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Morphogenesis of subslope ridges to the north of Hornsund, Spitsbergen *)

ABSTRACT. The analyzed ridges posses a varying morphology and dimensions. They are composed of rocky blocks of local origin only. The blocks are chaoticly arranged although a position transversal to a morphologic axis of the ridge predominates. The ridges occur mainly in places where distinct structural loosenings of the mountain massifs are noted, at the foot of fresh slopes. They define the periods when rockfalls were most intensive. The authors found the subslope ridges to be the nival moraines.

Key words: Arctic, Spitsbergen, nival moraines.

1. Introduction

Beyond the extent of the present glaciation of Spitsbergen, numerous ridges at the slope and its foot are worthy of notice. They occur among others in the area to the north of Hornsund — from Jens Erikfjellet and Gulliksenfjellet to Hyrnefjellet (Fig. 1).

A common occurrence of subslope ridges makes them to be a morphologic index of a definite morphogenetic environment that has acted in this area. So, there is a particular reason to discuss ones more these controversial features, taking their origin into account. The authors studied them in summer 1979, defining among others:
— their arrangement,
— their morphology and morphometric features,
— relation to a slope at which or, at the foot of which, they occur,
— altitude and type of the area covered by the ridges,
— lithology of rock blocks of ridges, and if possible,
— their structural-textural features.

The collected data enabled us to give a critical attitude towards the published opinions and a defining of a morphogenetic environment of the subslope ridges occurring to the north of Hornsund.

*) This paper was prepared within an interdepartmental state subject MR II 16B "Investigation and protection of a polar environment within the Earth's sciences, basing on field works of A. Karczewski, A. Kostrzewski and L. Marks during the expedition "Spitsbergen 1979/80", organized by Polish Academy of Sciences.

2. Previous studies over the subslope ridges in the Hornsund area

The subslope ridges have been already studied by many authors and mainly, at the opportunity of defining the extents of glaciations as well as studies over a rate and a magnitude of slope denudation. Up to now the ridges have been considered for end moraines of the older generation of Late Würm glaciation (Birkenmajer 1958, 1959), for older end and lateral moraines of the so-called Magdalenefjorden Stage (Szupryczyński 1968) or for nival moraines (Czeppe 1966). Jahn (1959 a, b) distinguishing a phase of "older ridges" of end and lateral moraines based it mainly on the analyzed features from Revdalen and other valleys in the Hornsund area. It is the principal detail of a chronologic type, Jahn paid attention to but for a defining of the age of marine terraces. He found that the ridges covered the terrace 65 m asl but all the lower terraces formed a cliff at the ridges; these observations suggested not only the age of the terraces but also of the ridges. Jahn (1959 a, b) found too that the ridges had been formed during a postglacial glacier advance at Spitsbergen, unknown previously. So, the Jahn's studies prove clearly that the ridges are older than the last Holocene glaciation.

According to Szupryczyński (1968) the older morainic ridges (that occur at the altitudes smaller than the terrace 65 m asl down to the terrace 5 m asl) have been formed in Holocene and of course, they are younger than the underlying terrace. Thus, after a formation of the terrace 5 m asl, there was a severe cooling of the climate at Spitsbergen; it caused a formation of valley, cirque and slope glaciers. By the analogy to other studies Szupryczyński (1968) estimated this glacier advance for about 2 400 years B. P. and named it the Magdalenefjorden Stage. So, the features studied by the authors, are classified by Szupryczyński (1963, 1968) as end and lateral moraines of larger glaciers and as moraines of slope-névé glaciers. A morphogenetic environment of these ridges was differently presented by Czeppe (1966) who found, on the basis of a detailed morphologic-textural analysis, the ridges to be the nival moraines. They have originated, according to him, during an intensive rock falling when vast firn fields existed.

No univocal opinion of the origin of these ridges was the principal reason to support the research problem, mentioned in the title of this paper.

3. Arrangement and morphology of subslope ridges

The analyzed ridges are called by the authors conventionally the subslope ridges. It should be admitted that they are not usually of a ridge shape but locally, they are semicircular. Instead, a system of semicircles and depressions forms large subslope features of more or less ridge-like shape.

As already mentioned in the introduction, the ridges occur discontinuously; they are noted at the foot of some mountain slopes from Jens Erikfjellet

