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LANDFORM EVOLUTION IN MOUNTAIN AREAS

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THE PRESENT-DAY DEVELOPMENT OF LANDFORMS AND LANDCOVER IN ALPINE ENVIRONMENT — TATRA MTS (SLOVAKIA)

Abstract. This paper is referred to morphodynamic spatial structures (units) and their importance in the landscape-ecological research of the high-mountain areas. This approach is relatively less developed in the landscape ecology and therefore some authors emphasise its necessity (Bailey 1996, Turner and O'Neil 2001, Hreško 1994). Geomorphic processes and their spatial composition create specific dynamic spatial units in the alpine and sub-alpine zone in which these extreme and dynamic processes operate. Their typical features are the transportation of great volumes of anorganic and organic materials and the significant contribution to the water and nutrient redistribution in these physiologically relatively dry areas. On the basis of long-term empiric research in the Belianske Tatry Mts we introduce the model of the spatial units, in which energo-material transfer is driven by rainfall, snow, or melting snow. Frequency and intensity of snow and mass movements processes rapidly increased and unusual morphodynamic phenomena arose. Our effort is to achieve representative spatial-time data sets for complex alpine landscape information system and their environment changes interpretations.

Key words: landform development, landcover, high-mountain, Belianske Tatry

INTRODUCTION

The landscape structure of high-mountain areas in Slovakia is determined by an array of natural, semi-natural and anthropogenic factors reflecting a dynamics and extreme conditions above or close to timberline. The current studies of relations between elements of landscape structure and components of high-mountain landscape refer to a dominant influence of morphodynamic processes on landscape character by means of vegetation patterns (Hreško, 1997). In the paper we present some approaches in research of high-mountain landscape in two valleys of the Belianske Tatry Mts. Particularly, it is the research of occurrence and effects of geomorphic processes and, in the next step, the research of changes in landscape structure and its large-scale mapping. The morphodynamic effects of processes in high-mountain landscape play the role as the indicator of changing climatic conditions as well as the factor that controls the forming of vegetation cover and its spatial distribution. We attempt to prepare methods for landscape-ecological research and applications, especially for the evaluations of sensitivity and ecological carrying capacity of the high-mountain landscape. The conception and thematic focus correspond with the principle of structure and function of the landscape according to R. T. T. Forman and M. Godron (1993) who see geomorphic processes, in interaction with climate, as one of the four main processes of development and changes in landscape.

RESEARCH AREA

The research area is situated within a high-mountain landscape of the Belianske Tatry Mts, rather on largely south slopes of the main ridge, sloping to the Predné Meďodoly and the Zadné Meďodoly valleys. The elevation of the area ascends from 1,220 m a.s.l. up to 2,151 m a.s.l. Relative elevation amplitudes reach 400–600 metres in saddles, 800 metres on peaks. Slope gradient varies from 7°–12° on foots of slopes and cones, 20°–25° in cone apexes and the upper parts of foot slopes, 30°–35° in the middle parts of slopes and troughs, and greater than 35° in the upper parts of slopes and troughs. The rock cliffs and walls are extremely

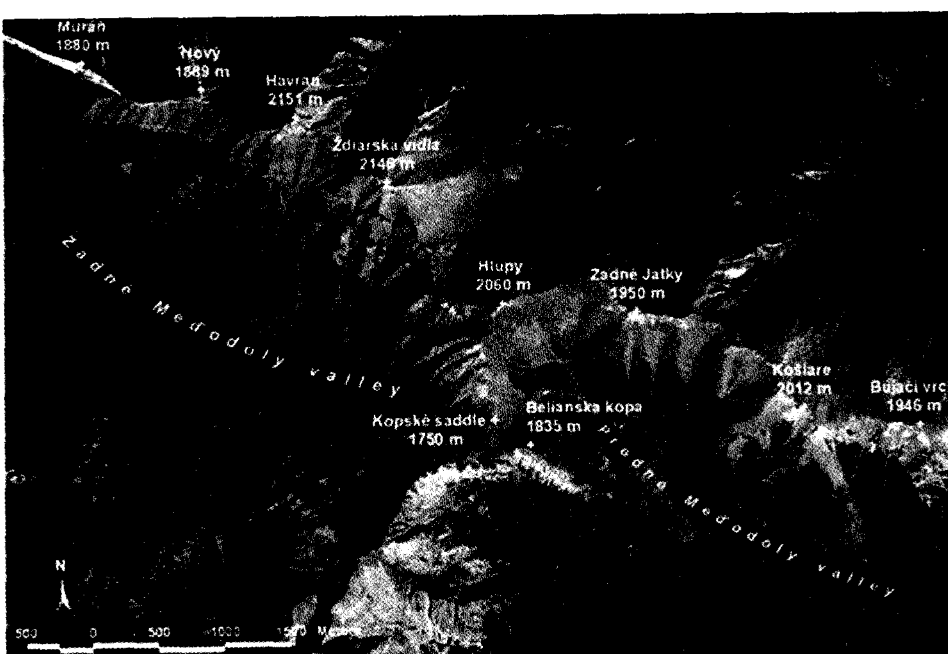

Fig. 1. Location of the Meďodoly valleys

steep even vertical, with slope gradients greater than 45°. The mean slope and/or trough longitude ranges about 1,500–1,600 metres in the Zadné Med'odoly valley, whereas 800–1,000 metres in the Predné Med'odoly valley (Fig. 1).

