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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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GEOMORPHIC RESPONSE TO ENVIRONMENTAL CHANGES IN THE SLOVAK CARPATHIANS

Abstract. This article focuses on the geomorphic response of the cryonival and temperate forest morphoclimatic systems to land use and climatic change in the Slovak Carpathians. It discusses the changes in the distribution and dynamics of geomorphic processes and in their effectiveness in the period between the beginnings of human impact in the natural landscape and the present, with a special emphasis on the last eight centuries. Authors confirm that vegetation, especially forest cover, is the main differentiating factor of the occurrence and operation of geomorphic processes in the Slovak Carpathians. The removal of the once almost continuous forests is associated with human interventions into the mountain landscape that became more pronounced only during the so-called Great colonization in the 13th and 14th centuries. Gradual forest clearance increased the area affected by anthropogenically accelerated processes. The most intense, extensive and from the human viewpoint damaging operation of the processes occurred in periods when human interventions overlapped with climatic fluctuations, mostly in the course of the Little Ice Age.

Key words: geomorphic processes, cryonival system, temperate forest system, land use changes, climatic fluctuations, the Slovak Carpathians

INTRODUCTION

The Slovak Carpathians are typified by a distinct spatial variability of geology and relief. This feature influences the occurrence and dynamics of geomorphic processes. The Central Carpathians, built of crystalline-Mesozoic complexes with the belt of the Flysch Carpathians in the north and the belt of volcanic Carpathians in the south (Lukniš and Plesník 1961), form the spinal cord of the Slovak Carpathians. Following the geomorphological division by E. Mazúr and M. Lukniš (1980), they are divided into the Western and Eastern Carpathians. The Western Carpathians clearly dominate in area and altitude, reaching 2,655 m a.s.l. in the Tatry Mts (Gerlachovský štít). The highest mountain of the Slovak Eastern Carpathians built of flysch and volcanic complexes is Kremenec (1,221 m) in the Bukovské vrchy Mts. The Slovak Carpathians, especially the Western Carpathians, do not compose a compact mountain massif as they are dissected into a mosaic of geomorphic units represented by mountain ranges of different types and intra-mountain depressions represented by basins or furrows (Fig. 1).

The occurrence and course of geomorphic processes does not depend only on geology and relief but also on altitudinal zonality. Vertical dissection of relief causes vertical variability of climate, which in turn determines the vertical vegetation zonality. Vertical climatic and vegetation zonality is reflected in the present-day altitudinal morphoclimatic belts (systems) characterised by sets of processes which determine specific types of landform development.

A. Kotarba and L. Starkel (1972) recognise two morphoclimatic systems in the Carpathians: the cryonival system and the temperate forest system. According to these authors, the two systems are separated by the upper timberline which in the Western Carpathians oscillates around the altitude of 1,500 m a.s.l. The upper timberline approximately coincides with the lower limit of the high-mountain glacial relief. The significance of the upper timberline is in the fact that it separates zones with different qualitative and quantitative characteristics. Observable above this limit is the disappearance of zonal processes typical of the lower altitudinal zone and a change in the rate of azonal processes. However, the influence of temperature and precipitation on the regime of geomorphic processes above and below the upper timberline is smaller than the effect of vegetation and soil cover. Both systems also differ in the proportion of chemical and mechanical denudation. A. Kotarba and L. Starkel (1972) characterised the processes within the cryonival and the temperate forest systems in the Carpathians against the changes of altitudinal vegetation belts in the Holocene. The aim of this paper is to characterise the occurrence, pattern and rate of geomorphic processes in the Carpathian part of Slovakia during the youngest Holocene, approximately from the beginning of more pronounced human interventions in the landscape with the special emphasis on the last eight centuries. The dynamics of geomorphic processes within this period was influenced by environmental changes, related to both human impacts and climatic fluctuations. From the long-term viewpoint, geomorphic processes have been more affected by human interventions. The Late Holocene relief modelling was most distinct in the areas unprotected by vegetation. As the destruction of vegetation (forest) cover was almost exclusively linked to human activities, its beginnings and progress are closely connected with the arrival of humans to the Carpathians and progressive development of settlement in the mountainous part of the present territory of Slovakia. In the course of the settlement, farmer settlers from below and shepherd settlers from above attacked primeval forest cover and gradually reduced its spatial extent. Intense forest clearance was also performed by miners and smelterers who were responsible for timber harvesting and production of charcoal in the surroundings of the sites of ore extraction and processing. Activities of all mentioned groups of colonists resulted in a gradual increase in the area affected by anthropogenically accelerated geomorphic processes within the deforested territories (Fig. 1). The most extensive and also the most damaging geomorphic manifestation of climatic fluctuations, mainly the Little Ice Age, occurred precisely in the areas most affected by human activity.