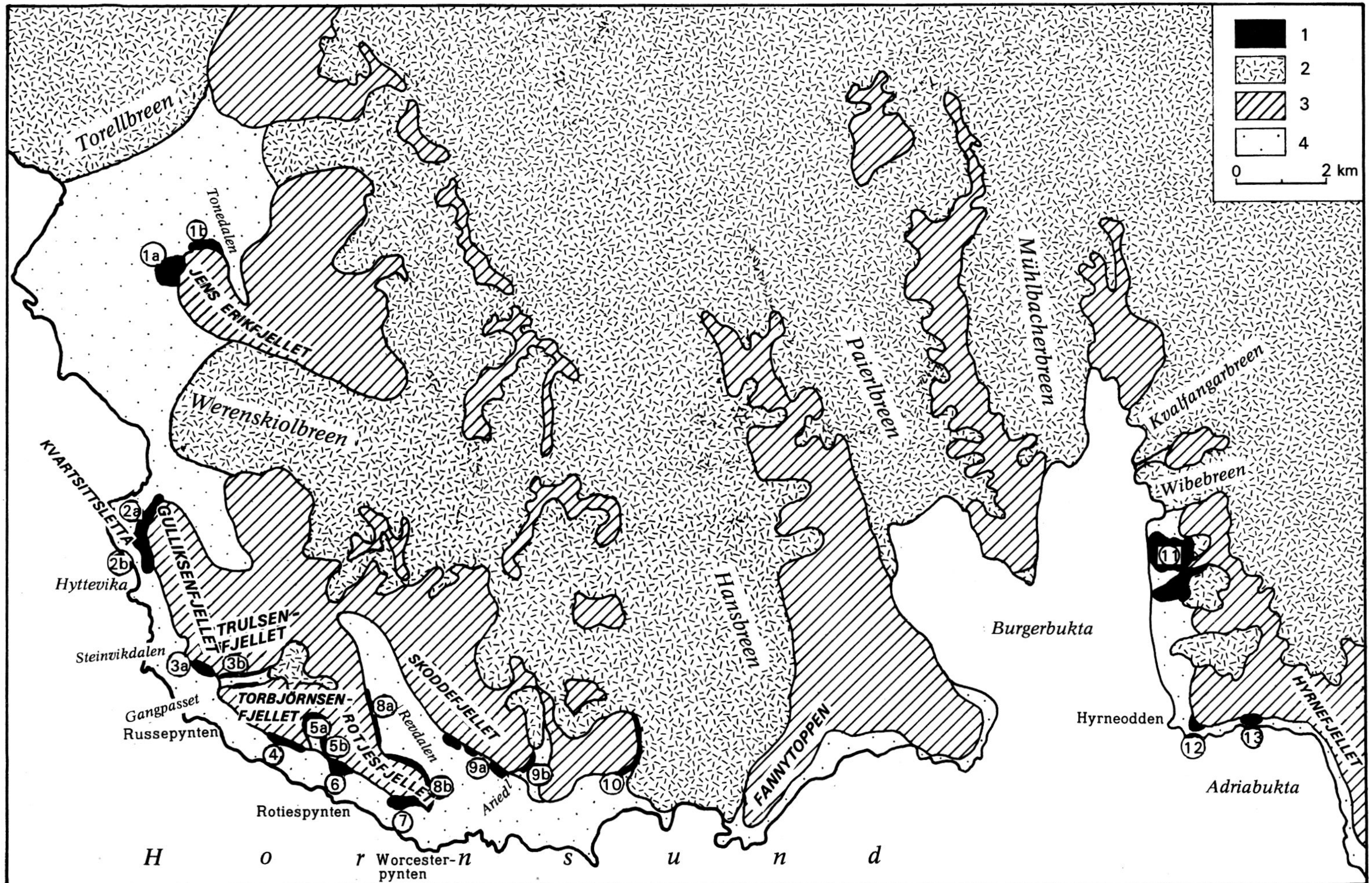

Fig. 1. Distribution of subslope ridges in the area to the north of Hornsund
1 — subslope ridges (described in detail in the text), 2 — glaciers, 3 — mountain massifs, 4 — sea shores

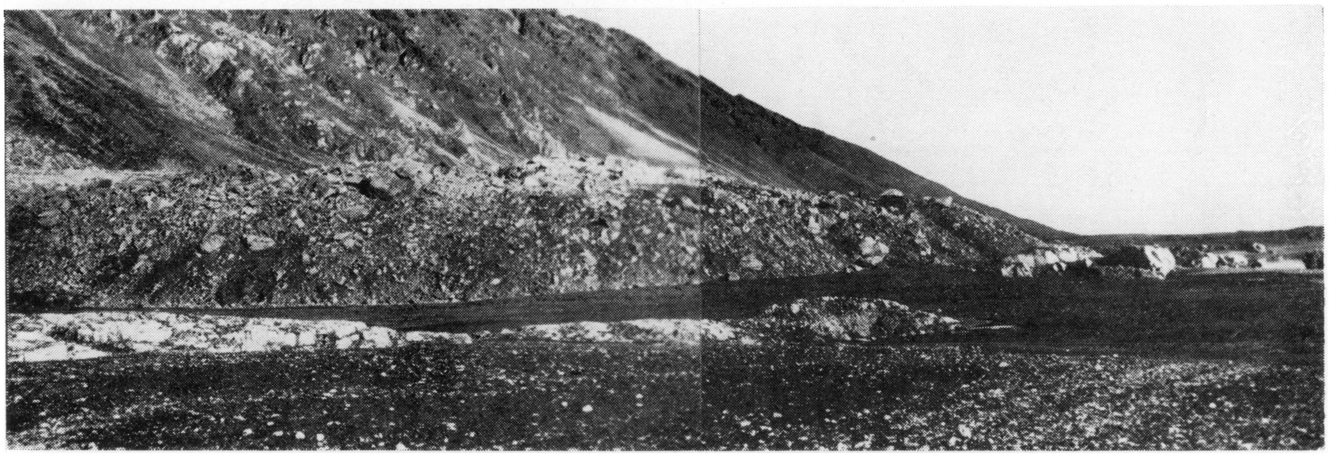

Fig. 2. Subslope ridge at the foot of Gulliksenfjellet 2a (comp. Fig. 1)

(Photo A. Karczewski)

