Pirineos, 136: 19 a 32. Jaca, 1990

OBSERVATIONS ON NIVATION AND ITS GEOMORPHOLOGICAL EFFECTS IN MOUNTAINS AT HIGH LATITUDE (WITH MT. NJULLA MASSIF IN NORTHERN SWEDEN AS EXAMPLE)[1]

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ABSTRACT.- This paper presents the geomorphological role of snow patches in the remodelling of mountain slopes in the periglacial zone based on the results of morphological mapping of Mt. Njulla region, Northern Sweden. Effectiveness of nivation is strongly controlled by geological structure. On the Eastern slope, at the foot of the hillside, nivation processes play a critical role in the creation of numerous transverse nival hollows and cryoplanation terraces. On the western slope, meltwater, originating from snow patches, facilitates weathering and transportation of wastes downslope. Vegetation of the studied region is influenced by nivation. Effects of nivation are limited to reshaping of the relief.

RESUMEN.- Este trabajo presenta el papel de las manchas de nieve en la evolución de laderas de montaña de la zona periglaciar, apoyándose en los resultados de cartografía geomorfológica de la región de Mt. Njulla, Norte de Suecia. La eficacia de la nivación está fuertemente controlada por la estructura geológica. En la vertiente oriental, al pie de la ladera, los procesos de nivación juegan un papel crítico en la creación de nichos nivales transversales y de terrazas de crioplanación. En la vertiente occidental, el agua de fusión, que surge de las manchas de nieve, facilita la meteorización y el transporte de materiales ladera abajo. La vegetación de la región estudiada también se halla influida por la vegetación. Sin embargo, los efectos de la nivación se limitan a retoques en el relieve.

RESUMÉ.- Dans cette étude on a discuté le rôle géomorfologique des taches de neige dans la transformation du relief dans la zone périglaciére, à la base de l'analyse de la carte morphologique de la région de Njulla, au nord de la Suède. On a constaté un rapport évident entre les effects des processus de nivation et la structure géologique. Sur le versant est formé sur le front de l'escarpement structural, les processus de nivation jouent un grand rôle dans la formation des niches nivales transversales ou des terrasses de cryoplantions. Sur le versant ouest l'eau provenant des taches de neige fondantes joue

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1 Received April, 1991

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un grand rôle dans l'érosion et dans le transport des éboulis en aval du versant. On peut observer également l'influence des processus de nivation sur le tapis végétal dans cette region. Néanmoins les effets de nivation sont limités à la retouche faible du relief herité.

Key words: *nivation, cryoplanation, geological structure, vegetation.*

Snow is considered to be a very important geomorphological agent in the periglacial zone (TRICART, 1970; WASHBURN, 1979; FRENCH, 1976; THORN, 1978), and nivation acting in the vicinity of numerous longlasting snow patches is treated as one of the most important processes modelling the relief. Geomorphological literature dealing with nivation effects is very comprehensive. However, only a few papers provide quantitative characteristics of forms and processes. Studies by Swedish geomorphologists emphasize the varying effectiveness of nivation in the mountains of Swedish Lapland (RUDBERG, 1972; RAPP, 1983; RAPP *et al*, 1986).

This paper's aim is to determine: 1) geomorphological role of snow patches in relation to local geoecological conditions; 2) differentiation of forms and processes associated with the presence of snow patches. The following discussion is based on geomorphological mapping on a scale 1: 25,000 performed during two weekly studies in summer of 1986 and 1988.

The study area is located in northern Sweden, north of the Arctic Circle, 68°21´ N and 18°15´ E on the southern shore of Lake Törnetrask in subarctic region. Njulla massif, where the studies were carried out, reaches up to 1169 m a.s.l. and protrudes high above Törnetrask Lake which is located at 341 m a.s.l. (Fig. 1).

