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Łódź

THE DISTRIBUTION OF PERIGLACIAL PHENOMENA IN NW-SÖRKAPP, SPITSBERGEN

Sommaire

Durant les saisons d'été consécutives (1957—59) l'auteur menait, au NW-Sörkapp, des observations du microrelief périglaciaire et de certains processus morphogénétiques ayant lieu aux pays périglaciaires actuels. Un nombre de sections a enrichi nos connaissances de telles phénomènes que les cercles de pierres, les polygons des fentes de gel et polygones de pierres, les sols striés, les lobes de congélifluxion, les champs de pierres, les parois rocheuses nues, les cannelures de gélivation et les buttes de glace intersticielle ainsi que des grèzes litées. On a essayé de déterminer l'efficacité de la gélivation et la vitesse de la congélifluxion. Une analyse de la répartition des formes et phénomènes périglaciaires au NW-Sörkapp nous a permis de constater, en premier lieu, qu'elle dépend: du caractère du relief précédant, de la lithologie, du caractère de débris, des conditions climatiques et hydrographiques locales. L'analyse de la répartition a permis ensuite de distinguer deux zones différentes: (1) orientale, où les processus morphogénétiques sont plus intenses et où la fréquence des microformes périglaciaires est plus grande et (2) occidentale avec un peu moins de microformes périglaciaires et où l'activité des processus morphogénétiques est moins vive. Une carte détaillée, enfin, représent la répartition de tous les phénomènes périglaciaires au NW-Sörkapp.

Under the auspices of the Third International Geophysical Year, a Polish expedition led by the excellent organiser and polar expert Doc. Dr. Stanisław Siedlecki, was sent to Spitsbergen. The group from Łódź, known as „Południe", i.e. „South", formed part of this expedition. Its members were: Professor Jan Dylik (in 1957), who was in charge of all the scientific work throughout the whole period of the expedition, W. Frankiewicz (in 1958), J. Jersak (in 1959), S. Jewtuchowicz (in 1959), and T. Klatka (in 1957). The present writer conducted his observations throughout three consecutive summers.

The Łódź group worked in the north and west coastal area of Sörkapp that stretches from the Körber Glacier and the Tsjebysjovfjellet[1] Massif in the east and continues along the nunataks of the Midifjellet and Robitzschfjellet to the Slakli valley and along it, to the Atlantic coast. Its northern and western borders consist of the Atlantic and the Hornsund coastline. The area covers approximately 100 sq. km.

The principal aim of the studies conducted here was not only to become properly acquainted with some of the characteristic features of the present-

[1] All geographical names are taken from the topographic map in the scale 1 : 100 000 Sörkapp sheet, published in 1948 by the Norges Svalbard og Ishavs-Undersökelser.

-day periglacial regions, but also to establish the nature of the interrelations between various structures and such features as slope gradient, the humidity of the soil, the type of material, the vegetal cover, the changes of the permafrost table, etc. A sound knowledge of morphogeny, of its mechanics, as well as of its topographic and geographic distribution, facilitates a better understanding of the Pleistocene periglacial environment, for such evidence is extremely important in the reconstruction of the climatic conditions of these regions which, in Pleistocene times, were under the influence of cold climate.

Preliminary work in 1957 under the personal supervision of Professor Dylik consisted of a detailed survey mainly of the Gåshamnöyra region, of a closer study of the stone stripes (Klatka, 1961), and of installing a series of reference points. The bulk of the work was completed in 1958. The territory adjoining Gåshamnöyra, in Andvika and in the Lisbetelva valley, was mapped in detail. Also a series of detailed morphological profiles of the slopes were made, taking as a basis short measured segments of sometimes as little as one metre in length. Thus, the precise distribution of individual periglacial structures on the slope surface could be ascertained. Also during this season, most accurate observations of mass movement were carried out using simple measuring instruments which afforded interesting new quantitative data. A large number of cross-sections cutting through microrelief forms were performed owing to which the structure of the material within could be established. Observations and measurements were supplemented by detailed drawings to a scale of 1:5, as well as by photographs. In 1959, further geomorphological field-mapping was made, transferring the work to the western part of Sörkapp on the Atlantic Ocean.

Spitsbergen is one of those regions where the conditions for research work differ widely from those encountered during field work in inhabited regions. On the one hand, observations can be easily carried out because of the absence or scarcity of vegetation which does not obscure the microrelief forms; the individual structures are therefore readily discernable. On the other hand, geological cross-sections are more difficult because of the high permafrost table and the saturation of the thawed ground with water. Unfavourable weather conditions also impede field-work to a considerable degree. K. Orvin (1940) drew attention to the difficulty of working conditions in Spitsbergen as follows: „All who have done surveying and geological work in the Arctic regions know how difficult it is to obtain satisfactory results. Fog and bad weather may for days make field-work almost impossible, and as large areas are covered by ice it is frequently difficult to connect the different field observations

... as the proper topographical base is lacking and the time is short. Often it is not possible to return to the most outlying areas, and the first work will then remain half-finished or incomplete for years".

The present writer has encountered all these difficulties during his work in NW-Sörkapp. He also realises that some of his observations are as yet incomplete, needing further study and confirmation. This particularly applies to the congelifluxion lobes on which reference points were set up in 1958 which may yield useful results only after a longer period.

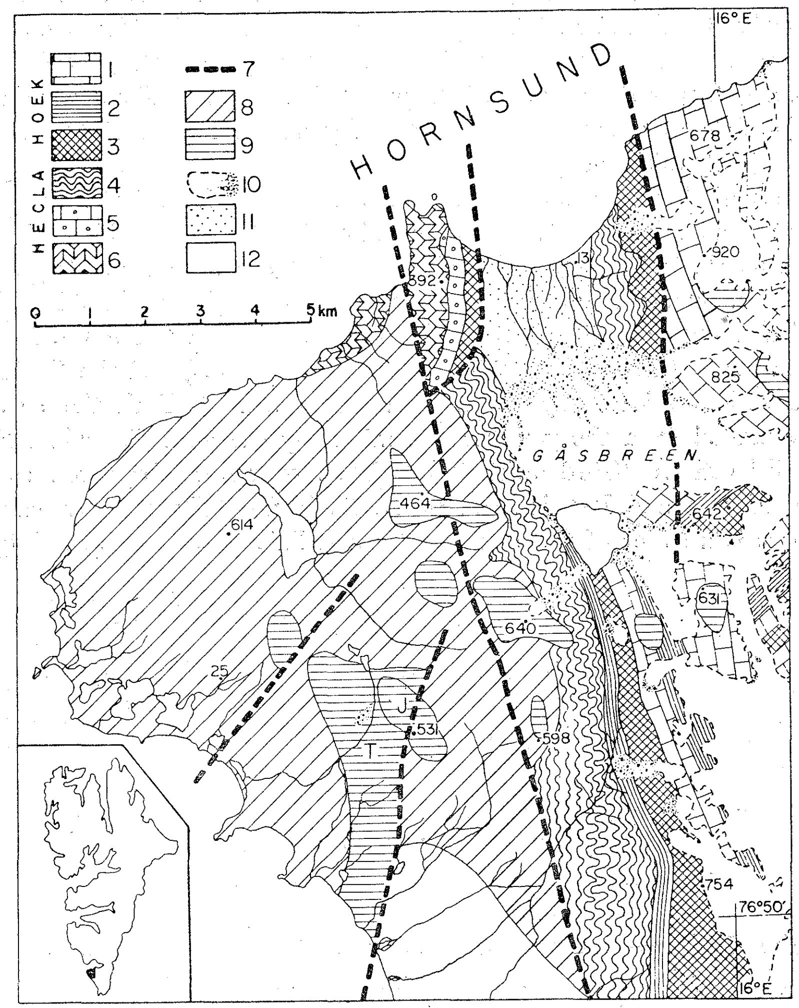

Fig. 1. Geologic map of NW-Sörkapp (after H. Major & T. S. Winsnes, 1955)

1. limestones; 2. shales; 3. quartzites; 4. phyllites; 5. oolite-limestones; 6. dolomites; 7. fault lines; 8. young Paleozoic; 9. Mesozoic (T, J); 10. glaciers and moraines; 11. sandr; 12. covered

CHARACTERISTICS OF THE REGION

GEOLOGY

The geological structure of Sörkapp Land consists of rocks ranging from Pre-Cambrian to Quaternary. Cambrian and Ordovician sediments are stratigraphically joined to form one unit, named, after Nordenskjöld (1863), the „Hecla Hoek" formation. Examples of it are found in Svalbard on Prins Karls Island, in the western part of the Vestspitsbergen, in Nordaustland and in Sörkapp. The eastern part of Sörkapp consists of Cretaceous formations whereas in the western part, rocks of the Hecla Hoek and Upper Paleozoic periods predominate. Carboniferous, Triassic and Jurassic sediments occur sporadically at the mouth of the Hornsund (Siedlecki 1960).

The lithological composition of the Hecla Hoek sediments as well as that of all the other Paleozoic formations in Sörkapp is widely diversified. The Hecla Hoek rocks in this region have been ascribed to several types. Major and Winsnes (1955), who mapped this area in 1952, identified a number of series, of which the most important are: the Höferpynten series (dolomites, oolitic limestones, quartzites) and the Gåshamnöyra series (mica-, phyllite- and sandstone shales). Both these series are separated from the younger formations by claer-cut discordant lines and dislocations (Siedlecki 1960). West of the Höferpynten series, Carboniferous and Permian sandstones lie horizontally, whereas east of it there is a series of folded dolomites and Paleozoic limestones (Fig. 1 and 2).

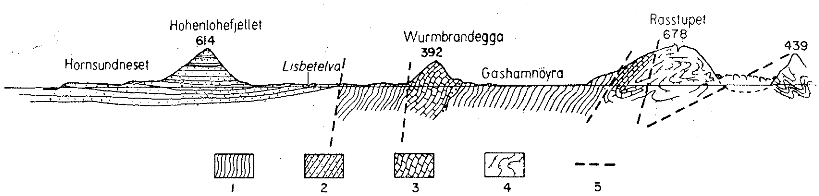

Fig. 2. W—E cross-section through the northern coast of Sörkapp (after K. Birkenmajer)

1. shales; 2. sandstones and quartzites; 3. dolomites; 4. limestones and marls; 5. fault and discordant lines

The N—S trend of the main geological units follows the same course as the Tsjebysjovfjellet, the Wurmbrandegga and the Struvefjella Massifs. These are mountain massifs consisting mainly of rocks that are relatively resistant to weathering such as quartzites, sandstones, dolomites and limestones. Soft, comparatively unresistant shales, chiefly phyllite and mica, are found in the intervening depressions. However, small patches of till and outwash sands, lying in front of the Gås Glacier moraine, as well as the sands and gravels connected with uplifted abrasion terraces, are Quaternary in age.

SURFACE RELIEF PATTERN

Old mountain massifs constitute the chief morphological features of NW-Sörkapp. The Struvefjella mountain range stretches along the western part of Sörkapp and consists of three massifs: (1) the Lidfjellet, at the southernmost extremity of the range, rising 531 m and steeping abruptly to the west; it is built of sandstones and dark shales. The deep incised Liddalen valley separates this massif from the next one, (2) the Sergeijevfjellet, which is similarly built of sandstones and Kulmian clay shales; this reaches a maximum height of 420 m. The eastern slopes of the Sergeijevfjellet are gentle in comparison to the western ones which sharply descend to the flat surface of the abrasion platforms. The mountain range terminates in the north by (3) the Hohenlohefjellet, whose highest point is 614 m above sea level (Pl. 1). This massif consists of sandstones and small intercalations of clay shales and coal.

Another major unit is the Wurmbrandegga mountain range comprising the massifs of the Gavrilovfjellt and the Kovalevskifjellet, which are composed of dolomites in the north, phyllite shales — in the central part, and sandstones and quartzites in the south. The Wurmbrandegga chain, running along the meridian, terminates in the north by the cape of Höferpynten.

Finally, the third and last major landscape unit in this region is the Tsjebysjovfjellet. This massif is built of dolomites and limestones, as well as of clay shales, in some parts. The intervening depressions are occupied by glaciers and running water. For example, the southern part of the Gåshamna depression is filled by the Gås Glacier whose outwash plain extends to the north. The Lisbetelva valley occupies the lower area between the Wurmbrandegga and the Struvefjella.

Worthy of note are the flat or very slightly sloping top surfaces of the Tsjebysjovfjellet, the Kovalevskifjellet, the Lidfjellet, and of other adjacent massifs. Major and Winsnes (1955) hold that these surfaces are an old, pre-Triassic peneplain, a theory which is borne out by the eroded pre-Triassic formations and by the overlying thinly bedded yellow Triassic sandstones.

The present-day relief pattern is the result of pre-glacial action, erosion and glacial accumulation combined with recent periglacial activity.

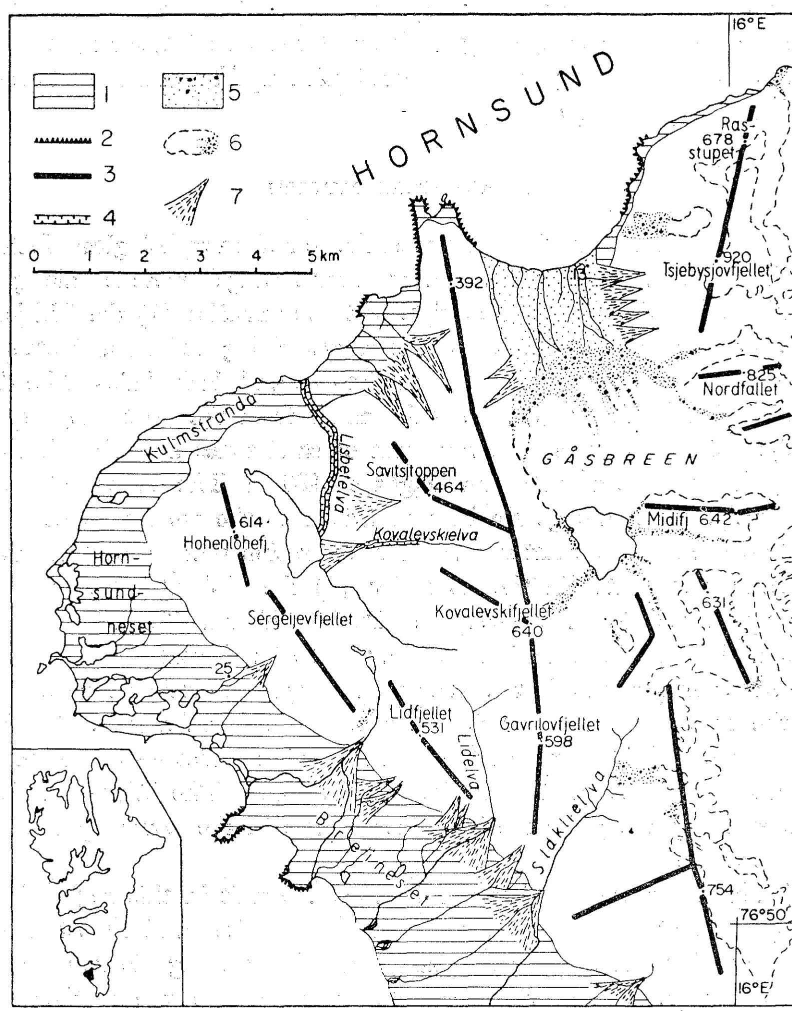

Fig. 3. Morphologic sketch of NW-Sörkapp

1. raised beaches; 2. cliff; 3. mountain crest lines; 4. gorges; 5. sandr; 6. glaciers and moraines; 7. alluvial fans

This area is bordered and sometimes encroached upon by ice-tongues flowing down from the large ice-field that covers the entire central part of Sörkapp. Only nunatak peaks are outcropping, thus marking out the trend of the hidden mountain ranges. The sole glacier that encroaches upon the NW of Sörkapp is the Gåsbreen, which slides down from the corries below the peaks of the Mehesten and deposits its moraine in the Gåshamnöyra depression, as described in detail by Szupryczyński

(1963). The area in question is separated by the Widerfjellet range from the nearest glacier, which also does not extend down to the sea.