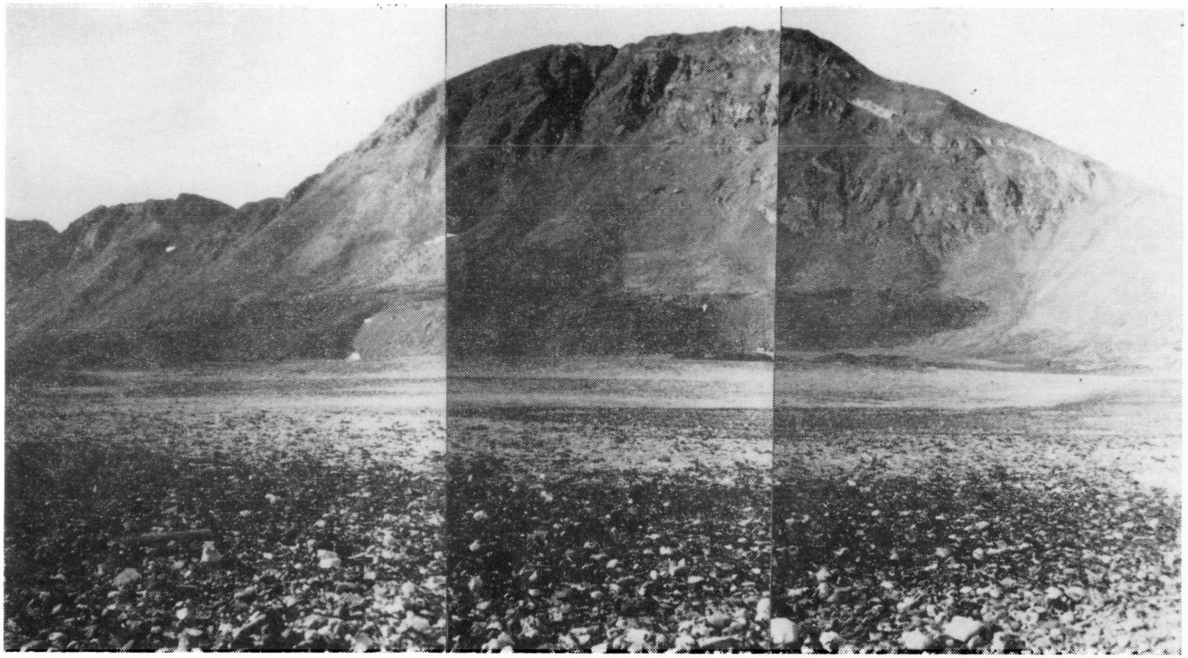

Fig. 3. Subslope ridge at the foot of Rotjesfjellet 7 (comp. Fig. 1)

(Photo A. Karczewski)

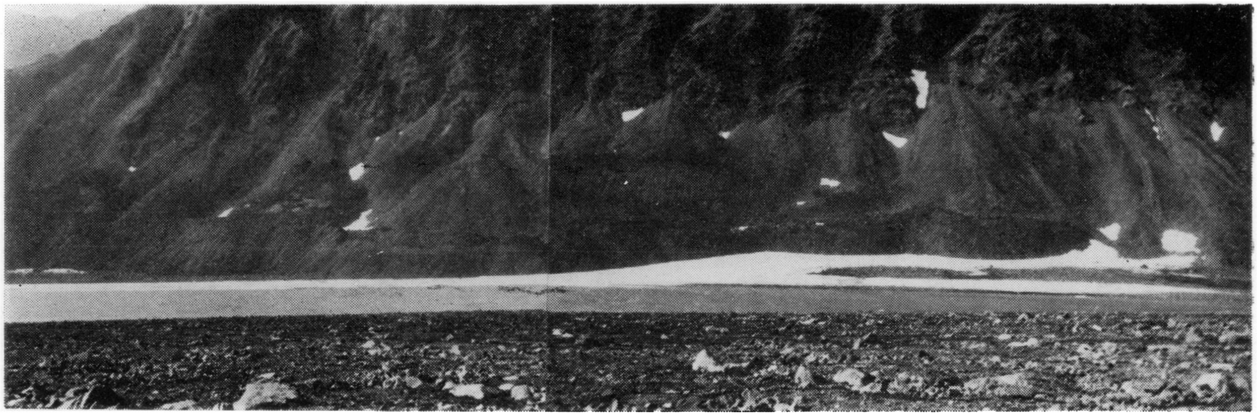

Fig. 4. Subslope ridges in Revdalen 8b (comp. Fig. 1)

(Photo A. Karczewski)

