis of the Buktkjölen block field (site 16). He considers that the net is a periglacial phenomenon, a nonsorted net. Frost fissures follow here the pattern of divisions in the rocks upon which the blocks lie. There is also a very peculiar tetragonal net at the block field on the hill to the west of Gednjevannet, which was studied by the present authors, and whose origin will be examined below.

SORTED POLYGONS AND CIRCLES

Sorted polygons and circles occur on the margins of block fields. In a typical situation at the bottom of slopes, where the surface inclination is 2—5°, there are sorted polygons (Pl. 2, 3), while higher up, with a slope angle of 10°, sorted circles are found. The ridge itself is covered with block fields; this situation holds at sites 16, 17, 28, 29 and 33 (Fig. 4).

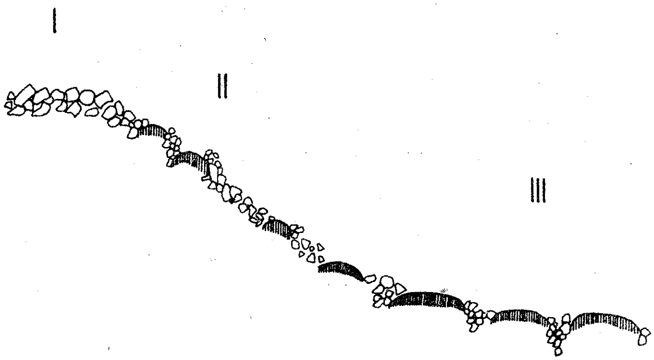


Fig. 4. Three sections of block-debris phonomena on the slopes

I — block fields; II — earth and debris islands; III — sorted polygons

The sorted polygons found on the peninsula are similar in appearance to the classical active forms observable for example in Spitsbergen, but are covered with grass, and stunted *Betula nana* and *Salix* sp. They are very regular, being circular or polygonal, and divided by furrows. The patterned ground shapes are flat, with a diameter of 3—4 m (site 17) or 1—4 m (site 16); there are boulders in the furrows. At site 17 there are no signs of present ground movement, and the polygons are without doubt fossil phenomena (Pl. 4, 5). At site 16, however, in the centres of the structures there were traces of current frost heaving, where the vegetation cover was broken. This reactivisation of soil movements is more marked in the „debris islands" which may be classed as sorted circles. Its center is convex and does not carry vegetation. Fissures and isolated stones are visible on the uneven surface. It is surrounded by a border of sorted, loose stones, covered by a layer of mosses with tufts of grass. Beyond this there are the stones of the debris field which are loose, and free from vegetation.

Even clearer traces of current frost activity can be found among the nonsorted phenomena of site 22, near the northern coasts of the peninsula (Kongsöyfjord, Risfjord) at a height of about 100 m (Pl. 3). In the continuous vegetation on a surface sloping at 2—3°, there are circular and oval islands of clay and gravel. This material contains relatively large amounts of fine sand and dust (60%), and clay (12%, Fig. 7). This phenomenon bears every resemblance to tundra craters or ,,Erdquellen", which are continuously every year active. The forms examined by us, in August 1974, could have been in existence since spring or early summer of the same year. The material was damp, and of a hard, plastic consistency. Fissures several millimetres wide were visible on the surface and the islands were surrounded by a low gravel border (Pl. 3). To a depth of 60 cm no permafrost was found. We suppose that these forms are linked to a cryostatic processes, developing on the basis not of continuous but of seasonal permafrost. The location of these islands, at the foot of the slopes of a pass, indicate their connection with slope water. They are laid out along lines following the angle of the slope.

Similar extrusions of clay are found at other places, for example at site 16. It may be the case that they occur throughout the peninsula, and are active in the present climatic conditions of the region. H. Svensson (1962) notes that in the eastern part of the peninsula near Bussesund (site 37); small recent frost-ground phenomena such as stone rings are seen on the surface (p. 187). Hence our conclusion that shallow frost activity, sorting, frost pavements, micropolygons, and reactivated debris island centres are characteristic processes in the current morphogenetic phase of the Varanger peninsula.

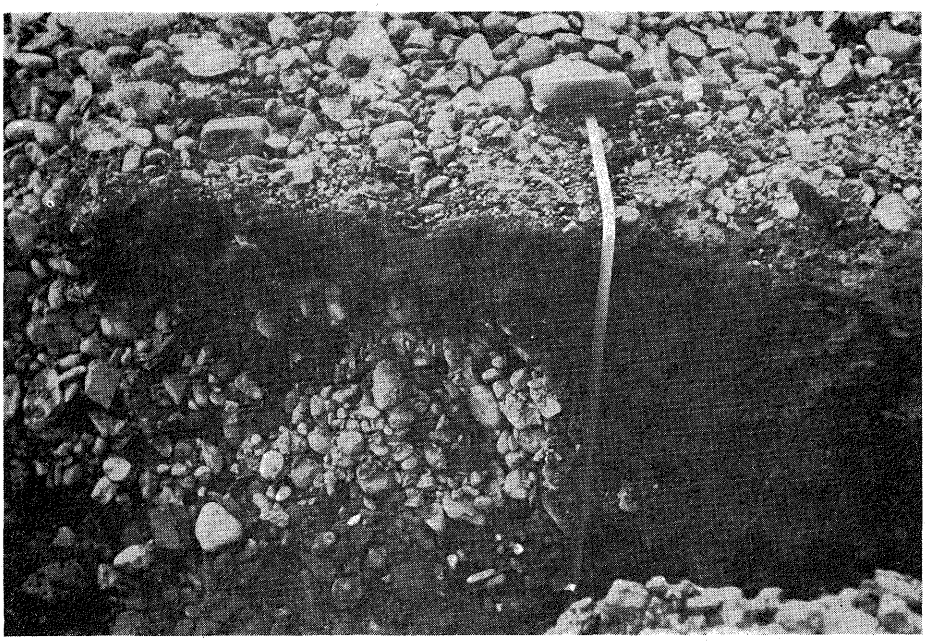
Another phenomenon which we feel should be included among current periglacial ones is that of stone pavements. On the surface of clay soils near Syltefjord, Batsfjord and Kongsöyfjord, where there is no vegetation, it is possible to observe a clear concentration of stones, which can only be explained by current frost heaving raising larger elements to the surface. It seems that climatic processes favour vertical ground sorting. It is worth adding that P. Bout and A. Godard (1973) observed sites of frost pavements (dallage de pierres) above Parsangerfjord, and linked their origin with snow patches (névé).

NONSORTED (FISSURE) POLYGONS

Among the periglacial phenomena described from the Varanger peninsula, the most common are fissure polygons. H. Svensson in numerous studies has paid great attention to this kind of forms. He differentiates polygons in the coastal zone and on the uplands. The former occur on uplifted coastal terraces and deltas, and have been examined in detail by A. Maack (see Svensson *et al.*, 1967), while the latter are to be found among upland block fields. Many new sites of

Photo by the author

Pl. 1. Pt. Hennequin. Sorted circles on the VIth marine terrace



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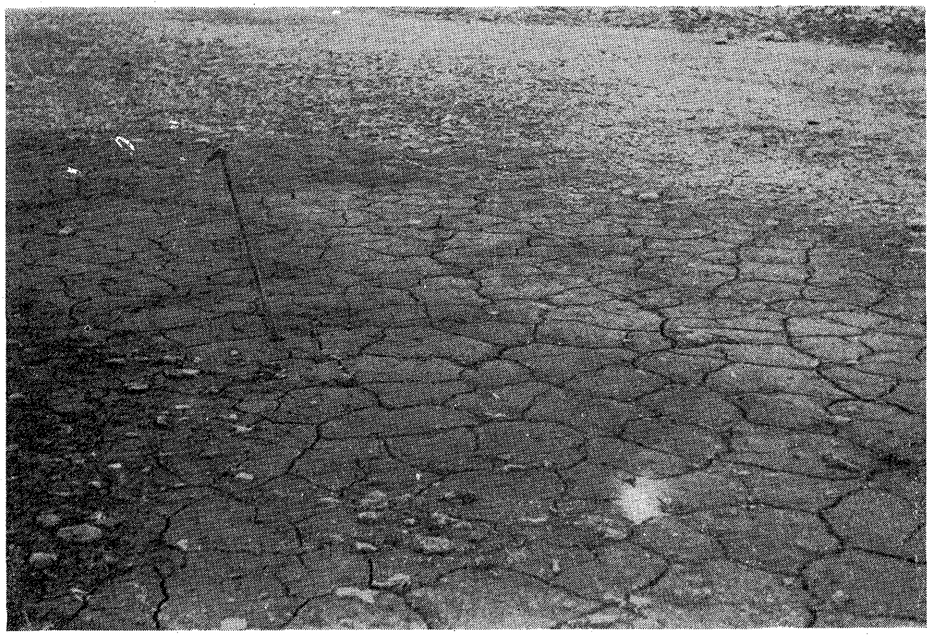
Pl. 2. Pt. Hennequin. Cross-section of the sorted circle



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Pl. 3. Pt. Hennequin. Desiccation polygons on the marine terrace

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Pl. 4. Small stone stripes

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Pl. 5. Pt. Demay. Gelifluction lobes. Corase material accumulates along sides of tongues and forms distinctive debris ridges resembling stone stripes

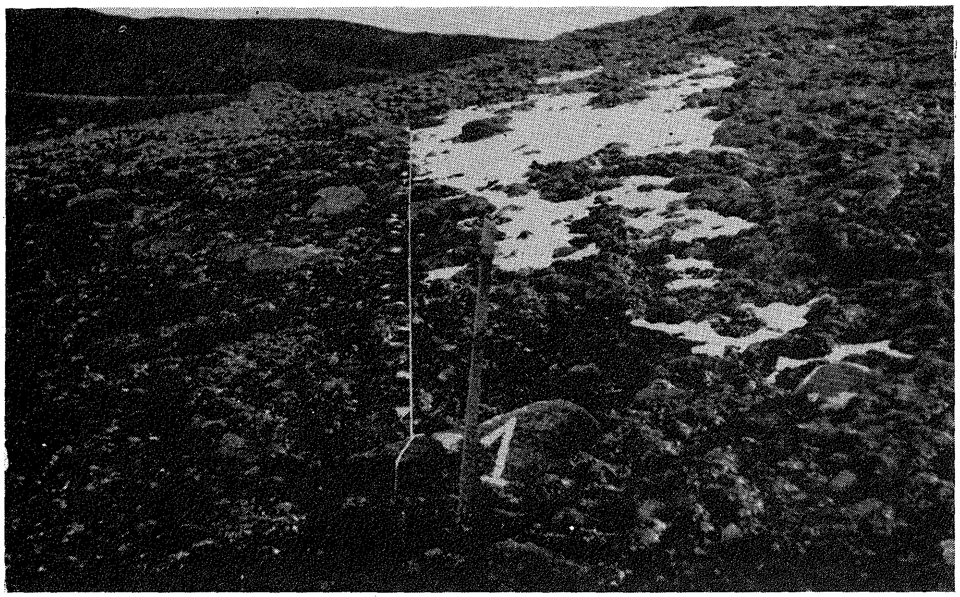


Photo by A. Szymański, 1979

Pl. 6. Penguin Ridge. Gelifluction lobes. White painted stones arranged in lines show waste displacement