THE STATE-OF-THE-ART REVIEW OF RESEARCH ON GEOMORPHIC PROCESSES IN THE SLOVAK CARPATHIANS

Results of earlier research into the selected groups of exogenic processes were summarized and evaluated in works published at the beginning of the 1980s — the studies of A. Nemčok (1982) on gravitational processes, D. Zachar (1982) on soil erosion and R. Midriak (1983) on the sets of geomorphic processes operating in high mountains. The results of research into processes in the Slovak Carpathians during the 1980s and 1990s were evaluated by M. Stankoviansky and R. Midriak (1998).

Since then, several studies and books have been published on various aspects of geomorphic processes both in the cryonival and in the temperate forest systems. R. Midriak (1999, 2001) discussed the occurrence and activity of geomorphic processes in the cryonival system in the Slovak Carpathians. J. Hreško (1997) assessed the effects of the processes taking place beyond the upper timberline on the changes in landscape pattern in the Západné Tatry Mts, J. Hreško and G. Bugár (1999), J. Hreško et al. (2003, 2005) did so for the Belianske Tatry Mts, M. Boltižiar (2001a) for the Vysoké Tatry Mts, M. Boltižiar (2001b), J. Hreško and M. Boltižiar (2001) for the Tatry Mts as a whole, and I. Barka (2003, 2004, 2005) for the Kriváň subunit of the Malá Fatra Mts.

Runoff and tillage processes and their geomorphic effect in the temperate forest system under changing environmental conditions were studied by M. Stankoviansky (2000, 2001, 2002, 2003a, b, c, d, 2005a, b) in the Myjavská pahorkatina. The author evaluated the effects of historical gully and tillage erosion, acceleration of runoff processes after collectivisation in agriculture, and the effects of current muddy floods in intensely cultivated farmland. Expansion of the gully network in the last four decades near the village of Plaveč in eastern Slovakia was studied by M. Ondrášik (2002). M. Stankoviansky et al. (2006) provide a broad discussion of the activity of runoff processes in the whole Slovak territory. Of the book publications we call attention to the monograph by E. Fulajtár and L. Janský (2001) on water erosion.

There are numerous studies by engineering geologists on the effects of gravitational processes, with the works by R. Ondrášik (1995, 2001, 2002), R. Ondrášik et al. (2002), J. Malgot and F. Baliak (2002a) being the most comprehensive ones. A. Klukanová and P. Ličšák (1998) and P. Wagner et al. (2002) provide information on the monitoring of gravitational deformations. To date, around 21,000 slope deformations have been recorded (Šimeková and Martinčeková et al. 2006). The works by J. Malgot and F. Baliak (2002b) on the human impact on the development of landslides in Slovakia or that of F. Baliak and J. Malgot (2001) investigating the effects of landslides on natural environment and construction works are closest to the theme of our paper. E. Fussgänger and D. Jadroň (2001) and M. Kopecký (2004, 2006) assess the effects of the present-day climate, primarily precipitation, on the development of slope gravitational movements. Studies dedicated to the past and present morphological activity of the Carpathian rivers include those of I. K u n s c h et al. (1998) and E. B i t a r a (1998) on historic floods and that of J. H a n u š i n (1999) on the causes, course and consequences of the 1997 and 1998 floods. The study of J. M i n á r et al. (2006) is a comprehensive depiction of geomorphic hazards in the whole territory of Slovakia. Country-scale spatial distribution of some geomorphic processes is also presented on some maps of the *Landscape Atlas of the Slovak Republic* (2002). The map of A. K l u k a n o v á et al. (2002) depicts the occurrence of slope deformations and the activity of wind erosion, the map of M. Š ú r i et al. (2002) shows the occurrence of actual water erosion and the map of R. M i d r i a k (2002) shows water erosion, snow avalanche and debris flow hazard in the high mountains.