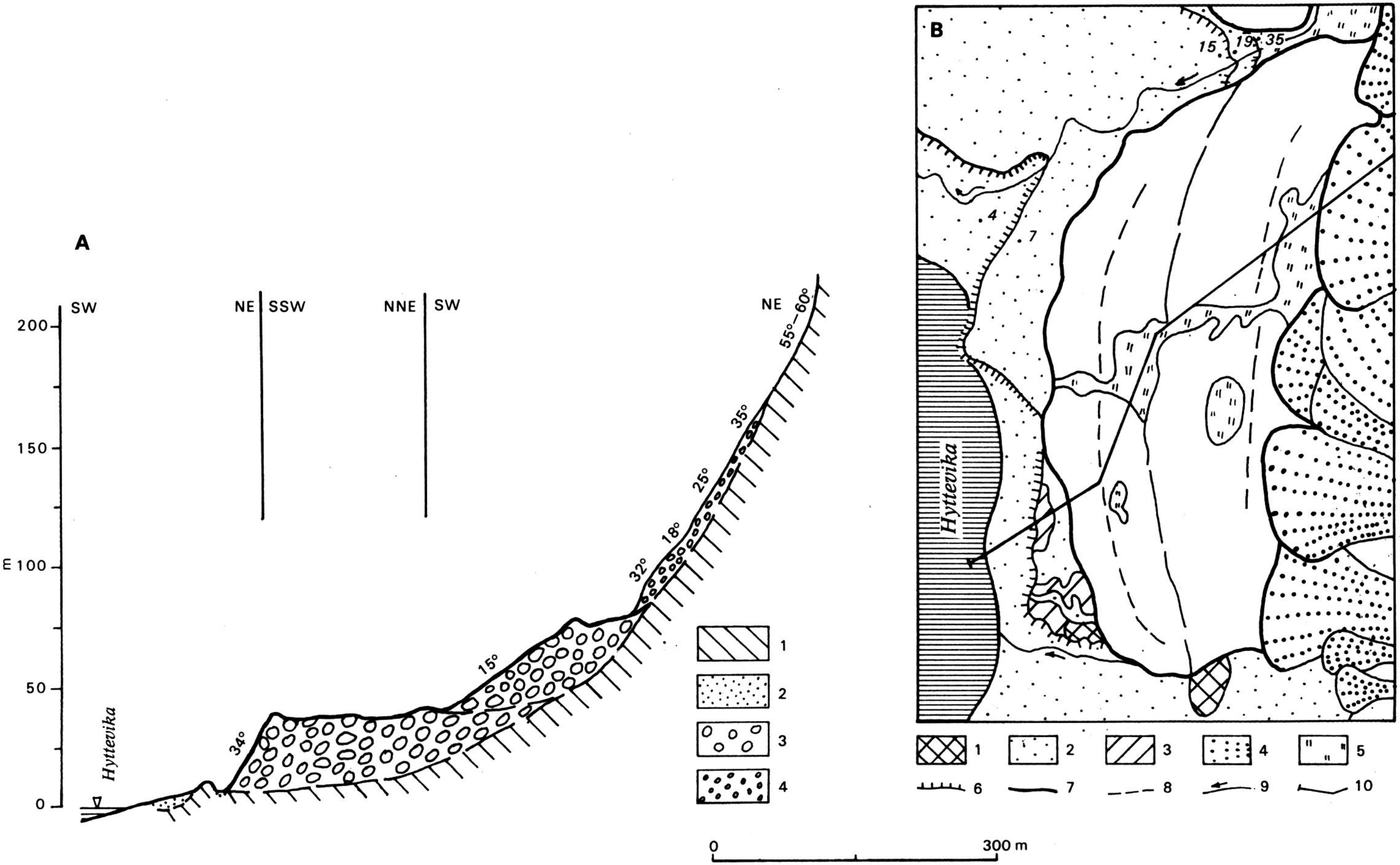

Fig. 5. Geomorphologic shetch (A) and section of a subslope ridge 2b by Hyttevika (B), (comp. Fig. 1). Scree fans get down from a mountain slope to the foot of the mountain
Explanations to A: 1 — bedrock, 2 — marine gravels and sands, 3 — ridge boulders and blocks, 4 — boulders of a recent scree fan

Explanations to B: 1 — rock outcrops, 2 — accumulative parts of marine terraces, 3 — abrasive parts of marine terraces, 4 — scree fans, 5 — bottoms of peaty depressions, 6 — edges of marine terraces, 7 — limits of a ridge, 8 — longitudinal axes of elevations within a ridge, 9 — rivulets, 10 — section line to Hyrnefjellet (Fig. 1) but especially, in zones of tectonic discontinuities. In the studied area they usually enter the lowermost marine terraces 8—12 m, 16—18 m, 32—35 m, 40—46 m asl but only seldom, the terraces 100—115 m and 220—230 m asl Therefore, no definite regularities are noted in an arrangement of the ridges. In many cases they occur simultaneously at several marine terraces. A frontal zone of the ridge is usually several metres high, locally it is flattened.

Detailed field works, supported by a cartographic analysis, prove that the subslope ridges have a varying morphology and sizes (Table I, Figs 2, 3 and 4). The largest ridges are about 2 000 m long, 400 m wide (locally to 1 200 m), up to 50 m high (locally to 100 m). Instead, the small ridges are about 300 m wide and 10 m high. Frequently, the ridges are divided into segments (Figs. 5 and 6) as e.g. in places where the ridges are cut by the streams flowing from the glaciers or by meltwaters from buried ice blocks within the ridges. Taking a morphologic criterion into account the following types of subslope ridges can be distinguished:

I. Single ridge, parallel to a mountain slope at the foot of which it is localized (ridges 1 b, northern part of 2 a, 5 b, eastern part of 7, 8 a, 8 b, 9 a; see Figs 1, 3, 4 and Table I).

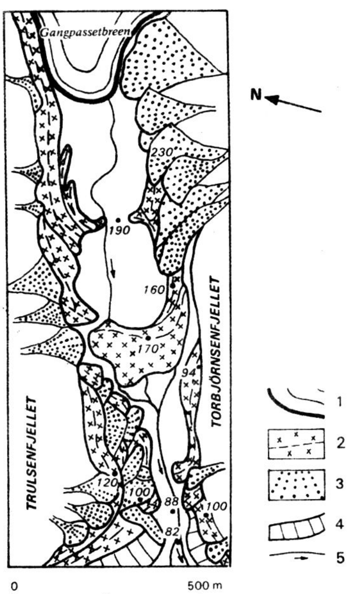

Fig. 6. Geomorphologic sketch of subslope ridges 9b in Gangpasset (comp. Fig. 1)
1 — glacier, 2 — ice-cored moraines, 3 — scree fans, locally passing into subslope ridges, 4 — edges, 5 — rivulets

The subslope ridges of this type are quite common; they are usually vast, to 1 800 m long, 10—50 m high and rather narrow (60—250 m). Usually they form isolated, long features at the foot of a slope, locally they occur in tiers (e.g. at the western side of the Rev Lake — Fig. 4).

An analysis of morphologic characteristics proves that the ridges compose of many heaped fans getting down from the neighbouring mountain slope. Generally, there is in any case a longitudinal depression, several metres deep, localized between the ridge and the mountain slope or the fresh heaped fan. Its bottom is usually wet, locally with moss layer, several centimetres thick. Frequently, these depressions are covered with snow patches — even in summer.

