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Morphogenetic processes and cover deposits of nunataks in the Hornsund area (SW Spitsbergen)*)

ABSTRACT: The paper deals with dynamics of present morphologic processes and cover deposits of nival and subnival stages in the area to the north of the Hornsund Fiord. Qualitative and quantitative parameters of the processes are described on the basis of direct measurements and radiocarbon datings. A particular attention was paid to the action of frost and gravitational processes in the specific morphoclimatic conditions of a nival landscape stage. The cover deposits are described from the point of view of their origin and physico-chemical properties. The age of the covers is defined on the ground of radiocarbon datings of fossil plants found at the nunataks for the first time in 1973. These datings enabled to distinguish the development phases of the morphogenetic processes during Late Holocene.

Key words: Arctic, Spitsbergen, geomorphology

Contents

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1. Introduction

Among the geomorphologic works there are many that deal with problems of present denudation and slope evolution in the periglacial conditions (Rapp 1960, Rapp and Strömquist 1976). In these papers there is a distinct trend to define the regularities and dynamics of geomorphologic processes with quantitative analysis based on absolute values received from direct measurements and from an analysis of cover forms and deposits (Chandler 1972, Czeppe 1961, 1966; Jahn 1961, 1967, 1976; Jania 1977, Martini 1975, Pękala 1975, Pulina 1974, Rapp 1957, 1960). The studies over morphogenetic processes and cover deposits were carried through with the reference to qualitative and quantitative analysis at the nunataks of subnival and nival stages, according to the terms of Różycki (1957). Field observations were collected from 20th June to 15th September 1973. The investigation should study a dynamics of the processes and their influence of evolution of slope covers. The fossil flora assemblages found at the nunataks for the first time allowed to define the age of cover deposits and to reconstruct the evolution phases of geomorphological processes in Late Holocene. During fieldworks a method of detailed geomorphologic mapping was applied with a use of air photographs and ground stereoscopic photographs.

2. General description of the studied area

The investigated zone included the area to the north of the Hornsund Fiord close to the nunataks of Werenskiöld and Hans glaciers (Figs. 1, 2 and 3). Detailed geomorphological studies were carried through at the nunataks of the mountain groups: Eimfjellet (641 m a.s.l.), Slyngfjellet (750 m a.s.l.), Skålfjellet (670 m a.s.l.), at the nunataks Tuva (552 m a.s.l.) and Vesletuva (542 m a.s.l.). For comparative purposes some reconnaissance observations were collected at Kopernikusfjellet (1055 m a.s.l.) in a typical nival stage (Fig. 4). The investigated area is specific for its considerably varying levels and big slope inclinations what results in great altitude gradients important for evolution of slope processes.

This area composes of metamorphic rocks of Precambrian Hecla Hoek Formation (Birkenmajer 1958, 1977; Birkenmajer and Narębski 1960; Smulikowski 1965) arranged in several folds dipping north-eastwards and intensively tectonicly disturbed. The latter is expressed by numerous changes of azimuth and dip of many tectonic movements what influences the evolution of morphogenetic processes and the features of relief as well as of slope covers. The Hecla Hoek Formation includes a complex of metamorphosed sandy-clayey sediments with inserts of limestones. The whole complex composes of several subformations (Isbjörnhamna, Eimfjellet, Deilegga and Sofiebogen) that are in turn subdivided into series (Birkenmajer 1958, 1977). The mountain massifs of Eimfjellet and Skålfjellet are built of amphibolites and quartzites. Vesletuva is included into the

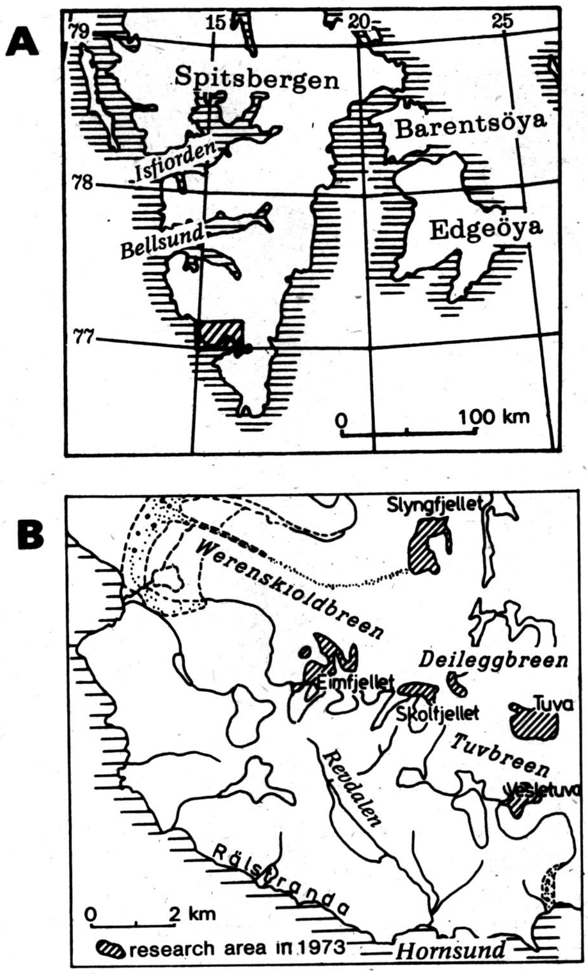

Fig. 1. Locality sketch of the area investigated in 1973

Isbjörnhamna Formation composing of the Ariekammen Series containing mainly garnet-biotite and calcereous gneisses, marble inserts and quartz reefs. The nunataks of Tuva, Deilegga and Slyngfjellet compose generally of schists mainly of chlorite, muscovite and biotite kind. The whole complex of metamorphic rocks (gneisses, amphibolites, schists, crystalline limestones) is strongly fissured, so it is particularly favourable for denudation processes. It is well reflected in the relief and in occurrence of coarse and fine-clastic covers. A deglaciation during the postglacial period has been an additional factor resulting in loosening of the rocks in a subsurface zone (Levis 1954, Harland 1957, Martini 1975, Baranowski 1977). A considerable thickness of the active zone of permafrost and a moister climate caused a spontaneous development of slope processes (Rapp 1960, Jahn 1967).

From a climatic point of view the Hornsund area is included into a zone with very cool and cool winters (mean temperature of February

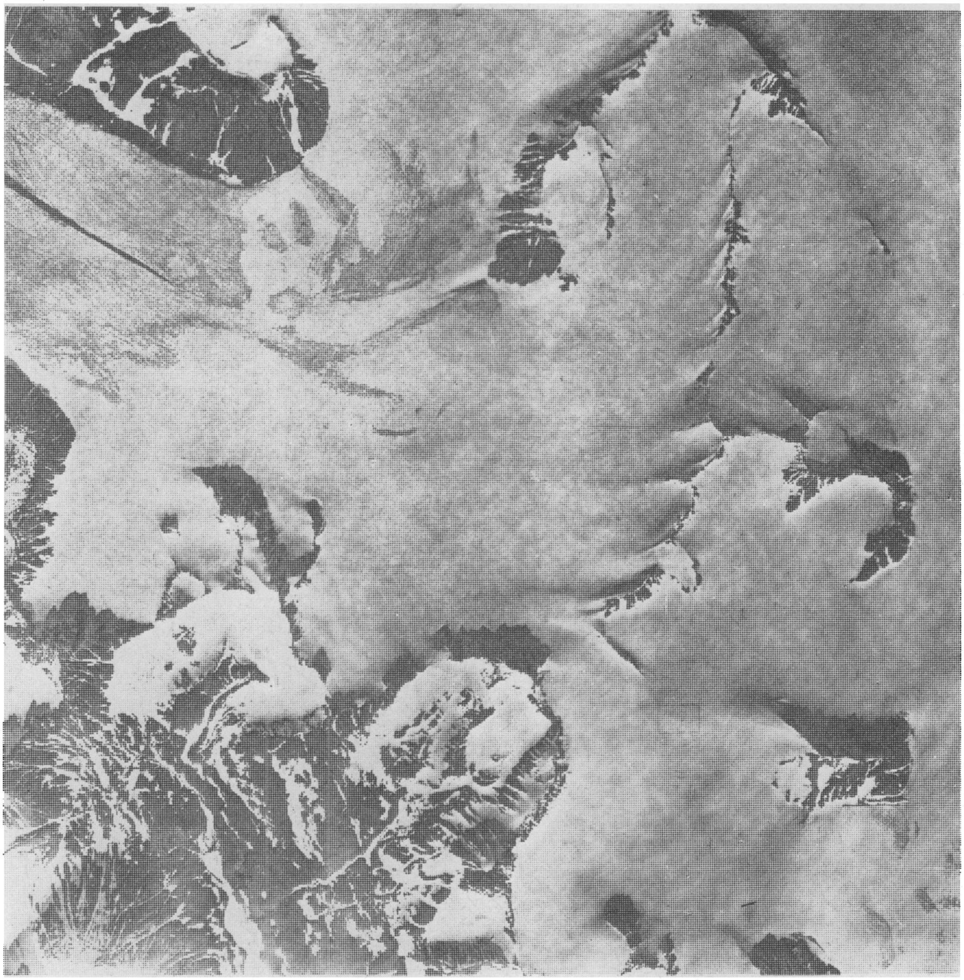

Fig. 2. Fragment of an air photograph including the investigated area of 1961, received from Norsk Polar Institutt at Oslo

is below — 10°C), with small precipitation (400 mm per year) and maritime influences (Corbel 1957, 1961). A full annual description of the climate and of thermal conditions in the tundra was prepared by Czeppe (1966) and Baranowski (1968) in connection with analysis of morphogenetic processes. In the Hornsund tundra 80 cycles of freezing and thawing in a subsurface air layer and 13 cycles in a soil at a depth of 10 cm were found during a year. A frequency of the thawing cycles is considerably greater in the mountaineous area farther from the sea-shore.

On the ground of meteorological observations in five places of the main base and the Werenskiöld Glacier the summers of 1972, 1973 and 1974 were found to be the warmest period that had been ever recorded in the Hornsund area (Pereyma, Baranowski and Piasecki 1975).