Photo by the author

Pl. 7. Strongly shattered rocks due to intensive mechanical (frost) weathering

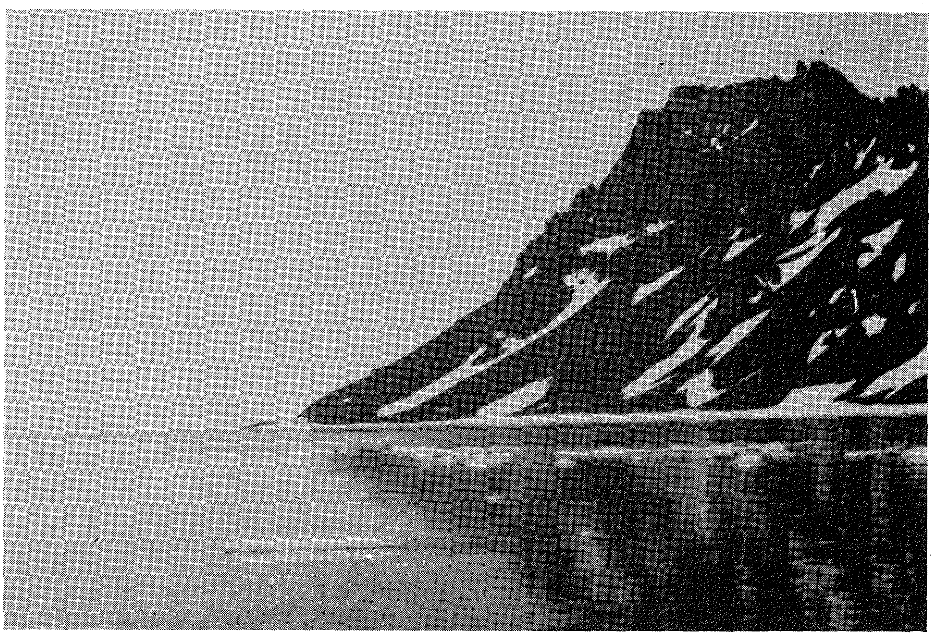
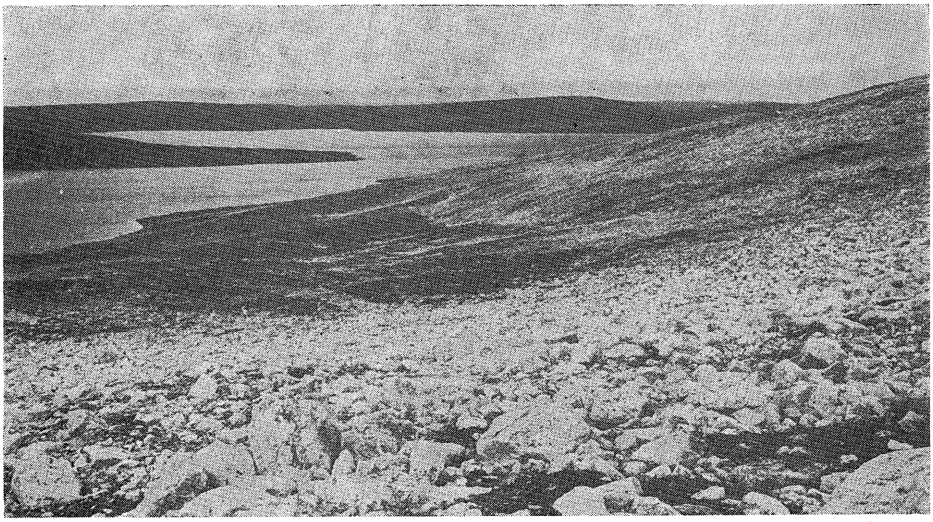


Photo by the author

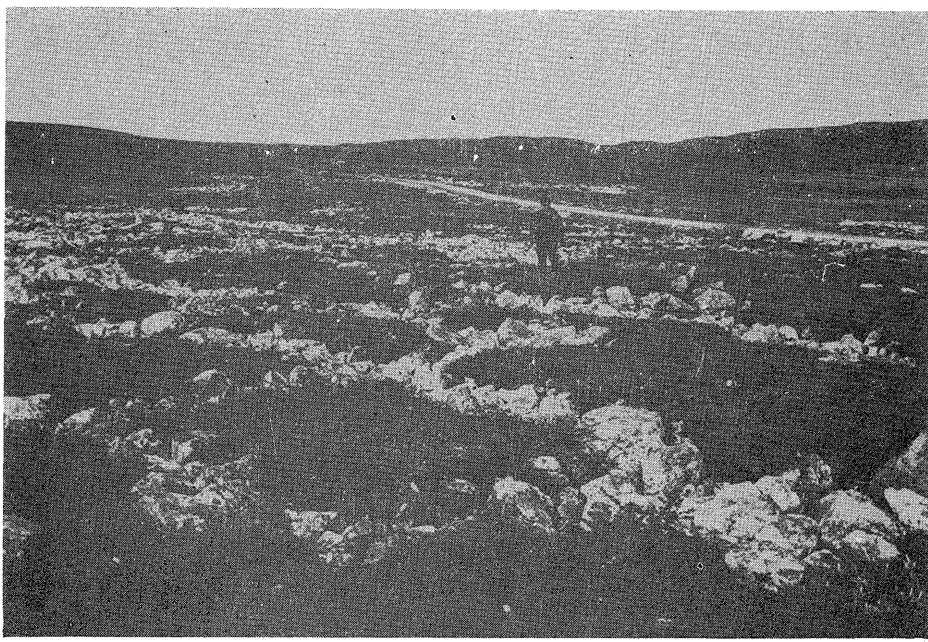
Pl. 8. Pt. Thomas. Steep free face and straight segment of debris slope



Pl. 1. Block fields on the slopes and ridges on the Varanger peninsula (site 15)

Pl. 2. Earth and debris islands, on the eastern slope of Båtsfjord, 450 m above sea level (site 29)

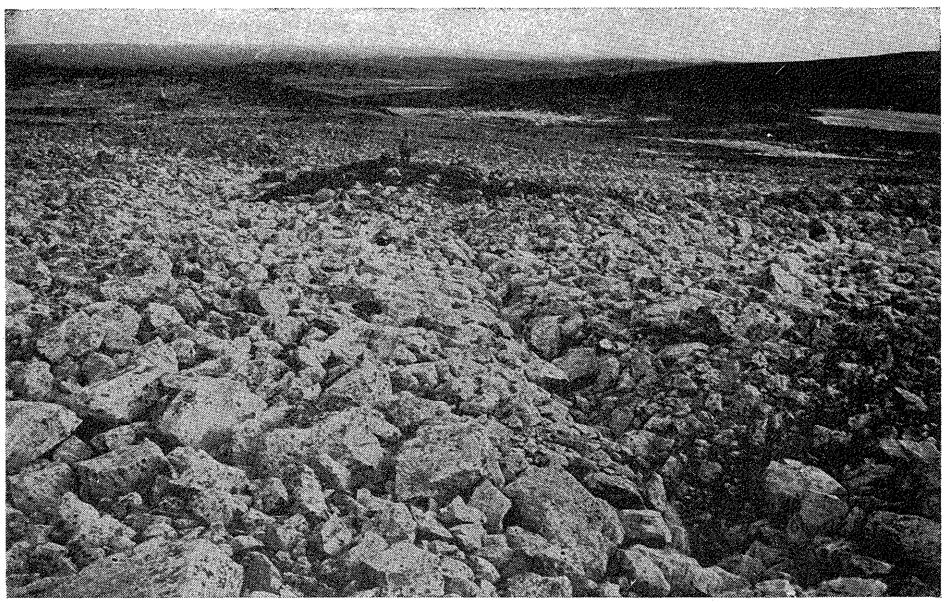
Pl. 3. Fresh extrusions of clay and gravel on the tundra near Kongsöyfjord (site 22)



Pl. 4. Sorted polygons in the Gaednialakka valley, 200 m above sea level (site 17)

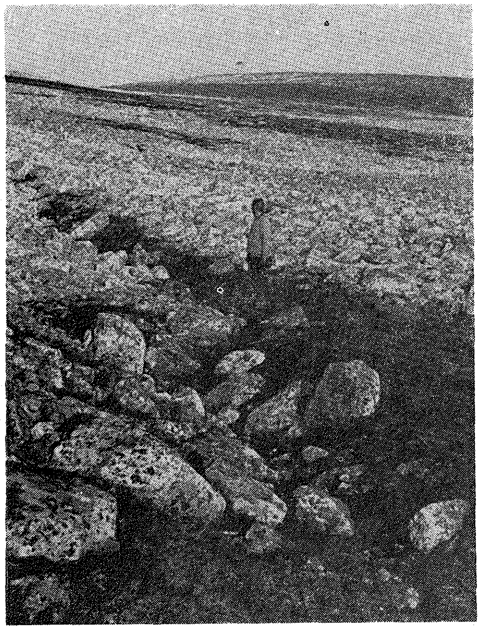
Pl. 5. Details of the polygonal net in the Gaednialakka valley

The inner fields of the net are covered with dense vegetation (grass and shrubbery). The furrows are filled with blocks on the surface of which are patches of lichen. The inactive polygons



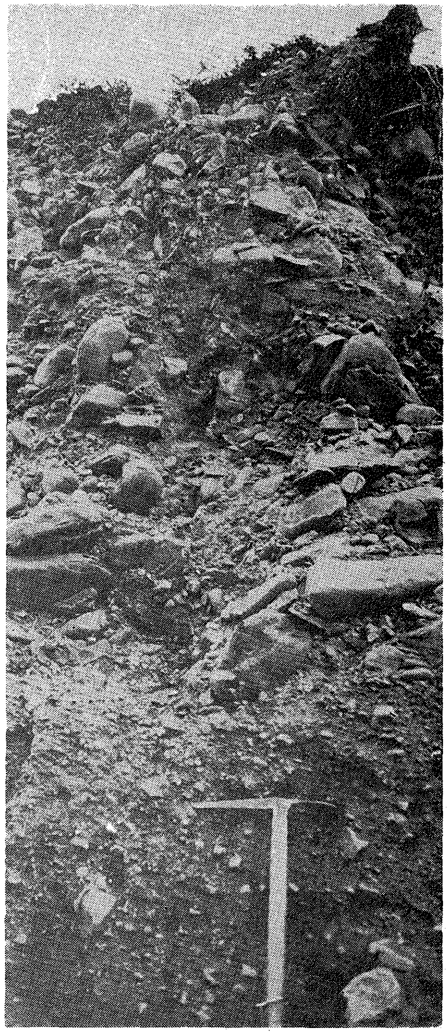
Pl. 6. Tetragonal net covered with blocks on the slope (site 15)

