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SLOPE DYNAMICS IN THE PERIGLACIAL ZONE OF THE TATRA MTS

INTRODUCTION

The aim of this paper is to show some aspects of a present-day modelling of slopes in the periglacial zone of the Tatra Mts.

The Tatra Mts. are the highest, rising up to 2665 m a.s.l., mountain massif in the Carpathians. The uppermost part of the massif is mainly built of crystalline rocks, granites and schists. Relief has an alpine character and it is of glacial origin. According to JAHN (1958, 1975) the area of the Tatras above the upper timberline, i.e. above 1500 m a.s.l., is in a mild periglacial zone (Fig. 1). This is evidenced by periglacial forms such as solifluction lobes and terracettes, nival niches and patterned ground

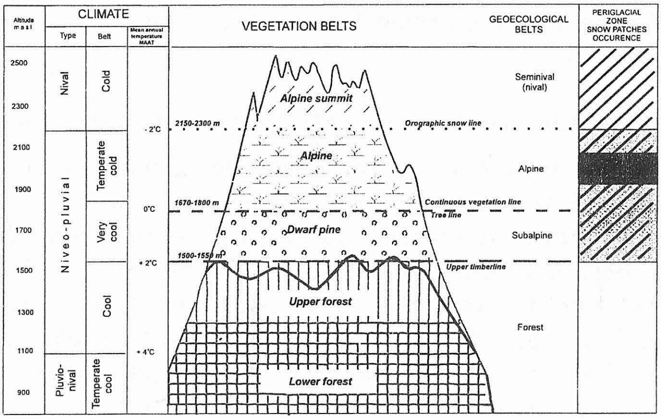

Fig. 1. Geoecological altitudinal belts and the periglacial zone on the northern slope of the Tatra Mts. (after A. KOTARBA 1976, modified)

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occurring in this zone. Based on geophysical examination Dobiński (1996, 1998) has stated here patches of permafrost. It should be noticed that not all the periglacial forms are active at present. This is especially the case if these forms occur at lower elevations. The most favourable climatic conditions for periglacial processes' activity (Fig. 1) are in a semi-nival zone where steep arêtes, rockwalls and rocky slopes prevail. Thus, at present formation of periglacial forms is mainly limited to alpine and subalpine zones.

The slopes in the periglacial zone develop due to action of periglacial processes such as: nivation, solifluction, frost creeping, frost heaving and action of needle ice, patterned ground, snow avalanches etc. That are particularly intensive during spring and autumn. During a summer season the slopes are modelled by non-periglacial processes which are related to water flow on slopes. The above include surface washing, linear erosion, debris- and earth flows as well as gravitational process such as debris- and soil creeping, and rock falls. The studies on the slope modelling processes in the discussed zone and on their rates and trends were carried out, among other, ~~by~~ Jahn (1958, 1979), Gerlach (1959), Kotarba (1976), Kotarba, Kaszowski, Krzemień (1987), Kotarba, Kłapa, Rączkowska (1983), Rączkowska (1993, 1995, 1997), Krzemień (1991), Dobiński (1996, 1998), Kędzia (1999). The studies were performed in the entire Tatra area and their results illustrate the slope dynamics in the periglacial zone of this region.

When considering the dynamics of the Tatric slopes in the periglacial zone one should answer the following questions; what are roles of periglacial and non-periglacial processes in the present-day slope modelling and which of them are more important for the slope development?

PERIGLACIAL PROCESSES VERSUS NON-PERIGLACIAL ONES

Nivation is one of the more important periglacial processes. Due to nival erosion nival niches are formed on mature slopes with a weathered material cover. Figure 2A presents an example of the niche developed on the slope of Beskid summit at elevation of 1700 m a.s.l. Based on the studies of 1989–1993 the rate of a niche edge retreat is estimated for 0–5 cm/year, especially due to frost heaving, needle ice action, linear erosion and creeping. The rate of the retreat varies in particular parts of the niches edges (Rączkowska, 1995, 1997). The floors of the niches are deepened by washing and linear erosion caused by both melt and rain waters. The weathered material is transported downslope for a distance of 1–2 m, and most often it is captured by sward. In the niche floor the material is transported by frost creeping or solifluction for the distance of a 10 cm per year. The nivation intensity and the rate of the nival niche development are rather small under average meteorological conditions in so called normal years.