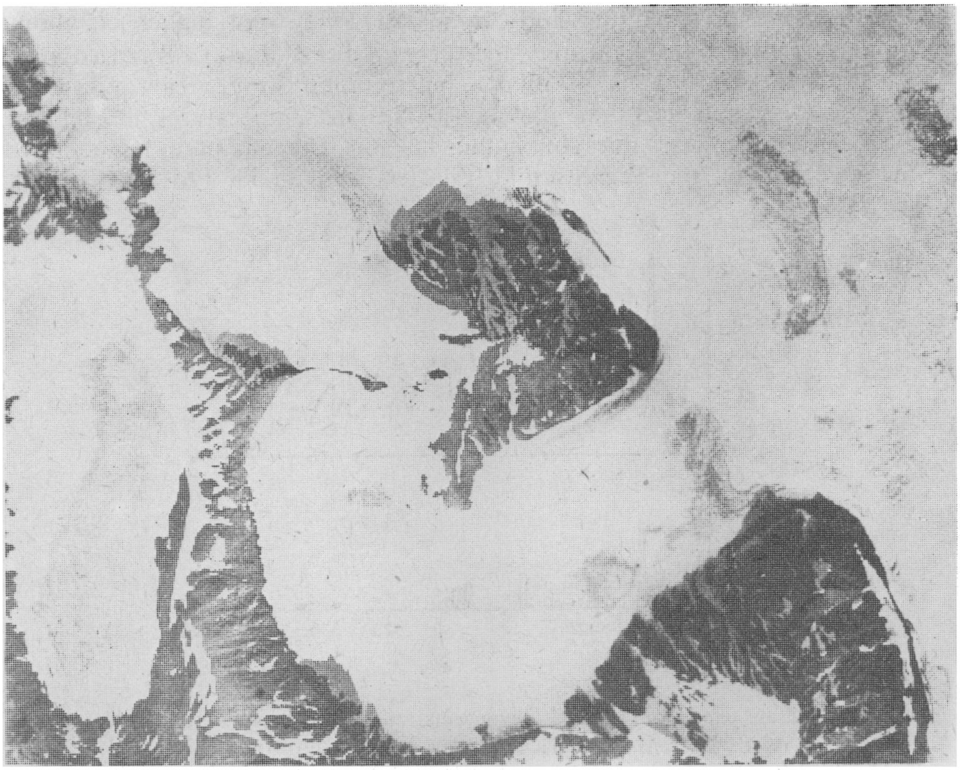

Fig. 3. Fragment of an air photograph presenting the nunatak Vesletuva, received from Norsk Polar Institutt at Oslo

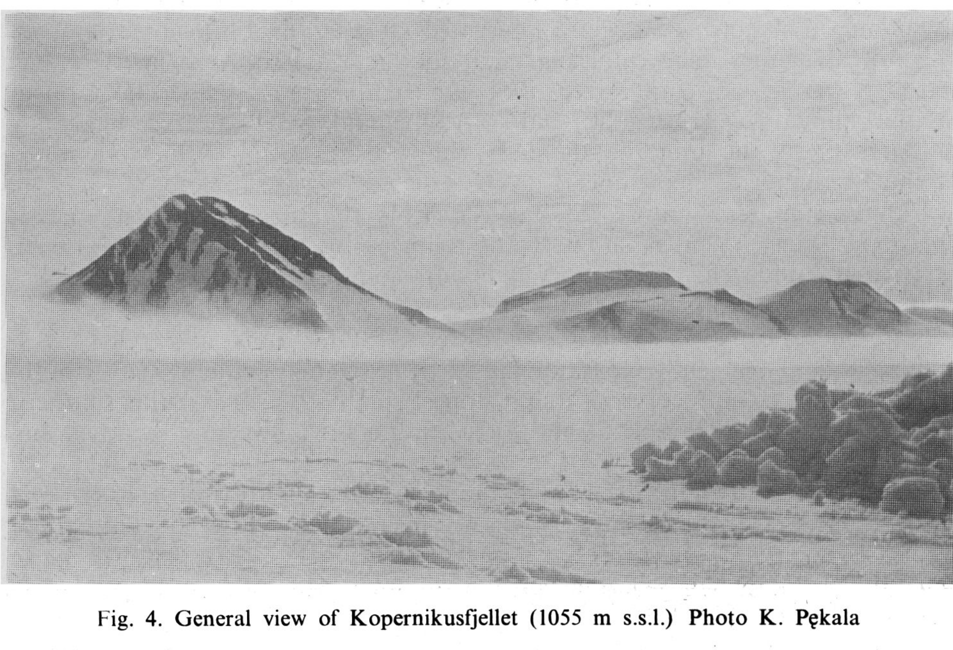

Fig. 4. General view of Kopernikusfjellet (1055 m s.s.l.) Photo K. Pękala

The temperatures of July and August in 1972 were higher of about 1°C than the many years mean values from Isfjord Radio (Baranowski 1975, Hisdal 1973). Sums of month precipitation were great and equal 55.3 mm in July and 94.1 mm in August. The air temperatures in summer 1973 had high mean day values (maximum 13.3°C). The maximum temperature at the moraine of the Werenskiöld Glacier was equal 19.9°C (Fig. 5).

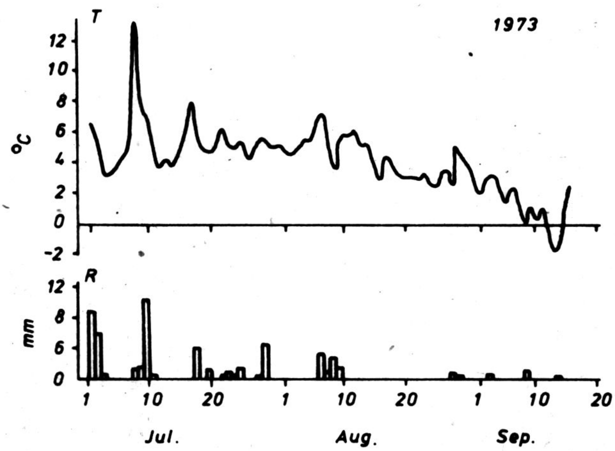

Fig. 5. Curve of air temperatures (after day means) and precipitation on the end moraine of the Werenskiöld Glacier during the expedition of 1973 (after Pereyma, Baranowski and Piasecki 1975).

The data of maximum and minimum temperatures at the Werenskiöld Glacier in a vertical section: moraine — firn field — nunatak Glaciologerknausen and at Isfjord Radio are presented at Fig. 6. From the point of view of dynamics of weathering and solifluction processes in the nival stage it should be emphasized that the temperatures below 0°C finish in the annual cycle at the end of July and start at the beginning of August. At the moraine the first temperatures below 0°C were noted at the beginning of September.

Quite high temperatures and considerable rainfalls resulted in a great ablation of glaciers and of snow. It was followed by activation of weathering, as well gravitational, solifluction and suffosion processes. These processes were favoured by morphological conditions of the analyzed nunataks.

The investigated nunataks have different dimensions and relief. Vesletuva and Tuva the separate hills with steep northern and south-eastern slopes, mainly of rockytalus slopes and with more gentle southern and western slopes (Figs. 3, 7 and 8). Their tops are leveled — without any greater outliers.

Slyngfjellet and Eimfjellet are the branched ridges with fresh rocky forms at the crests or with ice-snow caps and steep slopes (Fig. 9). The slopes are cut corrasive gullies and by nival niches (Fig. 10). Only a small nunatak of Eimfjellet group is a roche-mountonnée covered by morainic deposits (Figs. 9 and 11).

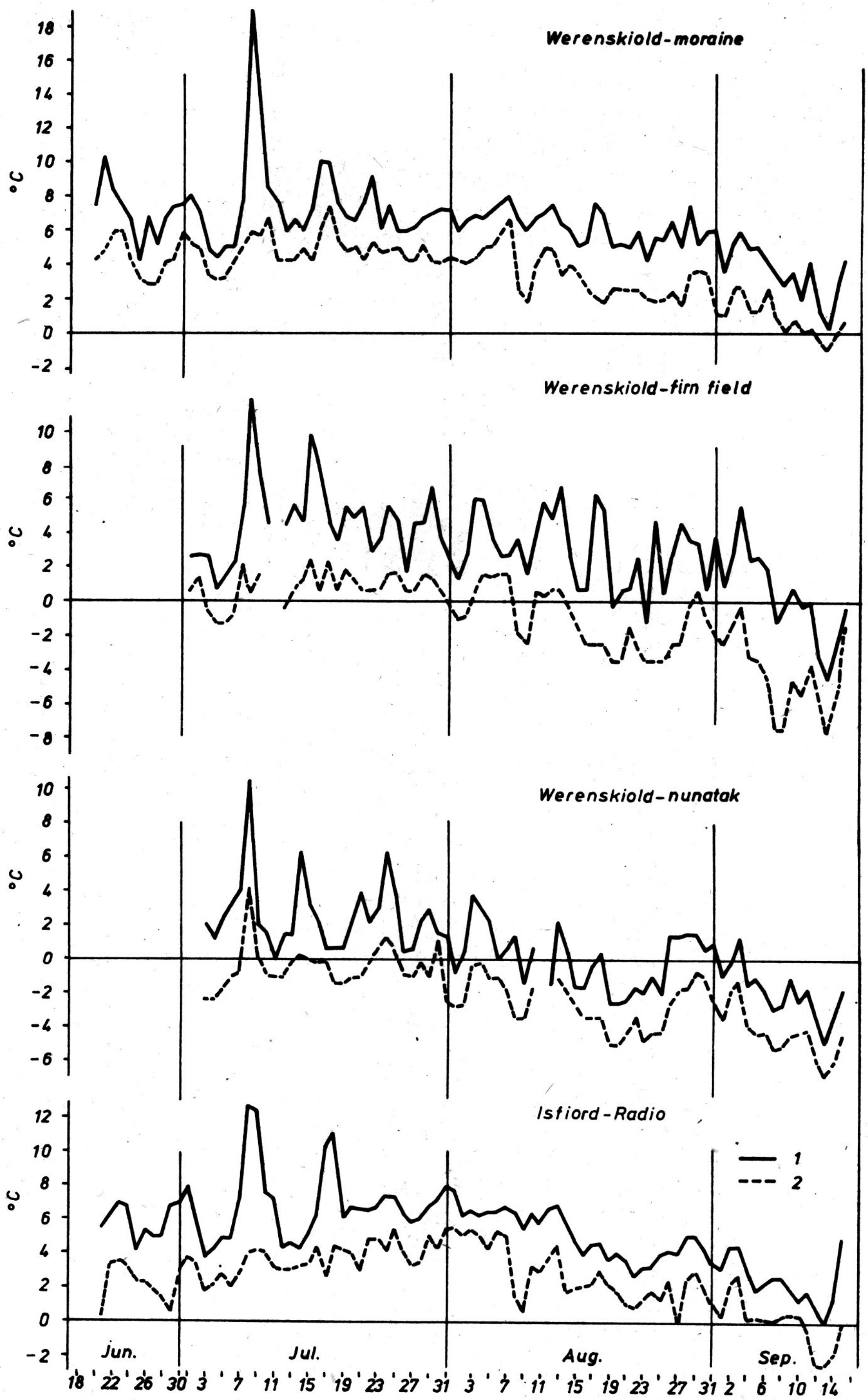

Fig. 6. Curve of maximum and minimum temperatures on the end moraine and the firn of the Werenskiöld Glacier as well as on a nunatak and in Isfjord Radio during the expedition of 1973

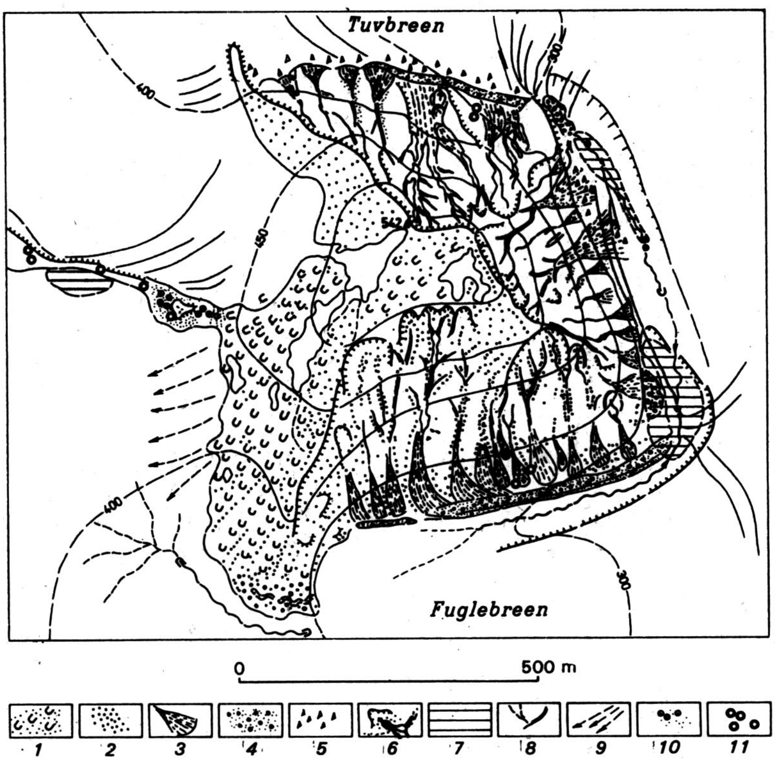

Fig. 7. Geomorphologic map of Vesletuva
1 — solifluction debris — clayey slopes, 2 — steep rubble slopes, 3 — talus-nival fans, 4 — lateral moraines, 5 — large talus blocks deposited on ice, 6 — edges of nival niches and corrasion gullies, 7 — periodical lakes, 8 — fissures and streams at the glaciers, 9 — slopes modelled by avalanches and washing, 10 — polygonal grounds, 11 — sites of palaeosols and fossil floras.