In the foreground of the photograph, furrows transverse to the inclination of the slope, almost completely covered with blocks. The characteristic arrangement of the blocks shows their repeated collapse into the fissure. The furrow on the right of the hill (a man) along the line of slope, is perpendicular to the transverse furrow

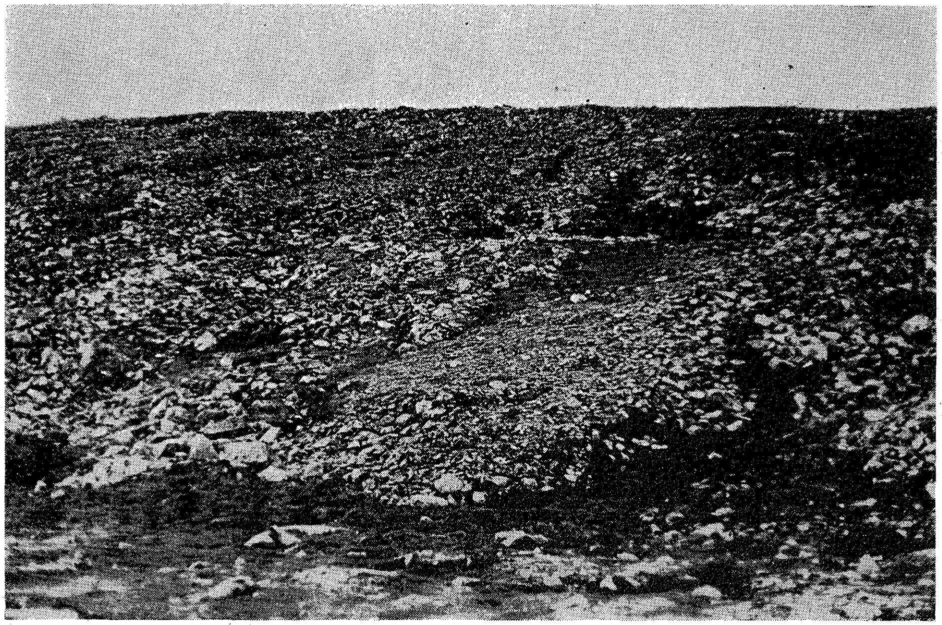


Pl. 7. Details of the teatragonal net on the slope (site 15)

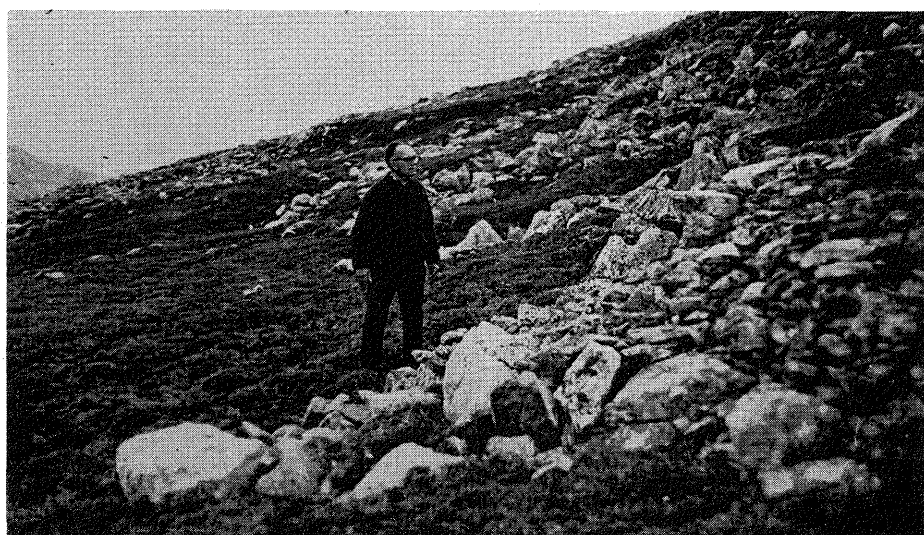
Grass path visible in photo represents the transverse furrow of a network partially filled with blocks (from above). (Phase 3, illustrated in fig. 6)



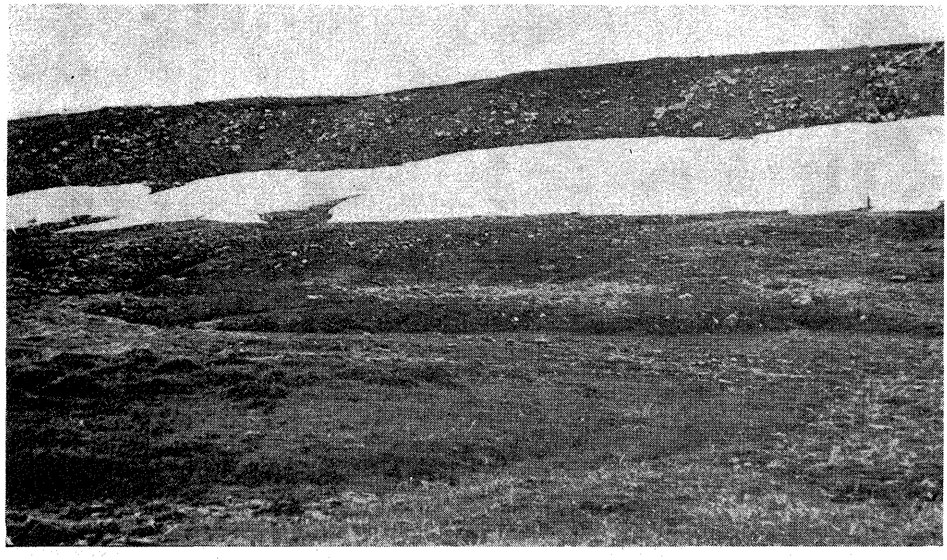
Pl. 8. Structures of the fossil ice wdges on Båtsfjord (site 26)



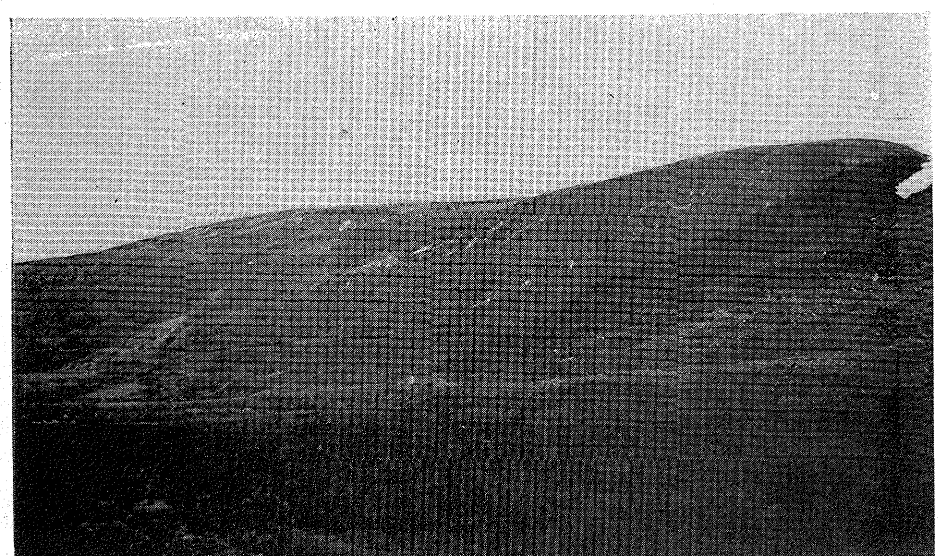
Pl. 9. Gelifluction lobes (tongues) near cape Nål on Kongsöyfjord (site 22)



Pl. 10. Details of the gelifluction lobes. Bloc fronts of lobes encroaching on fresh vegetation, which gives evidence of their actual activity



Pl. 11. Active gelifluction lobes beneath snow field. The upland of Davgevarri, 460 m above sea level (site 18)



Pl. 12. Gelifluction terraces on the slopes of Båtsfjordfjellet, absolute height of 400 m

Pl. 13. The earth hummock deformed by gelifluction on the sides of Syltefjord (site 32)

Pl. 14. Palsa mounds in the vicinity of Karlebotn (site 9)

these kinds were found and mapped by J. L. Sollid *et al.* (1973; sites: 3, 6, 19, 20, 21, 22, 24, 27, 29, 31). As an addition to observations made by Scandinavian researchers the present authors examined coastal polygons at sites 10 and 26, and upland polygons at the very important site 15.

It was H. Svensson who drew attention to the tetragonal shape of a large majority of the fissure polygons on the peninsula. This is conditioned additionally in the following way: on the raised terraces the principal direction of the polygons are parallel border mounds, while on the uplands the main direction is formed by the strike of the strata. The nets of the block fields are fitted to these, with the net elements ranging in size from 5 to over 60 m.

The net at site 15 (Fig. 5) occurs on the gentle slope of a mountain whose main summit is made up of a quartzite block field. The extraordinary regularity of the tetragons is striking, and is visible both from aerial photographs and in the field. The sides of the squares are longer than 50 m. Inside the squares is a secondary net, less regular in shape with a diameter of about 15 m.

On the lower slopes, near the lake, the net is clearly visible on the grassy surface; its grain-size composition is given in Fig. 7, curve 5. The fissures which cut through the brittle slate, and are grass-covered, are visible on the surface as furrows. On the upper slopes the same net occurs within an extensive block field. The blocks enter the fissures and furrows, partly filling them. Their vertical arrangement is very characteristic, with their long axes along the furrows. There is no doubt that these blocks slid down into the fissures over melted ice.

Furrows running down the slope are filled with blocks. However, furrows crossing the slope only have blocks to one side, as is shown in Fig. 5 and Pl. 6, 7. This fact indicates that transportation of blocks is younger than the creation of the fissures and the ice wedges filling them. The blocks, sliding down the slate slope, covered over the net of fissures and ice wedges. The downslope fissures eased the movement of the blocks, and were thus filled up. The cross-slope fissures, however, formed an obstruction to the movement of blocks, and a trap,

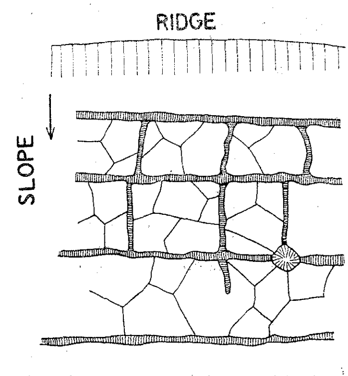


Fig. 5. Net of fissure (nonsorted) polygons covered with blocks on the southern slopes of site 15

Absolute height of about 400 m. The great trenches partly overgrown by grass indicated by double lines. The narrower fissures, completely filled with blocks and debris, are indicated by single lines. The drawing was made on the basis of an air photo especially when the ice wedges melted. The blocks fell in, as is very characteristic for these asymmetrical trenches. The movement of blocks was halted by them, while below the fissures the slate surface was exposed (Pl. 7). These steps in the transgression of blocks onto a fissure net, and the consequences of the melting of the wedges are illustrated schematically in Fig. 6. It should be added that the fissures and trenches of nets were further deepened and developed following the retreat of continuous permafrost by two types of process, by gravitational action (cross-slope trenches), and by the action of water flowing of the slope (down-slope trenches). In this way it is possible to explain the large size of the cross-slope trenches in particular which reach more than 4 m in depth in places.