PROBLEMS

The geomorphic processes represent either inputs or outputs of energy and material of each geosystem (Barsch 1990). According to A. Kotarba et al. (1987) and A. Kotarba (1992) and D. Barsch and Caine (1984), the geomorphic processes are active in the morphodynamic systems of mountain valleys. R. G. Bailey (1996) has introduced the term "geomorphic complex or unit" which corresponds with term "landscape mosaic". Landscapes at this landscape mosaic level consist of the pattern (catena or association) of local ecosystems (micro-ecosystems) matched to the sequence of topographic facets. F. J. Swanson et al. (1990) have in this connection referred to the interaction between landforms on the one hand and natural structures and ecosystem characteristics on the other hand as evidenced by the vegetation types of both steep and high mountain landscapes. The relations between vegetation and landforms and/or geomorphic dynamics have been studied by (Rohdenburg 1989; Kozłowska and Rączkowska 1996).

The impacts of geomorphic processes can be considered in two ways — as disturbing force that destructs the existing landscape structure, as well as creative force, active in a creation of vegetation patterns, land cover and landscape heterogeneity. The final composition of land mosaic can be easily and precisely delimited visually, by means of aerial photointepretation or field mapping, however, the classification of patterns in relation with types of vegetation cover and morphodynamics is problematic.

The research on present geomorphic processes is based mainly on their identification, using the methods of direct field observations and measurements. The field experiments are distinguished according to O. Slaymaker (1991) into three types: 1 — permanent experiments, 2 — hybrid experiments, 3 — quasi experiments. Our field measurements and detailed surveys belong rather to the type of quasi experiments. These experiments are based on measurements and observations of dynamic changes in year or seasonal intervals on selected profiles (transects). Transects characterise the heterogeneity of alpine environment both in horizontal and vertical gradients of the valley systems (Hreško 1994, 1997). This approach corresponds with researches in northern Sweden (Rapp 1960) and the Polish Tatra Mts (Kotarba et al. 1987). Significant results of observations and measurements, as well as research methods in the high mountains areas of Slovakia were compiled by R. Midriak (1983). The aim of measurements is to determine the intensity of processes in different types of slopes and, subsequently, to compare and verify the results with analogue data from another mountainous regions. The utilisation of such empirically verified, quantified and monitored data is wide-ranging, from the landscape sensitivity evaluations, assessments of landscape changes in connection with climatic changes, to the implementation of measurements into the databases of monitoring information systems for natural hazard assessment.

Our research on geomorphic processes is structured into three levels or approaches:

— Research of geomorphic processes as a component part of the landscape spatial structure (individual spatial units are delimited according to occurrence or predisposition of the main active processes);
— Research on environmental implications of the processes as natural hazards (individual or coupled geomorphic processes can cause disturbances in landscape and threats for humans, interpretations of natural hazards in specific spatial models);
— Research of geomorphic processes in relation with landscape structure — vegetation pattern (interpretation of landscape structure changes in time includes also visible surface effects of geomorphic processes).

RESULTS AND DISCUSSION

The research on present geomorphic processes was carried out also in the territory of the Belianske Tatry Mts (Midriak 1972, 1977, 1978, 1983, 1996) and was focused on the measurements of intensity of some typical processes in periniveoglacial zone. According to the classification of R. Midriak (1983), the occurrence of several processes or their groups has been confirmed (described bellow).

GRAVITATIONAL FAILURES OF THE ROCK MASSIFS

Geological structure of the Mesozoic massif of the Belianske Tatry Mts creates favourable conditions for development of subsurface creeping failures, following the definition of A. Nemčok (1982). The largest gravitational failure has been identified on westward slope of the Ždiarska vidla peak. It passes transversely the main ridge in a form of complicated system of scars and cracks in rock massif. Many failures of smaller dimensions occur in cliffs and rocky peaks, e.g. on the Hlúpy, the Zadné Jatky and the Bujačí vrch peaks. Cracks, furrows and disjunction rims of bedrock in a shape of rocky defiles represent the resultant forms of these processes. Another forms are those of the sloping towers and stacks with well-developed fissure system.