Kopernikusfjellet occurring in the central part of Wedel-Jarlsberg Land forms the highest coned elevation in this area (1055 m a.s.l.) It is composed of metamorphic rocks of Hecla Hoek Formation and of sedimentary rocks of Carboniferous and Permian. The slopes of the Kopernikusfjellet are covered by a weathering waste or by snow patches and they are steep. The mountain is diversified by exposed outliers (Figs. 4 and 12).

3. Evolution of morphogenetic processes and their quantitative analysis

Weathering and rock fall. The opinions of processes of mechanical weathering in the climatic conditions of Vestspitsbergen are not uniform. Since the times of Łoziński (1909), Högbom (1914) many other scientists with present geomorphologists as well (Büdel 1948, Peltier 1950, Jahn

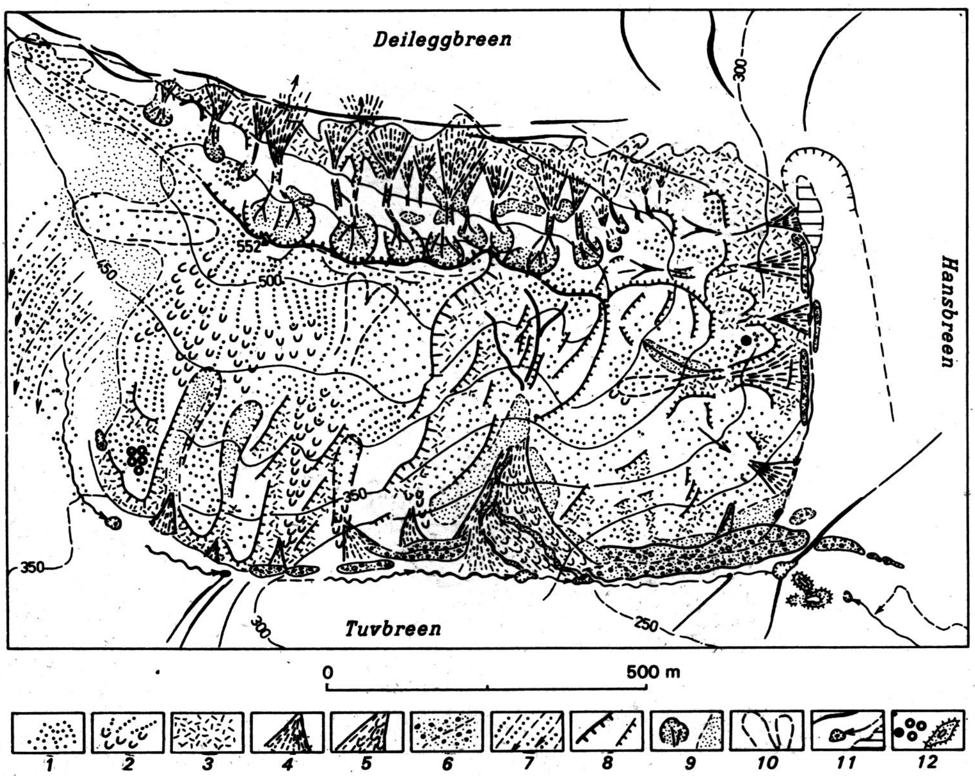

Fig. 8. Geomorphologic map of Tuva
1 — steep rubble slopes, 2 — rubble slopes with solifluction stripes and lobes, 3 — talus slopes, 4 - talus-nival slopes, 5 — talus fans on ice with forms of thermokarst and erosion, 6 — moraines, 7 — ice-debris slopes modelled by avalanches and washing, 8 — rock edges walls, 9 — kettles, nival niches and patches of many year snow, 10 — denudation niches, 11 — glacial fissures and pits, periodical streams and lakes, 12 — sites of polygonal grounds, fossil floras, glacier tables.

1960, 1961, Czeppe 1966) considered that the intensity of weathering processes was enormous in the arctic periglacial zone. Such opinion is supported by an occurrence of enormous rock rubble at the mountain slopes. A slow and slightly effective weathering process is suggested by Rapp (1960) who finds the climatic conditions too dry and frost cycles too short. Quantitative studies as well as analyses of covers supplied with new data that evidenced the first opinion (Martini 1975, Jahn 1976, Jania 1977).

A process of physical weathering is very difficult to be described by quantitative methods in the field. Therefore, a frost desintegration is quantitatively defined by a gravitation process i.e. by a rock fall. For this purpose a popular method of nets was applied. They were set up at the foot of rocky slopes. Besides, the waste measurements were done on the snow (Figs. 13 and 14). These methods are not precise but they

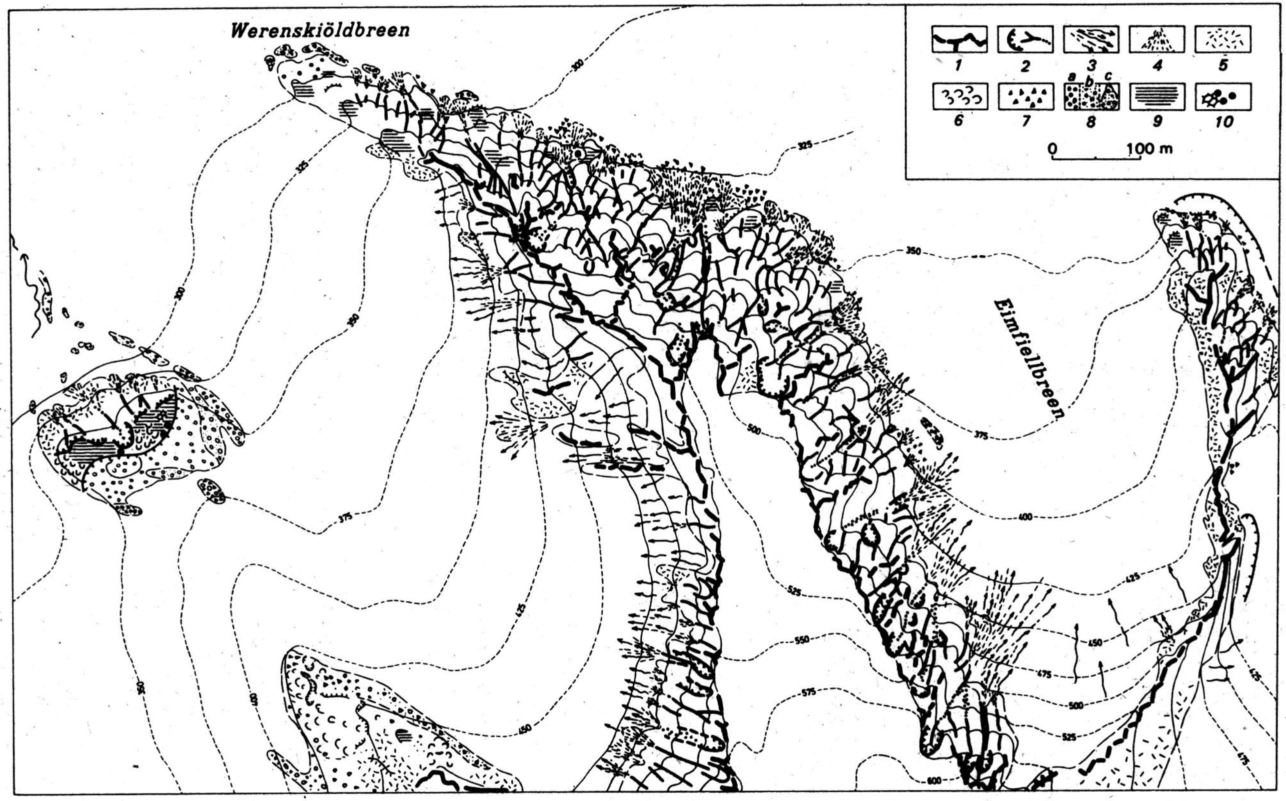

Fig. 9. Geomorphologic map of Eimfjellet
1 — crests and exposed rocks, 2 — nival niches and corrasion gullies, 3 — avalanche (debrissnow) fans, 4 — talus fans (debris and debris-snow ones), 5 — talus (rubble) slopes, 6 — solifluction (debris-clayey and debris) slopes, 7 — loose rock fall deposit, 8 — moraines, 9 — roche moutonnée, 10 — sites of fossil floras and polygonal grounds.

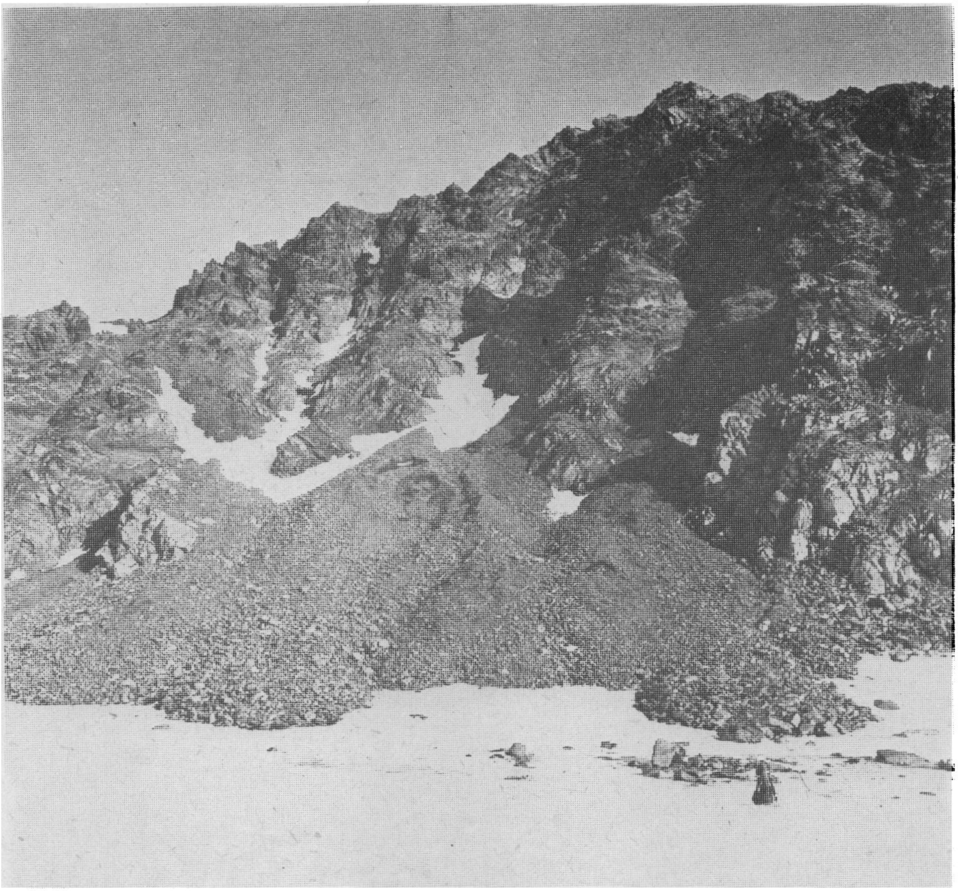

Fig. 10. Talus fans on a northern slope of Eimfjellet. In the back walls of landslide-solifluction niches the snow inserts are exposed.