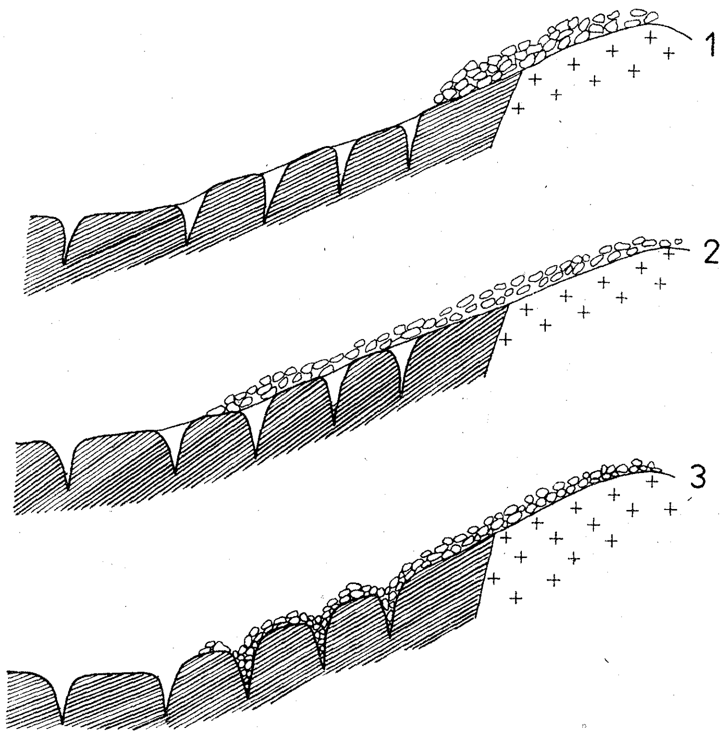


Fig. 6. Transgression of block cover on a slope to the west of Gednjavatnet (site 15), Varanger peninsula

1. the network of ice fissures and wedges in schist on a shallow slope. The block cover is formed on quartzites on the ridge. Intensive frost weathering phase; 2. block field shifts onto frozen net (permafrost). Phase of accelerated gelifluction; 3. degradation of permafrost, melting of ice wedges

Cross-sections of fissure polygons are known from the Varanger peninsula together with associated structures. H. Svensson (1962) described them from near Bussesund (western part of peninsula, site 37), and A. Maack (see Svensson *et al.*, 1967) from near Båtsfjord (site 26). The present authors examined sections near Båtsfjord (site 26) and came to the following conclusions (Pl. 8).

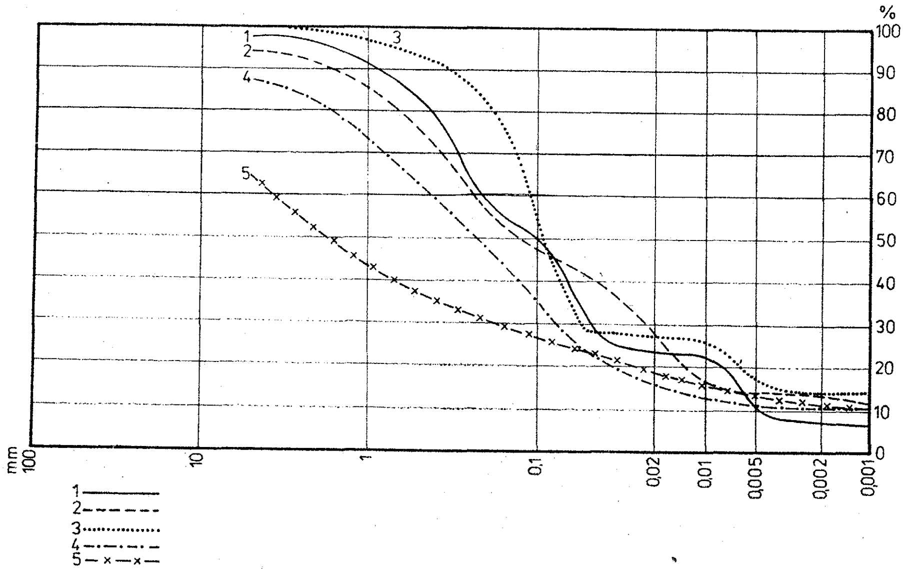


Fig. 7. Mechanical composition of certain materials undergoing frost processes, Varanger peninsula

1. and 2. material of turf and earth hummocks on the summit of Oar'duvarri, site 23 (stratum 3 and 4 in the drawing, Fig. 10); 3. material from the deformed gelifluction turf-earth hummock on Syltefjord (site 31); 4. material from the gelifluction terraces on Båtsfjord (site 27); 5. material from the polygonal network (site 15)

Wedge structures are not relatively large, maximum 2,8 m deep (Svensson observed 1,8 m at Bussesund). The average depth of wedges is 1,5 m. They occur in the gravels of the coastal terrace, and from the pattering of the gravel it can be seen which processes were operating during the existence of ice and immediately after its melting. We did not notice any signs of the pressure of ice wedges on the walls, nor did we see any raised structures, that is evidence of ice activity. The gravel always falls downwards, filling the fissure. The same conclusion is reached by H. Svensson and A. Maack as well. It is also significant that the humus horizon in the soil is present deep in the wedge. These kinds of structures may be classified as being formed after epigenetic wedges. They could be treated as ice veins were it not for the fact that the material filling them reaches a depth of over 2 m that is deeper than the established depth of the active layer of permafrost. Ice left these wedges at a definitely warmer climatic phase, when relatively thick humus soils, or even peat, was formed on the surface of the terrace. H. Svensson (1970) states that the age of the organic material, filling the wedges on the Bussesund terrace is 4 500—5 000 years B. P. on the basis of C-14 dating.

Taking into account the Båtsfjord observations, the present authors feel that the ice wedges which were formed on raised deltas at the end of the Younger Dryas, existed for a relatively long time, almost up to the climatic optimum (peat from Bussesund), but they were wedges which could be termed non-active.

This is indicated not only by the structure of the sediments filling the wedges, which may possess secondary features, but also by their small dimensions. The phenomenon of non-active wedges, described principally by T. L. Péwé (1966) from central Alaska, is typical for areas of discontinuous permafrost, with mean annual temperatures of —2 °C to —4 °C. It is thus possible that after the Younger Dryas, and before the climatic optimum, this kind of climatic conditions dominated the Varanger peninsula, yielding similar nets on all terraces with similar diameters and fissure depths. Only the slope net (site 15) could develop larger fissures, but achieved this through additional slope-gravitational activity. A. Rapp and L. Annersten (1969) also observed this kind of narrow fossil wedge structures in central Sweden, also interpreting them as structures linked to weakly active wedges.

Even today on the Varanger peninsula it is possible to find fresh ground fissures, formed either by the drying of the soil, or as a result of frost action. It is thus not be impossible given the current climatic conditions of this part of Norway that ground wedge structures could be formed.

GELIFLUCTION

Gelifluction is the most common phenomenon to be found on the slopes of the Varanger peninsula. In fact every slope, on which there is loose eroded material, displays traces of the mass transport of material.

The gelifluction of this area will be divided in terms of material into debris and turf movement, including sorted and nonsorted material, in terms of form into steps and lobes or tongues, and in terms of age into contemporary and fossil.

All these types occur in combinations dependent on local conditions. It is not possible to differentiate areas in which they are present. The most common link is between turf gelifluction and steps.

The most interesting gravel gelifluction is found at site 22, near Kongsöyfjord, near Cape Nål. Near the sea, on a south-facing slope at a height of about 100 m, there are gravel tongues (Pl. 9). On the upper parts of the slope at a surface angle of 26 °, the length of the tongues reaches 10—20 m, while lower, with a more gentle slope they become longer. They encroach on each other, and have clear fronts built of boulders, about 1—2 m high. The present activity of gelifluction is evidenced by the fact that the fronts of these tongues are advancing over contemporary vegetation, over turf (Pl. 10).

Active tongues are visible wherever the slopes are covered by snow patches. Towards the end of July 1974, when we were carrying out studies on the Varanger peninsula, many winter snow patches were lying in hollows on slopes, in general above 400 m. Fresh tongues, with full convex fronts, are to be found at the bases of theses patches (site 23, Pl. 11). Gravel terraces are another form of gravel gelifluction and are very common in the oceanic, northern part of the peninsula. An example is site 27 near Båtsfjord. The terraces are not large, up

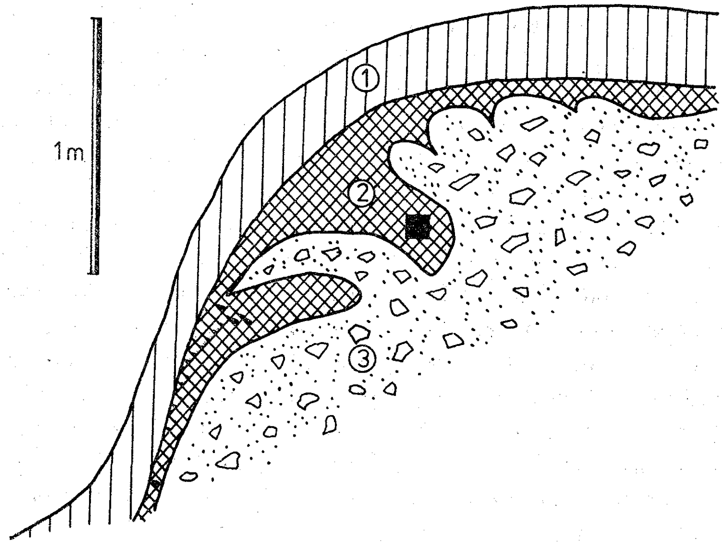


Fig. 8. Turf-earth hummock from Syltefjord, deformed by gelifluction (site 32)

1. vegetation (*Salix*) and turf; 2. peat; 3. sandy debris. Black square — place where sample was taken

to 0.5 m, but are very regular (Pl. 12). A section through such a form (Fig. 8, Pl. 13) indicates the continual renewal of the activity of the process. In the gravel material there is more than 30% of particles smaller than 0.1 mm (Fig. 7, curve 4). The turf covered by the gravel is relatively fresh. Thus while the surface of the terraces does not indicate any rapid current movement, the presence in them of subfossil soils is proof of the continuity of the process.