The present-day extension of the Sörkapp glaciers, just like that of all the others throughout the whole of the Svalbard archipelago, is lesser than it was during the Pleistocene, when a compact ice-cap covered the whole of Spitsbergen (Birkenmajer 1958; Jahn 1959; Büdel 1948). Later, the glaciers retreated considerably due to the amelioration of the climate during the post-glacial period. The moraines found on the sides of mountain valleys show their spread at that time. Examples of these can be seen in NW-Sörkapp on the slopes of the Wurmbrandegga and the Tsjebysjovfjellet at an altitude of approximately 40—50 metres above sea level. Moraines are also found on the lower slopes of the Hohenlohefjellet, the Sergeijevfjellet, and the Kovalevskifjellet.

In the Holocene, the glaciers flowing down to the Hornsund, show considerable fluctuations and their fronts are marked by contemporary ranges of terminal moraines. Pillewizer, who compared the extent of the glaciers shown on old Norwegian maps from 1928 with his own observations from 1936, established a considerable retreat of these glaciers. Likewise, a comparison between maps showing the reach of the glaciers in 1936 and the pattern of their fronts in 1958, proves that the retreat of glacier tongues is still in progress (Lippert 1960).

The land laid bare by the retreat of glaciers and that emerging from the sea became an area of vigorous activity of water, both organised and braided. The results of this activity are represented by small deeply incised valleys, and extensive alluvial fans around their mouths. Small valleys such as Sergeijevskardet, Kovalevskidalen, and Lisbetdalen cut down to a depth of several metres and the Liddalen forms a canyon, 50 metres in depth. The alluvial fans found at the mouths are rather large reaching sometimes as much as 1.5 km in lenght. Their surface gradient is negligible averging 3° to 5° (Pl. 4).

Uplifted abrasion terraces extend along the coast of Sörkapp. Traces of the former coastline appear in the shape of clearly marked undercuttings on the slopes of the coastal mountains and of the presence of marine gravels and old cliffs. Jahn (1959) and Birkenmajer (1958) have described the old abrasion surfaces and cliffs in the Hornsund region noting their height, their age and their relationship to the eustatic movements of the Svalbard archipelago. Jahn, basing his estimates on detailed measurements distinguished in Hornsund a series of uplifted terraces attaining respectively 2—4, 7—13, 16—17, 25, 32, 38—41 m above sea-level. Also marine gravels were found at high levels reaching altitudes of 75, 100, 135, 205, 230 metres. Jahn regards the 40 metre level as the most important terrace because it affords evidence of a break in the emergence of the land, which break was caused by a transgression just before the post-glacial climatic Optimum. Birkenmajer (1958), basing on clisimetric and altimetric measurements, gives similar figures for the lower abrasion terraces in Hornsund, i. e. 2.5—5.4; 6.5—7.0; 7.0—8.8; 10—15; 16—25; and 40 metres.

In NW-Sörkapp a series of abrasion platforms were identified, veneered with marine gravels and pebbles, and showing well-preserved cliffs and storm ridges. Fragments of these platforms appear on the mountain-sides of the Tsjebysjovfjellet sloping towards Gåshamna, and on those of the Wurmbrandegga and the Höferpynten. Best preserved, hovewer, are the terraces of the Kulmstranda and the Hornsundneset area. Here appears on the right-hand side of the Lisbetelva at an altitude of approximately 30—32 m a perfectly preserved storm ridge, consisting of pebbles of about 30 cm in diameter. Above this ridge, rises a cliff, the top surface of which is that of 40 m terrace. The left-hand side of the Lisbetelva shows a similar character. Small, tor-like rocks with rounded sides and top surfaces covered by marine gravels and pebbles often protrude at the surface of abrasion terraces.

CLIMATE

In discussing the problem of Arctic climate, Corbel (1961) lists several characteristics of the climatic conditions in this region. The entire Arctic region experiences an average annual temperature of $-10\,^{\circ}$C. On the whole, the summer is uniform throughout the whole region, i.e. the temperatures are equal, and this uniformity is still aggravated by the uninterrupted continuity of the polar day light. The winter temperatures, however, vary widely in the individual Arctic regions. Continental areas (Siberia, Canada) are subjected to very low temperatures ($-50\,^{\circ}$ and lower), which are caused mainly by long-lasting low-pressure centres forming above them, and partly by local topographic conditions (Parmuzin 1958). This is in contrast to the oceanic regions, which never show such conspicuous differences in temperature between summer and winter. On the basis of winter temperatures and the total of annual precipitation, Corbel distinguished between three Arctic zones: (1) very cold, with an average February temperature below $-30\,^{\circ}$C, which almost entirely corresponds to the area of very small annual precipitation (<200 mm); (2) cold, with an average February temperature from $-10\,^{\circ}$C to $-30\,^{\circ}$C, which lies in the area of scarce annual precipitation (<500 mm), and (3) moderately cold, with a February temperature from 0°C to —10°C and abundant precipitation amounting to more than 500 mm.

Spitsbergen lies in the second of these zones, which is characterised by an annual precipitation of 200—300 mm and by quite severe winters; Sörkapp is regarded as its coldest part (Corbel 1951). However the pattern of the mountain chains and the latitudinal course of the Hornsund contribute to considerable climatic differences in this area. That this region belongs to the maritime climatic variety is determined by the winter maximum of precipitation, mainly in the form of snow.

Summer in NW Sörkapp, when the air temperatures exceed 0°C, lasts about three months. The mean air temperatures during the summer months are undoubtedly somewhat above 2°C, as stated by Corbel (1961). According to the measurements taken by the writer at Gåshamna and according to those taken at the meteorological station of the Polish expedition at Isbjernhamna (situated 10 km north and on the other side of the Hornsund) the summer temperatures for 1958 and 1959 were as follows:

Table I

Station	Month	1958			1959		
		Average	Max.	Min.	Average	Max.	Min.
Isbjörnhamna	VII	4.5	8.1	1.1	—	12.8	0.4
	VIII*	4.5	9.0	1.5	—	—	—
Gåshamna	VII	4.0	7.5	0.8	4.1	12.8	0.3
	VIII**	4.0	7.0	0.5	4.1	10.5	0.2

* readings only until 15 VII 1959.
** readings only until 15 VIII 1958 and 1959.

Winter lasts longer, over 5 months, with average temperatures below —10°C (Czeppe 1961). Both the transitional periods are different: autumn lasts longer than spring which is short and lasts only 1—1.5 months, although the temperature rises quickly. It must be stressed that atmospheric temperature differs from ground temperature and does not fully represent the conditions which are directly responsible for periglacial action. A noticeable delay in the rise of ground temperature in relation to the atmospheric temperature occurs particularly in spring. Autumn precipitation and varying ground temperature are likewise considerably shortened in relation to the length of summer and winter (Czeppe 1961). The process of spring thawing and autumn freezing depends largely on the structure of the ground and the grain size of the material, but still more on the extent and density of the snow cover and the type or, in some cases, the absence of vegetation cover.

As a result of the general pattern of atmospheric pressures in the Svalbard region, and also, as a result of the ocean currents along the southern coasts of Spitsbergen, the Sörkapp Land is characterized by almost ceaselless fogs, frequent drizzles, and an extensive cloud cover. In 1958, 14 and 12 days were noted in July and August (only until 16. VIII. 1958) to be without either rain or drizzle. This is reflected in the amount of precipitation and the general humidity of both the air and the ground. The total of annual precipitation for the whole of Svalbard is about 200—400 mm (Corbel 1961). The total amount for the period from August 1957 to July 1958 recorded at the Polish base camp station in Isbjörnhamna was 346 mm. Czeppe (1961) finds this figure rather low and holds that 400 mm or even more may be safely regarded as the mean total precipitation in this area. This opinion is confirmed by the facts established at Isbjörnhamna for the period 22. VI.—15. VIII. 1959, which gave a total of 165 mm of precipitation for less than 2 months (Gadomski 1960).

The snow cover in Spitsbergen lasts for about 250 days, and its average thickness is of some 20 to 40 cm (Corbel 1961). In the area in question the thickness of the snow cover varies widely as a result of the prevailing winds. The snow disappears completely in the latter part of July with the exception of a few snow patches that linger throughout the year. The disappearance of the snow cover occurs most rapidly on the flat surfaces of abrasion terraces and on west- and south-facing slopes. The west-facing slopes of the Tsjebysjovfjellet lose their snow-cover several days earlier than the east-facing slopes of the Wurmbrandegga. Towards the end of July 1958, a snow cover 1 m in thickness was still lying at the foot of the debris slope of the Wurmbrandegga, along the borderline between outwash plain and slope.

Large quantities of water are released owing to the melting of the snow cover. This water, unable to infiltrate the still frozen ground, flows over the surface of the frozen snow and over the occasional patches of bare ground. During this period there is an almost complete lack of organised drainage: the water just flows along the whole surface. On the Gåshamnoyra outwash plain, at a considerable distance from the slopes, outflow begins to be more organised, yet, even here, water-streams often change their course. The amount of surface water at this time, and its mode of drainage depend largely on the amount of snow and ice as well as on the rate of lowering of the permafrost table, which is in turn controlled by the vegetation cover, as well as by the exposure and spread of the snow cover.

It was observed that in some places where the snow cover was very thin, permafrost appeared at the very surface, while close by its level was falling rapidly. It was noticed that in the immediate vicinity of the snow patch the depth of thawing averaged 1—3 cm at the beginning of July. Outside the snow patches, the top of permafrost fell considerably, sometimes reaching a depth of about 40 cm (Fig. 4). It was established that the thawing of the active layer progresses until late summer, since the permafrost table was still subsiding at the beginning of September. The depth of summer thaw varies ranging from about 1 metre to over 2 metres: this depends on the rock type, the amount of moisture in the soil, and the topographic and climatic situation. Shaded, water-saturated areas with an abundance of fine waste thaw down to shallow depths, while dry surfaces composed of coarse gravels (marine terraces) thaw more deeply.

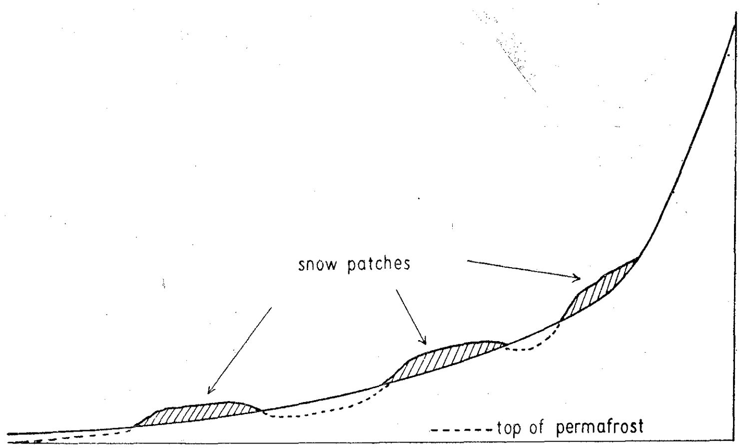

Fig. 4. Diagrammatic cross-section showing depth of top of permafrost in proximity of snow patches

As measured at the foot of the Wurmbrandegga, the thickness of the thawed layer was of 150 cm in the middle of September. This surface consists of dolomite waste mixed with marine gravels. At the same time it was noted that on the coastal terrace at Isbjörnhamna, the terrace-gravels thawed down to a depth of over 2 metres. The differences in thawing depend not only on the variety of rock material, but also on differences in topographic situations. The coastal terrace at Isbjörnhamna is free of vegetation and exposed all day to sunlight, whereas the base of the Wurmbrandegga is partly shaded emerging from it only at night and in the morning.

Wind action in this area is notable, though indirect. Its direct activity is reduced to the blowing out of fines from the outwash plain during the late summer months, when the surface is already dry. However, there are no larger accumulations of cryokonite; evidence of erosive wind action is found only sporadically in the shape of slightly smoothed eolised surfaces on some rocks or cliff-faces. On the other hand, the indirect role of wind is important. This is seen first of all in the shifting of snow, which results in an uneven cover of this area, and the formations of drifts, which often leave large surfaces, devoid of snow cover.

Wind directions in NW-Sörkapp also influence the general pattern of local climatic conditions. The prevailing winds are NE and E, of frequently gale strenght, connected with the North Siberian high pressure systems; they are strong föhn-like winds, blowing generally for 12 days

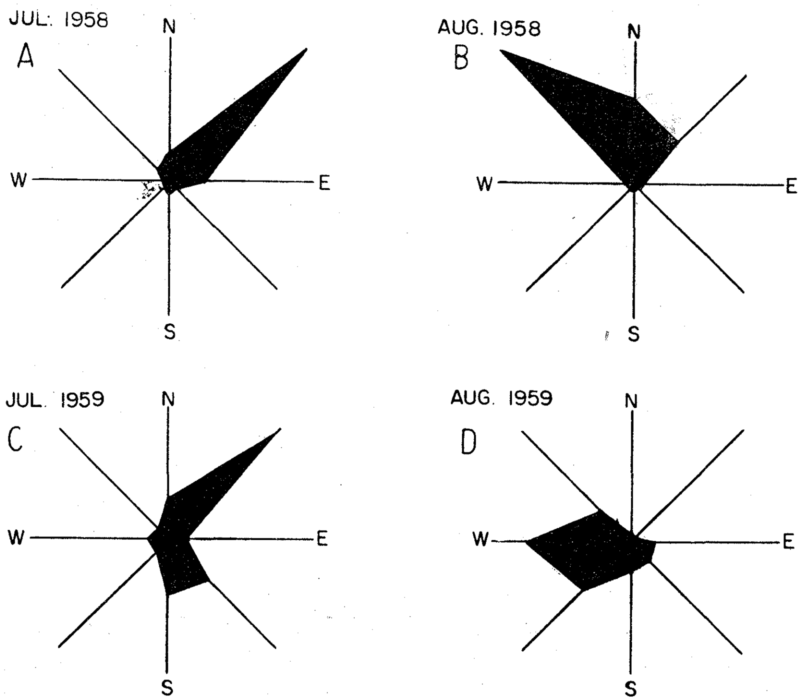

Fig. 5. Wind directions in Gåshamna (A, B, C) and in Björnskaubukta (D)

per month (**Makarewicz** 1960). Westerly winds resulting from changing lows are much weaker and occur less frequently. Such winds blowing right from above the Atlantic are those that bring about precipitation usually an increase in temperature, frequently drizzle. Even in summer, i. e. during two months, notable differences can be observed, according to the direction of the winds (Fig. 5). With persistently blowing easterly winds, the temperature falls even if the sky is cloudless, whereas westerly winds produce considerable humidity in the air, precipitation and a dense cloud-cover.