Photo K. Pękala

are simple and easy to be used during investigations in the arctic conditions. Such methods applied during works at the nunataks supplied with a good deal of quantitative information (Table I). The data were collected on 15th September 1973 but the nets still remained for the winter. By the end of the next summer season (on 21st August 1974) the second measurements were done. The results were found to be slightly different after a year in comparison with the data for the summer 1973. The absolute values for the rock fall during the summer equal 120 — 665 g/m^2. The annual values are over 340 — 580 g/m^2. A small amount of the matter fell of a slope in a tundra (25 g/m^2). In a typical nival stage at Kopernikusfjellet a quantity of the deposit was also smaller than at the analyzed nunataks in the Hornsund area and equalled 135 — 340 g/m^2.

A fossil flora was found in the slope talus covers (Pękala 1975). On the ground of its radiocarbon datings an attempt of quantitative

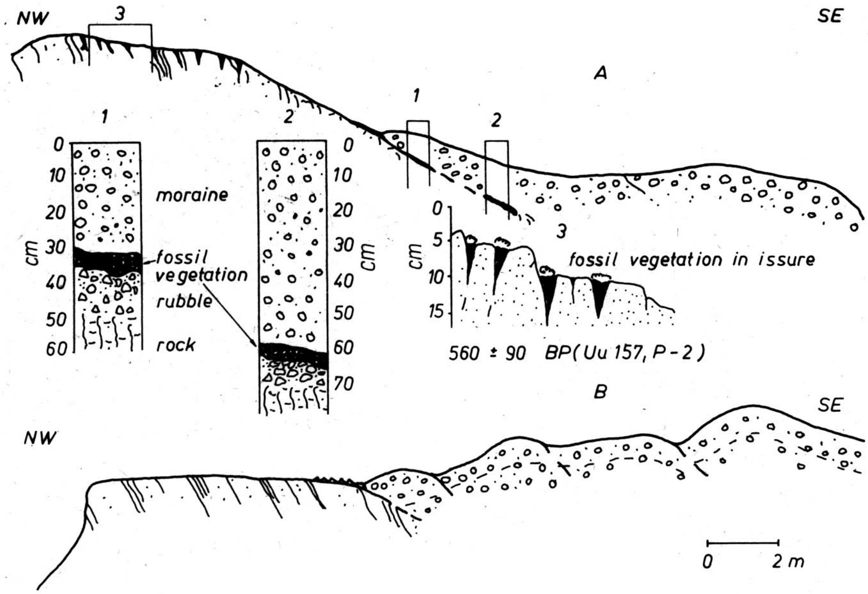

Fig. 11. Geomorphologic sections in the nunatak and the moraine that overlies the dated tundra fossil flora in the Eimfjellet group

A, B — different sections, 1, 2, 3 — enlarged fragments of section A.

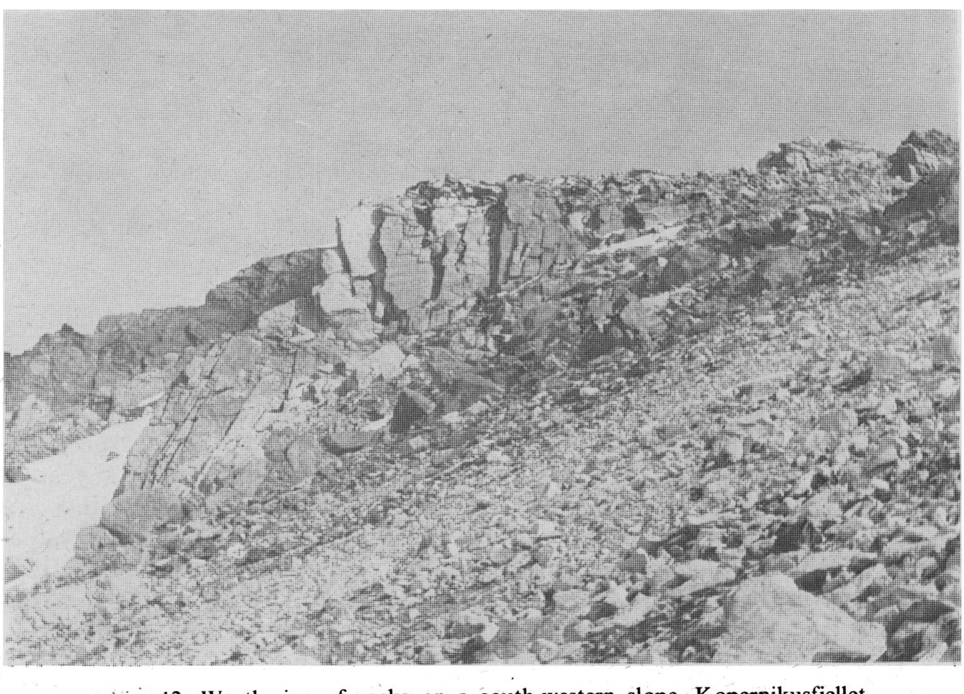

Fig. 12. Weathering of rocks on a south-western slope, Kopernikusfjellet

Photo K. Pękala

Fig. 13. Northern slope of Eimfjellet
Collector at the outlet of a corrasion gully is filled with rock debris (10th September 1973). The block edges were rounded during a gravitational transport.
Photo K. Pękala

Fig. 14. Fall-avalanche deposit on a snow at the foot of the northern slope af Vesletuva (28th June 1973)

Photo K. Pękala

Table I.
Weathering and fall-off at the nunataks from 27th June to 15th September 1973 on the basis of direct measurements on nets and snow

Site (nunataks)	Altitude (m a.s.l.)	Quantity (g/m^2)	Rock type
Vesletuva			
northern slope	300	665	schists
southern slope	400	543	schists
southern slope	400	580*)	schists
Tuva	300	470	schists
Tuva	550	325	limestones
Tuva	550	340*)	limestones
Tuva, "Nunuś"	440	410	schists
Tuva, "Nunuś"	435	215	amphibolites
Skalfjellet	550	120	amphibolites
Deilegga	500	517	schists
Slyngfjellet	450	453	schists
Glaciologerknausen	655	340	schists
Glaciologerknausen	655	370*)	schists
Eimfjellet	350	355	amphibolites
Eimfjellet	350	400*)	amphibolites
Eimfjellet	450	370	amphibolites
Eimfjellet — a gully	400	28 170	amphibolites
Ariekammen	350	25	limestones
southern slope	500	220	quartzitic sandstones
northern slope	500	330	schists
	Measurements on snow		
Kopernikusfjellet	950	135— 340	limestones, sandstones
Vesletuva	300	250—1720	schists
Skålfjellet	540	400— 600	amphibolites
Slyngfjellet	400	700—1420	schists

*) measurements made after a year (in 1974)

estimation of the denudation was done by calculations of the volume of talus fans (Figs. 15 and 16). The radiocarbon datings were done in the Radiocarbon Laboratory at Technical University of Gliwice and the results were published in Radiocarbon no. 2 (1978) at the numbers: Gd-278, Gd-279 and Gd-280. On the ground of the received data the upper parts of the slopes are found to get lowering 0.2 — 0.5 mm a year i.e. 560 — 1400 g/m^2. Such values can be also accepted as the annual mean of a slope degradation during the last thousand years.

The phases of intensified processes of physical weathering and rock fall were found to be quite distinct on the ground of morphologic observations and analysis of slope covers and especially, of their differentiated age. These phases correspond with the periods of deglaciation that influence a loosening of rocks and an intensification of weathering processes.

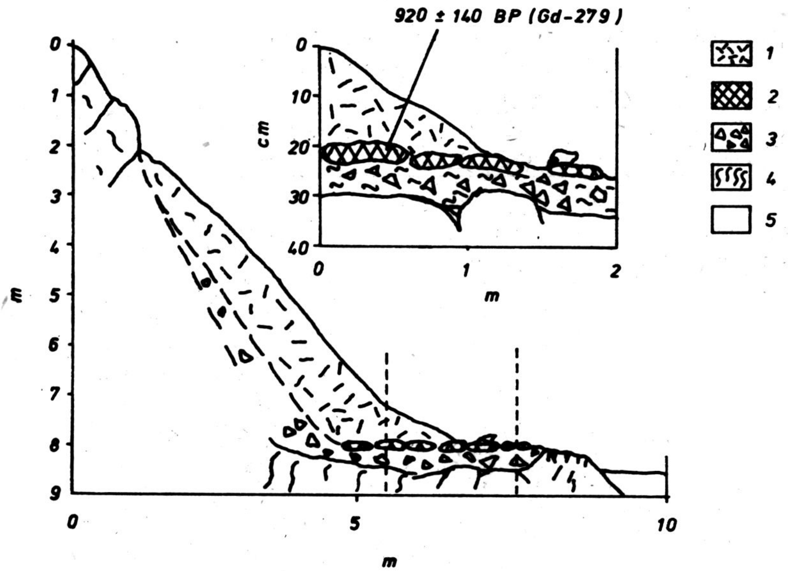

Fig. 15. Geologic section of cover deposits at the eastern slope of Ariekammen close to a watershed crest between Tuvbreen and Veslebreen
1 — talus-block covers, 2 — fossil floras radiocarbon dated, 3 — fine weathering debris on a cryoplanation ledge, 4 — bedrock, 5 — glacier.

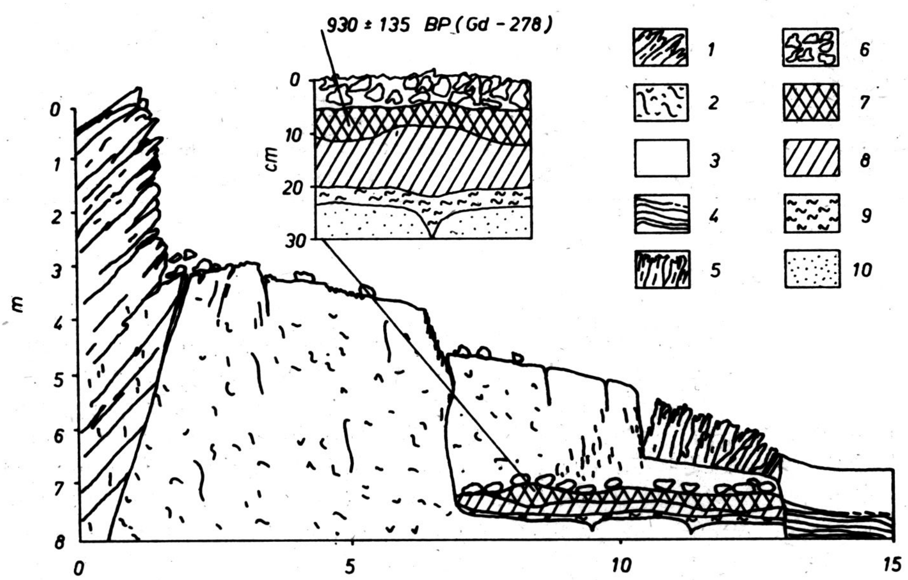

Fig. 16. Geomorphologic position of fossil floras at „Nunuś"
1 — schists, 2 — amphibolites, 3 — snow and firn, 4 — ice, 5 — block weathering waste „in situ", 6 — waste debris, 7 — fossil floras, 8 — soil, 9 — weathering loam, 10 — mother rock (amphibolite).