The subslope ridges of this type occur also in marginal parts of recent glaciers or in the areas just devoid of glaciers (among others the ridges 3 b, 9 b, 10; see Fig. 6). So, in this case the segments formed by slope processes and by glacier melting contact with one another. The fragments of the ridge, formed due to predominance of any of these processes, can be oriented perpendicularly to one another (Fig. 6).

II. Complex of elongated fans composes of many relatively narrow ends of heaped fans. In result there are transversal hummocks separated by narrow but quite deep depressions. All these secondary elements form an elongated ridge or rather, a longish lobe (ridges 1 a, 3 a, 4, 5 a, western part of 7; see Table I, Fig. 1). A frontal slope of such a ridge is usually not higher than 20 m and the ridge altitudes keep quickly increasing towards the mountain slope.

A ridge about 1 500 m long and to 350 m wide is the most typical feature of this type. There are also the ridges the length of which is almost equal the width (e.g. the ridge 5 a — 400 m long and 350 m wide, comp. Table I). The heights of such ridges are usually from 5 to 50 m. Among the subslope features of this type there are also fresh, just being formed heaps e.g. at the northern seashore of Adriabukta (ridge 13, Table I).

III. Fan-shaped ridges are not common in the analyzed area (southern part of the ridge 2 a, ridges 2 b, 6, 12; see Table I, Fig. 1). From a morphologic point of view the ridges of this type are formed of a flat and a vast fan each, with distinct and high (usually 25—30 m) fronts. At the upper surface there are shallow and vast depressions with a local peat cover. Such features compose also of several, concentrically arranged fans what suggests a multi-phasal evolution of the ridge. Most frequently such ridges are to 400 m long, to 200 m wide and up to 30 m high (in the case of double ridges — to 70 m).

IV. Talus ridges were distinguished due to a large extent of the feature; they compose of crests perpendicular to a mountain slope, of high altitudes (ridge 11, see Table I, Fig. 1). Usually they are built of chaoticly arranged rock blocks.

This short description of the morphologic types of the ridges suggest a close connection between a topographic position of these features and their specific morphogenetic environment. Basing on a morphologic criterion, we found that the ridges occurred at various morphologic levels and they represented various morphologic types. They were formed in several stages what can be referred to periods with an increased supply with rock pieces.

4. Structural-textural characteristics of subslope ridges

The subslope ridges are mainly composed of blocks, usually 1—2 m diameter although some blocks are over 10 m long. The rock blocks are of local origin only. It seems important that the ridges occur at the foot

Table I

Morphologic features of subslope ridges to the north of the Hornsund Fiord (based on previous and authors' studies)

Ridge symbol and locali- sation	Exposition of a ridge slope	Ridge length in m	Ridge maximum width in m	Ridge altitude in m asl	Ridge height in m	Altitude of marine terraces overlain by a ridge in m asl	Altitude at the foot of a ridge front in m asl	morphologic description
1 a Jens Erik-fjellet	west	800	650	17—55	5—30	8—12	12—25	many ridges, inner depressions, large rock blocks
1 b Jens Erik-fjellet	north	700	70—250	76—78	48—50	—	28—60	many ridges, inner depressions, large rock blocks (to 10 m diameter); a ridge is rather compact
2 a Kvartsitt-sletta	north-west west	1500	500	70	48	16—18, 22—25, 32—35, 40—46	16—45	many overlapping ridges, many de-pressions, large rock blocks (maximum to 20 m), in the north-west the ridge is single
2 b Hyttevika	west	650	250	76	69	8—12	7—11	three distinct heaped series, in contact zones of these series there are peat bogs
3 a Russepynten	south-west	400	200	63	27	8—12	36	many overlapping ridges of irregular run, depressions with peat, buried ice inside the ridge
3 b Gangpasset	south	450	100	100—115	25	80—95	80—95	single or two-stage ridge, inner depres-sions, noted influence of denuded and glacial processes
4 Torbjörnsen-fjellet	south-west	1000	250	72	47	8—12	25	many ridges perpendicular and parallel to a mountain slope, inner depressions — locally peat
5 a nameless valley in Rot-jesfjellet	south	400	350	245	10	220—230	235	many transversal ridges (3—4), de-tached-type deposit, depressions used by rivulets
5 b nameless valley in Rot-jesfjellet	west	300	50	170	10	100—115	115—150	narrow ridge along valley slope created by frontal parts of heaped fans
6 Rotjespynten	south-west	400	200	25	15	8—12	20	two-stage ridge parallel to a mountain slope, perpendicular in its middle part, inner depressions
7 Worcester-pynten	south	1100	350	66	37	8—12	29	narrow, single ridge in the east sepa-rated by a depression from a mountain slope, in the west-many transversal heaped ridges
8 a Revvatnet	east	1000	100	60—70	16	—	44	single, narrow ridges; upper is being formed and occurs in fragments, lower is quite compact
8 b Revdalen--mouth	north-east east	1500	150	70	30	8—12, 22—25, 40—46	15—40	generally single ridge, a break occurs at an orientation change
9 a Skoddefjellet	south-west	1750	200	70—80	30	8—12, 22—25, 40—46	25—40	usually single ridge, locally a two-stage one, with breaks, covered with fresh fans; cut by the Ariebreen river
9 b Ariedalen	south-east	500	60	204	35	—	150—160	single ridge, probable participation of glacial accumulation
10 Hansbreen	south, east	1800	100	about 100		—		single ridge, probable participation of glacial deposits
11 Burgerbukta	west	1000	1200	112, 128	112, 128	0,1	0,1	no distinct ridge, there are chaotic (two-stage?) rock rubbles of Triassic sandstones; the highest rubble parts occur at axes of glacial cirques and greatest narrowings (lowerings) of a mountain range between Kruseryggen and Hyrnefjellet
12 Hyrneodden	west, south	300	200	58	33	22—25, 32—35	25—33	single fan-shaped ridge, cut by rivulets, shallow inner depressions; local rock debris — of Triassic sandstones
13 Adriabukta	south	500	200	80	80	0	0	initial ridge: a frontal part of two heaped fans close to each other