In one place we were able to establish the age of the gelifluction. In Syltefjord (site 32), gelifluction forms occur on the slopes of a post-glacial terrace. The surface of the terrace is covered with turf and earth hummocks. These hummocks have been deformed on the edge of the terrace, and on the slopes of the terrace they change into gelifluction lobes or tongues. One such gelifluction deformed hummock was excavated, at the front of the lobe on the edge of the terrace; the cross-section is shown in Fig. 8 and Pl. 13. The terrace gravels, have a large proportion of fine-grained material, dust and clay, and consequently they are easily subjected to deformation (Fig. 7, curve 3). These sediments are covered by peat and turf. In the section it can clearly be seen that the gelifluction mineral mass has several times invaded the peat, which was subjected to pressure by the clay-gravel mixture. A sample of peat was taken from one of these pockets of peat (Fig. 8), and was C-14 dated by the Physics Institute of the Technical University of Silesia in Gliwice, with a result of 815 ± 110 years. The order of events here was as follows: terrace formation, peat development, peat-turf hummocks, gelifluction. Gelifluction is younger than the hummocks and the peat, and the movement of slope materials has occurred during the last several hundred years.

The gelifluction of whole vegetation covers is a phonomenon perhaps even more common than gravel gelifluction, especially on north-facing slopes (Fig. 9). There are whole systems of terraces in general diagonally orientated in relation to the contours (Pl. 12). It seems that their presence is dependent on slope moistness, and thus also on the type of rock. Slopes built of finely erodable material like slate more often have turf terraces than hard rock slopes. Since the moisture of the slope encourages vegetation, it can be seen that both phenomena will coincide. In this case WASHBURN's opinion seems fair, that „the control by moisture was (is) more important than any binding effect of vegetation" (WASHBURN, 1973, p. 188). Moisture conditions on the slope certainly determine the courses of the terraces. Since the fronts of the terraces are not in accord with the course of slope contours, and most often cross them diagonally, as was observed by H. KÄLLENDER (1967) on Mager Island near North Cape, it should be concluded that material moisture has more influence on the pattern of terraces that slope angle. It is for this reason too that one can note many lobes which locally bend the uniform fronts of the terraces.

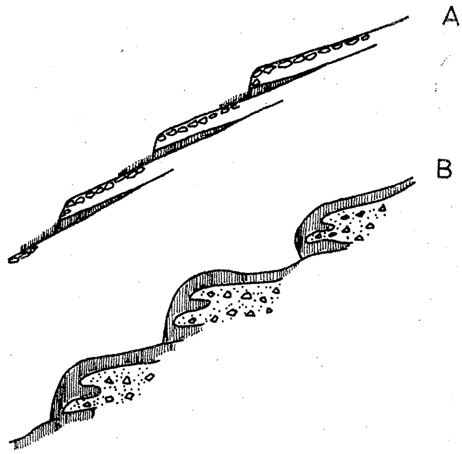


Fig. 9. Types of gelifluction terraces on the Varanger peninsula

A — debris terraces; B — turf terraces

Gelifluction is the process which has remained more or less active throughout the whole post-glacial period and the Holocene on the Varanger peninsula, and is indeed still active today. These are thus both fossil and active phenomena, linked together, from the oldest block streams (site 15), through several phases of increased activity in the Holocene (subfossil soils), to current moving tongues especially below snow patches. Gelifluction does not require permafrost, and hence its activity is not dependent on arctic or subarctic conditions, as for instance in the cases of sorted or non-sorted nets.

PALSAS AND STRING BOGS

Palsa hummocks have been known to be present on the Varanger peninsula for some time. H. SVENSSON (1964, 1970) described them, and during an excursion from subarctic Ecology Symposium held in 1966 in Helsinki, he showed the participants a palsa hummock near Karlebotn, Varangerfjord (site 9; A. JAHN was among those present). These phenomena were also mentioned by P. BOUT and A. GODARD (1973) who noted palsa sites in Sivertbugt on the southern shore of Varangerfjorden (site 11). In turn two studies have appeared, adding much to our knowledge of palsas in Scandinavia (SOLLID, SØRBEL, 1974; ÅHMAN 1977). R. ÅHMAN gives a detailed distribution of palsa hummocks on the Varanger peninsula, which we make use of here.

Dividing the Varanger peninsula into two climatic regions we find that palsa hummocks occur almost exclusively in the part of the peninsula characterised by a more continental climate (near-boreal Subarctic). These hummocks are principally found near Varangerfjord and according to J. L. SOLLID, L. SØRBEL (1974) and R. ÅHMAN (1977) this area is linked farther south with Norwegian, Swedish and Finnish Lapland, where palsas occur in groups and are very common. To the north of Varangerfjord on the boundary of the two climatic regions there are, according to R. ÅHMAN four isolated palsa sites (Fig. 1: sites 1, 14, 7, 39).

The present authors had the opportunity of examining some palsa hummocks near Varangerfjord (sites 8, 9, 13; Pl. 14, 15). We did not observe any palsas in the oceanic, northern part of the peninsula, but should state that some of the peat hummocks occurring here were reminiscent of palsas both in height (almost 2 m) and in form (site 18). We did not find any permafrost in any of these, so they cannot be treated as palsas.

Scandinavian authors have tried to define the relationship between palsas and climate. It was pointed out that there exists a double dependence between them, that is on continental climatic zones and on mountain climates. Palsas on lowland peatbogs in Lapland are the result of the first kind of dependence. Those in central and southern Norway, as for example the site noted by J. L. SOLLID and L. SØRBEL (1974) at a height of 1100—1200 m, are connected with the mountain and not the zonal climate of the region.

J. LUNDQVIST (1962) explained the relationship between palsas and the climate of Sweden. The forms occur where the mean annual temperature is not higher than —2°C, where there are more than 200 days in the year with frost, and where winter precipitation is limited. R. ÅHMAN (1977) found that palsas in northern Norway occur in areas with mean annual temperatures between 0°C and —1°C, mean temperature in the four winter months below —10°C, mean annual precipitation less than 400 mm, and mean winter precipitation less than 100 mm. The Varanger peninsula seems to confirm this regularity and this is why there are no palsa hummocks in the oceanic, northern part of the area.

There is a problem concerning the age of the palsas on the Varanger peninsula. While all students of Scandinavian palsas agree that they are contemporary forms, and thus correspond to the contemporary climate, opinions as to their origins and the role of the contemporary climate in their continued existence are varied. The palsas are younger than the peat-bogs within which they occur, often much younger, since in principle the layer of peat must be formed first, taking several thousand years, before it takes up its insulating role in relation to permafrost, which is the basic element in the formation of palsas. Since the peat is linked with the Atlantic climatic optimum, it seems that the palsas could not have been formed in the first period of the Holocene. R. Åhman (1977) calculated, using C-14 dating, that the beginning of the formation of palsas at Karlebotn, near Varangerfjord can be dated at 2450 B.P. There are also much younger palsas, for example Altvatn, 750 B.P.

A further proof of their age is the fact that they occur close to the sea, below the Younger Dryas deltas. They are younger than the Atlantic period. P. Bout and A. Godard (1973) also accept this view; this concerns of course the forms on the Varanger peninsula. It is difficult to say whether the forms are as young as K. D. Vorren (1972) suggests, with their origin dating from the seventeenth century climatic cooling. We feel, in accord with the suggestions of one of the authors (Jahn, 1976) that palsas may even be the result of small climatic changes, but that the effects of these variations are strictly limited to the peripheral areas of permafrost. The hillocks of this zone, the zone of discontinuous permafrost are formed, develop, and collapse — perhaps even cyclically as suggested by H. Svensson (1970) and L. E. Hamelin, A. Cailleux (1969), and this process may repeat itself many times, especially in this zone where the annual thermal balance, even with minor disturbances changes from above to below zero and *vice-versa*. A negative thermal balance in the surface of the peat bog creates the appropriate situation for the frost-raising of peat hummocks, but the raising of the hummock above the water surface, and the consequent change in the moistness of the peat can terminate the development cycle of the palsa, and can even lead to the collapse of the hummock. Climatic variations which condition the cycle of development and disappearance of palsas, thus concern the ground climate, even the local ground climate. Despite this, the whole local and cyclical process is within the framework of the general climate of the periglacial zone, which is characterised by mean annual temperatures close to 0 °C. We should add here that R. Åhman (1977) expresses the view that not only peat but also layers of snow can form the insulation needed for palsa formation. It is because of this that he distinguishes, apart from peat palsas, minerogenic palsas, with no layer of peat on the surface. The fundamental feature is the permafrost core of the palsa, in which the active factor raising the hummock is segregated ice.

String bogs are characteristic for the boreal zone, that is for Finland and northern Sweden. The authors also found them in the southern parts of the Varanger peninsula, and on the other, northern side of Varangerfjord. They may be observed from aerial photographs. They occur within the small basins of former lakes. Since some of them, like the palsas, are to be found close to the sea, below the delta line, which marks the post-glacial sea level, one can conclude that they began to develop in the second half of the Holocene, after the Atlantic phase.

EARTH AND TURF HUMMOCKS

This type of form is very common on the Varanger peninsula. According to J. LUNDQVIST (1962) small, turf covered hummocks contain a mineral core, and hence he includes them among ,,earth hummocks" or ,,non-sorted nets". They are present in the whole of Scandinavia, in the forest zone and above the tree line. H. KÄLLENDER (1967) paid considerable attention to such forms occurring on Mager Island near the Varanger peninsula.

From observations made by the authors on the Varanger peninsula, it was found that both turf and earth hummocks are present (Fig. 10). They are always in damp places of two types, on valley floors and terraces (sites 18 and 32) and on upland planation surface (site 23; Pl. 16). They occur singly and in groups, and on slopes exceeding 2—3° they are deformed by gelifluction. The turf hummocks are larger and more cone-like. Some of this type of form, at site 18, on the floor of the wide, waterlogged valley Gaedialakka even exceed 1.5 m in height, and in shape resemble palsas (Pl. 17). On the top there is light coloured young peat, while below is decayed, darker peat. We did not find any sign of frozen subsoil by sounding in fuly.

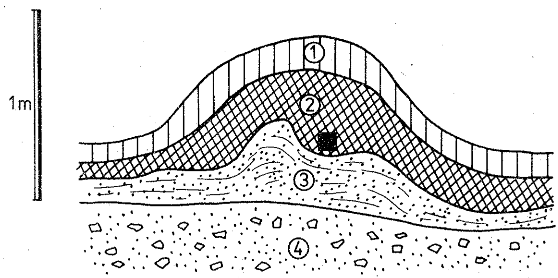


Fig. 10. Peat and earth hummock, on the Oar'duvarri upland (site 23)

1. young, pale peat; 2. dark peat; 3. dark sandy soil, with a disturbed structure; 4. sandy clay with stones (moraines); Black square — place where samples were taken for the C-14 analysis

The earth hummocks are covered by turf and peat, but the main element in their make-up is a sand or clay mineral core (Fig. 10). Their height reaches about 0.5 m; no permafrost was found in this case either. Their slopes are steeper than those of the turf hummocks, and they often are bell-shaped (Pl. 16).