PURE GRAVITATIONAL PROCESSES (ROCK FALL, CLASTIC FALL OFF, DEBRIS CREEPING)

The occurrence of gravitational rock fall and clastic fall off processes is conditioned by the occurrence of cliff forms and rock walls in apex, ridge or slope positions and the result is in a form of fields of rocky blocks and boulders, debris sheets, and scattered boulders on slopes and gully bases. These processes reflect

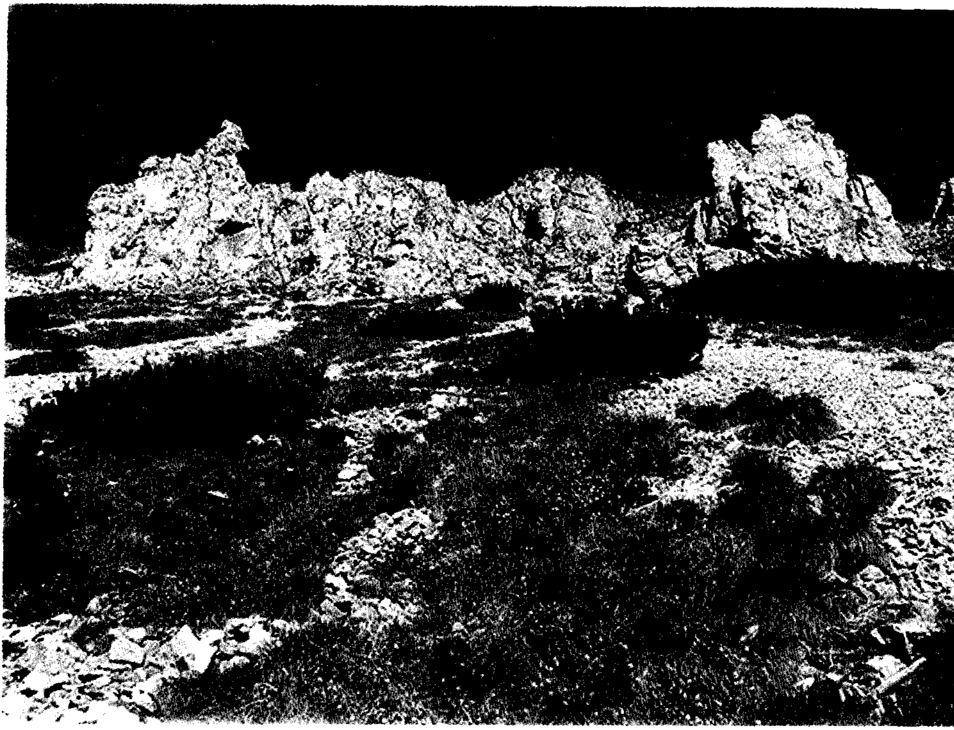

Photo 1. Rock fall and debris creeping on south slopes of the Belianska kopa

an effect of weathering in high-mountain landscape, where a number of factors, linked to the geological conditions, affect the rocks. The frost weathering by means of regelation concentrating in crack systems of limestones and quartzites is the dominant process, which generates rock disintegration (Photo 1).

NIVEO-GRAVITATIONAL PROCESSES (AVALANCHES)

The avalanches represent a significant and very dynamic process within the high-mountain landscape of the Belianske Tatry Mts. More than 10 morphosystems where the avalanche activity is dominant were identified by means of field investigations and aerial photo interpretation. Within the source zone, mostly the soil destruction is dominant and creates the favourable conditions for consecutive processes such as nivation, and in addition, accelerates the generation of water-gravitational processes. The isolated areas of bare soil cover begin to slide down gravitationally due to a great slope gradient (more than 35°), often with dwarf pine crop. Within the transportation zone, the avalanche movement zone alternatively, not only erosion processes in a form of initial water-gravitational furrows are activated, but also the debris flows that transport an accumulated clastic material within short distances. Within the accumulation zone, the effect of avalanches is proved mainly on spot soil cover destructions, especially in case of tree uprooting.

WATER-GRAVITATIONAL PROCESSES (DEBRIS FLOWS)

The basic condition of debris flow generation is to provide a sufficient amount of the clastic material fallen off down on foots of the rock cliffs and walls, eventually from the denude bedrock on slopes (e.g. on southward slopes below the Hlúpy peak, 2,061 m a.s.l.). The overload in waste material by precipitation, eventually by thawing water, under the conditions of exposed georelief with great slope gradient (generally 30–35°) provides a trigger impulse for debris flows. The debris flow generation is evident markedly in gullies or in upper positions of north oriented valleys (the Nový potok, the Tristárska dolina valleys, and the north kettle below the Jatky peak) permanently supplied by a clastic material via gravitational and water-gravitational processes. The resultant forms of debris flows, the erosion furrows, erode the bedrock or the own transported material. The bifurcation furrows with marked lateral mounds were formed in accumulation zone (Photo 2).