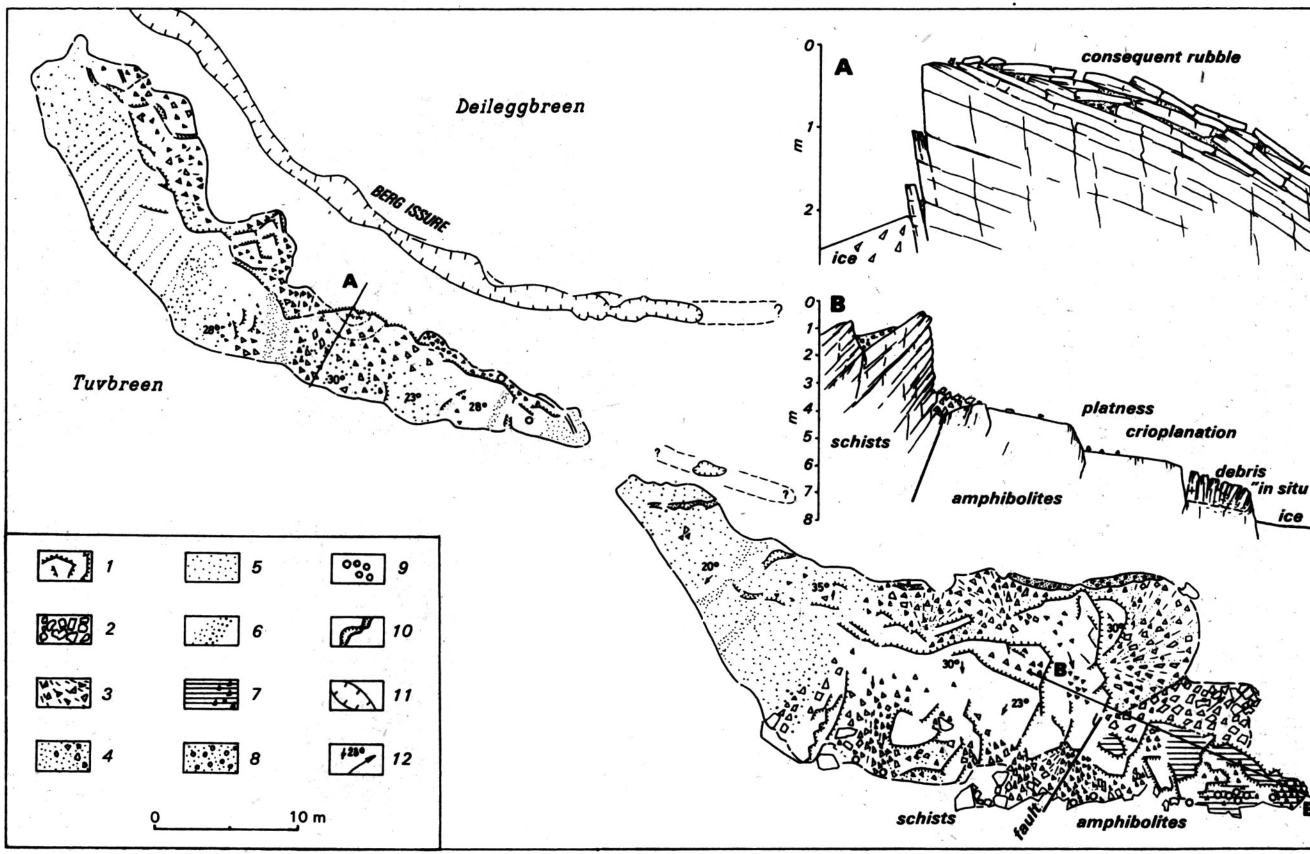

Fig. 17. Geomorphologic sketch and transversal sections of a small nunatak („Nunuś") occurring between Tuva and Kosibapasset (Fig. 2)

1 — edges of rocky walls, 2 — rubble, 3 — talus fans, 4 — consequent rubble, 5 — local and outside matter, 6 — sorted *ripes*, 7 — cryoplanation ledges (terraces) without debris and with debris, 8 — moraine, 9 — sites of fossil tundra vegetation, 10 — fissures, 11 — bergschrund, 12 — direction of material transport and slope inclination, *A*, *B* — different sections.

The observations collected at a small unnamed nunatak occurring between Tuva and Kosibapasset, named „Nunuś” for identification purposes (Fig. 17), clarify a bit the weathering processes. The weathering and denudation processes of the amphibolites have not been uniform during the last thousand years (Fig. 16). The most intensive weathering occurred in a fault zone; it was associated with tectonic fissures — there was 2 m displacement of a rock plane. Instead, in the massive amphibolitic rocks a cryoplanation level was formed, a frost edge of with moved about 1 m back. A rock waste was not removed from the cryoplanation plane but it got strongly crumbled at the contact with a bedrock (Fig. 18). An arrangement of the deposit at the cut rock plane makes the cryoplanation processes more clear; these processes are not common in the nival stage. For a development of the cryoplanation planes there must be a constant level of an active layer of permafrost for a longer period of time and its relatively great humidification.

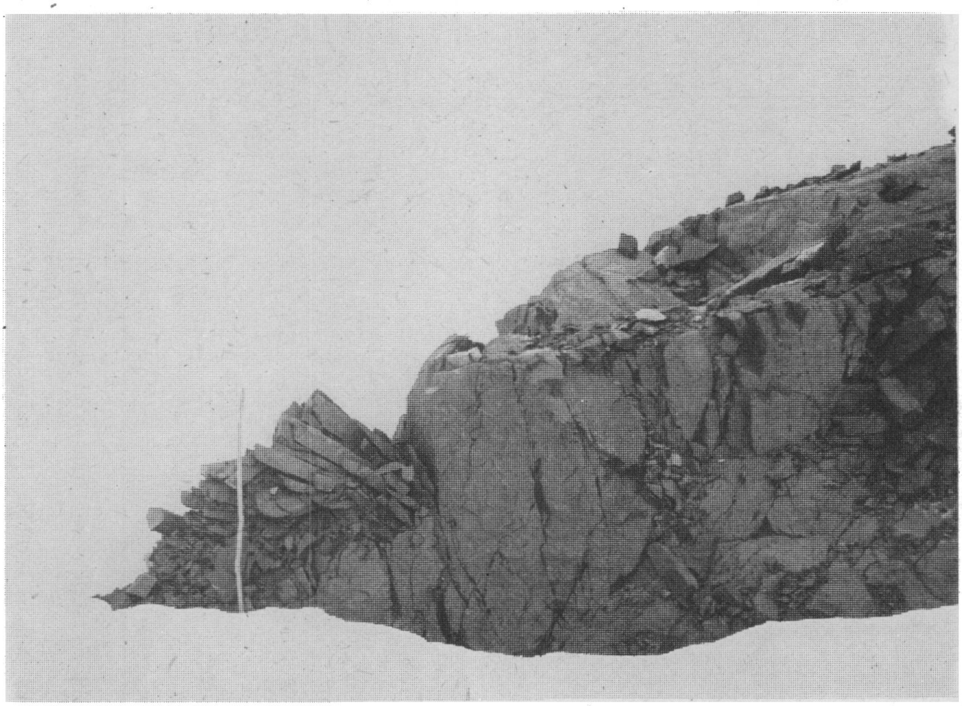

Fig. 18. Cryoplanation ledges formed im amphibolites

Photo K. Pękala

Chemical weathering occurs in nival and subnival stages mainly under the influence of rain and melt waters containing considerable quantity of carbon dioxide (so they are more chemically active — Corbel 1957). The vegetation is nowadays absent or occurs in small quantities and in few species. The effects of chemical processes were frequently observed during the fieldworks forming precipitation of varnish, dripstone and weathering crust type in the rock matter but no quantitative investigations have been carried through. These problems were described in a separate paper dealing with chemical denudation and karst phenomena (Pulina 1974). The chemical denudation, according to these data occurs with a speed of 0.02 mm/yr.

Snow avalanches and corrasion. A nival and a subnival landscape stage is mainly created by processes connected with a snow action and particularly, by snow and snow-rubble avalanches. These gravitational processes are accompanied by corrasion. Under its influence the slopes are intensively degraded what is expressed by an evolution of nival niches, corrasion gullies and talus fans (Figs. 9 and 10). An uneven accumulation of snow in the upper parts of the slopes results in its rapid flow along the lines accentuated by the morphology. The rock debris at the track is carried along. The snow with the included weathering waste erodes the channels in the bedrock (Różycki 1957, Rapp 1960, Jahn 1960, Piasecki 1968). Though the process of avalanche corrasion occurs in winter it is intensified very much and its morphologic effects are the greatest during spring and summer snow melting, mainly in May and in June (Figs. 13 and 19). If the snow has already melted in the subnival stage the gullies are modelled by erosion of waters produced by melting out of ground ice and by atmospheric precipitations (Czeppe 1966).

Washing and suffosion, erosion. Quantitative measurements of these processes in the nival stage are difficult. The observations of them were carried through on the ground of morphologic analysis of slopes and cover deposits. Much interest has been paid to these problems in other papers. Jahn (1961) estimated on the ground of many year studies in Vestspitsbergen that the slope keeps lowering 0.64 mm/100 yrs. In result of washing the waste is taken away quicker than it is created so, the denudation balance of these slopes is positive (Jahn 1968). Pulina (1974, 1977) evaluated a mechanical denudation taking into account a transport of suspended matter and a washing. It is expressed by lowering of the surface from 0.04—0.48 mm/100 yrs. in non-glaciated areas to 100 mm 100 yrs. in glaciated ones. It was found on the ground of observations that in nival and subnival stages a washing is particularly intensive at the slopes covered with waste that overlies a many year snow and ice (Figs. 7 and 8); such processes can be called the supranival ones (Jahn 1961,). They result in formation of covers of „grézes litées" type (Guillien 1951, Dylik 1955).

Erosion occurs in a marginal zone of the glaciers and along the axis of some large erosive-corrasive incisions in a subnival stage. A mechanical suffosion and a washing coexist and cooperate at the same slopes (Jahn 1961).

Processes of solifluction act at the slopes covered with a series of weathering block-debris and debris-clayey deposits, especially at Vesletuva, Tuva and Eimfjellet. An attention has been paid in this work to a process of solifluction displacement and sorting of the waste at a background of thawing depth and humidification.

Fig. 19. Outliers on a western slope modelled by rock falls that cause the snow avalanches Kopernikusfjellet