The first type of form has a principally biological origin, with certain frost effects, while frost is the principal factor in the construction of the second. A structure of raised, often compressed layers is clearly visible in the mineral core (Fig. 10). This phenomenon is known, and has been described by BESKOV

(1930) and J. Lundqvist (1962), and thus its origin will not be discussed here. It is worth noting, though, that many of these hummocks are suffering current degradation. While the degradation of palsas begins from the top, earth hummocks collapse by undercutting from below (Fig. 11). A fissure is formed between the raised hummock and its surroundings, which is widened by water flowing over the ground surface between the hummocks. Freezing water is here of considerable significance. Snow, which until late in the spring fills the furrows, provides water for the creation of something resembling horizontal ice wedges, which attack the hummock sideways. Through this, the hummocks are undercut at their roots, and the turf on the hummock surface dries up and dies out, and fissures are formed.

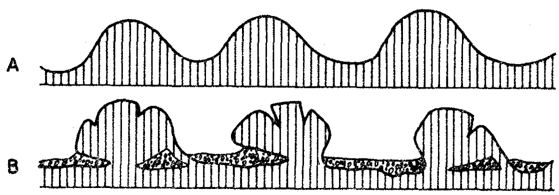


Fig. 11. Development (aggradation) and degradation of turf hummocks

A — stage of development, compact and fresh forms; B — stage of degradation, icision at the base, drying up on the surface (fissures)

Earth and turf hummocks are currently active forms. This does not mean that they did not develop in the past. Proof of this is the age of the peat which is involved in their creation. We have two C-14 datings of peat samples from site 23 (Fig. 10, Pl. 16), and site 32 (Fig. 8, Pl. 18):

site 23 (Gd—490) — 1 780 ± 80 years B.P.
site 32 (Gd—492) — 830 ± 110 years B.P.

(Dating; C-14 Laboratory, Institute of Physics, Technical University of Silesia, Gliwice)

The earth hummocks of site 23, located on the Oar'duvarri upland, 400 m, are composed of sands with humus, covered by two layers of peat of differing colours and consistencies. The sample for dating was taken from the lower part of the lower peat layer. Since under the peat there is a fossil soil (horizon 3 in Fig. 10), it may be held that the hummocks are younger than the warm phase during which the soil was formed. The peat was dated at 1 780 years B. P., at which time the hummock had not been formed. With the cooling of the climate frost processes disturbed horizon 3, and raised the peat horizon. This process on the upland surface is still active at the present time, despite the fact that some of the hummocks are subject to degradation, as shown in Fig. 11.

At site 32, on the terrace at Syltefjord, 40 m, there is a large field of mature hummocks with turf and peat on the surface, and pebbles and sandy gravel inside (Pl. 13). They are large forms, at present developing actively. At the edge of the terrace they have subjected to gelifluction deformation, and one of these forms which was examined in detail, is shown in Fig. 8. Gelifluction which is active periodically, has been moving onto the peat, covering the hummocks. Since the age of the peat covered by debris is 830 years it may be supposed that the process of gelifluction deformation, which is younger than the peat, is active at present. This conclusion also flows from the surface morphology. The whole edge of the terrace with traces of snow patches existing until late in the summer, is wrinkled, and shows signs of very fresh gelifluction flows.

SOME OTHER FORMS AND MORPHOLOGICAL PROCESSES

The active periglacial processes found on the Varanger peninsula include mechanical weathering on rock walls above the fjords of the north coast, increased slope erosion, and the transgression of slope debris onto vegetation.

In Syltefjord, Båtsfjord and Kongsöyfjord, the present authors found traces of a fresh debris layer on scree cones, which appeared light in colour in comparison with the layer it covered, which was composed of boulders covered with lichen; the light coloured debris apron did not reach the foot of the scree (especially site 30 and 34, Pl. 19). It is dissected by erosion channels, with natural levées. The intensive weathering of the walls which is the source of the light coloured scree apron, by analogy to Spitsbergen (Jahn, 1976), has only been occurring for the last 100 years, and possibly the last half-century. Apart from weathering there are also traces of increased water and avalanche erosion during this period. Flows of masses of debris and mud were observed on some cones. In total the cones display at present activeness, not only of the processes supplying fresh debris, but also of those transporting the material over the cones' surfaces.

Other signs of the reactivisation of degradation processes may be noted on ridges and slopes formed of less resistant slates (site 28). Where the vegetation cover has been destroyed, possibly by wind, it is possible to observe flows of debris moving downhill (Pl. 20, 21). The process is very young, with the debris occasionally covering fresh grass. This phenomenon is very regular, the debris is ordered by size, and it seems probable that spring melt waters cause this spreading of debris over the slopes. It is difficult to say whether it is a completely natural process, or whether it is some extent accelerated by the presence of man. We observed accelerated slope processes near roads.

There exists, or rather in the recent past, there existed the danger of interference with the equilibrium of the natural surface through the excessive pasturing of reindeer. One finds old herding enclosures as H. Svensson mentions (1963), and divisions between holdings. Despite this, there are also signs of increased slope degradation in places far from the coast which have remained subject to natural conditions.

One further process displaying more intensive activity is wind. Near Vadsö the whole surface of the marine terrace is covered with dunes — the site is known to Norwegian authors (Sollid *et al.*, 1973). It is not however impossible that the increased present-day wind action is linked to human influence. Traces of fresh eolian activity may be observed in the main near settlements. They have also been noted near larger rivers, especially in the Tana valley (Colinson, 1970). Eolian sands are to be found on river and marine terraces in the continental part of the peninsula. In the oceanic part, to the north of the main divide, they correspond to the mountain ridges degraded by wind described above, ridges which are the source of mobile debris.

THE AGE OF PERIGLACIAL PHENOMENA

All these phenomena result from the action of processes which began to operate after the retreat of the last glaciation ice sheet from the higher inland parts of the peninsula, and after the postglacial emergence of the coastline. In accordance with the views of Scandinavian scholars, the whole peninsula was glaciated during the Pleistocene which is evidenced by the occurrence of glacial striation, and subglacial and fluvioglacial forms such as kames and eskers. In any case, during the „Main Substage", corresponding to the Younger Dryas, the moraines of the ice sheet covering the interior of the Scandinavian peninsula stretched to the south of Varangerfjord. Since the oldest moraines on the Varanger peninsula running more or less along its northern edge, the „Domen Oksøyvatn Substage (Marthinussen, 1974) correspond to the Dani-Glaciation, the deglaciation of the peninsula occurred between 14 000 and 10 000 years B. P. The first periglacial phenomena, probably connected with the existence of continuous permafrost, appeared during this period, that is the Late Glacial, but the full development of these phenomena and their subsequent deglaciation only began in the Younger Dryas, and has not ceased.

Little information is available to assist dating these phenomena. A certain number of C-14 analyses have been undertaken, some of which are summarised below.

1. Peat, near Vadsö, shore bar, 7860 years (Marthinussen, 1960),
2. Peat from two sites from furrows in nonsorted polygons near Bussesund, 4890 and 4400 years (Svensson, 1970),
3. Peat from palsa hills in Karlebotn, from 7520 to 2450 years (Åhman, 1977),
4. Peat from palsa hills in Varangerbotn, from 4900 to 2900 years (Åhman, 1977),
5. Peat from turf and earth hummocks on the Oar'duvarri upland, 1780 years (Inst. Phys., Silesian Techn. Univ., Gliwice, Poland, 1977),
6. Peat from turf-banked gelifluction forms near Syltefjord, 830 years (Inst. Phys., Silesian Techn. Univ., Gliwice, Poland, 1977).

The results given above have been used as benchmarks in reconstructing the chronology of periglacial processes on the Varanger peninsula. The beginning of this scale is set by the end of the Younger Dryas, when the changing climatic conditions, was initiated. Certain processes continued actively then, intensified, weakened, and even disappeared. These changes may be unravelled by considering the interrelationships of periglacial forms and structures, especially where they overlie one another. In this way it was possible to construct a hypothetical distribution of process activity in time (Fig. 12). The oldest phenomena are the block fields[1] which came into being under the action of frost on newly-

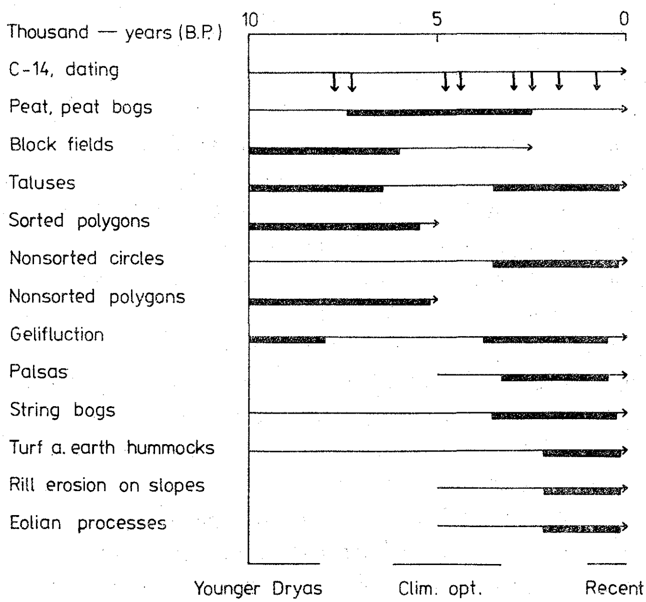


Fig. 12. Course of periglacial processes on the Varanger peninsula in the Postglacial and Holocene period. The thicker line signifies the increasing intensity of the processes

-exposed rock surfaces. Other processes, like debris sorting or gelifluction, could only develop after the creation of rock debris; in the same way, palsas could only be formed once peat bogs had accumulated. The most recent forms include frost phenomena like turf hummocks, and processes not connected with frost, such as water erosion on slopes, and eolian phenomena. Slope processes, chiefly gelifluction, were active through this whole period, but with varying intensities and are still operating now; they do not require permafrost. The invasion of fissure polygons by block streams and block fields (Fig. 5 and 6) shows clearly that the principal phase of gelifluction is more recent than the period when frost weathering and frost cracking were most intensive. It seems that those processes were

[1] A difference of views exists among Scandinavian scholars about the age of these block fields; the subject has been surveyed recently by S. Rudberg (1977). On the basis of observations. I am inclined to agree with R. Dahl (1966) and L. Strömqvist (1973), who set the age of the block fields as being post-glacial, being created in periglacial climatic conditions immediately after the retreat of the ice sheets.

most active before the climatic optimum. Gelifluction, on the other hand, intensified especially after the optimum, as has been indicated among others by P. Worsley (1974) on the basis of Swedish data. Using C-14 results, he asserts that a marked cooling took place during the Sub-boreal. At this time, gelifluction became more active, and new layers moving down-slope overtook and covered trunks remaining from retreating woodland. This period of climatic recession may be dated at about 3000 years B. P. In W. Karlen (1976) opinion the following periods of the cold climate appear in the Holocene of Swedish Lapland: 7500—7300 B. C., 4500 B.C., 2800—2200 B.C., and the XIX and XX centuries. A Holocene climatic optimum, probably in two phases, falls between 7300 and 4500 years B.C.