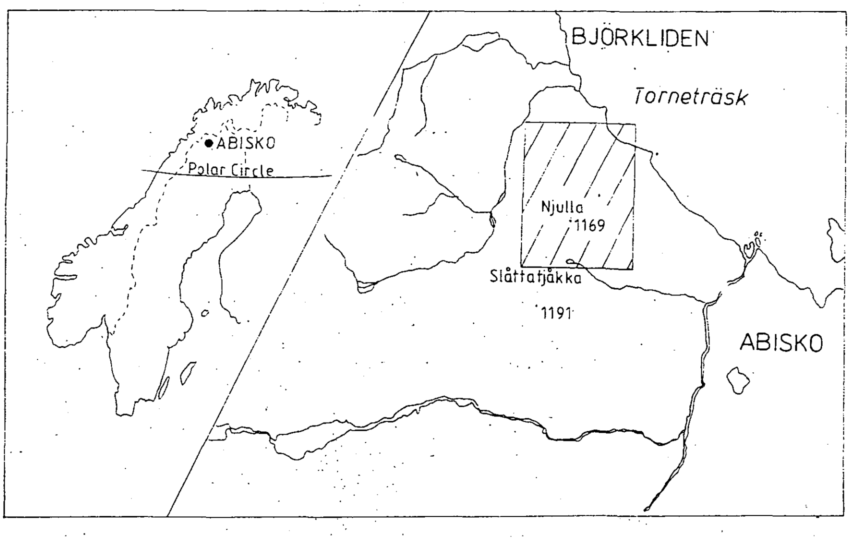

Fig. 1: Location of the study area.

1. Geological characteristics of the area

Njulla massif, like other mountain ridges occuring west of Abisko, is mainly formed by schists and marbles. Below, at lake level, there is a hard schists layer which is a complex of light, quartzitic schists with abundance of feldspar and is interbedded with dolomite marbles. This complex is overlaid with calcite marbles over which the biotyte schists series, covered with a series of a more resistant graphite schists, occurs. The uppermost part of the massif is built of less resistant and rather finely laminated granite-mica schists which fall apart into flat chips of various sizes during weathering and which produce a large amount of fine weathered material. Layers dip generally due west i.e. in the direction of the overlap (KULLING, 1964; LINDSTRÖM, 1955).

In the massif's morphology, particularly in its NE, E and SE slopes, there is an abrupt change in inclination at the height of 700–800 m a.s.l. It has been formed due to slopes undercut by valley glaciers which have remained after ice-sheet ablation (RUDBERG, 1962). In the case of steep undercut slopes (inclination of 30–40°), the major relief modelling factors are: snow avalanches, debris-mud flows and slush avalanches. Above the steep slopes, in lower sections of Njulla slopes, there is a gently sloping plateau with mature slopes and well pronounced structural escarpments. It should be emphasized that slopes in that region are covered with thin weathering mantle while some fragments of the slope are without mantle. Most frequently the thickness of weathering mantle does not exceed 0.5 meters. In the summit area, there are block fields originating from weathering *in situ*. On the lower located slopes, in the composition of weathered material, there are more fine particles (of sandy and loamy fractions) in which larger fragments are stacked. The middle and lower parts of the slopes facing S and SW are covered with almost continuous weathering mantle. Therefore, various cryogenic processes, especially solifluction, can develop. Sward cover on the slopes is frequently subjected to solifluction of the weathering cover beneath it. Fragments without weathering cover are very common on eastern slopes. Swedish scientists opinions on the presence of permafrost in that region are diverse. Despite the fact that some relief features suggest the presence of permafrost, the majority of Swedish geomorphologists disagree with it. According to AKERMAN & MALMSTRÖM (1986) permafrost may only occur in swamps and peat areas and according to LINDH (1984) only in the high parts of mountains. It can be expected in a lowering between Njulla and Slättatjäka in the region in question.

The study area is under maritime subartic climate. Climatic records are limited in the case of areas located at higher elevations. Table 1 presents fundamental available data on temperature and precipitation after ERRIKSON (1982, 1987). The thickness of snow cover varies from 76 to 100 cm and reaches maximum in March. In winter snow cover is discontinuous. Numerous parts of the slopes where snow is blown away are subject to frost weathering (mainly on convex sections of the slopes). The temperature does not often pass above freezing point; only a few times a month in summer time according to RAPP's measurements (1960). Daily changes do not occur, there are only two seasons: polar day and night. After the melting of snow cover, snow patches and snow fields are present mainly on E- and N-facing slopes; this is related to blowing of snow by prevailing western winds. Snow fields and patches are frequently associated with the surfaces of structural terraces. Smaller, irregular round snow patches occur on talus slopes. In the case of southern and western slopes, snow patches are present at the height of 1100-1169 m a.s.l. According to the results of the studies of LINDH & NYBERG (1989) areas of patches decrease by 20-30% on average when compared with maximum areas which are reached after patches have been formed out of continuous snow cover in June.