VEGETATION COVER

The vegetation of Svalbard, although very poor as regards the number of species (Środoń 1958), forms nevertheless a fairly dense cover in such places as are favourable to its growth. In NW-Sörkapp two zones of its occurrence can be distinguished. The first comprises the Atlantic coast and the lower slopes of the Struvefjella which are exposed to the influence of the Ocean, and the second comprises the area east of the Lisbetelva. The first zone is distinguished by a large quantity of mosses,

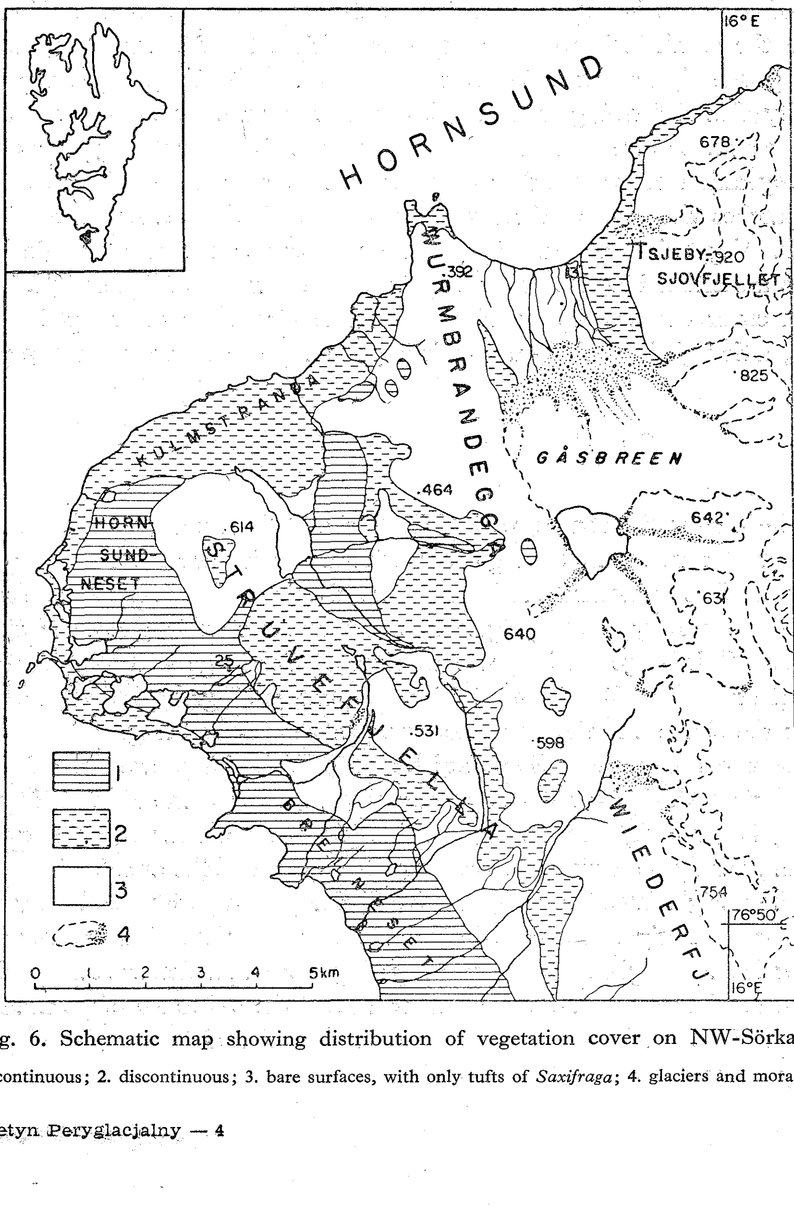

Fig. 6. Schematic map showing distribution of vegetation cover on NW-Sörkapp

1. continuous; 2. discontinuous; 3. bare surfaces, with only tufts of *Saxifraga*; 4. glaciers and moraines

grasses and flower plants, while the second shows a predominance of *Saxifraga* and Arctic polar willow. Both these zones differ also from one another by the density of their respective vegetal covers. The Atlantic zone cover is uniformly continuous in contrast to that of the area east of the Lisbetelva where large tracts are completely devoid of vegetation (Fig. 6).

The vegetal cover is quite clearly connected with the topographic exposure. Nearly all the areas that benefit from a larger amount of sunlight have a more luxuriant vegetation, whereas those that are deprived of it are either completely bare, or very poorly overgrown. The decisive role of exposure is best exemplified by the slopes of the Kovalevskidalen; while the south-facing slope is covered with a thick mantle, the north--facing one shows but a few tufts of moss and *Saxifraga*. The vigorous activity of land-forming processes does not favour the development of a vegetal cover. Hence, on slopes with most active morphologic processes the vegetation cover is either completely absent or dissected into scattered patches that are confined to places of relatively weaker waste movements. Vegetation appears immediately wherever the morphologic processes are either inactive or develop at a lesser rate. Consequently, a vegetation cover can also be found on old stone circles or on congelifluxion lobes, although in such instances it is generally discontinuous and ragged

CHARACTERISTICS AND DISTRIBUTION OF PERIGLACIAL PHENOMENA

The microrelief structures in NW-Sörkapp do not allow of any classification of forms based on genetic criteria for its areal extent is rather reduced. The structures and forms are therefore few and represent on the whole one type of periglacial environment that is characteristic of southern Spitsbergen. The present writer applies in general Washburn's classification (1956) whose division of patterned grounds is based on either the shape and the presence, or the absence of sorting.

Most common and characteristic of NW-Sörkapp are its microreliefs forms which first of all attract the observer's attention. Różycki (1957) is quite right in stating that „larger forms are far less discernable and can hardly be noticed before closer inspection of the area".

The periglacial microrelief of NW-Sörkapp is superimposed on glacial land-forms. Periglacial processes invade all the surfaces that are free from glacier-ice and begin to model them, giving them a particular stamp, which is typical of cold climate environment and of the existence of permafrost. This produces various effects and the traces of that action are found practically everywhere.

PATTERNED GROUNDS

Intensive frost weathering produces large quantities of fine waste, on which microrelief forms, termed patterned grounds, begin to develop. These structures, characterized by either circular or polygonal shapes, include both such forms as are created by sorting of material and such as are due to cracking. Hence, the presence of fissure polygons and of forms due to frost-heaving of the ground. The frost-heaving group may be taken to include such forms as stone circles, which show a clear sorting of material into one part consisting of fines encircled by another, forming a ring of rubble around the earthy centre of the form and the small patches of waste among either the rocky debris or the dense vegetation cover, (Pls. 10, 11).

Stone circles

Sorted stone circles in NW-Sörkapp are more or less circular in the plan, with centres of fine waste, ranging from 0.5 to 1.0 metres in diameter. The stone ridge surrounding the centre of fine-grained material has 20 to 40 cm in width. The inner part of the circles is slightly convex and rises several cms above the bordering parts. The height of the stone circle is rather negligible, some 15—20 cm on the outside, and 5—10 cm at the centre. Only in well-developed forms does the height of the border ridge attain some 20—30 cm and 10—15 cm respectively. Figure 7 shows a cross-section of a stone circle, developed in dolomite debris. In the stone ring the rock fragments average 1—2 cm in diameter, although some are larger including 5—10 cm, sporadically even big stones of 50 cm in diameter. Predominant, however, are angular cube-like fragments 1—2 cm in diameter. In this part of the structure the amount of fines is quite negligible and entirely absent on the top of the stone ring. They do appear only under the surface of the inner part of the form. The debris part is separated from the earthy one by a thin layer of very fine, angular fragments, 1—3 mm in diameter.

The stone ridges are clearly marked on the surface and slightly below, but become gradually obliterated and as deep as 0.5 m they merge into the constituent material of both the form itself and its surroundings. The arrangement of the rock fragments within stone rings is rather chaotic, though some of them, especially the longer ones, are set vertically and lean outward (Fig. 7). The stones occurring in close vicinity of the earthy centre are most distinctly oriented.

In the inner parts of stone circles the material fails to show the homogeneity in grain-size that can be seen in the stone ridges. There is a predominance of fine dusty waste with loosely scattered fragments of some 2—5 cm across. A certain degree of sorting appears in the thin, immediately subsurficial zone which shows somewhat larger accumulations of stones with numerous fragments set either quite or almost vertically. Below a depth of 40—50 cm there is no difference in structure between the material lying within or outside the circle. The geologic cross-sections made in Gåshamnöyra in 1957 and 1958 permitted to establish that the visible effects of sorting and frost-heaving reached down to depths of 50—60 cm. The stone ridges, conspicuous on the surface, widen downwards and at a depth of 50—60 cm they merge into a uniform rock material which fails to display any arrangement of the particles.

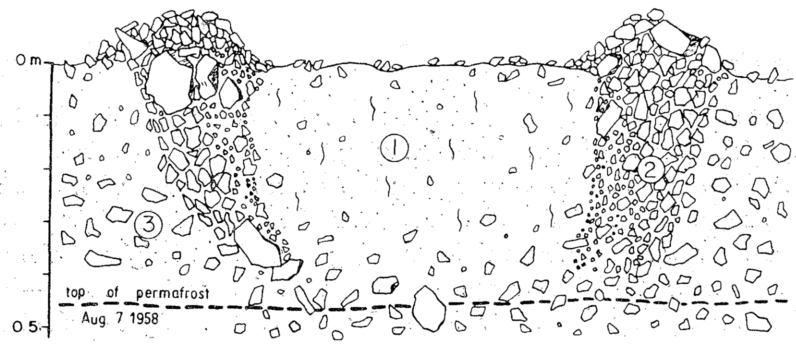

Fig. 7. Cross-section through stone circle at the foot of a debris slope of the Wurmbrandegga

1. centre of circle built of dolomite fines including some debris; 2. dolomite debris; at the contact of debris ring and centre visible thin layer of fine debris, 1—2 mm in diameter; 3. dolomite waste

Stone circles, containing well sorted material occur in places where waste both fine and coarse is abundant. Youthful forms exhibit only clearly discernable stone ridges, their inner part being hardly visible, while the mature or old ones show a well-marked division of material into two parts: a stony and a loamy one, contain a larger amount of fines within the ridges and a fairly thick vegetation overgrowing both stone ring and centre.

The stone circles in question occur on either flat or gently sloping surfaces up to 4° with a large number of cubic debris and considerable ground moisture. Hence, they can be found at the foot of the Wurmbrandegga debris slope (Pl. 11), and on flat top section of this ridge, along the lower margins of block fields on both sides of the Lisbetelva, and on the 32 m terrace at the foot of the Tsjebysjovfjellet slope. They are also sporadically encountered on the flat surfaces of the Hornsundneset around small lakes, in very boggy places. Best developed and fresh-looking stone circles are those occurring along the dolomite and quartzite part at the foot of the Wurmbrandegga and on the 40 m abrasive terrace, on the right side of the Lisbetelva.

Areas where fine-grained material with a minor admixture of debris is abundant, exhibit microforms similar in outline to those described above. They are reminiscent of the forms known from other regions and described in the literature as *Fleckentundra*, *tundra à ostioles*, *piatnistaya tundra* (Furrer 1959; Troll 1944; Govorukhin 1955) or as *non-sorted circles* according to Washburn (1956). They are either circular or oval and instead of the stone ring, which they lack, they are encircled by rings of vegetation overgrowing generally the entire area of their occurrence with a fairly dense mantle. Sometimes the muddy mass shows some irregular cracks or tiny polygons and a large quantity of debris lying at the surface. These forms that are generally loosely scattered, rarely appear in larger groups. These islands vary in size, the diameter of the fine centres ranging from 1 to 1.5—2.0 m while the width of the surrounding moss or peat ridges attain as much as 30 to 50 cm. Spotted tundra structures occur mainly in the area of the Hornsundneset where they constitute a dominant element of the periglacial microrelief.

Frost-fissure polygons

Frost-fissure polygons in NW-Sörkapp are differentiated in size as well as in the type of the material involved, in the places of occurrence and probably also in their origin. Therefore, it is possible to distinguish between large frost-fissure polygons, with diameters reaching 15—20 metres, small polygons with 0.5 to 2.0 m in diameter, and miniature polygons with no more than 5 to 15 cm, at the most 20 cm.

Large polygons, known in the literature as Taymyr polygons (Huxley & Odell 1924; Steche 1933), were seen only on the surfaces of abrasion terraces. They appear in a narrow stretch that runs along almost the entire coast, close to the coast-line. On the SE coast their occurrence is rather sporadic, but on Kulmstranda they stretch out almost uninterruptedly from Suffolkpynten to the Lisbetelva (Pl. 15). In the Andvika bay, the polygons again appear in isolated groups. However, the best-developed and most complete network was seen on the narrow terrace of the Hornstullodden promontory (Pl. 14), at the foot of the Tsjebysjovfjellet.

The intervening furrows are generally straight, commonly forming one clearly visible furrow connected with other either less clear or disrupted ones. In many cases the cracks fail to form a network of enclosed polygons, one or sometimes even two sides are often missing. Generally, however, the polygons are bounded by three or four well-developed furrows. Only some of the polygons are penta- or hexagonal.

The Sörkapp frost-fissure polygons vary in size but they are commonly rather small. Their average diameter is of approximately 15 metres, although both larger and smaller forms do occur as well. However, no polygons of more than 50 metres in diameter with intervening furrows of some 3—4 metres in width, i.e. such as those described by many investigators of tundra regions (Jahn 1961; Hopkins, Karlstrom and others 1955; Leffingwell 1915; Frost 1950), were found in this area.

On the surface of polygonal fields there is a complete absence of arrangement of the rock materials. Vegetation is here also either poor or completely lacking. Only the intervening furrows are overgrown with a thick mantle of vegetation (5 cm and more), consisting of mosses and *Salix polaris*. Right beneath the moss, appear gravels and sands with an admixture of fines and of coarse-grained debris. A vertical fissure cuts through these sediments; a few centimetres wide at the top it tapers rapidly towards the bottom. In some places the fissure cuts also through the vegetation cover. The depth of the fissures within the furrows was found to reach no more than 0.5 metre (Fig. 8).