As some studies are still missing in Slovakia, the compilation of this paper has also leaned on some studies of the Polish Tatry Mts (K o t a r b a et al. 1987; K o t a r b a 1992, 1997, 2004; N i e d ź w i e d ź 2004); R ą c z k o w s k a 2006). The study of A. K o t a r b a (2004) also contains results of the research conducted in the Valley of Zelené pleso in the Slovak part of the Tatry Mts.

ENVIRONMENTAL CHANGES IN THE SLOVAK CARPATHIANS

In the youngest period of the Holocene, the pattern and dynamics of geomorphic processes typical of the natural conditions distinctly changed in the majority of the Slovak Carpathians due to human interventions in the landscape and climatic fluctuations.

The history of human interventions in the mountain part of the Slovak territory is connected with the development of settlement, deforestation, land use changes in deforested areas and in some areas also with afforestation. The first local interventions in the landscape of the Carpathians coincided with the last phases of the Mesolithic when sporadic settlement of population dedicated to other than agricultural activity was impaired. This change can be attributed to the arrival of farming communities which created settlements and gradually colonized not only the fertile lowlands in SW and E parts of Slovakia but also penetrated to the Carpathians, namely the areas of Liptov, Turiec and Spiš. After a certain inertia, the higher situated localities were recolonized during the period of the Baden culture (2600–2200 years BC). During the first settling peak, in the early Bronze Age, farmers colonized the areas of central and northern Slovakia which until then had been scarcely settled. Settlement in the late Bronze Age was also altered by the great migration of tribes. One of the centres of such settlement was the Carpathian Basin and its surroundings where the people of central Danube urn fields lived. The mountain areas were subsequently largely depopulated and denser settlement persisted only in the north and central Slovakia where the Lusatian culture spread. In the 5th century BC the first Celts appeared and till the 3rd century BC they colonized almost the whole of the present Slovak territory, gradually progressing along the greater rivers to the areas settled by the people of the Lusatian culture. Since the beginning of the 1st

century, in the Roman period, the territory of Slovakia was under the influence of Germanic tribes who gradually pushed out the Celts. The latter remained only in the mountain areas, in the valleys of the northern and central Slovakia, where Celtic Kotins (or the people of the Púchov culture) lived in the 1st and 2nd centuries. In the eastern Slovakia Celtic-Dacian culture persisted. The departure of Germanic tribes in the 5th century was compensated by the arrival of the first Slavs (Demo et al. 2001; p. 6–7) that remained here until the present time.

The oldest Slavic settlements existed not only in the lowlands but also in the mountain valleys. This fact demonstrates that the Slavic economy did not rely only on farmers and shepherds but that they also prospected and processed ore. The settlement was relatively dense and by the beginning of the 6th century (before the Avar invasion after 568 AD), the Slavs had settled a substantial part of today's Slovakia. Neither then nor during the later Great Moravian period (9th century and the beginning of the 10th century) or even in the initial phases of the Hungarian State (end of the 10th century, 11th and 12th centuries), was the settlement dense in the territory situated above 400–500 m a.s.l. (Demo et al. 2001; p. 39–40). This means that the typical feature of the oldest settlement in the Carpathians was its spatio-temporal variability and periodic pattern, also reflected in the occurrence and effectiveness of anthropogenically accelerated processes. The number of periods typified by accelerated activity of geomorphic processes differs in various parts of the Carpathians, depending on settlement patterns and timing.

More significant human interventions in the Carpathian landscape can be dated to what is referred to as the Great colonization (feudal and German) in the 13th and 14th centuries (Plesník 1974). In its course, peasant colonization also reached the mountain part of Slovakia. Towns were founded and central Slovakia even became the land of mining and metallurgy (the development of metallurgy in the region of Banská Štiavnica was remarkable already by the end of the 12th century; (cf. Demo et al. 2001; p. 40). Another important intervention in the Carpathian landscape was the Wallachian shepherd colonization, which reached the territory of the today's Slovakia in the 15th century and peaked in the 16th and 17th centuries (cf. Chaloupecký 1947). The Wallachian colonization proceeded along the ridges of the Carpathians from the east and south-east, mainly to the regions of Horehronie, Orava, Liptov and the former County of Trenčín with the Biele Karpaty Mts and the Myjavská pahorkatina as the westernmost locations. The following shepherd (so-called Goral) colonization took place in the 17th–18th century. Gorals settled the territory in the upper reach of the Kysuca River, upper Orava and a part of the northern Spiš. Also important was the so-called "kopanitse" colonization the beginnings of which date to the 16th century and which culminated only in the 18th and the first half of the 19th centuries (cf. Huba 1997).