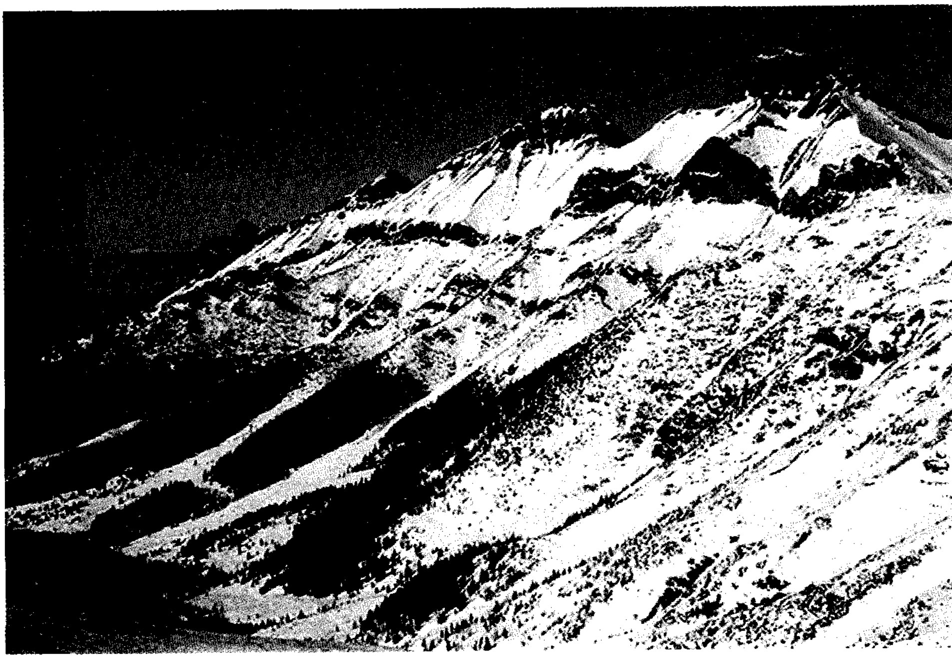

Photo 2. The Zadné Med'odoly valley with avalanche track series

CRYO-GRAVITATIONAL PROCESSES (SOLIFLUCTION)

The processes of solifluction-gravitational creeping within the soil layer affect the exposed, steep slopes in source areas of the morphosystems as well as on convex shapes of ridges (Photo 3). Typical feature of these processes is the terraced structure of soil layer, often with recent disjunction cracks that are modified by effects of surface run-off during the abundant precipitation and/or rapid snow melting (Photo 4).

Photo 3. Source area of debris flow on the south slope of the Hlúpy peak

Photo 4. Rainfall and snowmelt effects on solifluction-gravitational slope catena below the Kopské saddle

The effects of snow melting process during the spring season create marked nival depressions, especially in areas with a long-term occurrence of snow patches, generally on leeward parts of saddles and ridges. Nival niches represent another form of the nival process inducing a total destruction of soil or subsoil layer and can occur even in a form of erosion furrows (Midriak 1996). The exposures of wind erosion, rather the deflation of fine material and waste particles are concentrated mainly on saddle and apex positions of the Belianske Tatry Mts. The effects of wind are proved in soil cover structures as *bare soils* (Lukniš 1973) or *strip soils* (Midriak 1983, 1996). Another forms conditioned by wind corrosion, the aeolian niches, create small patches of various shapes with bare or denuded soil horizon. Their edges are bounded with overhangs fixated with root system of the vegetation, but eroded intensively by the attacks of solid particles drifted by wind. Additionally, the intensive rainfalls and/or snow melting trigger the planar outwash of niches and regression of their edges. Slates and marls provide favourable geological conditions for aeolian deflation and corrosion of the niches (Photo 5).

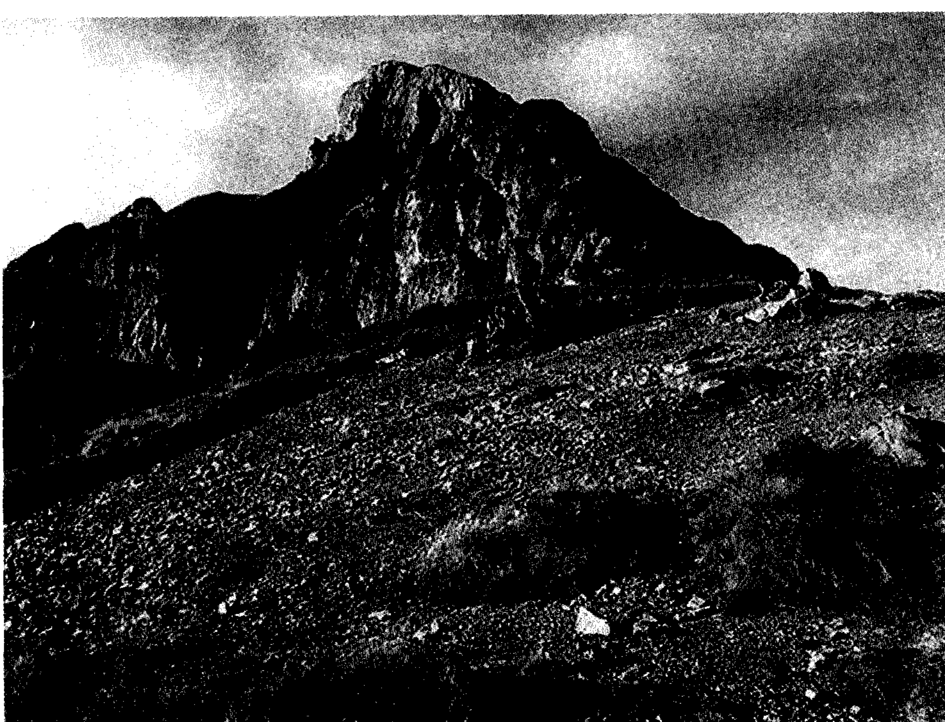

Photo 5. Aeolian niche near the Široké saddle between the Ždiarska vidla and the Hlúpy peaks