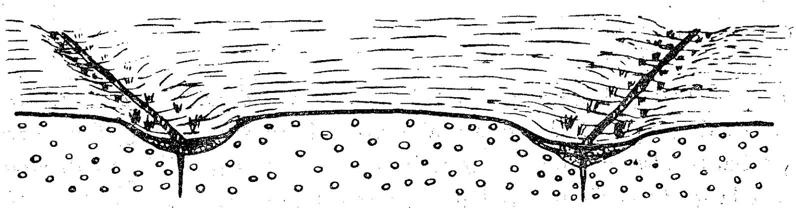

Fig. 8. Schematic profile showing fragment of a frost-fissure polygon on the Kulmstranda

The bordering furrows of the polygons have commonly a width of 0.5—1.0 m at the top and a depth of 20—30 cm (Pl. 15). The polygonal fields, however, rise to a height ranging from several to over 10 cm above the border furrows. These represent the high-centered polygons that are characteristic of permafrost area, as for example Alaska (Hopkins, Karlstrom and others 1955).

As regards the size of the Sörkapp polygons it is similar or even identical to that of the polygons described by Różycki (1957) from the Van Keulenfjord coast. Both these areas are characterized by high-centered polygons, however, there are striking variations in the frequency of their occurrence for in Sörkapp frost-fissure polygons are confined to small areas, whereas on the Van Keulenfjord coast they are rather common and dominant features (Różycki 1957).

The frost-fissure polygons described above are no dominant forms of NW-Sörkapp. By far more wide-spread is the smaller polygon type, measuring from some 10 cm to 3 m in diameter. Two varieties of these forms can be clearly distinguished. One of them is but slightly marked by fissures forming a network of cracks (Pl. 16) while the other shows a well-defined accumulation of rock fragments along the fissures.

Polygons of the first variety belong to the type known as fissure polygons or non-sorted polygons (Washburn 1956). They are small in size, usually some 50—60 cm in diameter. In such polygons the depth of the cracks is of ca. 50 cm, the open fissure has at the top a width of 2—4 mm and narrows downwards. These fissures do not contain any ice. However

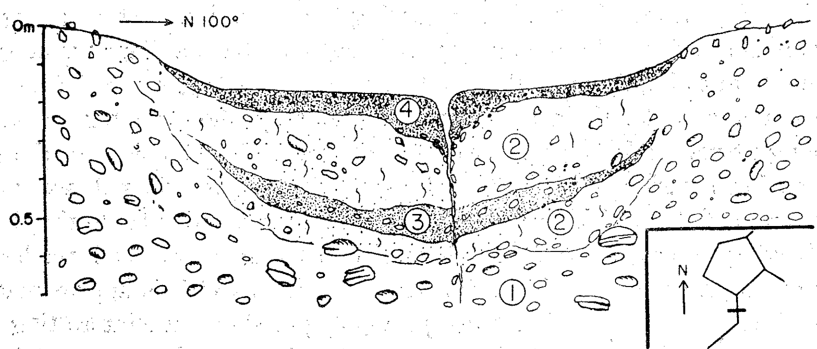

Fig. 9. Cross-section through the trough of a frost-fissure polygon

1. marine gravels; 2. sandy subsoil with pebbles and angular rock fragments; 3. mineral material including humus; 4. organic matter and sporadic rock fragments covered by vegetation

the formation of fissure polygons is obviously connected with ground dissication. Dissication of the ground progresses at a fairly rapid rate as soon as the snow cover disappears and the permafrost table subsided (observations from VIII. 1958). The rate of dissication is intensified by the still fairly dry föhn winds blowing from the NE. After a few days of such winds, the ground was quite dry and the first fissures, as well as the first fissure polygons began to form.

The network of fissures is not always dependant on the pre-existant structural patterns. Many stone polygons are cut by fissures, although cracks running along the stone border of the form are very common. The combined action of dissication and dehydration with that of frost-caused processes, seems to be an essential factor in the formation of that type of polygons.

The second type of small polygons is represented by forms which show well-defined ridges consisting of smaller or larger rock fragments.

Such stone polygons are perhaps the most common structures in NW-Sörkapp and occur almost throughout the whole area wherever conditions favour their development. They develop, therefore, in nearly all the flat or almost flat and relatively humid areas with a sparse vegetation which are either covered by weathering material or on raised coastal terraces — built of gravel including debris.

At the western extremity of Gåshamnöyra, along the base of the Wurmbrandegga massif extends a narrow stretch, where sediments derived from debris cones overlap with those deposited by water flowing from the glacier front and with marine gravels. The surface of this field exhibits, next to stone stripes and stone circles, also perfectly developed stone polygons (Pls. 16, 17).

In 1958, several observations regarding the formation of stone polygons were made in this field. The polygons found here have a diameter ranging from 40 cm to hardly more than 100 cm; only a few larger ones have some 150 cm across. In their horizontal outline they show pentagonal nets, although tetra- or hexagonal forms do occur as well. The sides of the polygons have various lengths, the longer sides being oriented according to the line of slope, the shorter ones — running perpendicular to the slope.

Sorting of the material is clearly visible being expressed by a larger accumulation of stones within the furrows, whose width is approximately 10—15 cm. A cross-section through a polygon shows an interesting arrangement of the material. The furrow itself, separating two adjoining polygonal blocks, is cut in muddy material including a small number of small rock fragments, 1 to 3 cm across (Fig. 10). The infilling rock fragments are set either quite or almost vertically and are almost completely free of fines which appear in insignificant quantity only in the lower part of the furrow. The polygon surface is covered by a large amount of rocky debris in which the major axes of many fragments are protruding vertically.

On the flat summit surfaces of the Wurmbrandegga and on the right bank of the Lisbetelva, near the small Savitsjvatnet lake, polygons were found, which exhibit a debris ridge protruding above the surface of the polygon block. The size of these polygons ranges from some 70 cm to 2—3 metres. They are characterized by a large amount of angular stones, set vertically, or with their longer axes oriented according to the line of the debris ridge. Around the Savitsjvatnet lake polygons have a diameter of 2 to 3 m and on the Wurmbrandegga — 0.7 to 1.0 m. The material of the border stripes includes debris which reaches, in large polygons (2—3 metres) a diameter of up to 30—40 cm, and in small ones (0.7 to 1 metre) some 5—10 cm. The largest fragments in the centre of the rubble ridge, decrease in size outside and towards the centre of the polygons.

On the 30 m terrace at the base of the Tsjebysjovfjellet, already largely covered by slope sediments occur polygons 1.5 to 3 metres in diameter. These forms have markedly flat but raised centres encircled by a 10 to 15 cm deep furrow containing stones. The width of the furrows is 30 to 50 cm. The surface of the polygons is covered by numerous stones averaging 5—10 cm in size. The furrows between the polygonal blocks are densely overgrown with vegetation. A cross-section, to a depth of some 1.5 m, shows a large accumulation of stones beneath the ridge, while inside of the polygons there is a visible predominance of fine-grained material.

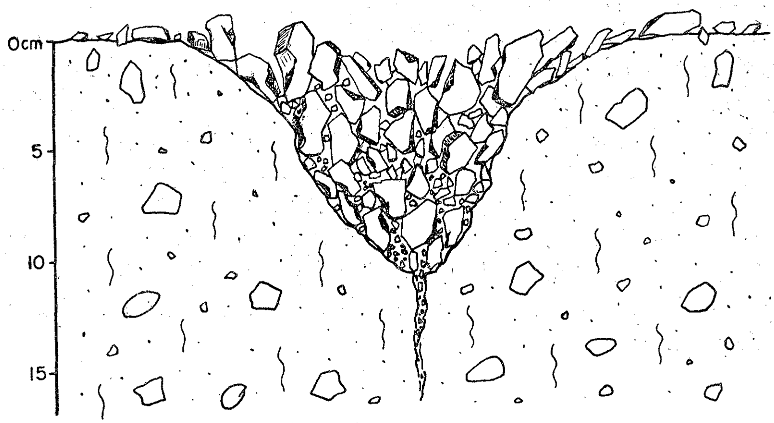

Fig. 10. Cross-section through furrow between centres of stone polygons. The furrow is filled with dolomite debris

A clearly marked division between the muddy centre of the polygon and its border part can be seen only to a depth of 0.5 m. Below, it disappears entirely.

Non-sorted polygons form a rather close network only in places showing a predominance of homogeneous fine-grained material, while stone polygons are common throughout the whole area. In the area under study, stone polygons were found in low-lying areas as well as high up in the mountains. The flat surfaces of coastal terraces at the foot of the Rasstupet, the Tsjebysjovfjellet, the Wiederfjellet, are the areas of their most widespread occurrence. Also slightly sloping surfaces in the summit parts of the Lidfjellet, the Kovalevskifjellet and the Wurmbrandegga are covered with networks of stone polygons (Pl. 17).

Stone stripes

Stone stripes are rather exceptional structures in NW-Sörkapp. Only at the foot of the northern part of the Wurmbrandegga range and partly of the Tsjebysjovfjellet, they occur in groups forming here even a predominant element among other periglacial microforms. To their sites of occurrence belong some of the lower parts of the Tsjebysjovfjellet and the Wurmbrandegga near Gåshamnöyra, Andvika, Höferpynten as well as less abrupt summit parts of the Wurmbrandegga range. These surfaces form either part of the mountain side of a massif (the Tsjebysjovfjellet, the Wurmbrandegga) or an abrasive terrace already invaded by formations derived from the slopes (Höferpynten, Andvika).

Such stripes vary in both shape and size. Larger stone stripes show convex stone ridges built of either sharp-edged dolomite debris or marine pebbles. The stripes are ca. 0.5 metre in width and rise some 20—30 cm above the intervening surface. These stone stripes are spaced 3 to 4 metres. They generally appear on surfaces sloping 8—10°. Stripes of that type occur in Andvika, and on the 32 metre terrace on the eastern side of Gåshamnöyra, but are probably most common and most typical in Spitsbergen (Ahlmann 1936; Büdel 1948; Klatka 1961; Troll 1944).

On the abrasive marine terrace of the Höferpynten promontory there are miniature stone stripes whose width ranges from 2 to 10 cm, the stripes being spaced 5 to 50 cm. The stone stripe lies at the same level as the intervening spaces.

MICROFORMS DUE TO MASS MOVEMENT

Transportation of the material crumbled by weathering is particularly intensive in NW-Sörkapp. Avalanches, landslides, debris avalanches, avalanches of snow and rubble, congelifluxion (solifluxion) and downwash are the morphologic expressions of this process. Such processes vary widely in both vigour and efficiency.

A preliminary study of the terrain suggests at once that congelifluxion is here the leading process whose activity is variously reflected in the microrelief forms. Debris lobes and ridges are the most common expressions of the gradual displacement of mineral masses.

Congelifluxion lobes

Microrelief forms built of mud including debris and produced by congelifluxion are very common on surfaces sloping more than 2—3°. Their structure shows striking difference which permit to distinguish between two categories which are: lobes consisting of well-sorted and lobes consisting of non-sorted material (Dutkiewicz 1961). Lobes with non-sorted material are less common and occur mainly in places where fines are predominant, while those that exhibit a clearly marked division between the fine-loamy particles in the centre and the debris ridge around its front and sides, are widespread throughout the area investigated.

Large though unconspicuous debris tongues occur in the western part of the Tsjebysjovfjellet massif slopes, on the mountain-sides of the Savitsjtoppen, the Kovalevskifjellet and the Gavrilovfjellet, at the base of steep debris cones and of abrupt walls. They reach 2—3 m in width and more than 5 m in length. Their rubble ridges are about 0.5 m wide and slightly rising up to 5 cm above the central part which is covered with a thick layer of rock debris (Pl. 20). The debris front of the tongue is ca. 0.5 m heigh. Jahn (1961) described from Bogstranda lobes with fronts as high as 1.5 m. Such lobes occur on surfaces sloping some 5—10° and covered with a thick vegetation mantle which is discontinuous only in the middle of the lobe.

Lobes composed of earth and debris and much better defined in outline than the former, occur on the uppermost and the lowermost slope segments of the Wurmbrandegga massif and in the Höferpynten. They are fairly large, the lateral stripes being spaced 1—2 m, and the whole lobe attaining some 4—6 m in length.

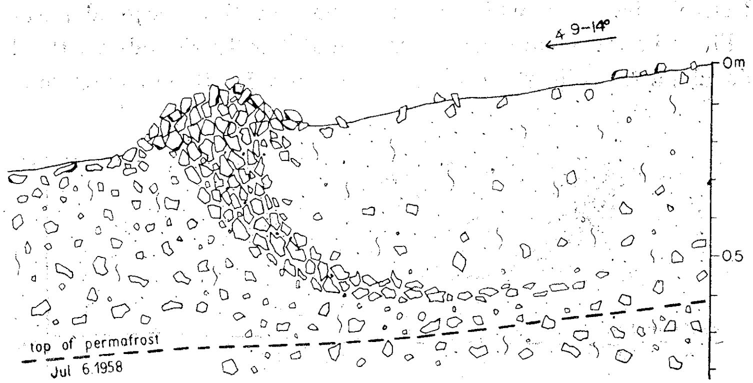

Fig. 11. Long profile of congelifluxion lobe built of dolomite debris and fines. In the inner part of structure an abundance of pulverulent particles and a random distribution of single larger rock fragments.

Cross- and long sections through the lobes revealed that the angular rock debris forming their front- and side ridges is almost entirely free of fines in the upper part of the form. The marginal elements of the structure penetrate the subsoil to a depth of 30—40 cm and underlie the central part of the lobe which is mainly built of loamy material including very small stones, 2—5 cm in diameter, and several larger rock fragments.

In the sub-surficial zone and on the surface of the lobe-center as well as on its foreground, the number of angular stones, 2—5 cm in diameter, increases ,some of which are vertically oriented (Fig. 11).

On the downward part of the waning slopes grading some 4—6° which contain an abundance of fines and ground saturated with water, lobes have a different appearance showing a considerable predominance of their longer axes over the short ones: they average approximately 1—1.5 m in width and 5—10 m in length. Their side-ridges, which are composed of fine rock-debris, 2—3 cm in diameter, attain 10—15 cm in width and do not rise above the surrounding level. A cut through the lobe shows that the stone-stripes reach downward 20—30 cm and underlie the lobe inside, wedging out opposite to the direction of movement. The frontal part of the lobe consists of one major accumulation of stones on its outer side and of some minor debris stripes which testify to combined movement during transportation of the material (Fig. 12).