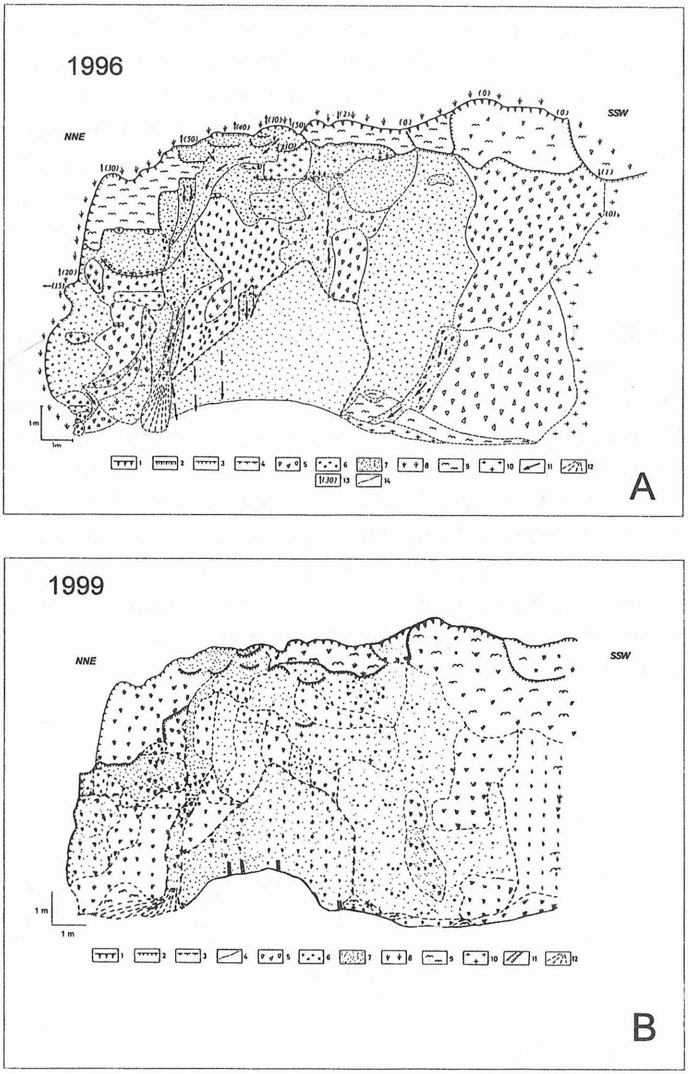

Fig. 2. Sketch of the nival niche on matured slope with weathering cover

A – 1996 year: 1. niche scarps > 60 cm; 2. niche scarps 40–60 cm; 3. niche scarps 20–40 cm; 4. niche scarps < 20 cm; 5. areas with debris of several cm in diameters; 6. areas with fine debris with admixture of sandy-clay material; 7. areas with predominating sandy-clay material; 8. tussocks and alpine sward; 9. mosses; 10. rocky outcrops; 11. erosional incisions and furrows; 12. alluvial cone; 13. magnitude of scarp retreat in cm/10 years; 14. line separating particular areas of the niche bottoms; B – 1999 year: 1. niche scarps > 40 cm; 2. niche scarps 20–40 cm; 3. niche scarps < 20 cm; 4. line separating particular areas of the niche bottoms; 5. areas with debris of several cm in diameters; 6. areas with debris with admixture of sandy-clay material; 7. areas with predominating sandy-clay material; 8. tussocks and alpine sward; 9. mosses; 10. rocky outcrops; 11. erosional incisions and furrows; 12. alluvial cone

Significant changes, especially in the floor of the niche shown in figure 2B, were formed during heavy rainfall of July 1997. Precipitation total of 4 days reached from 200 to 330 mm. The lower part of the niche has been dissected by numerous new erosional troughs. The weathered material, not only the finest but even rocky rubble up to a few centimetres in diameter, has been removed from a large portion of the niche floor. This way a solid rock has been exposed which can be subjected later to weathering processes. The weathered material was transported by rain-water downslope over the sward for a distance of a several dozen to a hundred metres. More pronounced changes in the niche front have not been observed. It should be noticed that the change in conditions of nivation process is an effect of the processes triggered by extreme precipitation.