The morphosystem (morphodymanical system) is understood as a spatial unit in which generally several processes, mutually interconnected through the energetic and material flow in the slope gradient direction, are registered (Hreško 1994). Besides the vertical structure of the processes, this study also regards the horizontal relationships, i.e. not gravitationally conditioned. The model of spatial structure of morphodynamic systems in south slopes of the Belianske Tatry Mts is presented in the study. Since the morphodynamic system classification issues both from vertical and horizontal relationships, the resultant synthetic operational units are available in the ecosystem research of the landscape as well as in various landscape-ecological applications. The essential step of the research is to design models of the morphosystems in GIS environment with relevant databases. Each spatial unit contains the information of dominant processes, their intensity and development tendency, as well as the morphometric parameters of the georelief.

The basic methodical step of the morphosystem definition consists of detailed terrain analysis and spatial identification of particular processes. This step was carried out by means of the aerial photo interpretations and detailed field investigation. In general, it is a "transect" method of data collecting and morphosystem description in gradient direction from the valley bottom or foot of the slope up to the ridge or peak. The detailed photo documentation is also a component part of field investigation (Photo 6). The method of measuring profiles and plots on which the intensity of geomorphic processes and their influence on soil cover

Photo 6. Avalanche-fluvial morphosystems on south-face slopes of the Predné meďodoly valley

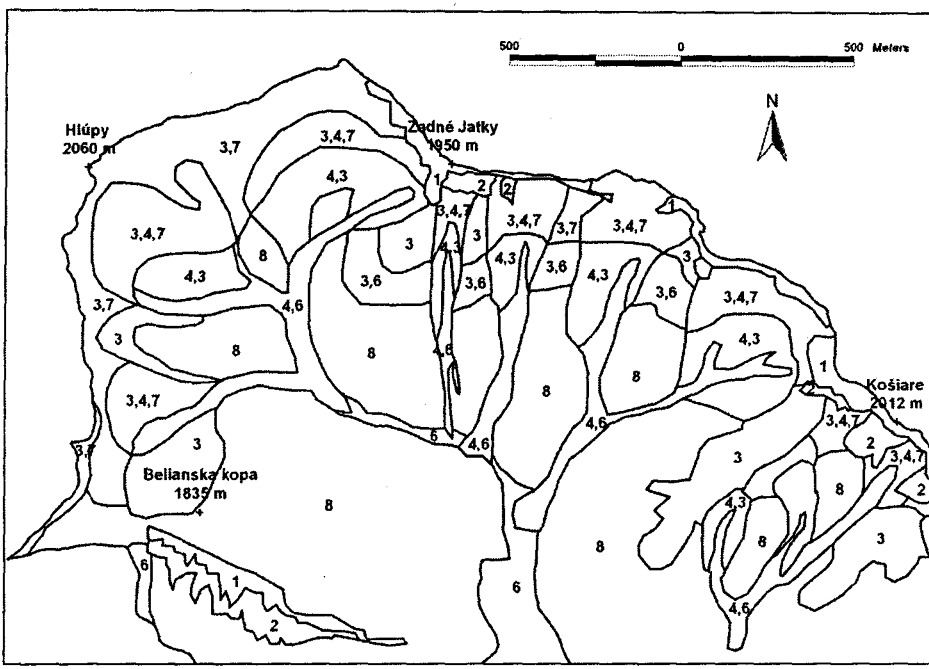

Fig. 2. Model of the avalanche-fluvial morphosystem of the Predné Med'odoly valley. Types of morphosystems: 1 — gravitational (rock fall and clastic fall off, gravitational failures), 2 — debris-gravitational (debris creeping), 3 — solifluction-gravitational (cryo-gravitational), 4 — avalanche (niveo-gravitational), 5 — avalanche-debris flow, 6 — fluvial, 7 — nival, 8 — periglacial-debris

destruction and spatial differentiation of vegetation is monitored was used to support the research. Locations of the plots and profiles were selected in order to capture the whole range of the processes and destruction types (Fig. 2).

ENVIRONMENTAL IMPLICATIONS OF THE PROCESSES AS NATURAL HAZARDS (EXAMPLE ON AVALANCHES)

The avalanche and nivation processes operate on base of transport, accumulation and melt of snow mass. Since winter 2000, the dynamics and frequency of avalanches come into one of its culmination levels during the last century. The occurrence of avalanche events was registered in areas not affected at least for 10 years (Fig. 3).