Congelifluxion lobes resembling those described above, occur on the surface of an old abrasive terrace on the Höferpynten promontory. The sides of these strongly elongated tongues are joined. They are built of fine dolomite waste with a considerable admixture of coarser particles, 0.5—2 cm in diameter, which predominate in the marginal parts of the lobes. Their lateral stripes are narrow and hardly rise above the level of the central part, while their fronts rise some 5—10 cm over the surface

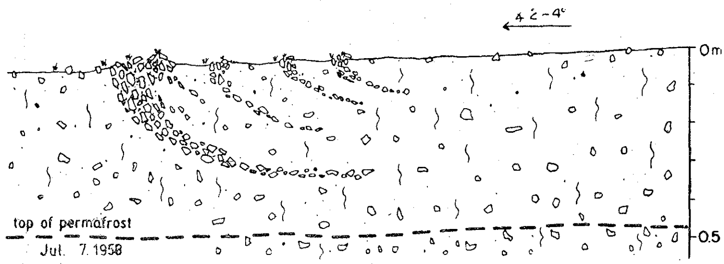

Fig. 12. Long profile of congelifluxion lobe composed of fine waste, dominantly shales

on which the lobe extends. The lobes develop on abrasive terraces. They overlie gravels and sea-pebbles thus forming a congelifluxion cover. Some of them have already reached the cliff and fall down on the present-day beach. A field of such elongated narrow lobes bears a striking resemblance to a series of stone stripes. The almost complete absence of vegetation affords evidence of a recent development of these forms, and one that is still in progress. The occasional tufts of *Saxifraga* in the frontal part become gradually covered with debris. This is also clearly confirmed by a displacement of the material that was recorded by means of pegs and

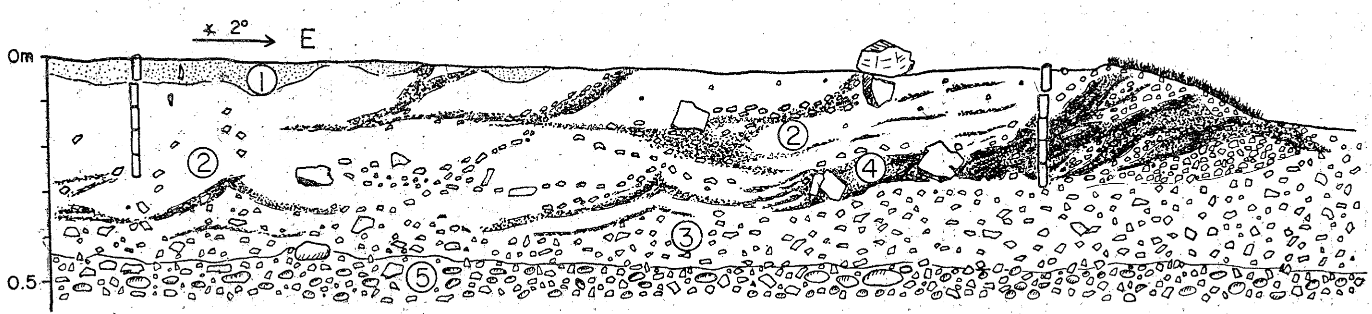

Fig. 13. Höferpynten. Cross-section through congelifluxion lobe on the surface of a marine terrace

1. light-grey shale waste, abundant dusty particles; 2. fine-grained material, light-grey in colour, with a random distribution of small rock fragments; 3. angular, dolomite and quartzite debris; 4. striae of organic matter and peated plant remnants; 5. marine sands and gravels; 5-cm segment pegs record differential creep of material

artificial stone stripes (Pl. 22). From August 1958 to July 1959, the most appreciable displacement of the material was 4 cm in one lobe, 1 cm in some others, though in several lobes no such movement was noticed. In the autumn 1957 a set of segment pegs was installed within the terrace-like lobes occurring in a small area on the Höferpynten, nearby the debris cones of the Wurmbrandegga slope. In the summer 1958 a cut that exposed the pegs (Fig. 13) revealed that the lateral creep of the material recorded by only two of the upper segments was quite insignificant (1 cm). This shows that the movement reached a depth of no more than 10 cm. Streaks of humus and peated plants also testify to the existence of some movement even though it were only very slow (Fig. 13).

During the summer 1958, downcreep of the ground to a distance of 2 m was also observed. This indicates that apart from very slow movement due to upfreezing and upheaving, also rapid one-time movement is taking place that displaces water saturated masses over considerable stretches on a frozen ground. Such extensive downslope displacements may under favourable conditions occur spasmodically.

FREE FACES AND GELIVATION FURROWS

Steep slopes appearing in the upper parts (over 300 m) of the mountain massifs are completely devoid of a vegetation cover. They constitute a characteristic feature of periglacial relief and are common throughout the area of Spitsbergen. Such precipitous walls are described in most of the papers dealing with periglacial relief forms and the processes modelling those of Spitsbergen.

In NW-Sörkapp abrupt slopes appear at two levels. The lower level is due to weathering and the action of sea waves. Such forms are either recent or old cliffs rising as high as 50 m above sea level, while the upper level appears in rock walls situated at altitudes above 100 m above sea level. These were produced either by undercutting by the glaciers flowing down in past times (like the western slope of the Wurmbrandegga) or by weathering under conditions of severely cold climate.

Free faces[2] crown the upper parts of the Wurmbrandegga mountain sides at altitudes of more than 150—200 m, the Hohenlohefjellet at above 300 m, and some parts of Sergeijevfjellet, the Lidfjellet, and the Gavrilovfjellet. The western mountain side of the Tsjebysjovfjellet massif terminates abruptly in the form of a steep rock face which from an altitude of some 300 m above the Niger glacier, and more southward from one

[2] The term *free face* is used here according to K i n g's scheme of slope development.

of 500 m above sea level reaches the flat top surface. The steep free face of the Rasstupet descends from an altitude of 670 m above sea level to 100—150 m forming a precipitous 500-metre high wall. The mountain-sides sloping down to the glacier tongues merge almost into the very ice from which they are separated only by small debris cones. These impressive free faces have several hundred metres in height as e.g. the Tsjebysjovfjellet mountain side rising above the Nordfall glacier or the Nordfallet slope (Pls. 25—30).

Free faces of the slopes show remarkable gradients up to 50°, their surfaces are cut by furrows and gullies. These furrows running almost vertically vary in both width and depth. Apart from concave forms these bare surfaces exhibit also ribs and shelves depending on either the degree of resistance of the rocks or on their stratification. Steep slope segments are cut by either oblique or horizontal steps, shelves or shelve fragments on which usually the debris derived from the upper parts accumulates forming small storeyed debris cones. Disintegration of these shelves proceeds rapidly and their fragments hang almost loose. In the subsummit part of the Lidfjellet even large shale blocks, detached from the parent rock of several shelves, can be easily pushed down onto the waste below. These small shelves as well as the uneven sharp-edged Wurmbrandegga crest with its peculiar steps, peaks and towers afford evidence of a destruction of the former relief by vigorous frost weathering.

Intensive frost weathering promoted by continually recurring exposure to its action operates mainly in the steep and bare segments of the upper slope parts of the Tsjebysjovfjellet, the Nordfallet, the Rasstupet, the Wurmbrandegga, the Midifjellet, and the Gavrilovfjellet. Within this zone, detached rock fragments and material are transported along furrows by gravity or displaced by snow avalanches. Steep faces are free of the snow that accumulates only in the furrows and gullies. Hence the rock fragments that fall off the walls and slide down along these depressions, may find better conditions when these are filled with snow. Even large blocks detached from the rock wall were observed to roll down along snow-patches, far away from the wall. However, most of the debris and blocks detached from the walls find their way downwards along erosional furrows and gullies.

The steep, free faces of the Wurmbrandegga, the Midfjellet, the Robitschfjellet, the Tsjebysjovfjellet and the Rasstupet, exhibit remarkably well developed gravitation furrows and gullies. Such furrows appear mainly along joints or in some other less resistant places of the solid rock. On the eastern mountain side of the Wurmbrandegga, furrows are narrow (0.5 m to several metres), deeply cut into the rock and run opposite to the dip of the layers. Most of them join to form large gullies or merge into gelivation niches in which snow patches were observed to linger till late in the summer (17.VIII. 1958).

In the shale part of the Wurmbrandegga ridge, the free faces are cut by deep and wide gullies that originate at the upper knick point of the slope. These gullies are separated by spurs in which the solid rock appears vigorously dissected. The bottom and sides of the gullies are covered with waste of various grain size (Pl. 28).

DEBRIS CONES

Debris cones are inseparately associated with furrows and gullies due to gelivation and gravity. Such forms appear generally grouped although it should be emphasized that they do not invariably occur above cones. In places where a free face segment became completely covered up to the top with waste there may be only a cone.

Debris cones are very common throughout the Spitsbergen region, but are most remarkable and numerous on the slopes of the Wurmbrandegga, the Hohenlohefjellet, and the Rasstupet in close proximity of the Körber glacier. They widely vary in size ranging from several (Höferpynten cones) to nearly one hundred of meters in length (Tsjebysjovfjellet, Hohenlohefjellet) dependant on the size of the mouths of the furrows or gullies at which they are formed. Extensive cones arise at the mouths of large and active furrows supplied by an abundance of transported material, while accordingly small furrows form small debris cones. Such cones grade usually from 25° to 40°, at the angle of repose of the material.

On the eastern slope of the Hohenlohefjellet at the mouth of a big niche a cone grading 40° is built of large sandstone blocks over 0.5 m across. A characteristic feature of the shale debris cones occurring on the eastern slope of the Wurmbrandegga is a much lesser gradient of some 26°. From active debris cones, vegetation is practically absent except for some isolated specimens of polar poppy and tufts of *Saxifraga*.

In both the vertical and the long profile, the rock material of cones is strongly differentiated. The largest blocks rest at the foot of the cone with dolomite debris 1—20 cm in diameter and sporadic larger blocks (0.5 m) lying on top. Fines filling the voids between coarser debris appear at a depth of 20—30 cm. Sometimes on the lee-side of a larger block, fine waste reaches the surface.

On the Wurmbrandegga slope, near the moraine of the Gås glacier, debris cones show a concave profile at the bottom, while a straight line of profile and an abrupt break at the bottom are characteristic of the cones on the eastern slopes of the Hohenlohefjellet and those of the Midifjellet. At the very extremity and outside the cones, blocks are scattered, many of which are disintegrated. Such debris cones have usually a straight profile, a notable gradient (even up to 40°) and an abrupt break at the bottom. They are frequently grouped, forming vast debris glacis (Pl. 31).

ALLUVIAL FANS

In areas rich in fines, arise alluvial fans. They appear below large gullies and niches with persistent snow patches. Concave in profile they grade notably up to 30° in their upper part and hardly some 4—8° in the lower one. Their bottom size varies from several to 100 metres and more. The largest fans occur on the littoral plain of the Hornsundneset. They grade no more than 2—3° and were deposited mainly by meltwaters flowing from the mountains (Pl. 4).

Alluvial fans develop most intensively during the melting of snow when abundant waters strongly erode the sloping surfaces, carrying down large quantities of material.

On smooth slopes appear deep furrows eroded during runoff; they dry up as soon as the water is drained. Such furrows, over 1 m in width and 50—60 cm in depth, were observed on the slopes of the Kovalevskifjellet, the Sergeijevfjellet and the Lidfjellet. High up they form a pattern of tiny trenches which downwards join to form one larger trough that is initially straight, but farther becomes winding and gradually disappears. It contains a large accumulation of material transported by downflow.

Gently sloping surfaces, controlled by slopes covered with coarse debris or debris cones, afford suitable conditions for the activity of waters, both braided and organised into a network of small trenches (Pl. 23). In such places water flows out of the slope debris cover into which it percolated during snow melting and rain-falls, thus washing out the fine waste and depositing small colluvial covers.

BLOCK-FIELDS

In the area investigated, intensive processes split and disintegrate the solid rock thus producing large quantities of debris and blocks. The block accumulations in NW-Sörkapp vary in both size and topographic situation. Covers of huge blocks appear most often on variously grading slopes but are also found on flat surfaces. According to Högbom (1914) such covers are as well allochtonous as autochtonous.

Rather compact, continuous covers extend over the Hohenlohefjellet slopes, and on the flat terrain between Lake Svartvatnet and the gorge of the Lisbetelva (Fig. 16). In other parts of the area they appear in smaller groups. The blocks composing the rubble fields are large ca. 40 to 70 cm, some even 1 m across. They are characterized by angular components and absence of fines. Fine-grained particles usually deposited by downwash, appear in the lower part or even outside the block cover.

Block fields consist of thick-bedded Carboniferous and Triassic sandstones or of quartzites. Frost weathering disintegrates these rocks into separate big blocks along joints and lines of weakness (Różycki 1957).

In NW-Sörkapp two types of block covers can be distinguished: one of which arose *in situ* and the second was displaced. The former is found in the depression between the Wurmbrandegga and the Savitsjtoppen where it appears in the form of a small sandstone block cover, and on both sides of the deep incised river Lisbet where it assumes the size of an extensive accumulation. The autochtonous origin of these covers is evidenced by outcrops of bedrock, the lack of alien material and the almost flat surface on which they rest.

Allochtonous block cover was observed on the sub-summit slopes of the 494 m elevation in the Wurmbrandegga ridge. This elevation is built of sandstone in its upper part and of schists in its lower part. A rubble field composed of sandstone blocks, covers the whole elevation and extends right down encroaching upon the schist surface. Also allochtonous are the block fields covering the Hohenloheskardet, and the lower parts of the Sergeijevfjellet, the Gavrilovfjellet and the Kovalevskifjellet. They consist of huge blocks detached from the upper slope parts and displaced by gravity. In the map, both these cover types bear the same mark as it was not always possible to establish with certainty to which group each of them belong (Fig. 16).

FINE-RUBBLE COVERS

Fine debris covers extend over vast stretches of Sörkapp. Their areas of occurrence are left as white patches in the map (Fig. 16) for they ought to be marked in several places where they exhibit such periglacial structures as lobes, stone circles, stone stripes etc. and this might obliterate the picture of the pattern. Practically all the surfaces of this region excepting the lowest terraces, the Gås glacier outwash plain, the free faces and the colluvial covers, may be said to be debris covered.

Such covers consist of rock fragments of various size, often including a larger or lesser admixture of fine muddy material dependantly on the composition of the solid rock. The finest grained material predominates in the schist-parts while those built of dolomite mostly consist of plain rubble.

Slopes covered with fine-grained debris are usually smooth, long and their profile fails to show any sharp breaks. In several places they are overgrown with vegetation. The Struvefjella ridge on the side of the Atlantic, the Savitsjtoppen, part of the Tsjebysjovfjellet, are covered with uninterrupted mantle of dense tundra vegetation. However, the rest of the fine debris mantle exhibits either only small patches of vegetation or isolated tufts of *Saxifraga*, dependantly on the degree of moisture and the exposure (Fig. 6 and 16). Bare debris-covered surfaces are nontheless also fairly common. They are diversified by intensive and lively processes productive of such structures as stone circles, stone stripes and particularly congelifluxion lobes.

Fine-debris covers vary in thickness according to slope gradient and length. On either flat, altitudinal surfaces or such as are remote from larger mountain sides, their thickness is hardly several to some tens of cms, whereas on long slopes, particularly in their lower parts, it amounts to more than 1.5 m. A detailed study of this type of covers is, however, no easy task as it requires very thorough investigations of both composition and structure of the deposits. Climatic conditions but in particular the difficulty of digging in that kind of material render this task still more arduous. Only in three places was it possible to identify rhythmically bedded debris deposits which were singled out and defined as a peculiar variety of the grèzes litées type.