TABLE 1
Precipitation and temperature characteristics

Station	Altitude m.a.s.l.	Location towards Njulla	Precipitation mm mean annual	January	June	% solid precip.	Temperature °C mean annual	January	June
Abisko	388	E	460	25	52	40	-0.9	-11.7	11.3
Njulla	655						-1.3	-10.7	10.2
Läktatjäkko	1220	W	2190	220	100	80			
Katterjäkk	515	W	1230	69	80	51	-1.7	-11.7	10.5
Riksgränsen	508	W	1425	80	93	51	-1.5	-11.3	10.5

Source ERIKSSON (1982, 1983), HOLMGREN - personal communication

A characteristic feature of vegetation in the studied area is its zonal pattern. The tree line is located between 550-650 m a.s.l. (SONESSON & LUNDBERG, 1974). According to RUNE (1965) classification a zone of subalpine birch forest forming the tree line can be distinguished. Above, up to an elevation of 600-800 m there is a low alpine belt of willow shrubs and lower vegetation zone. This zone is subdivided into several groups depending on exposition and substratum. At the height of 1000-1050 m, there is a middle alpine belt of mainly low alpine plants where numerous plant associations occur according to the vegetation map (ANDERSSON, 1983). Characteristics of plant associations are given in Table 2. Above this zone, the high alpine belt of mainly mosses and lichens and without vegetation in the prevailing parts occurs.

TABLE 2
Characteristic of vegetation types after Vegetationskarta Över de Svenska Fjällen. Kratblad nr 2 Abisko

Type	Main species	Altitude m.a.s.l.	Altitudinal belts after RUNE (1965)
Grass heath	Carex bigelows Juncus trifidus	>1020	
Extreme dry heath	Loiseleuria Arctostaphylos alp.	>960	
Dry heath	Vaccinium myrt. Empetrum herm. Betula nana	>500	middle-alpine belt
Fresh heath	Betula nana Salix spp Juniperus	>460	
Meadow with low herbs	Poaceae Asteraceae Saxifraga	>780	
Willow shrub	Salix	>600	low-alpine belt
Birch forest -heath type with mosses	Vaccinum myrt. Empetrum herm. Juniperus	<600	sub-alpine birchwood belt
Birch forest -meadow type with tall herbs	Salix spp Prunus padus	<500	

2. Morphology of the area and processes

There is a strong contrast in the morphology of the eastern and western slopes of Njulla (Fig. 2), related to the geological structure of the area. The longitudinal profile of the western slope is graded against the eastern slope which is step-like in profile. As has already been mentioned, geological strata dip towards the west, and because of this the eastern slopes of the masif form the toe of the *cuesta*. Due to the differing resistance of the strata, numerous terraces or benches of various sizes have been eroded. The largest bench is found on the northern slope, along Törnetrask Lake at a height 900-950 m a.s.l. This bench has been eroded within less resistant schists overlying marbles. Differences in lithology are reflected in vegetation as well. Composition of vegetation on the bech surface has indicated that limestone rocks are present in the substratum.