of slopes with fresh relief. It is particularly well noted at the eastern seashore of Adriabukta (ridge 11) where the rubble composes mainly of blocks of Triassic sandstones, coming from the upper parts of the crest Kruseryggen — Urnetoppen. At the same time, the highest parts of the talus occur at the axes of the cirques and the most narrow (and also the lowermost) sections of the mountain crest.

The orientation of rock blocks along two section lines of the subslope ridge at Gulliksenfjellet (to the north of Hyttevika, Table II, Fig. 7),

Table II

Azimuths of long axes of rock blocks (%) along the section lines of a subslope ridge 2a (comp. Fig. 1) at the foot of Gulliksenfjellet
I — section by Hyttevika, II — section from Kvartsittodden

	Azimuth of a long axis of rock blocks							
	0°—90°		90°—180°		180°—270°		270°—360°	
Length of rock blocks in metres	I	II	I	II	I	II	I	II
0—1.0	3.7	3.1	2.4	2.0	6.1	5.1	2.4	7.1
1.1—2.0	6.1	10.3	12.2	7.1	22.1	9.2	14.6	9.2
2.1—3.0	7.3	6.1	6.1	3.1	6.1	6.1	3.7	8.2
3.1—4.0	—	5.1	2.4	1.0	1.2	5.1	1.2	2.0
4.1—5.0	—	4.1	—	—	1.2	3.1	—	—
over 5.0	1.2	1.0	—	1.0	—	—	—	1.0

supports a heaped type of the rubble. Beneath the rock slopes of Gulliksenfjellet there are scree fans or quite compact block-debris covers. The debris is fresh and for that reason it is completely different from the rock blocks A fresh scree debris covers the upper and the middle parts of a heaped slope that in turn, covers a primary rock slope (Fig. 8). There are also the traces of recent transport of single rock blocks along the slope and coming from fresh rock-falls. Slope waters influence much a relief of scree fans and blocky — debris covers. The morphologic effects of such action in summer are noted as long erosive-corrasive chutes or mudflows. There are also distinct morphologic features of a solifluction (Jahn 1967).

Unlike a recent, complex, denuded system of slopes at Spitsbergen, recent morphologic processes are badly developed at the subslope ridges. The latter are the areas that are already morphologicly stabile. There is only quite an intensive action of mechanic weathering on the surface of rock blocks, acting of subsurface waters, landslips and displacements of rock blocks. The subslope ridges are usually separated from a mountain slope by a depression several metres and locally even 10 m deep. The depression is usually wet and with peats; it is the place favourable for a deposition of snow, at which the rock blocks slipped down. Locally, the snow patches occur in these depressions all the year round. In the case of the ridges at the eastern seashore of Burgerbukta (ridge 11) the blocks have probably slipped down over the glacier ice when the latter filled completely the