Specific weather situations in Tatra Mts during the last 5 years induced the increase of so called forest avalanches when the starting, transporting and accumulating zones remain within the forest area. They start mainly in juvenile small valleys with episodic watercourse and their accumulations end in a bed of recipient.

In region of the Belianske Tatry Mts, within the study area in the Zadné Med'odoly and Predné Med'odoly valleys, several great avalanches were registered. The most effective one (or more) rolled down in February 2000 from the steep grassy slopes of the Havran Mt and the Ždiarska vidla Mt and totally de-

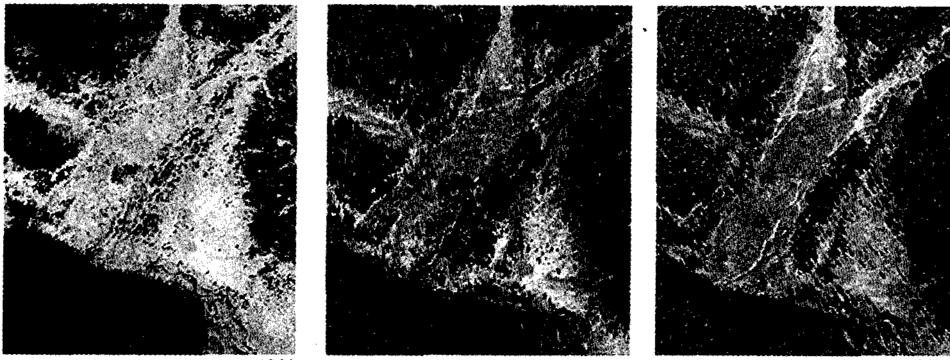

Fig. 3. Effect of great avalanche event after a longer period of repose (accumulation zone of avalanche tracks in the Zadné Meďodoly valley)

stroyed the young (15–30 years old) succession spruce growth on debris-alluvial fan below, and partly 100 years old forest on foot part of the opposite slope. Another specific sort of avalanche, sliding down of a relatively thin layer (ca 20 cm) from the first snowing in season has been registered in last years. Seemingly, the avalanches affect the landscape adversely. From another point of view, they can supply the water and nutrient deficit and regulate formation of linear corridor structures in rock or soil-substrate complexes as well as in grass-herbaceous, shrub or tree forest growths.

The process of avalanche hazard assessment is not being an end in itself, because it is taken in a context with landscape. The landscape contains a certain potential (resources) as well as limits and mainly a level of carrying capacity. Calculation of the avalanche hazard intensity (Av) can be execute by the following formula (according to Hreško 1998):

$$Av = (S + Al + Ex + Fx)\,Rg$$

Av — value of avalanche hazard intensity; S — factor of slope gradient; Al — factor of altitude; Ex — factor of slope aspect (exposition); Fx — factor of slope shape; Rg — factor of surface roughness.

The formula concentrates mathematical operations of numerically estimated factors. The values of each factor were calculated from exact mathematical-statistical procedures, alternatively, they were derived from the known relations (Hreško 1998; Hreško and Bugár 1999). The altitude combined with slope shape and exposition substitute indirectly a snow mass distribution that increases generally together with the higher altitude. The values of Rg factor were estimated according to M. Quervain and B. Salm (1961). From accounted values of the avalanche hazard a 4-level scale was created. The larger number had been calculated, the higher avalanche hazard intensity was assigned to a given spatial unit. The result map of avalanche hazard (Fig. 4) shows a spatial expres-