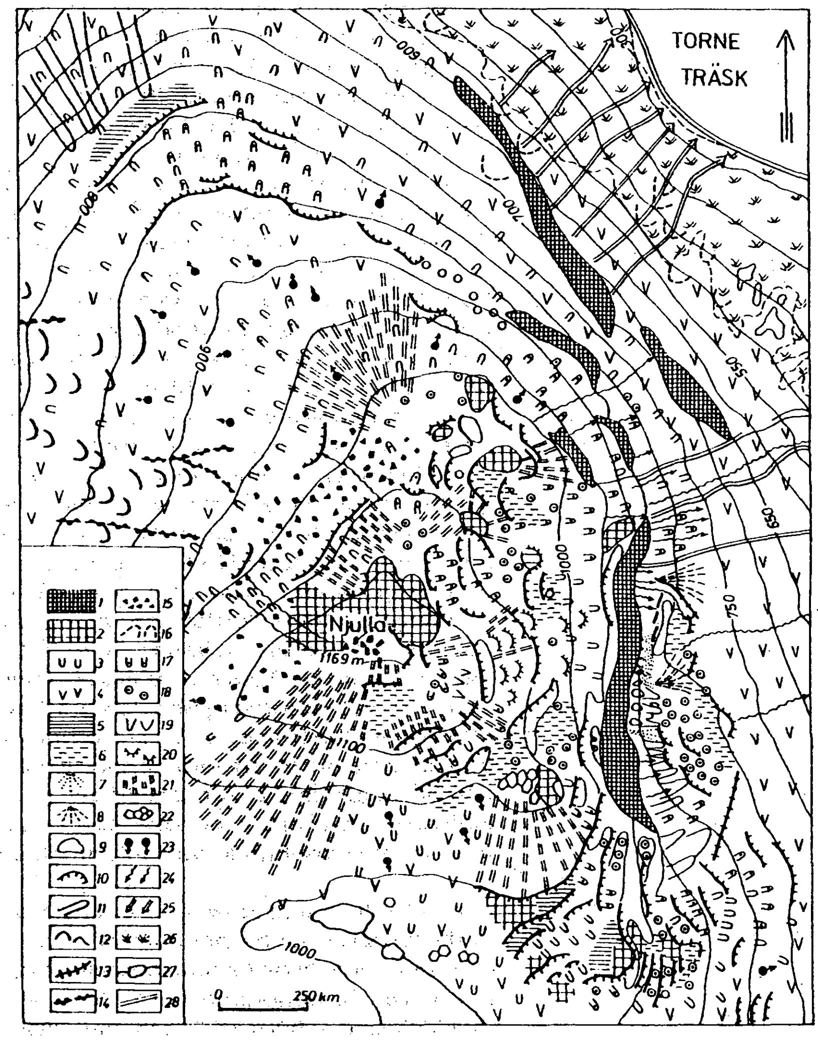

Fig. 2: Geomorphological map of Njulla Massif. 1 - rocky wall or rocky slope. 2 - rocky outcrops. 3 - debris-mantled slope remodelled by solifluction and soil creep. 4 - debris-mantled slope stabilized by vegetation. 5 - surfaces of planation. 6 - zone of highly saturated weathering cover (swampy area). 7 - snow patches. 8 - scars of transverse nivation hollows or cryoplanation terraces. 9 - depression without distinct scars. 10 - longitudinal nivation hollows. 11 - protalus ramparts. 12 - structural ridges. 13 - gravitational talus cone. 14 - alluvial talus cone. 15 - blockfields. 16 - soil creep niches. 17 - solifluction due to meltwater. 18 - creep of highly saturated waste. 19 - solifluction tongue. 20 - solifluction terracettes. 21 - non-sorted strips. 22 - polygons. 23 - ploughing blocks. 24 - rill erosion. 25 - debris flows and avalanche gullies. 26 - birch forest. 27 - lake. 28 - road from Kiruna to Narvik.

The morphological features of ledges occurring on the eastern slopes of the massif coincide with descriptions of cryoplanation terraces (JORRÉ, 1933; DEMEK, 1969). The ledges in question are up to a few hundred meters wide. Inclinations of the ledge surfaces are 4-6° and certain fragments are almost horizontal (gradient 1-2°). Here, 3-6 m high-frost riven scars are steep and their gradients reach 40-60°. The rocky surfaces of the ledges are frequently lacking weathering mantle. In the case of weathering mantle presence, a rich, complex of landforms created by solifluction or cryogenic processes (including polygons of various types) occurs over the bench. If slope gradients are larger, ca. 15-20°, there is a tendency for 1-2 m wide unsorted-debris strips to be developed. The strips, built of fine weathered material with protruding coarser stones of which the long axes are oriented in the direction of slope dip, are separated by sward with dwarf willow. Debris strips are often dissected by 0.2-0.3 m high transverse terracettes. At numerous spots under the lee of ledge-scars there are transverse snow patches which are several hundred meters long and up to 10 m thick. Presence of those snow patches is the real reason for increased moisture and twice as intensive mechanical weathering of scars (NYBERG, 1986). Water dripping over the scars originates from the melting of a lingering snow patch located above and shows oversaturation of substratum. In locations where snow patches are found transverse nival hollows or even cryoplanation terraces are formed. In certain fragments of nival hollow floors, however, there are nival pavements remodelled by frost action. Numerous cobbles vertically positioned show upfreezing of objects. Meltwater from the snowpatch saturates the weathering cover beneath and promotes development of more or less regular polygonal landforms of various kinds. Figure 3a presents the most common sequence of such landforms. At the most distant spot from the snow patch, i.e. where the solid bedrock is likely to be closest to the surface, there are only grass tussocks submerged in water. The final element of the landform series is usually another ledge undercut by a scar of consequent terrace.

If the gradient of the floor of the nivation hollow or that of the terrace surface is larger and if the thickness of weathering cover is larger, then abundant flow of meltwater from snow patches causes solifluction or creeping of highly saturated wastes (Fig. 3b). Such phenomena have been observed on slopes oriented to SE at the height of 900-1000 m a.s.l. Solifluction lobes are frequently countersunk into the subsequent terrace or hollow located downslope. The front of such solifluction lobe is ca. 1 m high (maximum - a few meters high, and ist gradient reaches 20°. Inclination of the lobe surface is ca. 10°. According to RAPP's measurementes (1960) the solifluction rate is up to 30 cm/year depending on inclination.