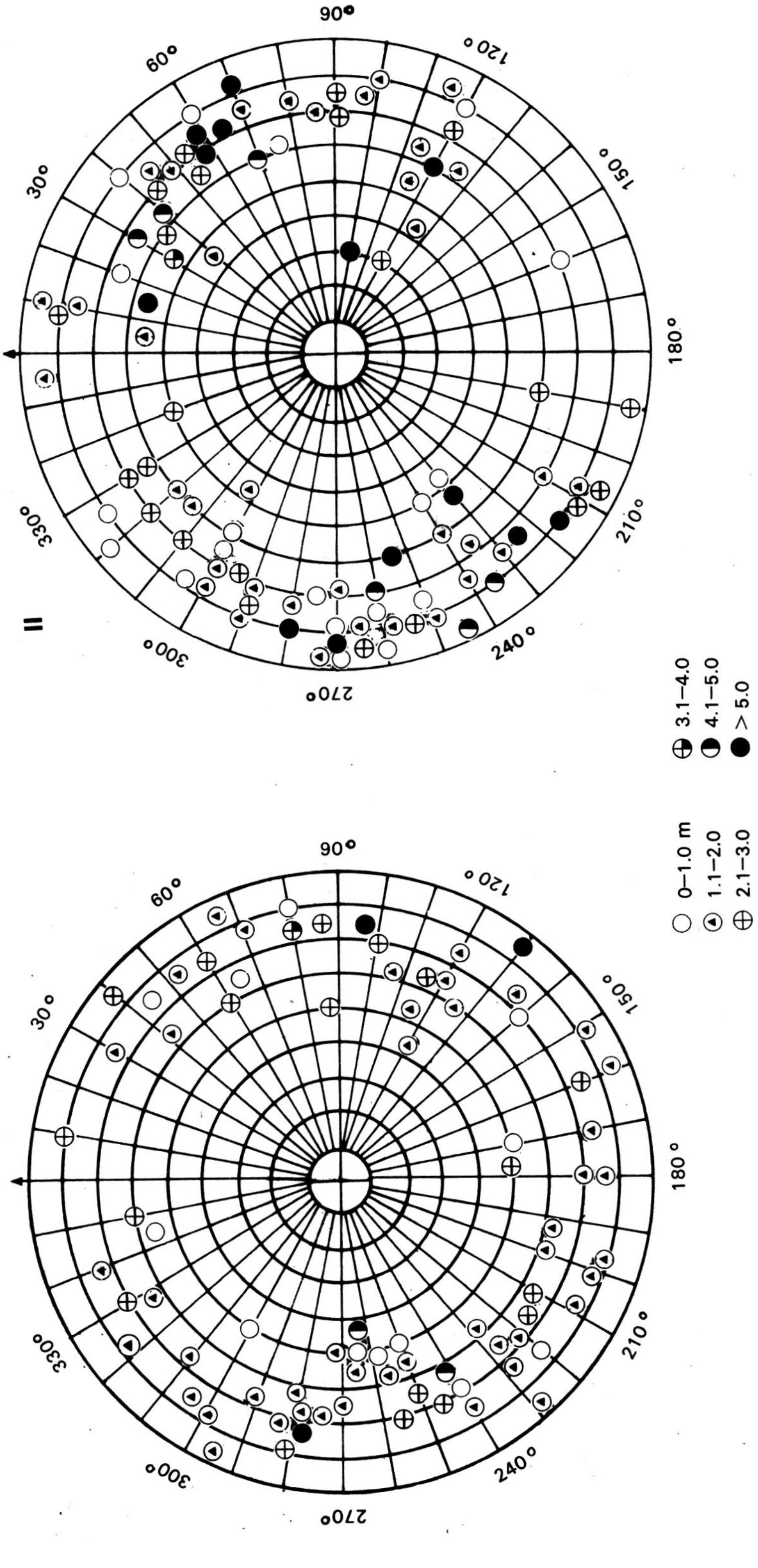

Fig. 7. Azimuth and dip of longitudinal axes of rock blocks of definite sizes along two section lines (I and II) at a subslope ridge 2a at Kvartsitsletta (Comp. Table II). Symbols mean lengths of longitudinal axes of rock blocks

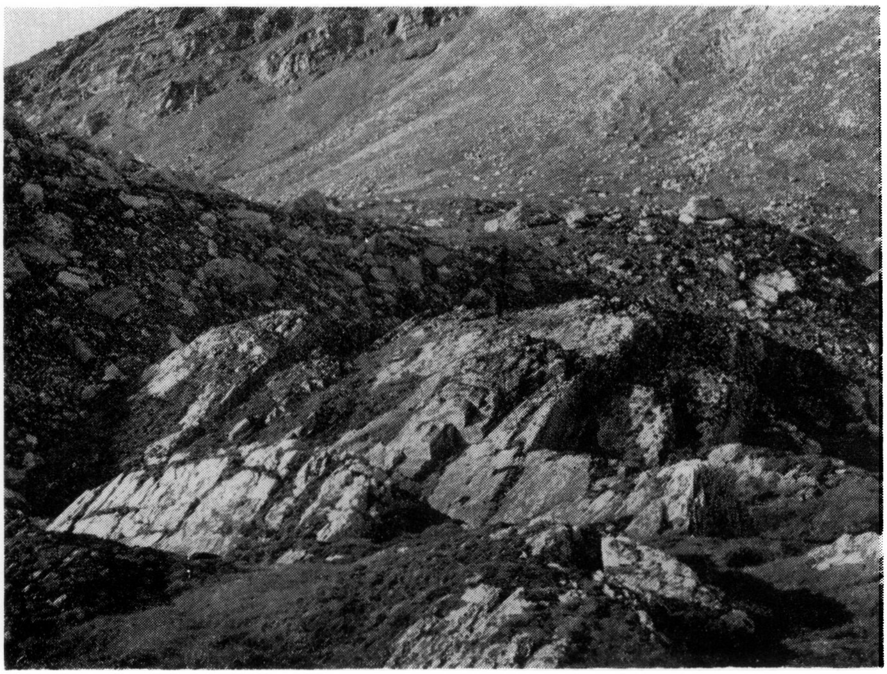

Fig. 8. Fragment of the lower part of the Gulliksenfjellet slope, covered by debris and blocks (ridge 2b, comp. Fig. 1)

(Photo L. Marks)

cirques at the slopes of Kruseryggen, Urnetoppen and Marietoppen. As mentioned previously in the description of morphologic features of the subslope ridges, there are the breaks in relatively compact longish forms. At the ends of these isolated ridge fragments that reach the slope with a small bend, the depressions are absent or there are only slight hollows.

The upper surface of the ridge is uneven, there are numerous collapses. Everywhere at the surface there are great angular rock blocks, usually 1—3 m large although there are also blocks 10 m long. In the subslope ridges of the IInd morphologic type there is noted a circular block pattern that defines the phases of more intensive rockfalls.

The rock blocks at the top surface of the ridge by Gulliksenfjellet are chaoticly arranged although a block orientation perpendicular to a morphologic axis of the ridge seems to predominate (Table II, Fig. 7). At the slope exposed to the mountain massif the blocks are usually parallel to a morphologic axis of the ridge. Distinct frontal parts of the ridges are several metres high and inclined from several to 30°. In the chaotic arrangement of the rock blocks of this part of the ridge, their perpendicular position to a morphologic axis of the form predominates (Table II, Fig. 7). We know that the orientation of the rock blocks is not obviously of a primary origin in many cases due to re-orientation after their deposition.

The collected field data made us to conclude that the rock blocks of the ridges come from the denunded slopes, at the foot of which they occur and that the ridges represent geneticly the type of nival moraines. Therefore, their origin should be connected with periods of more intensive rockfalls.