GRÈZES LITÉES

Towards the end of the period of investigation in 1959, some forms exhibiting very characteristic rhythmically alternating layers, composed of coarser and fine debris, were found at the foot of the Lidfjellet massif. These layers, some 5 cm in thickness consist of series of rock fragments, ca. 1 cm in diameter, and of very fine waste including a few fragments 0.5 cm in diameter. From the petrological view-point they are a result of the weathering of sandstone and still more of that of strongly sandy schists.

A like structure of debris deposits was also recognized below the Midifjellet and on the north-facing slopes of the Wurmbrandegga. In a cross-section at the foot of the Wurmbrandegga, alternating bedding is clearly visible (Fig. 14). Layers composed of coarser debris (ca. 2 cm) show an openwork structure and hardly include any fine particles, while those consisting of finer material exhibit some bipartition and heterogeneity in grain-size. The coarser fragments are directly overlain by a series of very fine waste (0.1—0.2 mm in diameter) including single larger particles. This in turn is overlain by another layer of the same thickness, composed of small rock-fragments almost equal in size (2—5 mm) with a slight admixture of fine particles in the top of the layer. The thickness of these layers varies 5—8 cm. Their boundaries are well-defined and their succession, as observed in the section, is very regular. The whole formation consists of angular dolomite debris.

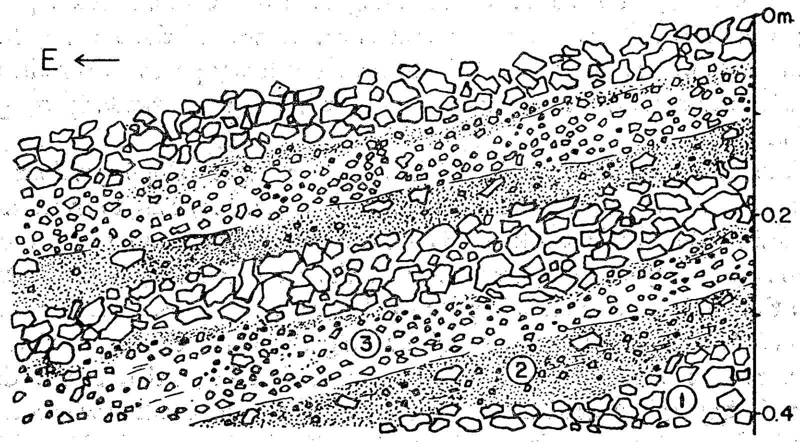

Fig. 14. Section of rhythmically bedded slope deposits of the grèzes litées type
1. angular, coarse debris of dolomite; 2. fine dolomite waste with larger rock fragments; 3. thin layer of fine debris, 1—2 cm in diameter, and dust particles

The bedding pattern of the deposits parallels the line of the slope and the layers dip some 5 to 10° at the foot of the Lidfjellet and up to 38° on the Wurmbrandegga slope. Alternation in grain-size is also visible in the long profile. The distal parts of the Lidfjellet slope-cover contain smaller fragments than the proximal ones. The opposite was observed on the Wurmbrandegga slope where a larger quantity of coarse debris occurs in the lower slope parts.

Deposits of the grèzes litées type are probably wider spread in the Sörkapp area than according to the present description. However, the writer does not consider himself entitled to discuss them, as their retarded recognition still requires detailed studies.

NEEDLE-ICE HUMMOCKS

In the Gåshamnöyra region, in Kulmstranda and in Hornsundneset some very peculiar forms composed of large ice needles were observed in 1958. In basal outline, such forms are either circular or elongated. Their size ranges from several to more than 20 metres and their centres rise ca. 1.5 m. These hummocks consist of 10—15 cm long ice cristals. A very thin, 0.2—0.5 cm, intercalation of dark ice divides the needle-ice layers into separate stories of cristalline ice. This intercalation grades 5—10° from the centre to the margins, while the ice-needles are set perpendicularly to the intercalation lines (Pl. 33).

In the Gåshamnöyra outwash plain ice mounds thinly covered with outwash pebbles, over ten centimetres in thickness, and with blocks upheaved together with the surrounding material were observed in 1958. Such mounds easily split into separate ice blocks. As the thin mineral cover, devoid of vegetation, fails to protect them from the effects of warm temperature they rapidly degrade and vanish completely towards the end of July 1958. In other sites however, which are densely overgrown with vegetation such forms persist much longer. As late as on August 12th 1959 moss covered hummocks were still fairly compact in the area of Kulmstranda and Hornsundneset where their decay was observed to proceed at a much slower rate. A remarkable fact is that not only the moss mantle but also large blocks, 0.5 m in diameter, were upheaved to as much as 1 m above base level.

The needle-ice hummocks occurring in NW-Sörkapp are connected with the axes of drainage. In the Gåshamnöyra region they arose in stream beds or at the junction of several torrents flowing across the outwash plain. In the Hornsundneset area they also occur in the axes of outflow or in particularly boggy sites.

THE DISTRIBUTION OF PERIGLACIAL PHENOMENA

The Svalbard Archipelago lies in the zone defined by Büdel (1948) as rubble zone as distinguished from the tundra zone which lies south of the former and is characterized by milder climatic conditions. However, according to Berg (1936) the present-day periglacial regions may be divided into 4 zones: (1) Arctic desert, (2) Arctic tundra, (3) shrub tundra, and (4) forest tundra. Grigoriev simplified this division calling Berg's Arctic desert and Büdel's rubble zone — the Arctic, and the tundra zone — the Subarctic. The Arctic includes the area beyond the 73° of north latitude, including Spitsbergen, the North Land and the Franz Josef Land. As the outstanding characteristics of these regions Grigoriev (1946) enumerates: sparse vegetation, shallow ground thaw, and formation of typical structural soils.

The situation of NW-Sörkapp within the Arctic region determines the nature of this country. The operations of periglacial processes and the character of the microrelief are here controlled by severe climatic conditions. Such factors as low temperatures, a poor vegetation cover, intensive frost weathering supplying abundant material for displacement by congelifluxion, permafrost with shallow summer thaw afford suitable conditions for the development of frost-caused forms and phenomena. As cited in the literature, the values of thawing in the Arctic zone are insignificant, hardly some 30—60 cm in Franz Josef Land (Ivanov 1931; Sukhodrovski 1962), while in Spitsbergen the active layer of permafrost varies from 80 cm to 1.5 m (Dylik 1958; Jahn 1961; Czeppe 1961). These values depend on various local conditions such as: nature of the material, ground moisture, vegetation cover, etc.

Rock disintegration, a pre-requisite and basic factor of all further geomorphic processes, it extremely vigorous in NW-Sörkapp. Its action can be inferred from the presence of residual waste and of weathered boulders lying on the most recently emerged sea-shore terraces. Quantitative data collected by Jahn (1961) confirm this assumption. The rubble desert along the western edge of Gåshamnöyra, in Höferpynten, in Andvika and in many other places consists of vast quantities of angular, cubic fragments forming either structureless debris covers or entering into the composition of various periglacial structures. This fact is somewhat puzzling as it seems to be rather inconsistant with the opinion of some investigators who hold that frost weathering in Spitsbergen is but slightly effcient (Czeppe 1964; Rapp 1957).

The huge blocks at the foot the Wurmbrandegga on which reference points were installed in order to obtain some quantitative data that might permit to determine the intensity of weathering, showed already after a year remarkable traces of frost- and ice actions. Also the absence of lichens affords evidence of continual splitting off of small rock fragments, that accumulate at the foot of large blocks. Numerous debris cones, gelivation furrows and free faces clearly testify to intensive weathering, which combined with mass movement, that contributes to a recurrent exposure of the rocks to weathering, produces most significant morphologic results.

Frost weathering in Spitsbergen assumes various aspects chiefly depending on the rock-type. Dolomite and limestone rocks are weathered by macrogelivation (Tricart 1956; Dylik 1958) producing large quantities of angular cubic fragments, 0.5 to more than 2 cm in diameter, and a negligible amount of dusty waste (Pl. 8). Weathering of quartzite and hard sandstone by macrogelivation supplies generally coarse waste and sandy particles. Schists however, are usually weathered by microgelivation operating along joints and abundantly supplies fine waste, 0.02—

—2 mm in grain size, including some coarser fragments, 2—5 cm in diameter.

The occurrence of waste covers composed of finer or coarser particles depends on the outcrops of schists, dolomites, sandstones and quartzites. Periglacial structures vary in type and nature according to the kind of waste of which they are composed. Congelifluxion lobes are usually developed in waste with a predominance of fines. They are, therefore, less conspicuous than those including coarser material. The occurrence of certain structures in one place and their absence from others, their various aspects depending on the nature of the component waste and the pre-existant relief, their topographic situation, the degree of ground moisture and other local conditions, gave rise to a zonal differentiation of microrelief forms and phenomena in NW-Sörkapp.

Although the area investigated is reduced and lies within the same climatic zone, a fact that does not contribute to a wide variety of periglacial forms, nontheless the influence of the former relief pattern, the geologic structure of the area, its petrology, its local climatic conditions and its vegetation introduce certain variations in the appearance of the microrelief forms and phenomena. The interrelations between the causes of that diversification render it difficult to estimate the individual importance of each. Relief pattern and petrologic composition combined with local climatic and hydrographic conditions seem to play a preponderant role. Other environmental elements either emphasize or obliterate the differences observed in the forms. In face of these differences in the distribution and the development of periglacial structures, two separate zones may be distinguished in NW-Sörkapp: (1) a western one on the Atlantic coast, and (2) an eastern one, inland. Although these zones differ from each other in both microrelief pattern and course of some modelling processes the boundary that divides them, running along the Struvefjella chain is not clearly defined (Fig. 16).

The eastern part of the area thus divided lies east of the Struvefjella range involving comparatively narrow surfaces of abrasive terraces, the long Wurmbrandegga ridge and of its prolongations: the Kovalevskifjellet massif and the Savitsjtoppen as well as the Gåshamnöyra depression barred on the south by the Gås glacier and its protruding nunataks. In the easternmost part, the lofty Tsjebysjovfjellet massif grades abruptly towards Gåshamna and Hornsund. This part of Sörkapp exhibits a wide diversity in the pattern of both large-relief forms and periglacial microrelief, frost-caused processes being here much more active than in the western part. Periglacial structures such as congelifluxion lobes, frost disintegrated blocks, stone circles, -polygons, and -stripes, are characteristic