In the case of slopes oriented to NE, where gradients are steeper, wastes highly saturated with meltwater from the snow patch are subjected to creeping. The slope surface, usually with poor moss tussocks, is characterized by a tendency for the hummocks to be developed in a form of small, several cm long lobes with semicircles over them. In lee of the hummocks, which are faces of the semicircles, there are small depressions filled with water.

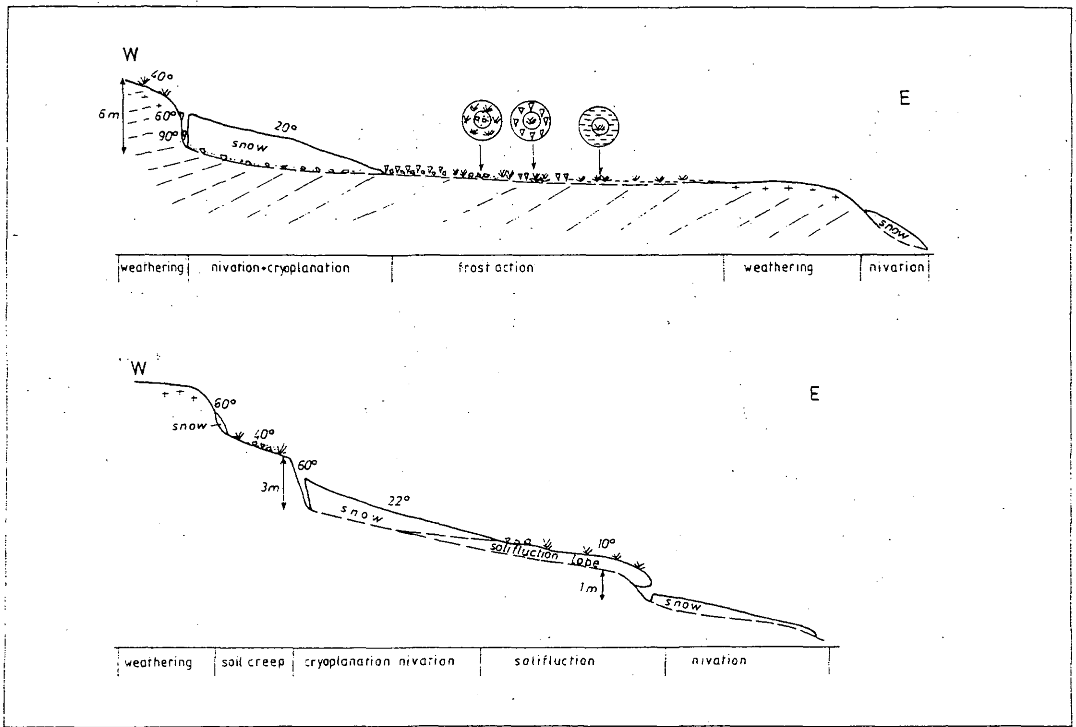

Fig. 3: Cross-profiles of nivation hollows and cryoplanation terraces on the east facing slope of Njulla Mt.

Presence of snow-patches on the surface of extensive benches shows the contribution of nivation to their evolution. Some of them exhibit features typical of transverse nival hollows, e.g. slightly overdeepened floors. Features of others correspond to cryoplanation terraces described in literature. However, it is often doubtful whether the form is either a structural bench or nival hollow or cryoplanation terrace. Measured strikes of the strata coincide to a large extent with strikes of scars under the lee of which the snow patches occur. The azimuth of strata strikes is ca. 340° while that of scars varies from 0-34°. Undoubtedly scars of nival hollows and cryoplanation terraces are structurally controlled, although in certain locations the scars of those landforms cut off structural benches which have been probably formed due to glacial erosion. Nevertheless, development of those landforms without structural control, only as an effect of nivation, would not have been possible.