Photo K. Pękala

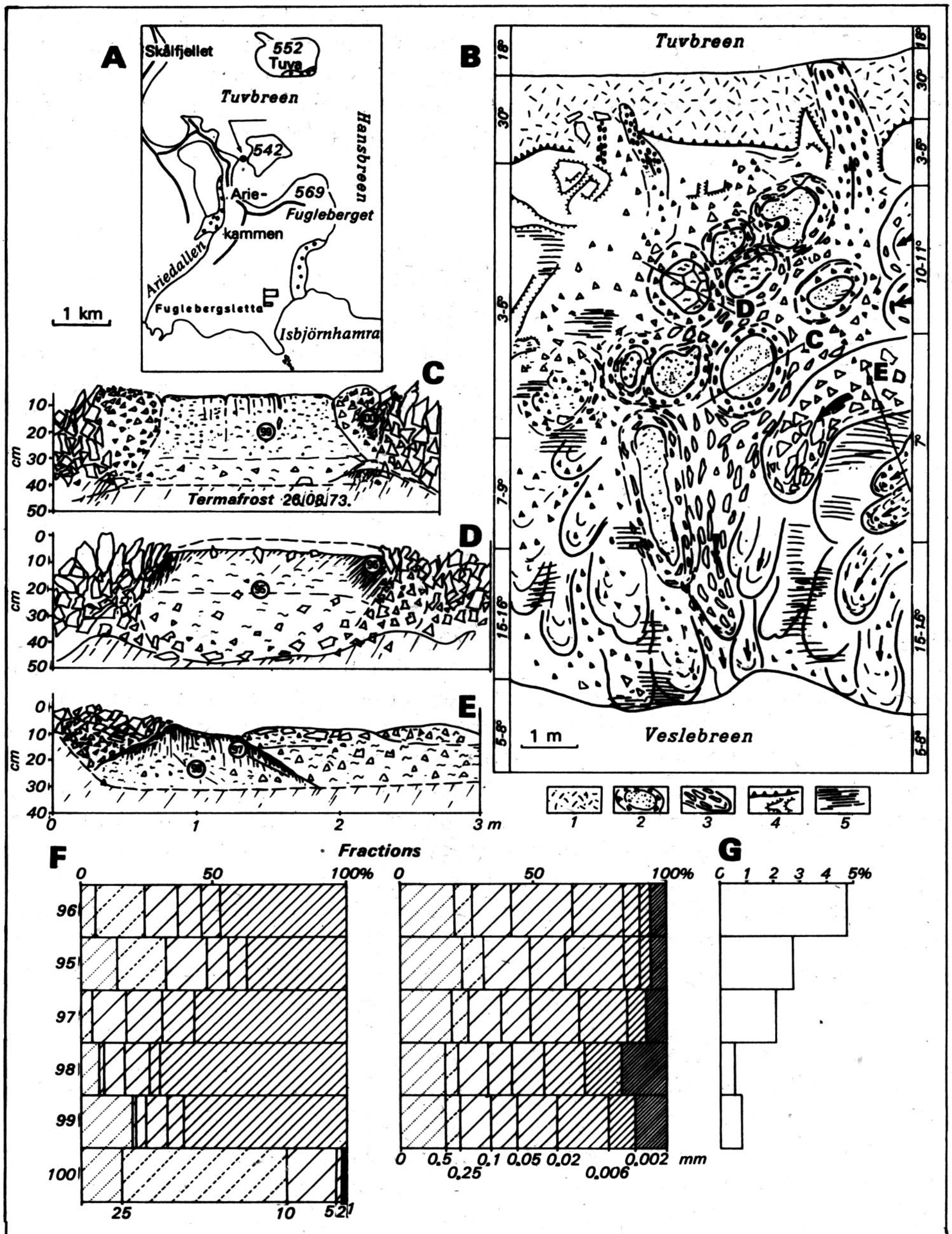

Fig. 20. Position (*A*), geomorphologic sketch (*B*), sections (*C*, *D*, *E*), mechanical composition (*F*), humus content (*G*) in deposits of polygonal grounds of Vesletuva

1 — talus slope, 2 — polygonal grounds, 3 — solifluction lobes and directions of movement along a slope, 4 — rock edges and walls, 5 — concentrations of humus and of intensively destructed fossil vegetation; hadched areas mean a percentage content of a fraction.

Processes of solifluction were studied in the Hornsund area in detail by Klimaszewski (1960), Jahn (1961), Czeppe (1966), Klatka (1968) and others. In a subnival stage the solifluction acts intensively at the slopes due to great humidification of the covers by waters coming from a snow melting and from rainfalls. At the south-western slopes of Vesletuva (Figs. 7, 20 and Table II), southern slopes of Tuva (Fig. 8) and

Table II.

Content of trace elements (ppm) in deposits of polygonal grounds of the Vesletuva nunatak

Sample number	B	Pb	Mn	Mo	V	Cu	Zn	Ni	Co	Sr	Cr	Ba
96	78	trace	640	8.0	70	38	160	46	39	72	78	660
95	84	„	600	6.0	80	41	188	42	34	60	68	370
97	80	„	740	5.5	68	33	60	39	33	24	54	270
98	88	„	4400	8.0	64	46	160	44	52	74	45	710
99	49	„	1020	11.2	88	20	250	46	45	46	70	74

at small parts of Eimfjellet the processes of solifluction cooperate with a mechanical suffosion. Intensity of solifluction displacements of soils keeps changing along the slope. In the upper part of the slope of 15° inclination the displacements are from 2.5 to 7.5 cm per day in the first phase of thawing (to the depth 10 cm). It was favoured by great humidification and in this phase a sorting of the matter occurs in result of which the sorted stripes are formed (Fig. 21). Due to a loss of water the process is broken but keeps intensifying in a middle and a lower part of the slope where a water flow within the covers is concentrated. So, larger forms of lobal solifluction are developed (Fig. 22 and Table III) and the waste is displaced up to 1.5 m. On the ground of observations and several measurements in summer 1973 a mean solifluction velocity in this area can be evaluated for 3—5 cm per year.

Processes of frost heave and sorting in the nival stage are rare (Różycki 1957). They were only found in a subnival stage at Tuva and Vesletuva and at a roche-moutonnée within the Eimfjellet group (Figs. 20 and 24). The carried soil and floristic investigations prove that most of these forms are old, connected with warmer and more humid climatic conditions. Nowadays they are being partly transformed by frost processes. Initial small forms were recorded at Tuva in September. They seemed to be the seasonal features. It is striking that in the clayey cores of polygonal structures the frozen matter contained about 20% of air bubbles. Niveo-aeolian processes play a considerable part in slope modelling. They were separately described in another paper (Baranowski and Pękala, in press). Niveo-aeolian processes are evaluated for 117 g/m^2 per year in the stage of analyzed nunataks. A mean index for the Hornsund area equals 29 g/m^2 per year and can be treated as an approximate one.

Fig. 21. Southern slope of Vesletuva
Present sorted structures.

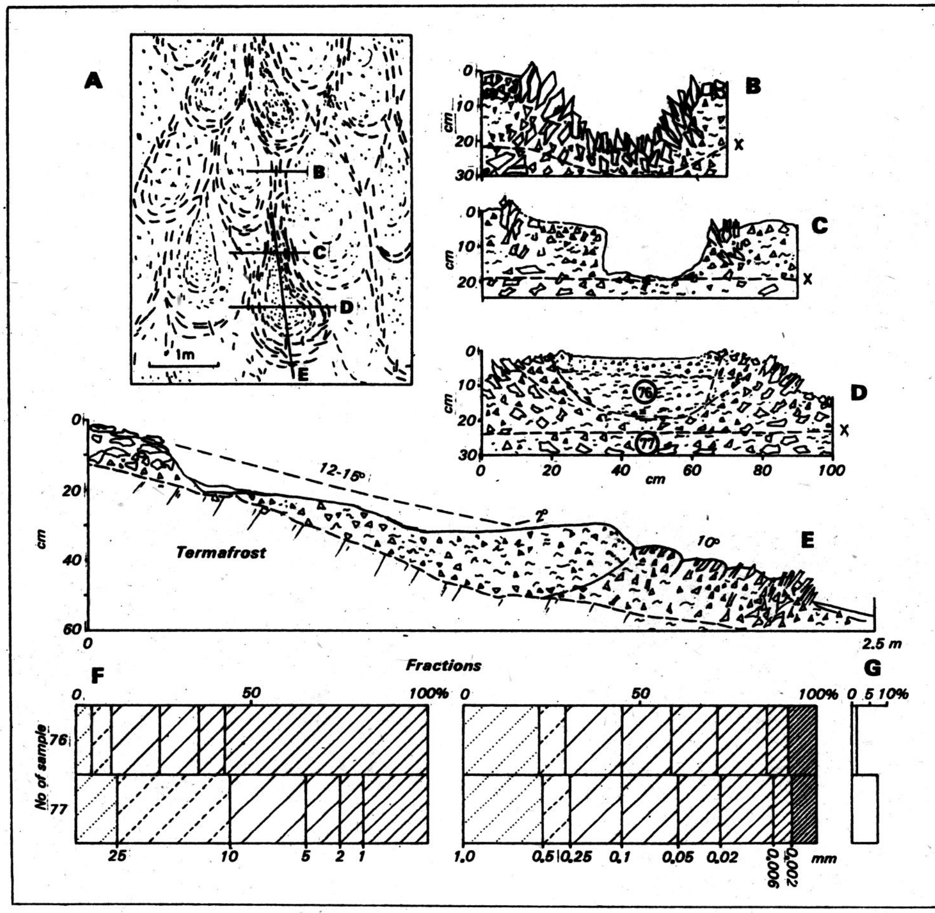

Fig. 22. Present solifluction structures on a south-western slope of Vesletuva
A — field sketch, *B*, *C*, *D* — transversal sections, *E* — longitudinal profile, *F* — mechanical composition of deposits, *G* — humus content.

The described groups of morphogenetic processes of nival and subnival stage are of a year rhythm (Fig. 25) resulting from morphoclimatic conditions.

4. Features of cover deposits

The weathering covers occurring in the area of investigated nunataks can be subdivided into several types on the ground of morphologic and lithologic criteria and movement mechanics along a slope (Washburn 1969, Strömquist 1973, Martini 1975, Pękala 1975, Jania 1977).

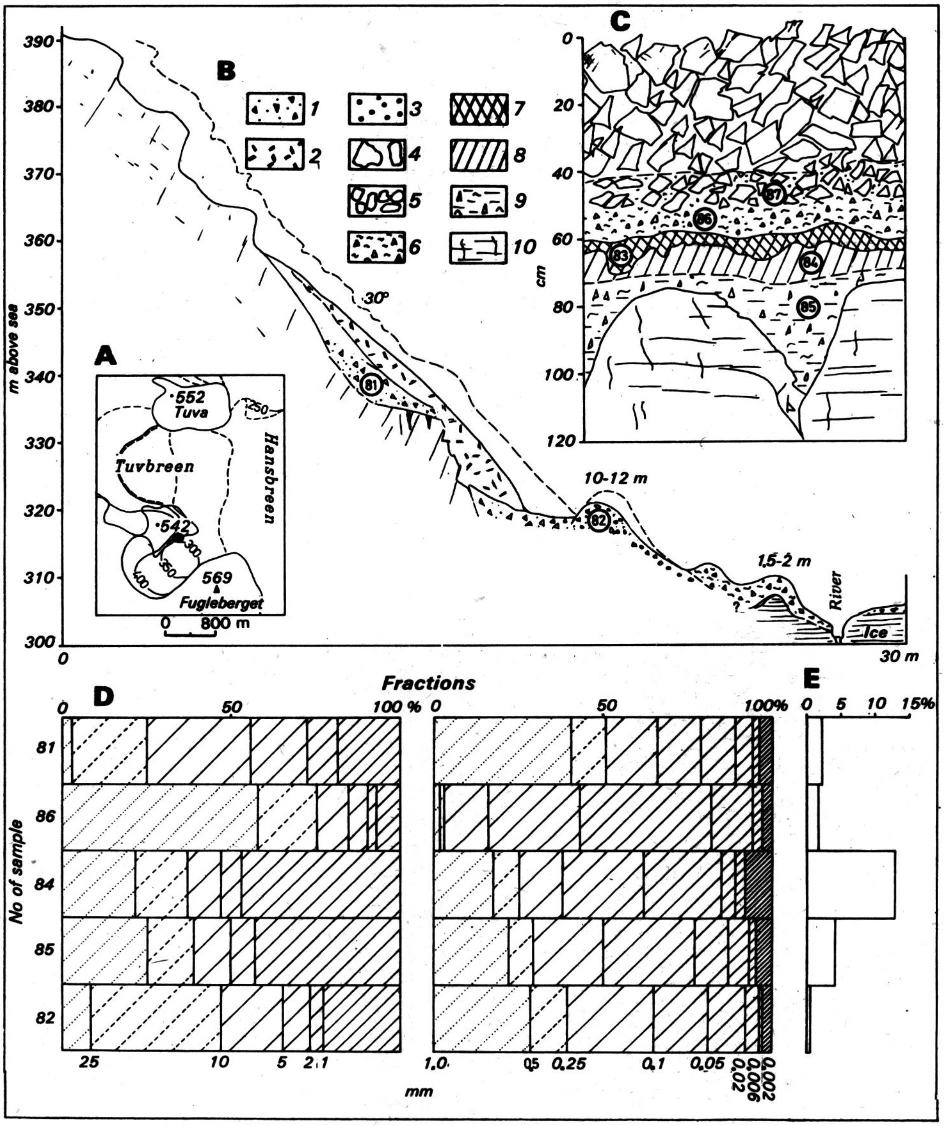

Fig. 23. Cover deposits on a south-eastern slope of Vesletuva
A — position, *B* — section in slope deposits and moraines, *C* — structure of talus fan, *D* — mechanical composition, *E* — humus, 1 — slope covers, 2 — present covers, 3 — moraines, 4 — blocky deposits of a fan, 5 — fine debris, 6 — fine debris, rock pieces, loam; 7 — fossil flora, 8 — humus loamy layer, 9 — loam with debris, 10 — rocks.
Numbers in circles are the symbols of samples analyzed for defining their mechanical composition, contens of humus and trace elements.