5. Conclusions

The collected data on a topographic position, morphologic features and structural-textural characteristics of subslope ridges resulted in the following general remarks:

1. The ridges are common in the Hornsund area (from Jens Erikfjellet to Adriabukta). They accompany the mountain slopes and represent various morphologic types — single ridges, complexes of elongated fans, fan-shaped ridges and talus ridges. An inner segmentation of the ridges is noted that proves their gradual evolution. They do not form compact zones but are divided into separate parts of varying size.
2. The ridges occur at various marine terraces of a seaside tundra; they hide the edges or make them more distinct. They are separated from the mountain slope usually by a depression — the basis of scree fans. The depression has been favourable for deposition of snow, over which rock blocks of slides got down. In spite of an apparent chaotic arrangement of rock blocks, their position transversal to a morphologic axis of the ridge predominates. There are also the rock blocks parallel to a morphologic axis of a ridge, particularly, at the slopes exposed to a mountain slope. A block re-orientation in result of subsidence or secondary displacements, is also possible. A zonal arrangement of the blocks proves successive periods of more intensive landslides.

3. The subslope ridges in the northern Hornsund area are the nival moraines. A topographic position of the ridges, their relief and inner structure speak for such a morphogenetic conclusion.
4. The subslope ridges are stabile now. Rock blocks are subjected to mechanical weathering. We can note a surface destruction of blocks and a deposition of debris due to their weathering. The debris and the blocks to a smaller degree, are received from a neighbouring mountain slope. Also an intensive action of subsurface waters (circulating at the bottom of a ridge or in the inter-boulder breaks) and action of surface waters locally within the ridges is noted. A subsidence and further re-orientation of blocks are also possible. A solifluction, especially in places with more debris, is to be observed too.

6. Summary

On the ground of morphologic criteria four types of ridges can be distinguished in the area to the north of Hornsund (Spitsbergen): single ridges (Figs. 3, 4 and 6, Table I), complexes of elongated fans (Fig. 4), fan-shaped ridges (Figs. 2 and 5) and talus ridges; they differ from one another by a mutual relation of secondary elements.

The ridges were found to occur at various marine terraces and in zones of tectonic discontinuities. They are composed of boulders and rock blocks of local origin, to several dozen metres long and arranged in the way typical for rock failures (Fig. 7, Table II); many a time there evidence for a polyphasol evolution of the ridges (Fig. 5).

The subslope ridges were geneticly classified by the authors as the nival moraines, in connection with a definition of Czeppe (1966). They had been formed in periods of intensive rock failures, occurring over a snow cover in a depression at the contact of a ridge and a mountain massif. Now, the subslope ridges are modelled due to supply with debris from a mountain slope, some rock failures, by weathering and nivation, by waters circulating in inter-boulder breaks and at the botton of ridges, by solifluction and melting of the ice buried inside the features.

7. Резюме

На основании морфогенетических критериев можно выделить четыре типа моренных валов на территории, расположенной севернее фиорда Хорнсунд (Шпицберген): отдельный (рис. 3, 4 и 6, таблица I), комплекс подолговатых конусов (рис. 4), веерообразный (рис. 2 и 5) и свалочный, отличающийся взаимоотношением второстепенных элементов.

Констатировано, что валы выступают на разных морфологических уровнях (морских террасах) и зонах тектонического распущения склонов, у подножья которых они расположены. Они построены их валунов и скальных блоков локального происхождения с длиной до нескольких десятков метров и уложенных характеристически для обрывов (рис. 7, таблица II); они неоднократно указывают на много этапность развития (рис. 5).

Описанные подсклонные валы были генетически классифицированы авторами как нивальные морены, навязание к определению, примененному Чеппемым (1966). Они возникли в период насиления скальных обрывов и отпадания происходящих по снежному покрову, залегающему в понижении между валовой формой и горным склоном.

Современные подсклонные валы формируются путем поставки грузового материала из склона, редкие обрывы путем выветривания и нивеляции водами кружащими в меж-

валунных перерывах и в почвенных партиях, путем воздействия солифлюкции и вытапливания льда, выступающего внутри.

8. Streszczenie

Na podstawie kryteriów morfologicznych można wydzielić cztery typy wałów w obszarze położonym na północ od Hornsundu (Spitsbergen): pojedynczy (rys. 3, 4 i 6, tabela I), zespół stożków podłużnych (rys. 4), wachlarzowaty (rys. 2 i 5) i zwałowiskowy, różniące się wzajemną relacją drugorzędnych elementów.

Stwierdzono, że wały występują na różnych poziomach morfologicznych (tarasach morskich) i w strefach zluźnienia tektonicznego zboczy, u podnóża których leżą. Zbudowane są one z głazów i bloków skalnych lokalnego pochodzenia, o długości do kilkudziesięciu metrów i ułożonych w sposób charakterystyczny dla obrywów (rys. 7, tabela II); niekiedy wykazują wieloetapowość rozwoju (rys. 5).

Opisane wały podstokowe zostały genetycznie zaklasyfikowane przez autorów jako moreny niwalne, w nawiązaniu do określenia zastosowanego przez Czeppego (1966). Powstawały one w okresach nasilenia obrywów skalnych i odpadania, zachodzących po pokrywie śnieżnej zalegającej w obniżeniu pomiędzy formą wałową a zboczem górskim. Współcześnie wały podstokowe są modelowane przez dostarczanie materiału gruzowego ze stoku, rzadkie obrywy, przez wietrzenie i niwacje, przez wody krążące w lukach międzygłazowych i w partiach spągowych, oddziaływanie soliflukcji i wytapianie lodu występującego w ich wnętrzu.

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