On the other hand, on talus slopes in locations occupied by snow patches, the accumulation niches develop mainly due to a slope accretion in a vicinity of the snow patch while the slope surface under the snow patches is protected against both erosion and accumulation (RĄCZKOWSKA 1995, 1997). Geomorphic role of the meltwater is limited as it percolates into voids among rocky pieces building a talus slope. The rate of the niche development varies from 0.03 to 0.6 cm/year and depends mainly on lithology and a slope aspect. Figure 3 presents a sketch of the niche of this type and a small protalus rampart at its foot which occur on the west-facing slope at 1950 m a.s.l. in the alpine zone. The nival niches develop on debris slopes at the foot of the rockwalls.

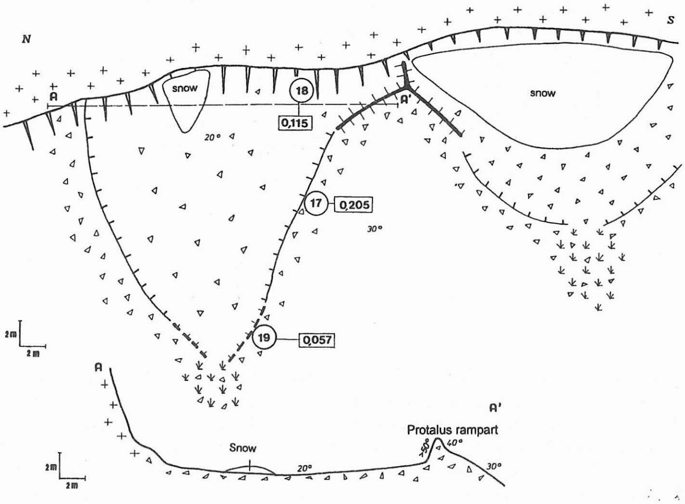

Fig. 3. Sketch of the accumulation nival niche on talus slope of Zawratowa Turnia with cross profile. Rates of accretion in rectangular frames

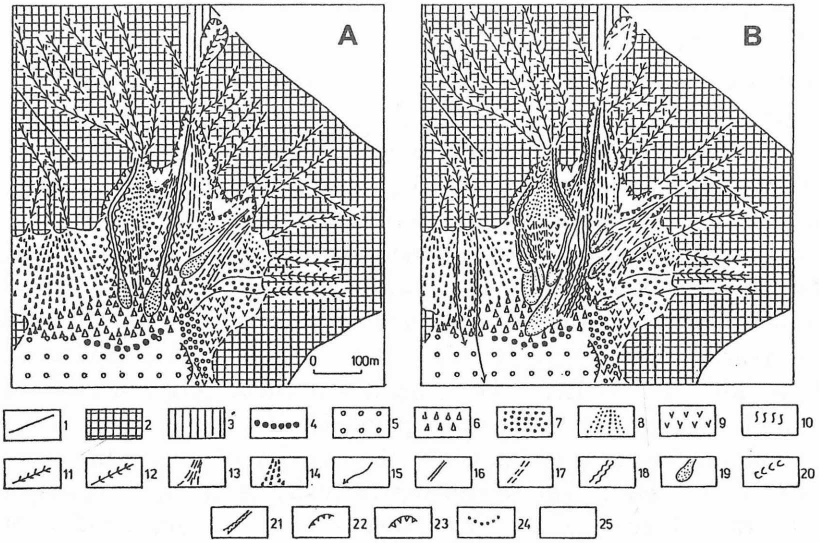

Fig. 4. Geomorphological sketch of Świnnicka Kotlina valley

A – 1987 year, B – 1988 year: 1. ridges; 2. rockwalls and rocky slopes; 3. slopes with weathering cover; 4. moraine ridges; 5. glacial drift deposits; 6. blockfield; 7. inactive talus slope; 8. fresh talus slope; 9. slope with vegetation cover; 10. slope with alluvial cover; 11. rocky chutes; 12. gullies cut in weathering cover; 13. gravitational-alluvial cone; 14. rockfall talus cones; 15. erosional incisions; 16. debris flow gullies; 17. inactive debris flow gullies; 18. debris flow levèe; 19. debris flow tongue; 20. debris flow gullies > 5 meters width; 21. debris flow < 5 meters width and < 3 meters depth; 22. nival niche with edges cut in solid rock; 23. nival niche with edges cut in weathering cover; 24. protalus rampart; 25. bottom of nival niche.