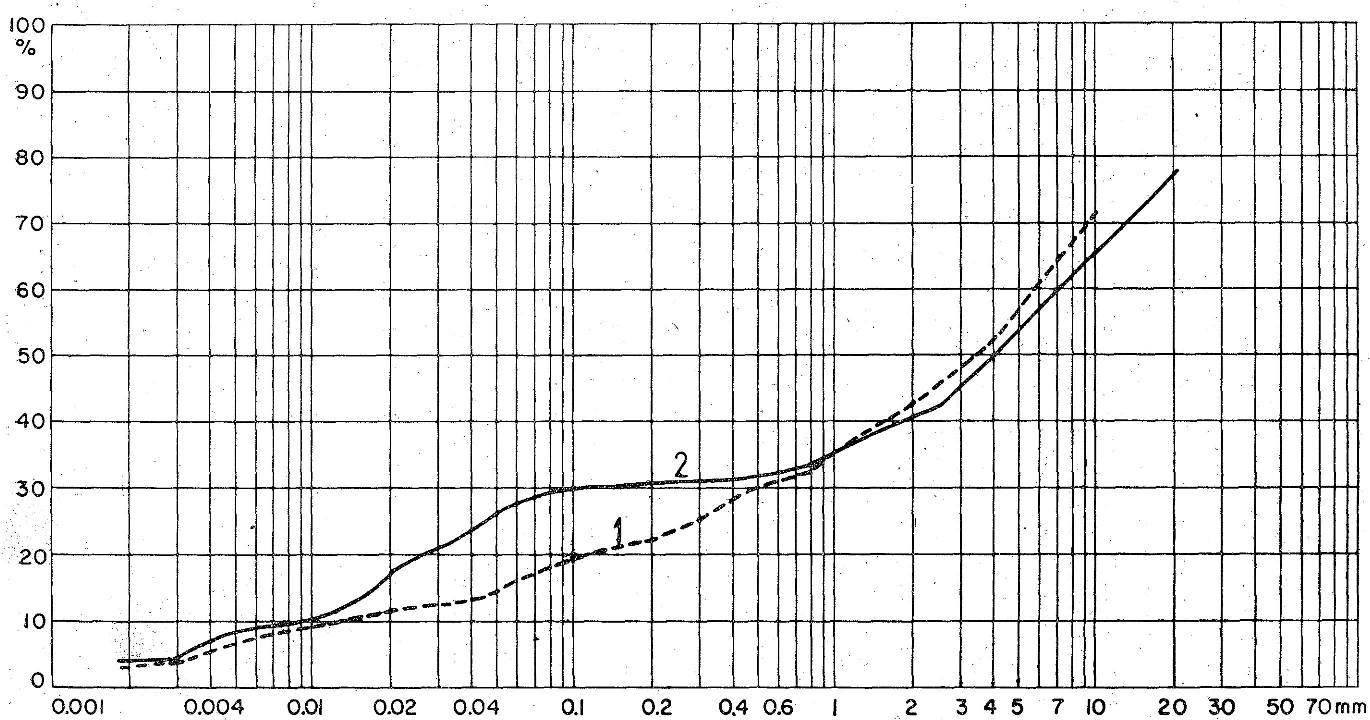

Fig. 15. Grain-size curves of weathered material taken from the Wurmbrandegga

1. phyllites; 2. dolomites and shales

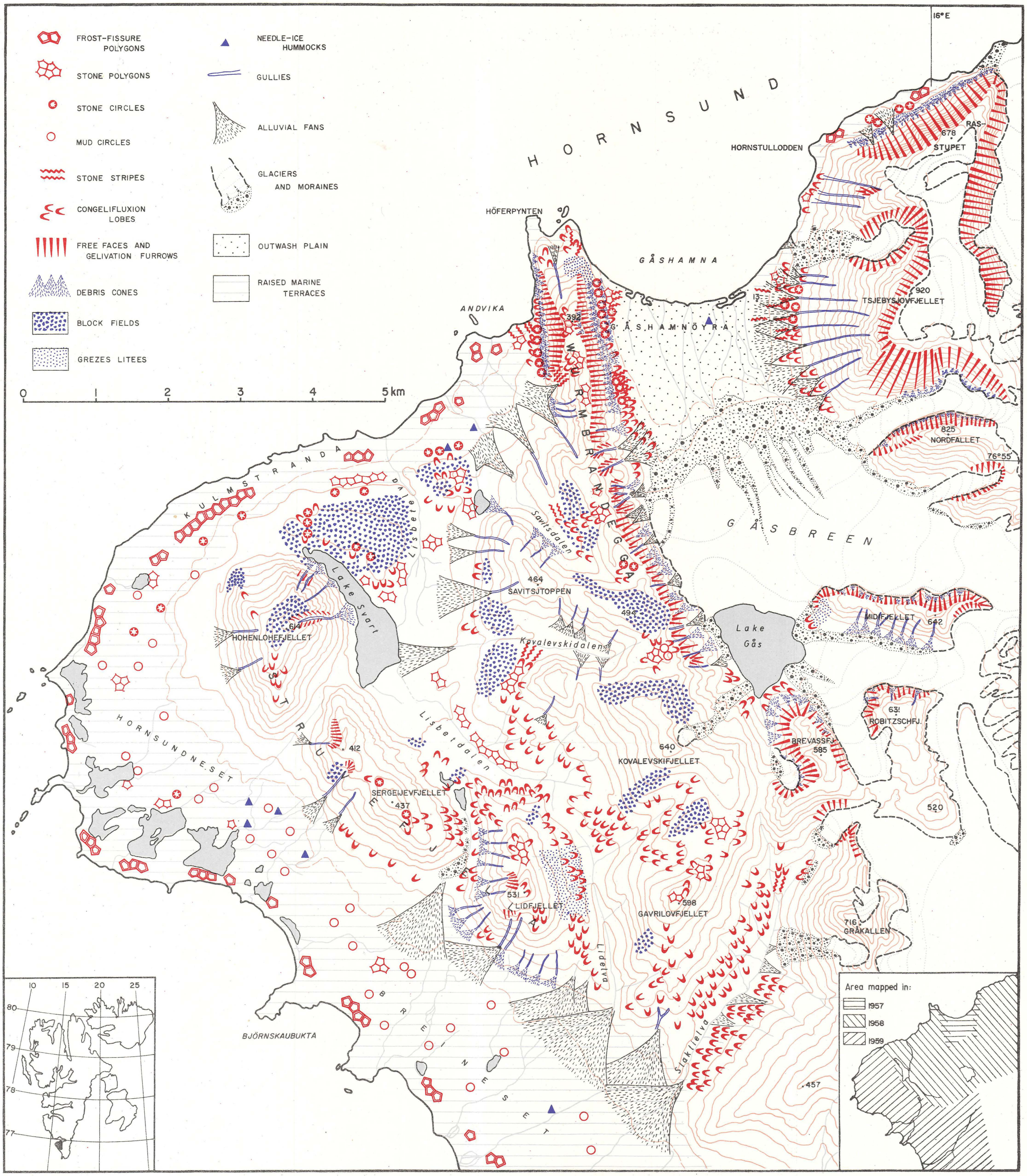

Fig. 16. Distribution of periglacial phenomena in NW-Sörkapp, Spitsbergen

of this zone. Numerous debris cones, free rock faces, gelivation furrows, surfaces devoid of vegetation, give this region the severe appearance of a debris desert with isolated tufts of *Saxifraga* (Fig. 6, Pl. 7). All the micro-relief forms in the eastern part of NW-Sörkapp are recent in origin and their development is still in progress. Only in a few exceptional instances the process of evolution seems to be extinct. In this area, the formation of periglacial structures is not inhibited by plant growth for, in contrast to the western part, vegetation is here rather poor and less continuous.

Owing to the pre-existant glacial morphogeny, the relief pattern of the eastern part is widely diversified, the flat surfaces of coastal terraces form only narrow borders adjoining the slopes; only in Andvika they are somewhat wider. This relief pattern which constitutes the substratum of such periglacial structures as are developed to-day, determines their distribution and the course of their development. The flat and gently sloping summit surfaces of the Wurmbrandegga, the Tsjebysjovfjellet, the Lidfjellet, and the Kovalevskifjellet, the slope planations of these massifs, the lowermost parts of debris slopes, the knick-points between debris-slope and waning slope — all of them are here areas of common occurrence of such residual structures as stone circles and stone polygons which, in their pure form can only originate on gently sloping surfaces grading no more than 2—4°.

More sloping surfaces (more than 4°) exhibit amorphous structures such as congelifluxion lobes, often forming a terrace-like pattern, stone stripes, mud or debris streams, and alluvial fans. With gradients of 15—20° and more, the material is displaced by gravity, a result of which are the numerous debris cones, widespread in this area where they coalesce to form extensive debris glacis (Pl. 31, Fig. 16).

The pre-existant relief, which in the eastern part of NW-Sörkapp is widely diversified, controls the formation of periglacial structures owing to the differences in surface gradient. It manifests itself not only through the common occurrence of congelifluxion lobes and stone stripes but also through the interrelation between some structures whose origin is due to the fact that flat and sloping surfaces border directly on one another. Well developed regular stone circles on flat surfaces often become — with increasing slope gradient — deformed and elongated until they are finally converted to congelifluxion lobes or stone stripes. Büdel (1963) in his observations from Spitsbergen has already emphasized the preponderant influence of surface pattern upon the formation of such structures as stone circles, stone polygons, congelifluxion lobes and stone stripes as well as the relationship between residual and amorphous structures and between the associated processes. Jahn (1960) claims actually that the shape and the development of a slope, hence also the processes operating on sloping surfaces largely depend on the pre-existant relief pattern.

Apart from the course and the sites of periglacial processes this pattern controls also the distribution of colluvial covers, which occur mainly in the eastern part of the area investigated on faintly sloping surfaces such as mountain bases or slope planations. Such covers are usually small and composed of fine particles, less than 0.2 mm in diameter, including isolated stones (1—2 cm). They were deposites by runoff waters that washed out the fines from the debris covers lying on slopes. The largest covers of that type occur at the base of the east-facing slope of the Tsjebysjovfjellet, at the foot of the Wurmbrandegga and the Lidfjellet but also in other sites of eastern NW-Sörkapp at the foot of waste-rich slopes.

Mainly responsible for these differences between the periglacial forms and phenomena occurring in both these zones is the petrologic dissimilarity of the eastern and the western part of the area in question. In the eastern part of NW-Sörkapp, especially in the Wurmbrandegga range and farther eastward, dolomites, schists and limestones predominate, supplying apart from stones also large quantities of fines (Figs. 1, 2, 15). The waste of these rocks being less pervious retains moisture for a longer time and shows a low limit of fluidity (22%) which affords very suitable conditions for the development of congelifluxion.

For, nature of the waste and moisture conditions may be also regarded as factors determining the contrasts between both these zones. The common occurrence of well-developed lobes in the eastern zone and their scarcity in the western one are undoubtedly due to a notable difference in the nature of the waste. In schist and dolomite areas containing a good deal of fine-grained moisture-retaining waste, all the pre-requisite conditions for the development of such microforms as congelifluxion lobes, stone stripes, stone circles and stone polygons are readily available. Hence, the wide-spread occurrence of vast fields of congelifluxion lobes in such areas as the lower mountain-side parts of the Tsjebysjovfjellet, the Wurmbrandegga, the Lidfjellet and the Kovalevskifjellet. Neither is there any other reason for the occurrence of stone circles and stone polygons on flat surfaces at the base of the dolomite part of the Wurmbrandegga and on the flat pass between the Gavrilovfjellet and the Kovalevskifjellet. In these sites they are generally grouped, for the character of the relief pattern and the presence of suitable material promote their development.

Apart from lithology, the quantity and distribution of water are no less important factors which, though dependant on the nature of the waste, are also controlled by the topography and local climatic conditions. The development of all the periglacial processes requires appropriate ground moisture, for temperature oscillations around the freezing point or even below, are inapt to produce periglacial microforms, unless they are assisted by such factors as freezing up water and ground ice. Jahn (1961), Troll (1954) and other investigators of Arctic regions emphasize the importance and the action of water in the development of recent periglacial processes. Czeppe (1961) holds that boggy sites afford the most suitable conditions for the development of stone circles. Once the site dries up, the development of these forms ceases altogether or for some time. Numerous and well-designed stone circles and stone polygons were observed in places with a considerable degree of permanent ground-moisture, i. e. around small lakes on coastal terraces, at the foot of long slopes with persistent snow patches, and on valley bottoms. Congelifluxion lobes, however, occur on steeper slopes.

In the eastern part of the area investigated the degree of ground-moisture due to the nature of the waste, to the relief pattern, and the local climatic conditions, is much higher. The waste mantle is rather impervious and permanently humid as a result of predominant fines, especially in places with a larger supply of shales. Owing to abundance of water during the spring melting of the snow cover and the snow patches that linger until late in the summer, the material is soaked to such a degree that even during the summer the waste is almost at the limit of fluidity, thus creating suitable conditions for the development of periglacial processes and microforms. Although in the summer a stagnation in periglacial processes was observed (Jahn 1961), the negative temperatures of the spring and the autumn tended to intensify all the morphogenetic processes. More diversified and more humid, the eastern part of NW-Sörkapp exhibits a larger number and variety of periglacial structures than the western one.

The general climatic conditions of Spitsbergen create a periglacial environment but they do not seem to have a decisive influence upon the differentiation of the forms and phenomena. The insignificant fluctuations in air and ground temperatures as noted throughout so extensive an area as Gåshamnöyra and Isbjörnhamna (tab. I) fail to suggest this conclusion. More important are the local variations in meteorological factors whose changes depend on the topography. This is proved by the observations made in the Kovalevski valley on 5.VIII. 1958 which showed that in the daytime the air temperature of a sun-facing slope reached some 6°C, while in the shade of the Kovalevskifjellet, a thin subsurficial ground layer was frozen. Similar differences in temperature were noted late in the summer at the foot of the Tsjebysjovfjellet in the morning, and of the Wurmbrandegga in the afternoon. This proves that even within a restricted area, remarkable thermal differences may occur as a result of topography.

The chief agents of mircoclimate are: precipitation (generally snow), wind-action and differences in insolation of the slopes. Large quantities of snow accumulate in all the depressions and in the lee-ward places, being at the same time blown away from open spaces. Hence, the uneven north-facing terrains are well supplied with water from slowly melting snow, and afford suitable conditions for the development of periglacial processes, in particular congelifluxion and downwash, the more so that those are not inhibited by a dense vegetation cover. Widely diversified in its relief pattern, the eastern part of NW-Sörkapp is therefore rich in snow (and water) accumulating in depressions, slope niches, breaks at the slope-bases owing to which, the ground retains moisture. Meridian mountain ranges and valleys are convenient sites for accumulation of snow, provided the prevailing winds be easterly. The eastern part of the area in question is exposed to strong winds blowing from the ice plateau, and attacking the windward slopes. The influence of the Ocean from the west are here less pronounced being inhibited by mountain ranges, whereas in the western part, in the Hornsund lowland, in Breineset and on the Struvefjella slopes it is strongly marked.

Periglacial structures are not uniformly spread throughout the eastern part of NW-Sörkapp. From some places periglacial microforms are completely absent save for tiny folds, a few centimetres in size, consisting of mineral material including plant detritus. Such folds and ridges are a result of the creeping of a thin surficial layer of water-saturated ground. Examples of such sites are the abrasive terraces of Andvika or some segments of the Höferpynten.

The western part of the area showing a somewhat different landscape lies west of the Struvefjella range, part of which it comprises excluding, however, the downward segments of the east-facing slopes of the Hohenlohefjellet, the Sergeijevfjellet and the vast surfaces of the raised marine terraces stretching along the western coast of Sörkapp. Numerous patches of spotted tundra (non-sorted circles), needle-ice hummocks and extensive structurless fine-rubble covers characterize this area. In humid places, near small lakes and on water flow axes, stone circles and stone polygons occur sporadically. Congelifluxion lobes are few and develop only in places with outcropping schists. Large frost-fissure polygons are fairly widespread in this zone, but cannot be regarded as a distinctive feature of both the regions in question, for they occur as well, though less commonly in the eastern zone. Neither in this zone nor in the whole of NW--Sörkapp do they constitute so predominant an element of the landscape as those reported by R ó ż y c k i (1957) from the Torell Land. A relatively luxuriant vegetation of moss, grass and *Salix polaris*, and — in drier places — of various species of *Saxifraga* overgrow nearly the whole surface. Alone on active alluvial fans, on block fields and on a few free faces, vegetation is poorer and sparser. A rather remarkable feature of this region is that many structures showing symptoms of old age and stagnation are overgrown with vegetation. The complete absence of larger bare surfaces and free faces gives this landscape less severe an appearance than that of other polar regions.

In this area, like in the eastern part, periglacial microrelief and frost-caused processes are controlled by the pre-existant relief pattern, the nature of the rocks and the local climatic conditions. Flat marine terraces with outcropping tor-like rocks constitute the main part of this zone. A more intensive relief is here only that of the Struvefjella range at the eastern extremity of this part of NW-Sörkapp (Fig. 3). The vast lowland of Kulmstranda, Hornsundneset and Breineset might be expected to display numerous residual structures and — on the Struvefjella ridge — congelifluxion lobes and stone stripes. In fact, however, periglacial microforms are very rare in this area. It seems as if despite the topographic conditions which might favour the formation of certain structures, the nature of the rock material and reduced moisture constitute inhibiting factors.

The western part of NW-Sörkapp is mainly composed of Kulm sandstones and partly of sandy schists occurring in the upper segments of the Sergeijevfjellet (S i e d l e c k i 1961). Disintegration of sandstones, strongly cemented with a siliceous matrix, supplies coarse waste and large blocks forming block fields. Such waste is not liable to displacement by congelifluxion on account of its perviousness, of the almost total absence of fine components (T r i c a r t 1956) and because of its relatively high degree of fluidity. The loose material covering the Hornsund lowland, includes also marine gravels into which rain- and melt-waters can easily percolate thus draining into depressions and small lakes. The distant Struvefjella range is inapt to supply the fines that might be transported by downwash. Accumulation of fines at the near-slope mouths of water streams and somewhat farther along the drainage routes of runoff waters, shows however that some fines are being washed out (J a h n 1961; B a r a n i e c k i 1965).

In this area the ground is poorly saturated also as a result of the absence of larger and persistant snow patches. While in the eastern part vast stretches were still thickly snow-covered, with high snow-drifts here and there, the Hornsund lowland was free of snow. A few small snow-patches were found in August 1959, in the upper segments of the Struvefjella range. As a result, the nearby area had retained ground moisture, and wherever ground contains schist waste lobes develop vigorously, e. g. in the upper part of the Hohenlohefjellet and the Sergeijevfjellet.

The western part of NW-Sörkapp differs from the eastern one in the number of its structures which are here moreover confined to certain restricted privileged sites, while east of the Struvefjella periglacial structures are widespread.

As already mentioned, the vegetation cover in Sörkapp though rather poor deserves attention on account of its role in the development of morphologic processes. Congelifluxion and downwash by runoff waters are here very intensive (Jahn 1961) constituting potent morphologic factors under the present-day climatic conditions of Spitsbergen. The NW-Sörkapp plants have a very shallow root system that is inapt to prevent displacement of the material by congelifluxion. Therefore, wherever the slope gradient, the degree of moisture and the nature of the waste tend to promote the formation of lobes, vegetation is almost completely absent. When these processes develop at a slower rate and fall to destroy all the plants, the vegetation mantle is nontheless disrupted and the structures include organic matter. The east-facing slopes of the Wurmbrandegga, the Gavrilovfjellet slopes, and those of the Slakli valley where congelifluxion is particularly intensive, are almost entirely free of vegetation. In contrast, the dense vegetal covers of the SW-facing slopes of the Tsjebysjovfjellet, the Savitschtoppen and the Kovalevskifjellet protect the ground so firmly as to make mass movement almost impossible. These slopes show only a number of deep erosional gullies, cut in the spring by turbulent meltwater streams. In the summer period of investigation these gullies were dry.