Table III.

Content of trace elements (ppm) and chemical composition of primary rocks on a south-western slope of the Vesletuva nunatak

Sample number	B	Mn	Mo	V	Cu	Zn	N	Co	Sr	Cr	Ba
76	84	860	6.7	64	420	104	40	36	44	48	380
77	62	800	6.8	70	440	trace	36	34	60	58	440

Sample number	Loss (%)	Content (%)								Total
		SiO_2*)	R_2O_3*)	Fe_2O_3**)	Pb_2O_5**)	Al_2O_3**)	K_2O**)	CaO**)	MgO**)	
19	2.96	63.17	25.95	7.47	0.10	18.38	3.39	1.14	2.59	99.20
29	2.67	63.12	27.02	7.68	0.11	19.75	3.14	1.42	2.54	99,91
89	2.58	63.46	25.11	6.61	0.88	18.42	3.61	0.88	3.11	98.75

*) Gravimetric method, **) Colorimetric method

Fig. 24. Sorted circles on Vesletuva (comp. Fig. 20)

Photo K. Pękala

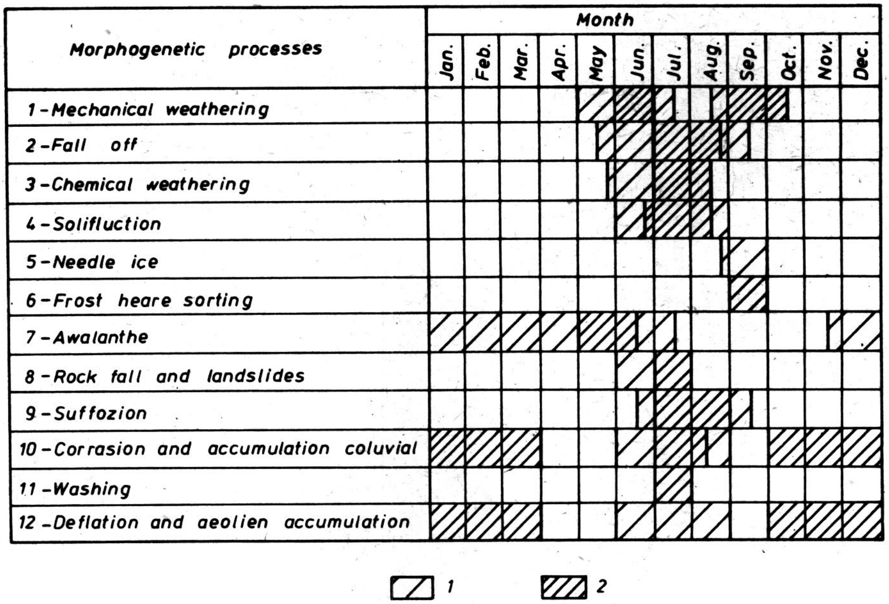

Fig. 25. Annual rhythm of morphogenetic processes in nival and subnival stages 1 — weak intensity, 2 — strong intensity.

The following types can be distinguished:

a) weathering waste „in situ" on flat and slightly inclined planes (mountain top detritus),
b) rubbles on steep slopes (block or debris slope),
c) talus-landslide covers (scree slopes),
d) covers of talus fans with rockfalls,
e) solifluction covers,
f) covers of „grézes litées" type,
g) morainic deposits.

a) Weathering waste occurs „in situ" on slightly inclined slopes or on flattenings of cryoplanation type. It is popular on a watershed crest between Tuvbreen and Fuglebreen, on a crest and ledges (glacial barks) of Tuva, on a roche moutonnée nuntak of the Eimfjellet group (Figs. 9 and 11). On the nunatak „Nunuś" the covers of this kind occur on the surface of a cryoplanation terrace just by a frost cliff (Figs. 16, 17, 18 and 26. Such covers are only slightly displaced, size of the waste is varying whereas block and debris fraction predominates.

b) Rubbles on steep slopes (inclined up to 40°) are connected with a mother rock and form a block-debris waste. Such covers occurring on the Ariekammen slopes are called the consequent ones (Martini 1975). In the lower parts of the slopes they include an admixture of fine fractions and many of their structural features result from the shape of block and debris waste. From a chronological point of view two series were distinguished: present and older than a thousand years (Fig. 15).

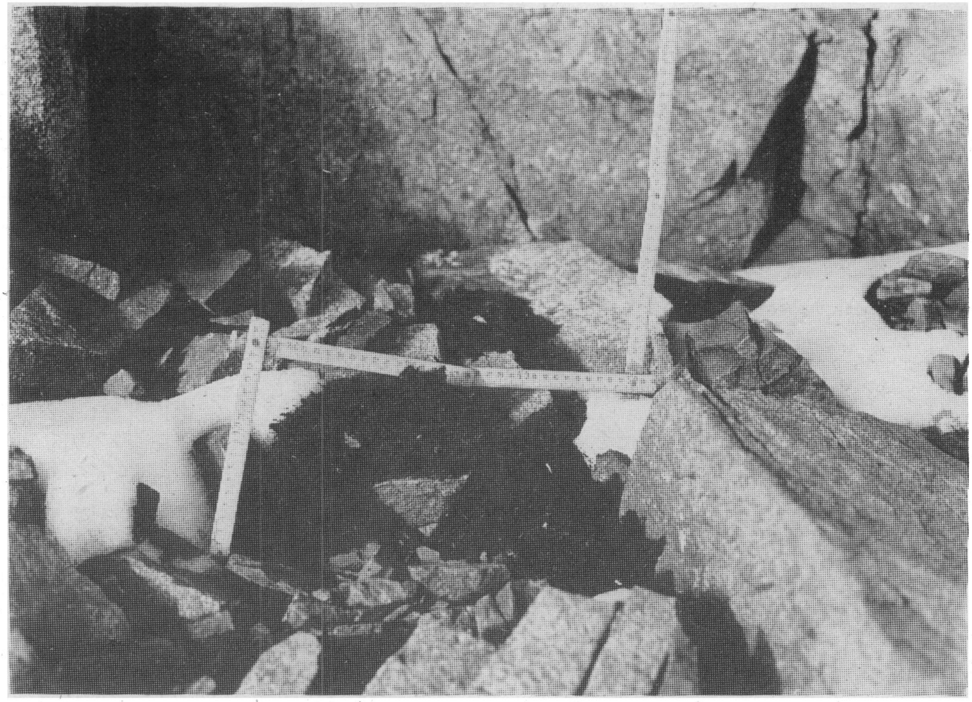

Fig. 26. Fossil plants dated for 930 ± 135 BP (Gd-278) found at the nunatak ("Nunuś")
Photo K. Pękala

c) Scree slopes occuppy an intermediary place between rock rubble and talus fans. Usually they compose of a complex of mature talus fans, generally strictly connected with outcrops of rock (Figs. 10 and 27). The covers of this type are displaced gravitationally due to nival, landslide and solifluction processes.

d) Talus fans with rockfalls are the most popular type of covers occurring in subnival and nival stages. Usually they occuppy the foot of steep slopes modified by nival processes, corrasion and erosion. For their distinct morphologic features they have been frequently analyzed (Jahn 1947, Różycki 1957, Rapp 1960, Piasecki 1968). The talus fans on the analyzed slopes are of a complex lithological structure and age. Nowadays another phase of their formation or of their adding can be noted (Figs. 13, 26, and 27 and Table IV). On the slopes above the lower snow limit the talus fans are formed with a participation of avalanches. Their structural and textural features are lightly different than the ones of typical talus fans.

e) Solifluction covers occur on the nunatak slopes that are mainly exposed southwards and westerds and in the zones occuppied by rocks supplying with fine clayey waste (Figs. 7, 8, 27 and 28). Within these covers a specific microrelief has developed due to mass movements in humid conditions: debris stripes and lobes, terraces. On slightly inclined planes there are polygonal grounds (Fig. 24). On the basis of structural

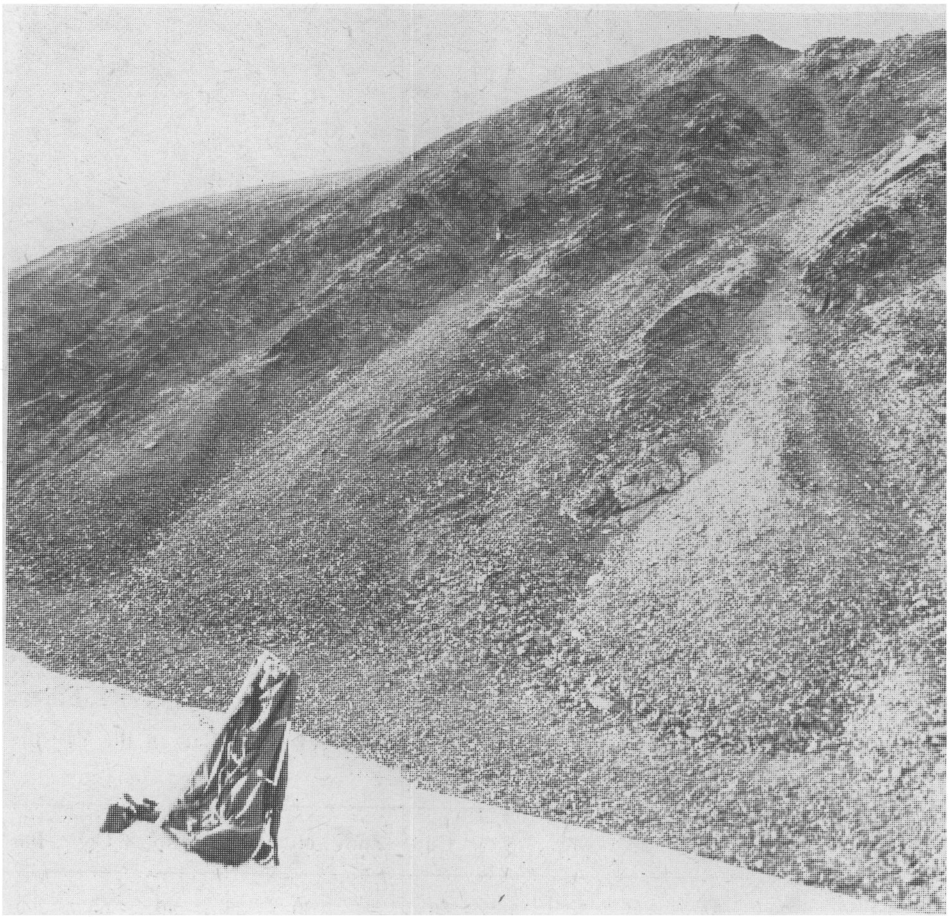

Fig. 27. Fresh talus overlying the lateral moraine of Veslebreen; Vesletuva
Photo K. Pękala