The post-glacial climatic optimum in Scandinavia may be placed around 5000 years B.C. If so, the peat in nonsorted polygon furrows on the Varanger peninsula may be dated at 4700 years B.C. (Svensson 1970), it would seem that the frost cracks existed before the climatic optimum; J.L. Sollid *et al.* (1973) share this opinion. It is possible to infer from the character of wedge structures that they represent the remains of inactive ice wedges, associated with discontinuous permafrost. It may be accepted that immediately after the Younger Dryas, when full periglacial conditions with continuous permafrost were in force, there followed a long period of mild periglacial conditions with discontinuous permafrost. This continued to the climatic optimum, when permafrost ceased on the Varanger peninsula. After the optimum, climatic conditions worsened, as noted by P. Worsley (1974) and W. Karlen (1976), gelifluction intensified on slopes, and sporadic permafrost became established in peat bogs, which increased in thickness greatly during the optimum. This milder periglacial climate still dominates the peninsula, with minor variations taking place within the historical period. Periglacial processes are locally differentiated, according not so much to frost, as to the insulation of the ground surface from frost action. There are two principal kinds of insulation, snow and vegetation. Consequently, debris sorting continues at present where soil is exposed to frost. The activity of other erosion processes can be observed on ridges where snow is usually removed by wind, on slopes without vegetation, or where vegetation has been destroyed, or on rock faces exposed to erosion (Pl. 20). Other than on the Varanger peninsula, most of Northern Scandinavia is subject to this transitional kind of periglacial activity. In especially severe winters, where the snow cover is thin, it is possible to find permafrost which may last for several years, with thin vein or wedges of ice; an occurrence of this type is reported from the Padjelanta basin in Swedish Lapland by A. Rapp and L. Annersten (1969). The Icelandic fissure phenomena, renewing themselves on old polygons, have a similar character (Friedman *et al.*, 1971). From the tabulation of the duration and intensities of geomorphological processes on the Varanger peninsula in the Holocene, it may be seen that some of the processes are at present completely inactive, having been active in the Early Holocene, and that the forms and structures associated with them, like block fields, and sorted and non-sorted polygons, are now relict. Other processes are partially active, such as gelifluction and the upheaving of palsa hills, and finally a number of processes are fully active, like the formation of turf and earth hummocks, and rill erosion. Of course, not all these processes are periglacial.

THE SIGNIFICANCE OF THE VARANGER PENINSULA FOR THE DISCUSSING OF THE FOSSILISATION OF PERIGLACIAL PHENOMENA IN EUROPE

Active morpho-climatic processes give rise to specific forms and structures. When, as a result of climatic change, some process ceases to act, the forms and structures created by it are described as „inactive", „relict" or „dead". If the change is lasting, and may be treated as closing a geological period, then the forms and structures may be known as „fossil". The covering of an old structure by new sediments unquestionably renders it a fossil structures on the present surface, not covered by more recent deposits.

In line with the change in climate from the Pleistocene to the present, the action of periglacial processes concerned with frost action has undergone modification. They are active at present in the Arctic, but their intensity and type varies as one moves southward, into the subarctic and boreal zones. In these zones, where some periglacial processes, such as gelifluction, are still active, it is possible to find traces of formerly operating frost processes that are inactive, relict or even fossil phenomena and structures. Central Europe, now in the temperate zone, was in the Late Glacial still in the active periglacial zone. For example, in central and southern Poland fossil structures may be observed representing almost all periglacial processes (Dylik, 1956; Jahn, 1975).

Our attention was attracted to the Varanger peninsula (Fig. 13) since it is an area in between the fossilised periglacial phenomena of Central Europe [2], and the active periglacial processes observable for example on Spitsbergen. In this area recent structures and forms exist in association with those dating from the Pleistocene. The peninsula has approximately the same altitude as the plains of Central Europe, 200—400 m, reaching 700 m at the highest point. Because of this, the kind of mountain periglacial environment, existing in Central Norway, does not exist here, and the climate may be defined as subarctic. Consequently it is possible to compare the periglacial phenomena of the Varanger peninsula with those of Spitsbergen and Central Europe.

In order to evaluate the temporal variability of typical periglacial phenomena, and to compare these phenomena with those in Spitsbergen and Central Europe, non-periglacial processes were excluded from consideration. The occurrence of fifteen types is shown in Fig. 14, which was constructed using the method also

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[2] Central Europe is used here in a North-South sense, running in a belt, from France to the Soviet Union, where the occurrence of fossilised periglacial phenomena has been recorded (Veličko, 1973).

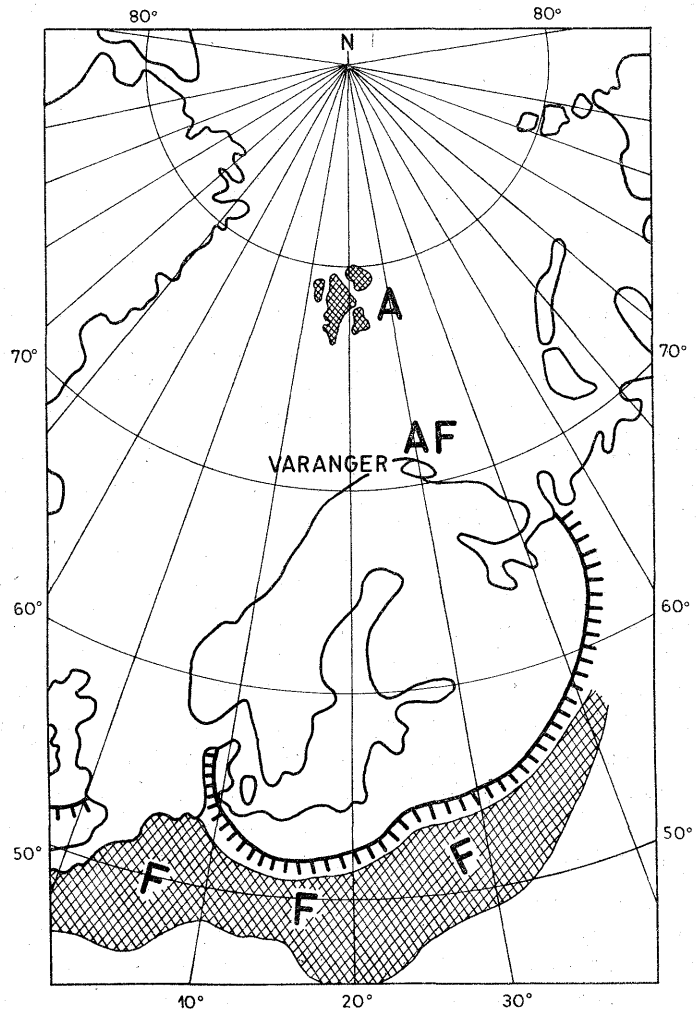
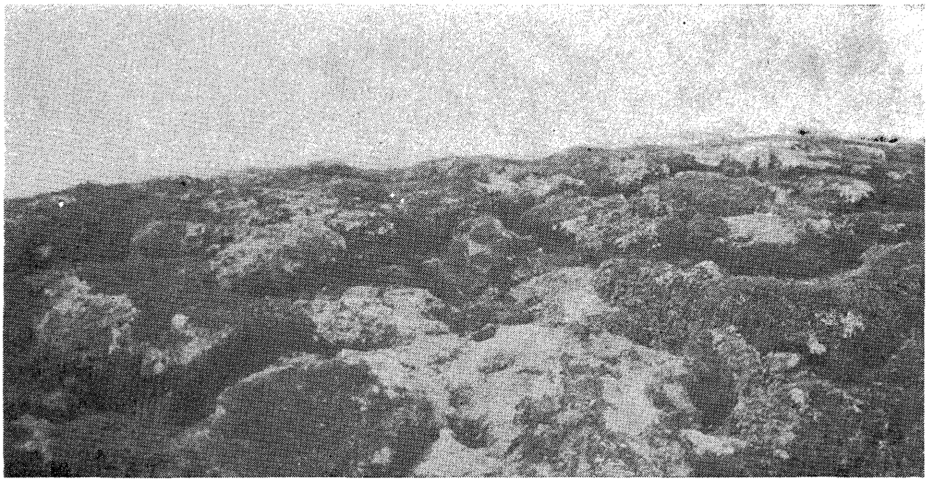


Fig. 13. The position transitional periglacial phenomena of the Varanger peninsula in relation to active phenomena in Spitsbergen and Central European phenomena

used by E. Schunke (1977) to differentiate between the continental and oceanic types of periglacial zone.

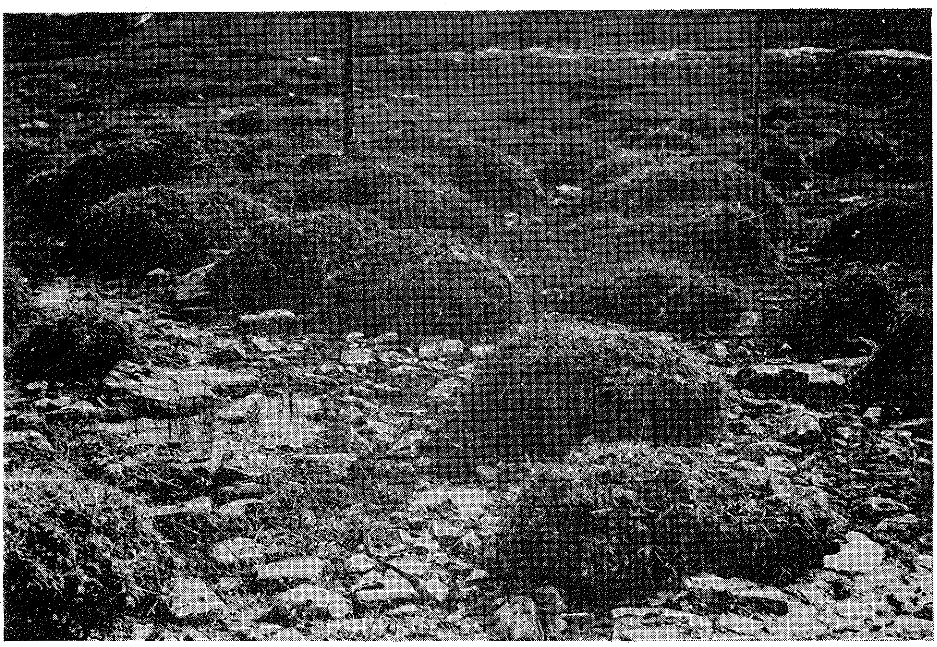
Almost all the high Arctic periglacial processes are active on Spitsbergen (Jahn, 1963, 1975). It is doubtful whether palsa hills are being formed at present in such classical periglacial areas, but the main type of phenomenon known on the Scandinavian peninsula does rather belong to the peripheral forms of periglacial zone — as mentioned above — corresponding to the belt of discontinuous permafrost.