Particularly interesting is the largest bench located on NE slope, located on the side of Törnestrask Lake (Fig. 4). In the west this bench is limited by a tremendous rocky wall protruding up to ca. 1000 m a.s.l., i.e. the wall is ca. 100 m high. Extensive snow patches are found above the bench while gravitatio-

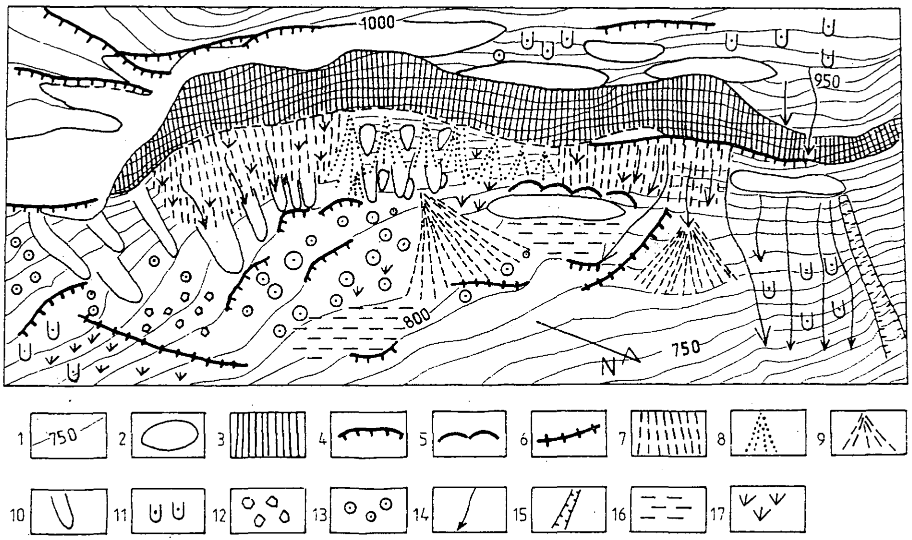

Fig. 4: Geomorphological map of the structural bench. 1 - contour line. 2 - snow patch. 3 - rocky wall and rocky slope. 4 - scars of nivation hollows. 5 - depression without distinct scars. 6 - protalus rampart. 7 - talus heaps. 8 - gravitational talus cone. 9 - alluvial talus cone. 10 - solifluction tongue. 11 - solifluction due to meltwater. 12 - polygons. 13 - creep of highly saturated waste. 14 - rill erosion. 15 - debris flow and avalanche gullies. 16 - zone of highly saturated weathering cover (swampy area). 17 - debris-mantled slope stabilized by vegetation.

nal processes have formed talus heaps and talus cones at the foot of the bench. The bench surface is almost flat and its gradient reaches 4-6°. To the south and north of the bench there are inactive protalus ramparts descending downward. The ramparts are 2-5 m high. The ramparts in question were probably formed under conditions of more severe climate during deglaciation when the bench was occupied by a huge patch of permanent snow. This climate probably caused intensified weathering and various wedging effects which, in turn, promoted the formation of protalus ramparts at the foot of the snow patch. It should be emphasized that at present not only protalus ramparts are absent in the Njulla region, but rocky walls suitable for delivery of weathered material necessary for formation of such ramparts as well. Water flow from the snow-patch occurring above the southern rim of the bench generates large solifluction tongues which almost reach the bench floor. Smaller solifluction lobes reaching the flat bench floor (Fig. 5) develop at the foot of the talus heap. Meltwater flowing over rocky walls in gullies dissects the talus heap with erosional troughs (0.5 m deep at average) and forms the lobes mentioned above. The bench surface, in turn, is dissected by scarps of small semicircular nival hollows in which diameters and depths reach several meters and which are arranged in step-like pattern. Large fragments of the bench are swampy indicating that bedrock is very close to the surface. In the direct vicinity of rocky walls, on talus slopes, there are small nival depressions. They are formed due to the fact that the presence of snow-patches over the fragments of talus slopes is protection against the accumulation of debris delivered from rocky walls by gravitational processes. The neighbouring snow-free areas are subjected to accretion. This way a concave landform is created in the accumulation zone. Such forms occur on talus slopes in the Alps and Tatras as well. Longitudinal profiles of slopes above the bench correspond to a model of concave periglacial slope (Fig. 5) proposed by JAHN (1975). The slope which was formed during deglaciation is subjected to degradation now and is secondarily dissected by nivation.