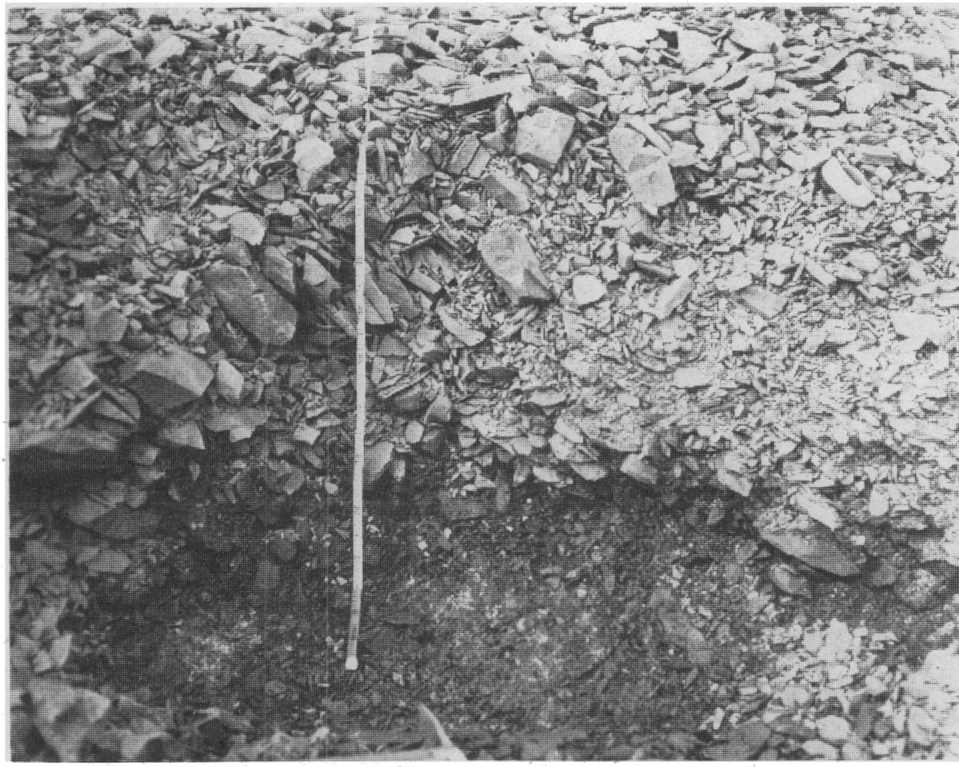

Fig. 2 . Solifluction covers on a southern slope of the nunatak Vesletuva
Photo K. Pękala

Table IV.

Content of trace elements (ppm) in cover deposits on a south-eastern slope of the Vesletuva nunatak

Sample number	B	Pb	Mn	Mo	V	Cu	Zn	Ni	Co	Sr	Cr	Ba
83	70	35	370	5.2	86	50	74	30	23	40	66	290
84	70	76	380	6.2	82	52	140	37	30	18	52	148
85	86	trace	700	8.2	78	70	trace	42	33	52	58	330
86	80	„	800	7.6	64	37	140	40	34	58	54	480
81	70	„	560	9.0	80	38	180	43	38	21	48	156
82	76	„	400	5.4	64	46	40	32	24	42	56	290

and textural features, chemical composition and radiocarbon datings two generations of solifluction covers were distinguished: a present cover and the one preceding the Little Ice Epoch.

f) In a typical nival stage and in the rocks supplying with fine weathering waste there are the covers rhythmicaly stratified parallel to a slope surface. Such deposits are known to be called the „grézes litées" (Guillien 1951, Dylik 1955, Jahn 1961). They were found at Kopernikusfjellet, Tuva and Vesletuva.

g) Morainic deposits in the nival stage form the agglomerations of mineral matter of varying age on surfaces of glaciers and on firn fields. Instead, in the subnival stage they form lateral moraines (Figs. 7, 8, 9, 11 and 23. Hornsund moraines have been described by many geomorphologists among others by Szupryczyński (1963, 1968), Troickij (1967), Troickij et al. (1975), Karczewski and Wiśniewski (1976, 1979) so, in the present analysis. a particular attention was paid to dating of these deposits. The morainic deposits at the nunatak in the Eimfjellet group were found to be underlain by fossil flora dated for 590 ± 90 years BP (Qu-157, P-2). The morainic deposits form three series that overlie one another (Fig. 11); these series are at various phases of their overgrowing by vegetation (Fabiszewski 1975). These flora assemblages should be paralleled with the ones melted out in the forefield of the Werenskiöld Glacier at the ground moraine (Baranowski and Karlén 1976). They are most recent morainic sediments dated for the first time in the nunataks of the Hornsund area.

5. Phases of evolution of processes and covers during Holocene

The evolution phases of morphogenetic processes and cover deposits should be considered at the background of changes of Spitsbergen glaciation during Holocene. This problem was already discussed by Szupryczyński (1968), Boulton and Rhodes (1974), Baranowski and Karlén (1976), Baranowski (1971) and Boulton (1979), On the ground of accessible datings and of isostatic movements of the coast they distinguished six phases of climatic changes resulting in advance or retreat of Spitsbergen glaciers.

A period before 11 000—7 000 years was specific for its intensive isostatic uplift of the land due to vast deglaciation. It resulted in loosening of rocks, in an increase of physical weathering and accelerated the gravitational processes.

A period before 7 000—3 500 years is the main phase of climatic optimum with a great glaciation stability and small isostatic movements, The rubble covers overgrown by vegatation were submitted to chemical weathering. Processes of frost sorting, washing and solifluction were also active.

In period 3 500—2 000 years ago there was another glacier advance that accelerated the nival processes, resulted in removal of waste covers at nunataks and in destruction of vegetation.

In a period 2 000—600 years ago there was a retreat of the glaciers and of the coast line. In result the bedrock was loosened whereas weathering and gravitational processes were activated. The vegetation has also covered the nunataks with a delay of about 1 000 years in comparison with a zone of glacier forefields. So, a chemical weathering was accelerated.

600—100 years ago there was a cooling of the so-called Little Ice Epoch during which the vegetation at nunataks was destructed or fossilized. Processes of weathering and gravitational denudation were activated.

During the last 100 year mass loss and glacier retreat are noted. At the same time the vegetation considerably enters the covers of a subnival stage, particularly the older sediments with remnants of fossil soils of the Viking period.

Instead, the present period is for the slope processes modelling relief and covers, the phase of slight increase of weathering and of activation of gravitational processes. Most covers, especially the coarse-clastic ones, are in an unstable equilibrium.

6. Summary

In 1973 the investigations were carried through at the nunataks of Werenskiöld and Hans glaciers (Figs. 1, 2 and 3) to study a dynamics of morphogenetic processes of nival and subnival stages and their influence on development of slope covers.

On the background of a general description of physicogeographical conditions an evolution of morphogenetic processes is presented with an attempt of their quantitative analysis.

A relief of the analyzed area (Figs. 7, 8, 9 and 17) is created by many processes among which the most important are: physical weathering, gravitational processes and niveo-aeolian processes. An index of weathering and rock fall equals 340—580 g/m^2 per year (Table I): the maximum values are noted close to the snow limit. On the base of radiocarbon dating of the deposits the upper parts of slopes are found to get lowering from 0.2 to 0.5 mm per year. A considerable morphogenetic part is played by snow and snow-debris avalanches that result in formation of nival niches, corrasion gullies and talus fans at the slopes (Figs. 9 and 10). In result of solifluction the deposits are displaced 3—5 cm every year. A mean index of annual niveo-aeolian processes in a stage of analyzed nunataks equals 117 g/m^2.

The morphogenetic processes that create nival and subnival stages keep changing in an annual cycle (Fig. 25) due to morphoclimatic conditions.

Among the cover deposits that develop nowadays, several types were distinguished on the ground of their origin and morphological relations. Taking into their age the colluvial deposits of weathering-gravitational origin are differentiated. Their age was suggested by radiocarbon dating of fossil flora assemblages found for the first time in 1973 at the nunataks in a nival morphoclimatic stage (Figs. 11, 15 and 16).

On the basis of process analysis and morphological criteria as well as of data of absolute datings the evolution phases of morphogenetic processes and of cover formation in Late Holocene were distinguished.

7. Резюме

В 1973 г. на нунатаках Ледников Ханса и Веренскиольда (Шпицберген), (рис. 1, 2 и 3) проведено исследования динамики морфогенетических процессов нивального и субнивального этажа, а также их влияния на формирование склоновых покровов.

На фоне общей характеристики физико-географических условий представлено развитие рельефообразных процессов, вместе с попыткой их количественного анализа.

Рельеф исследованной местности (рис. 7, 8, 9 и 17) формирует группа процессов, среди которых решающую роль играют: физическое выветривание, гравитационные

и нивео-эолические процессы. Указатель выветривания и оседания составляет 340—580 г/м²/год (таблица I), причём максимальных величин достиг вблизи границы вечных снегов. Используя датирование осадков методом ^{14}C подсчитано, что верхние участки склонов понижались в год на 0,2—0,5 мм.

Большое рельефообразное значение имеют лавины снежные и снежно каменные, под их влиянием, на склонах развиваются нивальные ниши, коррозийные ущелья и россыпные конусы (рис. 9 и 19). Итогом солифлюкции является перемещение материала в темпе 3—5 цм/год.

Средний указатель годовых нивео-эолических процессов в этаже исследованных нунатаков составляет 117 г/м².

Морфогенетические процессы формирующие нивальный и субнивальный этаж меняются в годовом ритме (рис. 25) в связи с морфоклиматическими условиями.

Среди покровных образований актуально формированных в.у. процессами выделено несколько типов в зависимости от генезиса и морфологических отношений. В вековом отношении колювиальные образования с выветренно-гравитационным генезисом являются разнообразными. Они документированы исследованиями ^{14}C ископаемых флор впервые найденных в 1973 г. на нунатаках, в нивальном морфоклиматическом этаже (рис. 11, 15 и 16).

Основываясь на анализе приведенных процессов и морфологических критериев, а также данных с абсолютных датирований выделено фазисы развития морфогенетических процессов и образования покровов в младшем голоцене.

8. Streszczenie

W 1973 r. prowadzono na nunatakach Lodowców Hansa i Werenskiölda (Spitsbergen), (rys. 1, 2 i 3) badania dynamiki procesów morfogenetycznych piętra niwalnego i subniwalnego oraz ich wpływu na kształtowanie pokryw stokowych.

Na tle ogólnej charakterystyki warunków fizyczno-geograficznych przedstawiono rozwój procesów rzeźbotwórczych wraz z próbą ich ilościowej analizy.

Rzeźba badane o terenu (rys. 7, 8, 9 i 17) kształtowana jest przez zespół procesów, spośród których decydującą rolę odgrywają: wietrzenie fizyczne, procesy grawitacyjne i niweo-eoliczne. Wskaźnik wietrzenia i odpadania wynosi 340—580 g/m²/rok (tabela I), przy czym maksymalne wielkości osiągnął w pobliżu granicy wiecznych śniegów. Wykorzystując datowanie osadów metodą ^{14}C obliczono, iż górne odcinki stoków były obniżane rocznie od 0,2 mm do 0,5 mm. Duże znaczenie rzeźbotwórcze mają lawiny śnieżne i śnieżno-gruzowe, pod których wpływem na stokach rozwijają się niższe niwalne, żleby korazyjne i stożki usypiskowe (rys. 9 i 10). W wyniku soliflukcji odbywa się przemieszczanie materiału w tempie 3—5 cm/rok.

Średni wskaźnik rocznych procesów niweo-eolicznych w piętrze badanych nunataków wynosi 117 g/m².

Procesy morfogenetyczne kształtujące piętro niwalne i subniwalne zmieniają się w rytmie rocznym (rys. 25) w związku z warunkami morfoklimatycznymi.

Wśród utworów pokrywowych współcześnie kształtowanych prze w/w procesy wydzielono kilka typów w zależności od genezy i stosunków morfologicznych. Pod względem wiekowym utwory koluwialne o genezie wietrzeniowo-grawitacyjnej wykazują zróżnicowanie. Udokumentowane one zostały badaniami ^{14}C flor kopalnych znalezionych po raz pierwszy w 1973 r. na nunatakach w niwalnym piętrze morfoklimatycznym (rys. 11, 15 i 16).

W oparciu o analizę opisanych procesów i kryteria morfologiczne oraz dane z datowań bezwzględnych wydzielono fazy rozwoju procesów morfologicznych i tworzenia się pokryw w młodszym holocenie.

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