An example of an area where the niches of the above type develop in the Tatras at present is the Świnnicka Basin in the upper section of the Sucha Woda valley. Presence of numerous, long-lasting or multi-annual snow patches and nival niches points to nivation as the one of the most important processes modelling the slopes here (Fig. 4A). Nivation also remodels the debris flow gullies which were filled up by snow patches. The changes in the cross-section, as evidenced by measurements, were up to 10–15 cm/year. The gully was accreted in one spot while in the other dissected, and layout of these changes varied in particular years which could have masked former modifications.

The role of nivation as a relief-forming process is insignificant especially when compared with the processes induced by the extreme rainfall. Figure 4B presents geomorphic results of an intensive storm rainfall of the intensity of 40 mm/hour. The relief in the Świnnicka Basin has been modified almost completely, mainly due to debris flow action. New forms of the gullies, levèe and tongues of debris flows developed, and the old forms were dissected to the depth of several tens of centimetres to 1 metre. The debris flow gullies dissected also the existing nival niches. The mature slopes with the weathering cover in the periglacial zone of the Tatras are also modelled by various slow-acting mass movements. Intensity of theses processes has been measured since 1996 by means of lines of wooden plugs placed on different morphodynamic surfaces in the Kocioł Gąsienicowy cirque at Kasprowy Wierch and in Świńska Goryczkowa valley that have been mapped in details in 1:1000 scale (RĄCZKOWSKA *in print*). Solifluction processes, nivation, frost heaving and frost creeping, as well as debris and soil creeping take part in the modelling of mature slopes in both areas. Certain fragments of the slope were stable and did not show any traces of the active modelling.

The most active are the surfaces modelled by the processes related to water flowing on slopes, mainly to slopewash and linear erosion as the debris slopes on the present-day mature slopes are little active. However, numerous inactive, stabilised by sward, forms of the gullies and levèes of the debris flows are visible. The intensity of these processes was being determined by measuring the shift of painted lines.

The results of the measurements of the activity of particular processes are presented in table I. The modelling intensity of these slopes is rather small. The rate of shift of the plugs due to creeping and solifluction in 1996 was within an error limit and did not exceed 1 cm per year or was confined to transferring of singular pieces without any disturbance of the painted line in the case of fresh erosional surfaces. Extreme precipitation of 1997 caused a significant increase in the process intensity. The marked material of the erosional niches has been removed outside while the lines have been completely washed out. On the slopes modelled by creeping the plugs were transferred for a distance of a few to several centimetres. Acceleration in the rate of the slow mass movements referred mainly to creeping, and in a lesser extent to solifluction. Transferring has not been stated on the slopes presumed to be stable.

Table I

Displacement of weathering cover on mature slopes of the Gąsienicowa valley on the Kasprowy Wierch in cm.

PROCESS/YEAR	1996	1997	1998	1999
Solifluction	2,8	3,0	3,3	4,8
Soil and debris creep	0,1–1	0–0,3	0,1–6,8	1–7,8
Erosion	(1)	(3)	(2)	(1)

Notes: evaluate of erosion is based on lines painted on the slope surface, in scale from 1 till 3. 1 – single debris removed, 2 – few debris removed but line is visible, 3 – all painted material removed.

CONCLUSIONS

The presented above examples and results of the studies by the authors mentioned in the introduction indicate that the slope dynamics in the periglacial zone of the Tatra Mts. is small at present. Periglacial processes play a significant role in remodelling of the slope relief, yet alluviation of the slopes seems to be more important at present than the activity of the periglacial processes. Heavy downpours cause the process intensity to increase. What is more, the extreme, short-lasting precipitation result in formation of new landforms. The role of periglacial processes at present is limited mainly to remodelling of the relief forms.

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