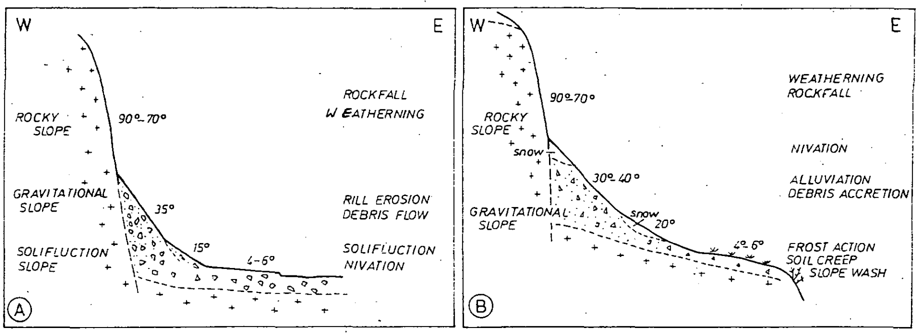

Fig. 5: Profiles of slope upon the structural bench. A - profile of talus heap, B - profile of talus cone.

The evolution of penestructural slopes takes place in a different manner. The opposite, western Njulla slopes are formed under the lee of the *cuesta,* and slope gradients are thus parallel to strata dips. The longitudinal profile of those slopes is almost entirely graded. These are rocky slopes with shallow weathering cover. In the uppermost parts, the slopes are covered with block fields originating from weathering *in situ.* The grain size composition of weathering cover changes in the lower parts of the slope. There, the amount of fine fraction increases and promotes various mass movements. Snow-patches in summer time can occur on that slope in the uppermost parts only, above 1000 m a.s.l. The zone between 950 and 1050 m a.s.l. is the area of intensive meltwater action from snow-patches. Water percolating via joints into rock cracks saturates and loosens a given rock causing its various wedging effects into blocks with the lengths of short axis of 0.5-1.0 m and of the longg axis of 1.0-4.0 m. Those blocks glide downslope over the saturated fine weathered material which acts as a lubricant. (Fig. 6). The orientation of the long axis in the direction of slope-dip shows the gliding. The lithology of schisths favours weathering of this type. Meltwater from the patches carries fine weather material into cracks. In the case of slopes of smaller inclination, ca. 20°, the same mechanism is responsible for formation of belts of smoothened bedrock outcrops without weathering cover but with single gliding boulders as well as for creation of belts of depressions elongated in the direction of the slope-gradient and filled up with creeping fine weathering cover in which single large cobbles are buried. Sometimes the weathering cover in question is fastened with sward. As the amount of fine material in weathering cover has increased, solifluction tongues and lobes or cover flowage develop on the slope below. In the lower part of the slope vegetation typical of dry heath occurs while that of fresh heath occurs at the height of 800 m a.s.l. On the discussed slope, there are numerous poorly developed depressions which favour formation of episodic snow patches. However, these depressions do not exhibit features characteristic of nival hollows. These might be older niches whose scars have been buried due to solifluction and which have been fastened by vegetation under conditions of milder climate. Snow patches occurring at present conserve only the shapes of the niches. Larger basin-like depressions which are likely to be structurally controlled are found on the slope in question as well.

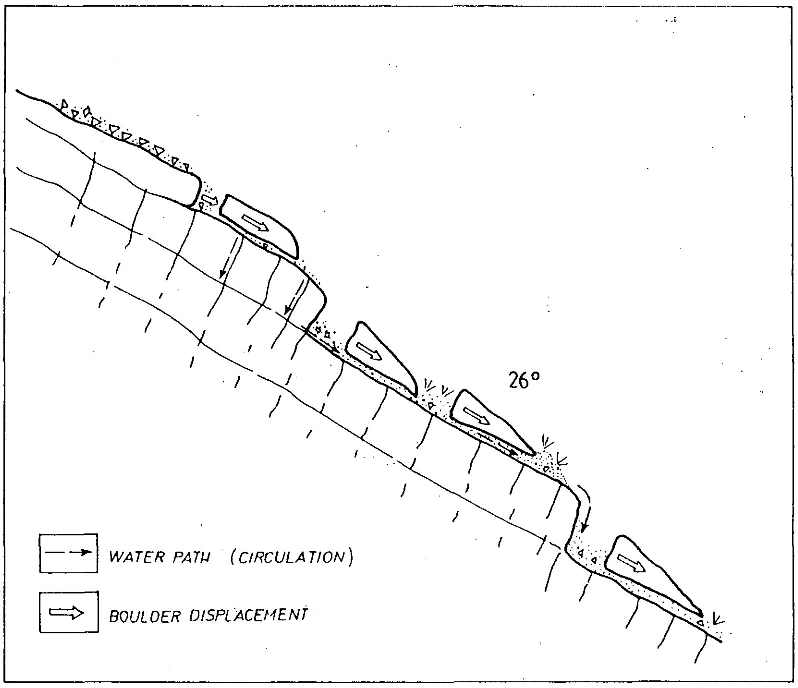

Fig. 6: Scheme of weathering and transport due to meltwater in upper part of the west facing slope of Mt. Njulla.