From Fig. 14 it can be seen that Varanger only exhibits eight active periglacial processes. There are no massive ice phenomena (pingos) nor are there

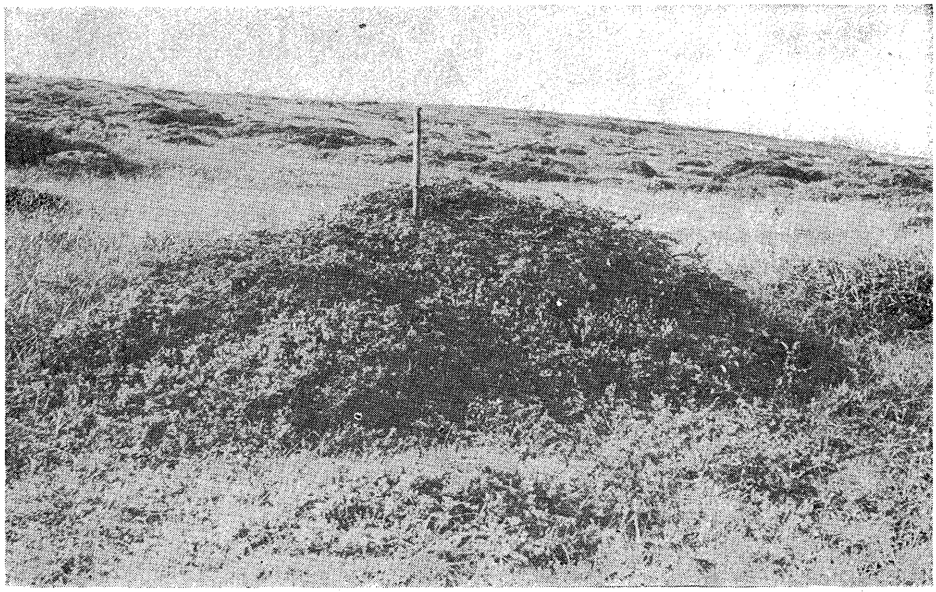


Pl. 15. Details of the peat surface of palsas of site 9

The deep desiccation fissures are the evidence of thei nitial phase o the degradation of the hill



Pl. 16. Turf and earth hummocks on the summit of Oar'duvarri upland, absolute height of about 400 m (site 23)



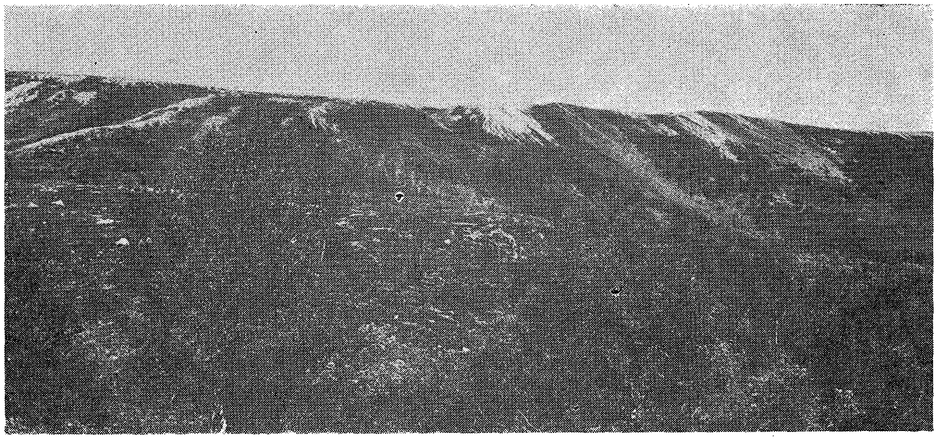
Pl. 17. One of the biggest turf hummock with the peaty core, 1.5 m high, on the bottom of the Gaednialakka valley (site 18)

Pl. 18. Cross-section of the earth hummock in Syltefjord (site 32)

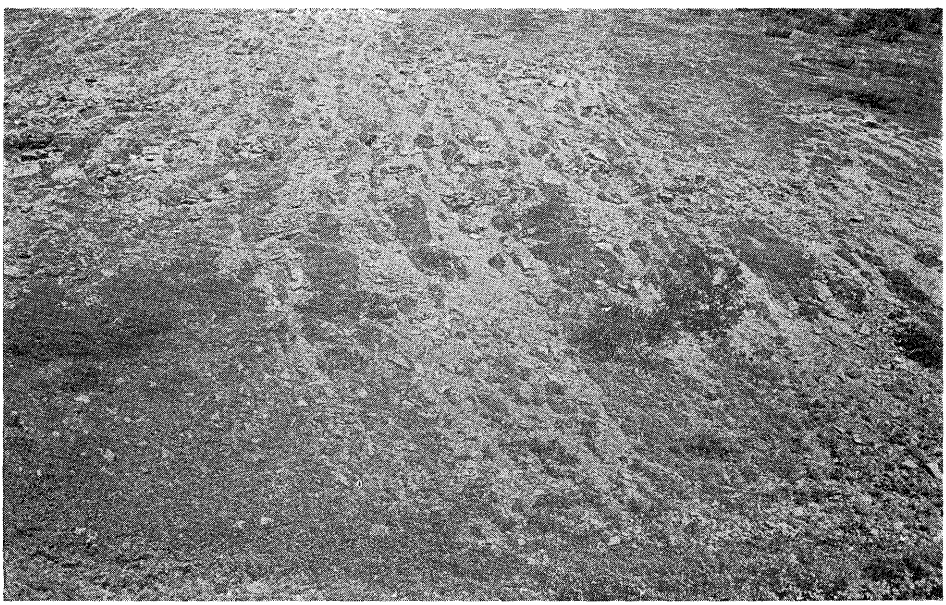
The spade is 16 cm long. Layers: 1. turf; 2. gravel; 3. subfossil soil; 4. sand

Pl. 19. Accelerated processes of weathering and erosion and their influence on scree slope. Syltfejord area (site 30)

XIX



Pl. 20. Phenomenon of accelerated soil erosion on the ridges of Måresvaejkai'di, in the south of Båtsfjord (site 28)



Pl. 21. Accelerated process of degradation of the slope surface. Debris streams encroaching on vegetation, Syltefjord area

	Spitsbergen	Varanger	Central Europe
Block fields	+		
Sorted polygons, nets and circles	+		
Stone pavements, debris islands and micro-polygons	+	+	?
Nonsorted circles and tundra-craters	+	+	
Pingos, massive icy forms	+		
Ice wedges, sand wedges, large nonsorted polygons	+		
Frost cracks, ground wedges, small nonsorted polygons	+	+	?
Macrogelifluction lobes and terraces	+	+	
Microgelifluction frost creep	+	+	+
Palsas	?	+	
String bogs		+	
Turf and earth hummocks	+	+	+
Thermokarst	+		
Thermoerosion	+		
Cryoplanation terraces	+		

Fig. 14. Active periglacial processes in Spitsbergen, Varanger peninsula and in Central Europe

any active sorted or nonsorted polygons, since those which do occur may be classified as relict forms. In this mild subarctic climate, without continuous permafrost, but allowing for seasonal and sporadic permafrost, only half of the arctic periglacial processes are active, including gelifluction. S. Rudberg (1977) states that the lower boundary of active gelifluction in this part of Norway is almost at sea level.

In the belt of Central Europe under consideration here almost all periglacial forms and structures have become fossilised (Poser, 1947; Dylik, 1956; Kaiser, 1960; Maarleveld, 1976). In this classical area of Pleistocene periglacial structures, only a few frost processes are at present active, and even then their action is very limited in scope. It is possible to encounter frost creep and traces of upfreezing which may perhaps lead to the formation of pavements. In addition there are turf hummocks on peat bogs. It is worth adding that in the temperate zone in North America, far outside the periglacial zone, frost fissure processes may be observed (*cf.* Washburn, Smith and Goddard 1963). It is known that severe winters in the European part of the Soviet Union can give rise to frost fissures. H. Svensson (1977) gives many examples of the contemporary formation of frost fissures in the south of the Scandinavian peninsula „far outside the Arctic and Subarctic". These are, however, only sporadic forms, and it seems unlikely that they could lead to the creation of soil wedges or nonsorted polygons.

If we accept that Spitsbergen possesses 100% active periglacial processes, then the transitional area of Varanger has only 53%, and Central Europe only 20%. These indications, plotted schematically, illustrate the extent of fossilisation of periglacial phenomena from the Pleistocene to the present day (Fig. 15). This diagram oversimplifies the situation, since it only shows zonal variability

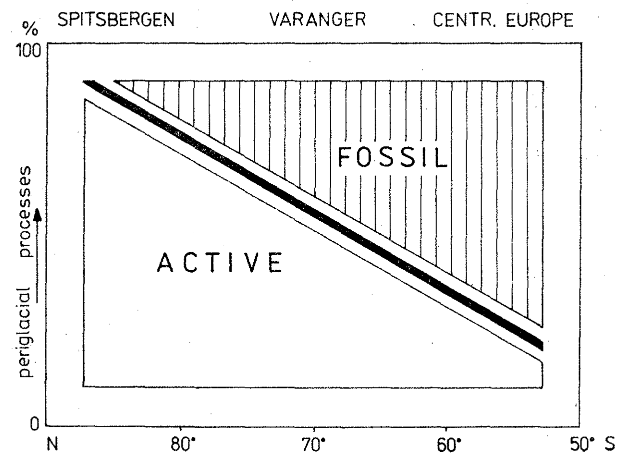


Fig. 15. Diagram illustrating schematically the variation of periglacial phenomena by latitude along the 20 °E long. Spitsbergen processes 100% of the total of periglacial phenomena and processes

in periglacial processes. Considerable deviations may be introduced by local factors. Even on Spitsbergen not all periglacial processes are active, and in dry places, for instance on gravel terraces, it is possible to observe the fossilisation of periglacial phenomena.

Even if some periglacial processes are locally inactive on Spitsbergen, this inactivity is not permanent. Small variations in the local climatic and moisture conditions will surfice to reactivate them. The action of man and animals, by the destruction of vegetation, may also assist in their renewal.

Varanger, a transitional periglacial area between the fully active Spitsbergen and the fully fossilised Central European belt also displays varying intensities in its periglacial processes, but here the activity or inactivity of the processes have lasting features. Only a general, zonal change in climate could change the specific position of Varanger, with its half-fossilised periglacial phenomena.

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