The influence of the vegetal cover on the development of periglacial processes in NW-Sörkapp is by no means decisive, although its role in the course of some of the processes is considerable. As regards the area described, the vegetation mantle which undoubtedly depends on the local climatic and hydrologic conditions, clearly reveals the differences between the eastern and the western part of NW-Sörkapp. The simultaneous occurrence within one and the same climatic zone of densely overgrown surfaces (Hornsundneset, Breineset) and of others from which vegetation is almost totally absent (eastern part of NW-Sörkapp) testifies to a much wider diversification than that hitherto assumed and Jahn (1960) is probably right in holding that this part of Spitsbergen should not be totally included as into Büdel's rubble zone.

THE DIFFERENTIATION OF PERIGLACIAL PHENOMENA IN THE VERTICAL PROFILE

Both these areas differ not only in their horizontal but also in the altitudinal profile, a fact that is most conspicuous in the eastern part of NW--Sörkapp. The lowermost zone of the pattern shows the flat raised marine terraces rising 40 m above sea level and even higher (Jahn 1959). In the immediate proximity of the sea, the prevailing relief-modelling processes are wave action and the modification associated with ice blocks buried by beach deposits. Farther inland such structures as stone circles, polygons, lobes, stone stripes, needle-ice hummocks and small colluvial covers deposited by downwash, are widespread. Above, the second zone represented by debris cones is lying and upward it adjoins free rock faces. This zone of debris cones begins at the level of some 50 m rising up to 200—300 m and more, dependant on the height and size of the free faces (Pls. 25—27). Within the basal parts of the cones, gravity combined with congelifluxion are the chief agents.

A zone of free faces, gelivation furrows and gullies appears above the debris cones. The abrupt and precipitous rock faces are cut by furrows that begin at a level of 200 m and reach the summits i. e. 500—600 m or even 900 m above sea level as in the case of the Tsjebysjovfjellet. Thus, they advance above the perennial snow line entering the nival zone. Worthy of note is the fact that within the mountainous interior area, the lowermost (first) zone is either restricted or totally absent. On the nunataks of the Midifjellet, the Robitzschfjellet and others there is only a zone of free faces and debris cones adjoining the glaciers. Różycki (1957) in his work on zonal divisions in the Torell Land distinguished similar zones in the vertical pattern which he attributed to climatic changes connected with altitudes. Jahn (1960) however, holds that the individual slope components (free faces, debris cones and wanning slopes) were modelled by slope processes and are, therefore, largely due to the pre--existant landscape, to geologic pattern and to local climatic conditions. The present investigations in NW-Sörkapp tend to confirm rather Jahn's opinion. Free faces occur here at various altitudes while congelifluxion lobes or stone circles are encountered both on low-lying coastal terraces and on mountain summits.

CONCLUSIONS

In conclusion, it may be stated that in Sörkapp, periglacial forms and phenomena are diversified in both their horizontal and their vertical pattern. This permits to distinguish two parts: the western one which is characterized by a lesser intensity of periglacial processes and the eastern one where the action of these processes is more vigorous. The course of such processes is largely controlled by the pre-existant relief-pattern, the geologic composition of the area, the nature and the degree of moisture of the waste, and the local climatic conditions.

The most conspicuous traces of relief modelling occur on sloping surfaces with even a very faint gradient. In contrast, coastal terraces are generally areas of occurrence of needle-ice hummocks and structureless fine-rubble covers. Most intensive are such processes as frost weathering, upheaving of blocks, and mass movement by congelifluxion whose annual values of displacement of the material range from 5 to 10 cm in length reaching as much as 30 cm in depth.

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Photo by the author, 1958

Pl. 1. Hohenlohefjellet, 614 m, the highest summit of the Struvefjella range. Large niches and debris cones at the outlets of gullies. NE-view

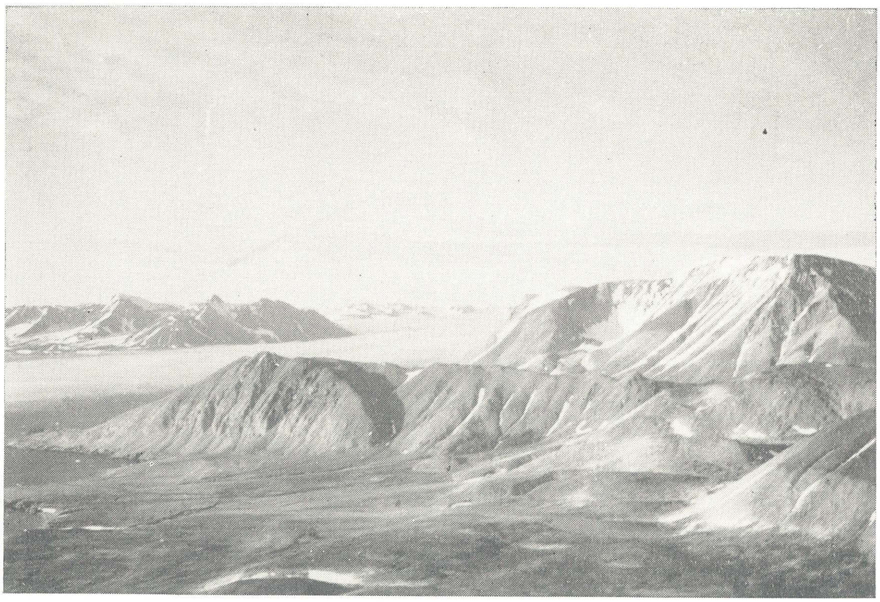

Photo by the author, 1959

Pl. 2. The Wurmbrandegga range in the foreground and the Tsjebysjovfjellet (920 m) on the right side of the background

Photo by the author, 1959

Pl. 3. Deep incised valley of the Lidelva river. Snow patches on NW-facing lee slope

Photo by the author, 1959

Pl. 4. Breineset. Vast alluvial fans at the outlets of the Lidelva and the Slaklielva rivers

Photo by the author, 1958

Pl. 5. Surface of raised abrasive terraces near the Andvika bay. Note the sparsity of vegetation

Photo by the author, 1959

Pl. 6. Hornsundneset. Continuous vegetation cover of moss, grass, and Arctic willow. Isolated structures of spotted tundra

Photo by J. Dylik, 1957

Pl. 7. Gåshamnöyra. Tufts of flowering *Saxifraga groenlandica*

Photo by the author, 1958

Pl. 8. Gåshamnöyra. Angular dolomite debris

Photo by J. Dylik, 1957

Pl. 9. Gåshamnöyra. Completely weathered dolomite boulder

Photo by the author, 1958

Pl. 10. Andvika. Stone circles. Earthy centres overgrown with mosses

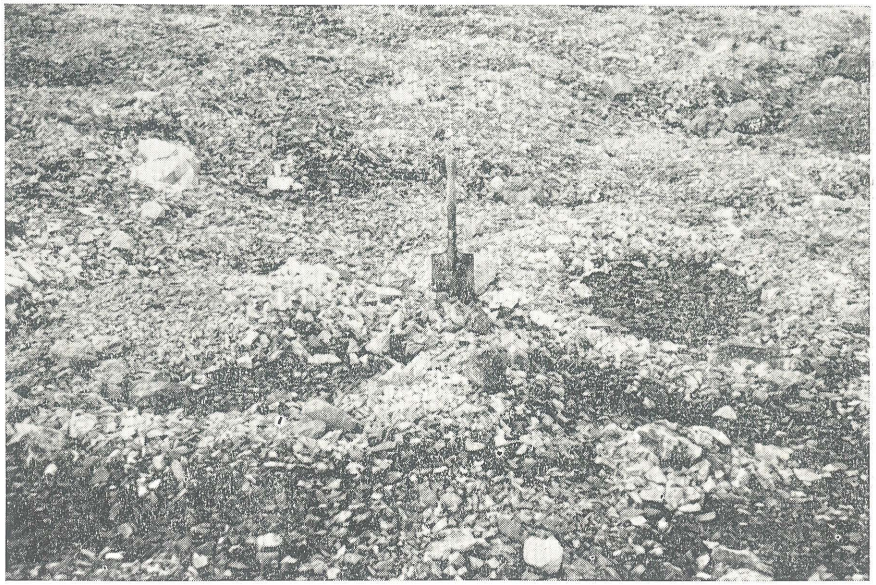

Photo by the author, 1958

Pl. 11. Gåshamnöyra. Stone circles at the foot of a debris slope of the Wurmbrandegga

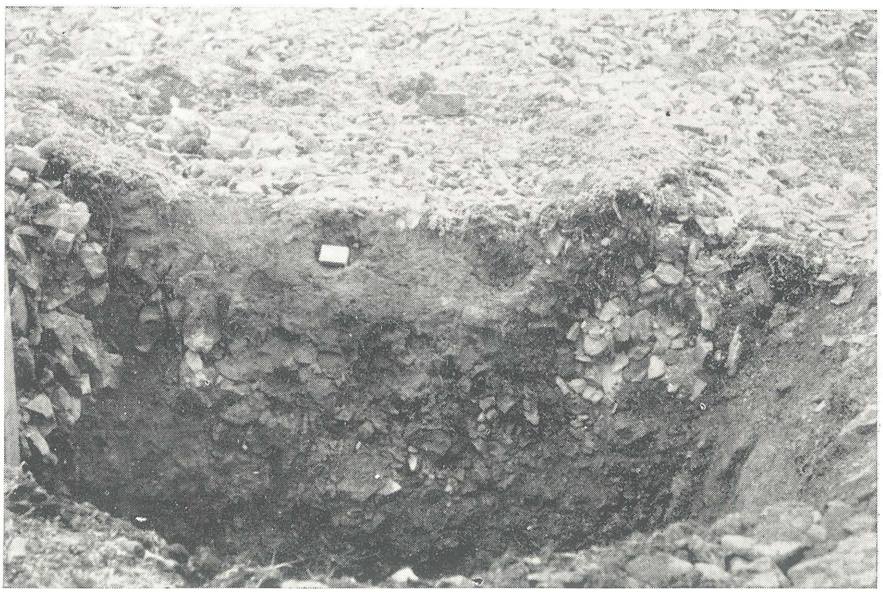

Photo by the author, 1958

Pl. 12. Höferpynten. Cross-section through stone circle

Photo by the author, 1958

Pl. 13. Gåshamnöyra. Cross-section through stone circle (shown in Pl. 11)

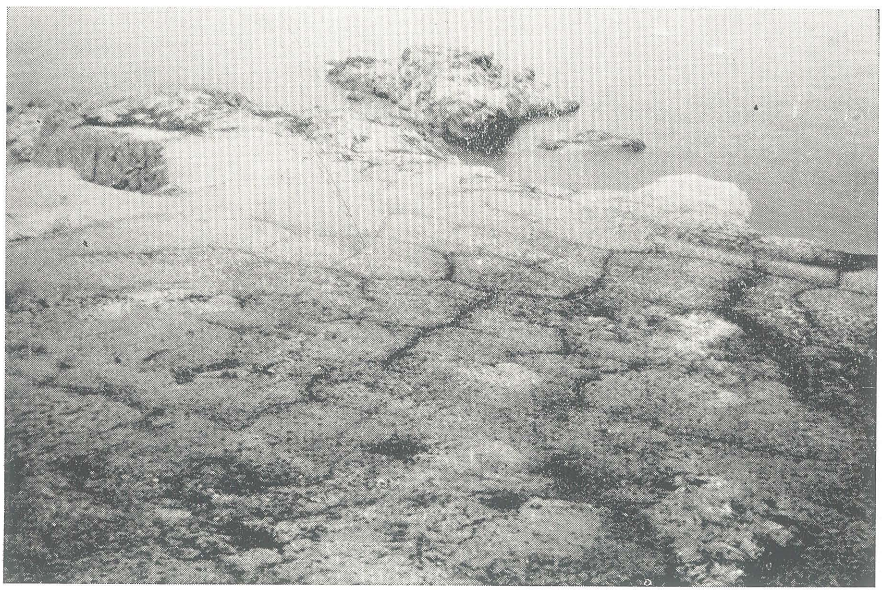

Photo by the author, 1957

Pl. 14. Hornstullodden. Frost-fissure polygons

Photo by the author, 1959

Pl. 15. Hornsundneset. Troughs of frost-fissure polygons

Photo by J. Dylik, 1957

Pl. 16. Gåshamnöyra. Stone polygon net at the foot of the northern Wurmbrandegga

Photo by the author, 1958

Pl. 17. Gåshamnöyra. Stone polygons on a flat surface of the Wurmbrandegga summit

Photo by J. Dylik, 1957

Pl. 18. Höferpynten. Miniature stone stripes

Photo by the author, 1958

Pl. 19. Andvika. Stone stripes on surface of the raised terrace near western slope of the Wurmbrandegga

Photo by the author, 1958

Pl. 20. Gåshamnöyra. Congelifluxion lobe on a waning slope of the Tsjebysjovfjellet

Photo by the author, 1958

Pl. 21. Gåshamnöyra. Congelifluxion lobes on a waning slope of the Wurmbrandegga

Photo by the author, 1959

Pl. 22. Gåshamnöyra. Congelifluxion lobe. Curvature of the stone stripe indicates the value and the differentiation of movement over 1 year

Photo by the author, 1958

Pl. 23. Gåshamnöyra. A net of small rills originated by downwash

Photo by the author, 1959

Pl. 24. Lidfjellet. Erosional troughs cut by rapid meltwater streams in the spring. The troughs are cut in deposits of grèzes litées type

Photo by the author, 1959

Pl. 25. Furrows and gullies in top segments of bare slopes of the Tsjebysjovfjellet, the Hornsundtint, the Nordfallet and the Mehesten

Photo by the author, 1959

Pl. 26. Free faces, furrows, gullies, and debris cones on slopes of the Robitzschfjellet and the Brevassfjellet

Photo by the author, 1958

Pl. 27. Abrupt slope of the Rasstupet dissected by furrows and gullies

Photo by the author, 1958

Pl. 28. The Wurmbrandegga range, built of phyllites and shales, dissected by large gullies

Photo by the author, 1958

Pl. 29. Debris cones on eastern slope of the Wurmbrandegga

Photo by J. Dylik, 1957

Pl. 30. Gåshamnöyra. Debris cone on eastern slope of the Wurmbrandegga, built in this segment of dolomite

Photo by the author, 1958

Pl. 31. Andvika. Debris glacis formed through coalescence of several cones

Photo by the author, 1958

Pl. 32. Kulmstranda. Block-field of large sandstone blocks

Photo by W. Frankiewicz, 1958

Pl. 33. Remnants of moss overgrown needle-ice hummock

Photo by J. Dylik, 1957

Pl. 34. Gäshamnöyra. Traper hut occupied by the Łòdź group of the Polish Spitsbergen Expedition during the summer seasons 1957—1959