3. Geoecological relations between processes and vegetation

Figure 7 presents the nivation influence on differentiation of vegetation cover in that area. Types of plant associations and their ranges have been determined based on the vegetation map on the scale of 1:100 000 (ANDERSSON, 1983). Field mapping has contributed to the determination of complex of processes. Differentiation of both vegetation and processes is more pronounced on slopes oriented to E. That differentiation corresponds to step-like pattern of the slope profile and to prevailing western snowdrifts. Each terrace forms a geoecological micro-complex which, like the benches, is repeated within one geoecological zone. Changes in climatic conditions depending on elevation are determinants of geoecological zones. Above the zone of willow shrubs the mosaic of heaths of various types predominates. This reflects, among others, various moisture conditions which, in turn, are related to the presence of snow patches. The performed observations suggest much larger differentiation in that area than has been depicted on the map. Weathering is most important in vegetation-free terrains while slipping in various forms dominates in regions with sward. Mass movements are typical of the areas with shrubs and dwarf trees.

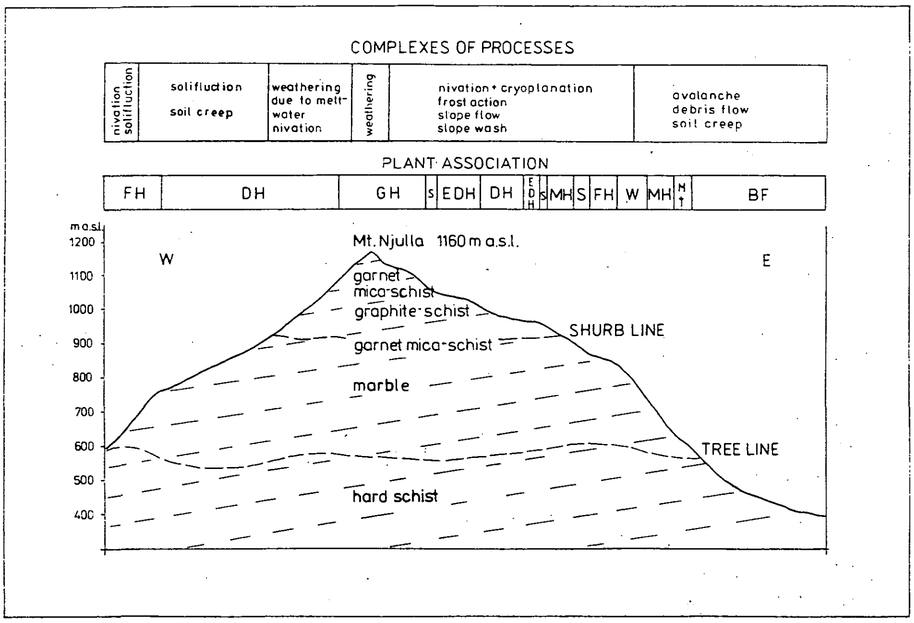

Fig. 7: Scheme of distribution of present-day geomorphological processes and vegetation types on the slope of Mt. Njulla. FH - fresh heath, DH - dry heath, EDH - extremly dry heath, GH - grass heath, MH - meadows with low herbs, MT - meadows with tall herbs, W - willow shrubs, BF - birch forest, S - snow patches.

4. Conclusions

Briefly discussed peculiarities of landforms in the Njulla region and nivation effectiveness in the remodelling of slope relief in this area allow one to state that nivation plays the dominant role in the present-day relief remodelling of the slopes of mountains found in periglacial climate zone. Common nivation processes show this. Snow patches occurring there are usually accompanied with geomorphological action of water flowing from melting snow. As results from the studies carried out in Njulla region, nivation effectiveness depends on the conditions under which the process takes place (particularly on lithology). In the case of slopes built of the same schists, nivation effects are different depending on the geological structure (referring particularly well to erosional effects). Relief of Njulla which has been remodelled by nivation was created by glacial erosion which has been structurally controlled. Nivation has eshaped the former relief only slightly. However, morphometry of some forms suggests that nivation was much more important in the past when more severe climate conditions existed. Therefore, present-day influence of nivation on the mountain reliefs of the periglacial zone is not as strong as is ascribed to it by certain scientists working in this area (ST-ONGE, 1969).

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