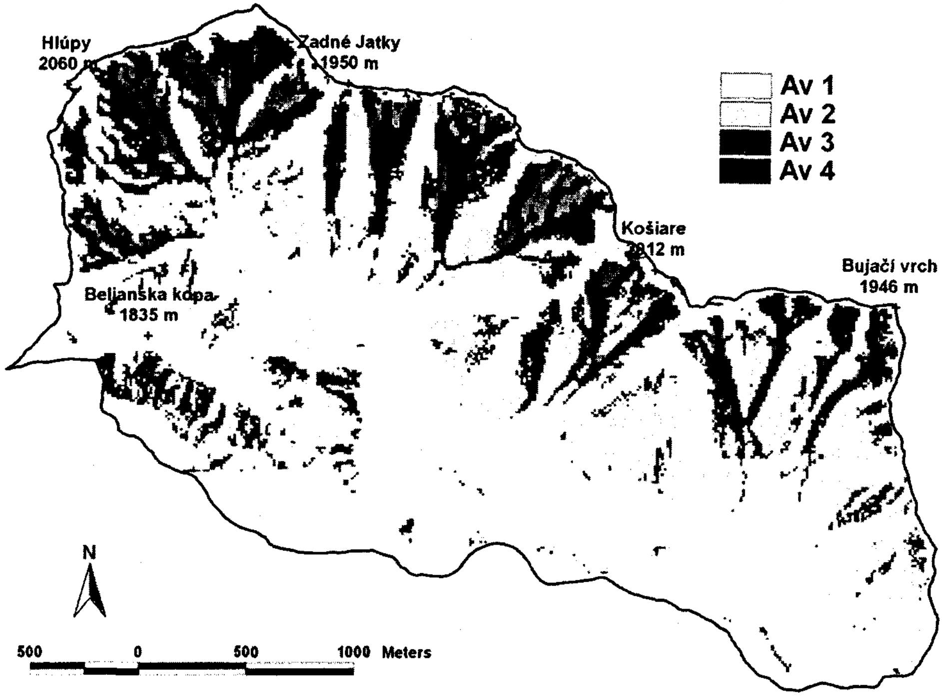

Fig. 4. Map of avalanche hazard in the Predné Meďodoly valley. Values of avalanche hazard intensity: Av1 (less than 10.0) — non or low hazard, Av2 (10.1–15.0) — moderate hazard, Av3 (15.1–20.0) — high hazard, Av4 (greater than 20.0) — extremely high hazard

sion of potential avalanche initiation and occurrence, i.e. it does not feature the impacts on affected areas. The map consists of a set of complex units with calculated value of avalanche hazard for each of them.

PROCESSES IN RELATION WITH LANDSCAPE STRUCTURE (EXAMPLE OF LANDSCAPE STRUCTURE CHANGES IN THE PREDNÉ MEĎODOLY VALLEY IN 1949–1998)

Landscape structure of the Belianske Tatry Mts was determined by a lot of natural as well as anthropogenic factors. In 1954, since the cattle and sheep grazing were prohibited, the stands started to regenerate and come to native communities. Nevertheless, many native communities were replaced by poor secondary stands. Natural succession and additional artificial planting of dwarf pine has supported the increase of ecological stability of landscape system and deceleration of destruction processes.

The tested area was delimited on the south slopes of the Predné Meďodoly valley with total area of 48 hectares (Fig. 5, 6). Within the area, five classes of land cover were distinguished: dwarf pine, tallus-herbaceous stands (alpine grasslands), debris covers, rock formations, and disturbed areas (i.e. areas affected by erosion processes). At present, the dwarf pine stands occupy 38% (30.2 ha) of the

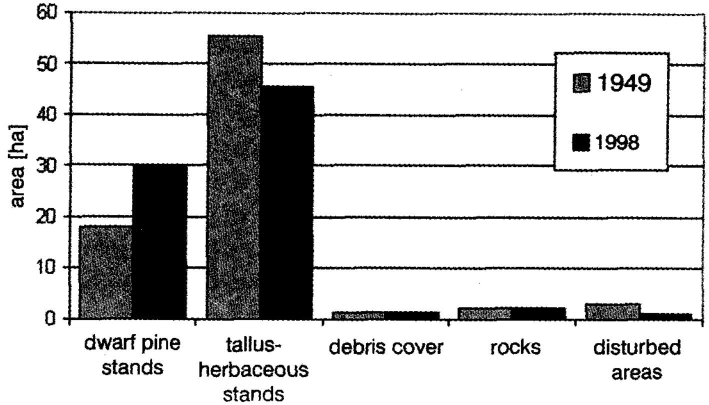

Fig. 5. Areal expression of landscape structure classes in 1949 and 1998

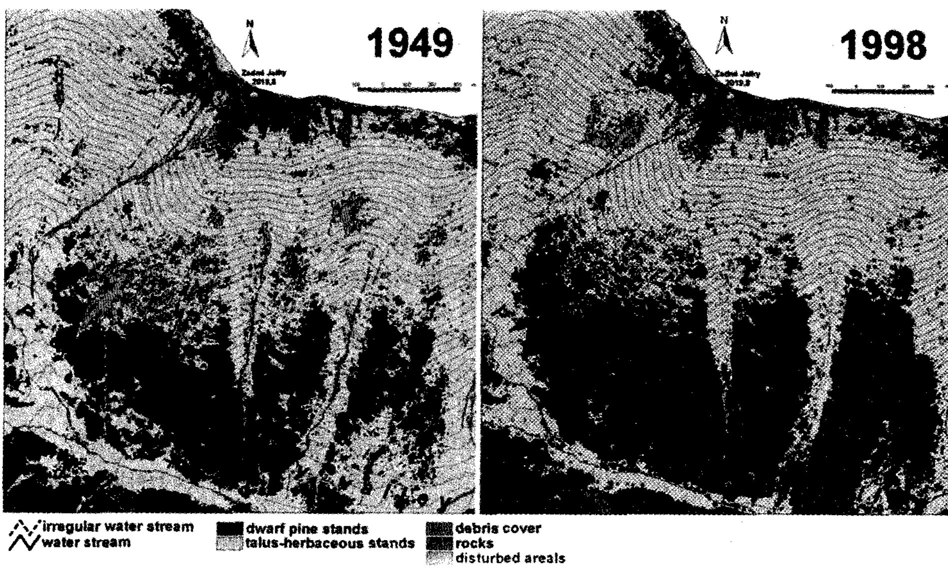

Fig. 6. Map series of landscape structure changes in the selected part of the Predné Med'odoly valley (1949-1998)

study area. The area of this class has been enlarged since 1949 by 13 ha (75% increase), which is the largest change from all observed classes, partly in consequence of plantation by humans. Unfortunately, the areal extent of planted dwarf pine is unknown so far. The area of tallus-herbaceous stands has been reduced from 24.2 to 14.2 hectares (41% decrease), particularly due to dwarf pine expansion. In consequence of successional processes, the debris cover class has receded by 0.1 ha. The rocks formations did not change in area — they represent the most stable element in the study area. As the consequence of prohibition for grazing, in 80s also for hiking, the disturbed areas have been reduced by 65% (from 3.1 to 1.1 hectares). Disturbances of vegetation and soil cover, highly predisposed to erosion owing to a bedrock character, are common especially along the tourist paths. The negative influence of hiking exposed in destroyed paths accelerate soil erosion and cause changes in vegetation (Barančok 1996).

The character of landscape structure is not a stabile parameter. The landscape undergoes continual or sudden changes of different, particularly physical origin, starting from seasonal metamorphosis (in these latitudes), long-term climate change with effect in temperature, precipitation, soil evolution as well as georelief changes. Our present terrain observations are focused on geomorphic processes of non long-term character, i.e. strong, relatively rapid morphodynamic disturbances such as avalanches and debris flows (Hreško and Boltižiar 2001). Landscape structure is hereby in state of dynamic stability what means that it is an object of two mutually interfering forces — evolution and disturbances (Forman and Godron 1993).

CONCLUSIONS

The present structure of high-mountain landscape of the Belianske Tatry Mts is largely consequent upon the activity of geomorphic processes interacting within the morphodynamic systems. On the other hand, a significant influence of historical human activities, e.g. mining and pasturage, is evident. Among the natural processes active in the territory, the avalanches, aeolian deflation, debris creeping, cryo-gravitational processes, and secondary destruction of soil mantle by torrential rains are the most effective ones. Niveo-gravitational processes with subsequent activation of fluvial processes arisen from a rapid snowmelt appear as a new phenomenon of dynamic changes of the high-mountain landscape. Pluvial activity is evident on less stabile slopes affected by niveo-aeolian and solifluction-gravitational processes.

Cognition of genesis of the vegetation pattern structure allows to understand genesis of the landscape structure of high-mountain environment as well as its function and content. Many of the outlined relations and implications bear an array of direct and indirect effects. For instance, the formation of vegetation pattern by debris flows, shifts or avalanches is driven not only by purely mechanical processes but also by nutrient-translocation (edaphic) effect of these processes. Thereby, they come indirectly into the evolution of biodiversity of high-mountain environment. In connection with climate changes indicated by an increasing intensity of water-induced processes in mountainous regions, we expect the increased share of morphodynamical effects on vegetation patterns and landscape structure. According to observations from the Austrian and Swiss Alps, the amount of snow decreases in general. This has an effect in reduction of populations, alternatively their migration to the higher places. Specific recent forms of georelief are able, among others, to catch and accumulate the snow, which is important especially for biocenoses fixed on positive water regime in spring season. In this context, the micro- and meso-forms of simultaneously acting geomorphic processes can represent the substitutive habitats with convenient edaphic conditions.

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STRESZCZENIE

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WSPÓŁCZESNY ROZWÓJ RZEŹBY I ZMIANY SZATY ROŚLINNEJ W PIĘTRZE ALPEJSKIM TATR SŁOWACKICH

Morfodynamika stoków Tatr Bielskich jest przedmiotem rozważań w ramach studiów geoekologicznych wykonanych w dolinie Zadnich Koperszadów w przedziale wysokości od 1220 m do 2151 m n.p.m. Wykonano obserwacje i pomiary współczesnych procesów morfogenetycznych w obrębie wyodrębnionych jednostek stokowych. Równocześnie zbadano wpływ poszczególnych procesów lub zespołów dominujących procesów, jako naturalnych zagrożeń dla szaty roślinnej. Wprowadzono pojęcie systmu morfodynamicznego jako jednostki przestrzennej, w której jest analizowany przepływ energii i materii pod wpływem procesów morfogenetycznych.

Z badań wynika, że aktywność procesów jest uwarunkowana w znacznej mierze przez ingerencję człowieka w ubiegłych stuleciach, w tym zwłaszcza przez górnictwo i pasterstwo. Najbardziej efektywnymi współczesnymi procesami są procesy niweograwitacyjne, związane z obecnością pokrywy śnieżnej, a przede wszystkim z jej zanikaniem. Ponadto geomorfologiczna działalność lawin, spełzywanie gruzu oraz deflacja. Do procesów drugorzędnych zaliczono erozję wodną na stokach. Niektóre zmiany w systemach morfodynamicznych przedstawiono na modelach i przy pomocy powtarzanych zdjęć lotniczych.