Between the 13th and 19th centuries, during the above-described colonization waves, the gradual deforestation was followed by exploitation of the acquired plots, bringing about an important increase of open areas, affected by accelerated geomorphic processes at a scale incomparable with the entire preceding period.

Within the last millennium there were also important climatic changes. Palaeoclimatologists recognize four periods — the Medieval Warm Epoch (MWE), the transitional period of climate deterioration, the Little Ice Age (LIA) and the period of global warming. According to H.H. Lamb (1984), the MWE took place in the most of Europe between 1150–1300, while the LIA occurred between in 1550–1850. The LIA was characterised by an increased frequency of extreme meteorologial-hydrological events. Several works document the influence of climatic fluctuations during the LIA on the acceleration of some geomorphic processes such as runoff processes and especially gullying (cf. Stankoviansky 2003a, c, d) or debris flows (Kotarba 1992, 1996, 2004).

However, it is obvious that also some other gravitational processes such as landslides, earth flows and mudflows as well as fluvial processes must have been activated in conditions existing during the LIA.

GEOMORPHIC PROCESSES IN THE CRYONIVAL SYSTEM

The highest parts of the Slovak Carpathians are typified by cold mountain climate and the occurrence of cryogenic and nival processes. In the Western Carpathians these processes typically occur above the climatic timberline i.e. above 1,500 m a.s.l. There are six geomorphic units in Slovakia with altitudes exceeding the upper timberline; these are usually called "high mountains" (Lukniš and Plesník 1961) and include the Tatry Mts, Nízke Tatry Mts, Veľká Fatra Mts, Malá Fatra Mts, Oravské Beskydy Mts and Chočské vrchy Mts (Fig. 1). The total area above the upper timberline is approximately 49,000 ha (1% of Slovakia's territory) but within the mentioned geomorphic units it ranges from 2% of the unit's area in the Chočské vrchy Mts to 50% in the Tatry Mts. As it was already mentioned, areas above 1,500 m a.s.l. in the Western Carpathians belong to the cryonival system. The characteristic landforms developing recently are those created by frost and snow action. Nevertheless, runoff processes dominate in intensity (Midriak 1999).

In the Tatry Mts, the highest massif of the high mountains, A. Kotarba et al. (1987) identified three geoecological belts within the cryonival system: subalpine belt, alpine belt and seminival belt, the latter in correspondence to the nival belt in the Alps. An idealised and simplified model of the actual morphodynamics was based on the characteristics of the prevailing processes within each belt.

The highest, i.e. seminival belt is situated above 2,150–2,300 m a.s.l. It comprises the system of ridges and peaks with steep rock cliffs. As weathering mantles are thin or absent physical weathering, rock falls, corrasion by sliding debris and cryogenic processes are the main geomorphic processes in this belt. Gelifluction occurs locally. Snow avalanches are frequent, but have little morphological significance. However, as the main difference between seminival and alpine belts is based on the character of relief (which is relic), and with the mean temperature of the warmest month being higher than 0°C the climatic snow line is not present in the Tatry Mts (N i e d z w i e d ź 2004), the existence of climatically conditioned seminival belt may be uncertain.

The alpine belt starts from 1,650–1,800 m a.s.l. The slopes and ridges are mostly covered by weathering mantle and dissected by chutes. Microrelief is highly variable. Gravitational processes on cliffs and rocky slopes, frost creep, gelifluction and creep of debris covers, wind erosion and nivation are typical of the alpine belt. Debris flows and snow avalanches are more dynamic processes.

The subalpine belt is situated above the upper timberline. The presence or absence of dwarf pine is an important factor for the occurrence and intensity of present-day geomorphic processes. The subalpine belt was highly influenced by the Wallachian colonization, especially where geological substratum consists of carbonate rocks. Runoff processes, snow avalanches and piping are among the most intensive geomorphic processes. Deposition of the material from higher geoecological belts is an important process in the Tatry Mts.

If this model of geoecological belts is applied to all high mountains of Slovakia, the situation would be as follows: all the belts together are present only in the Vysoké Tatry Mts — the highest part of the Tatry Mts; alpine and subalpine belts can be found within the Tatry Mts in the Belianske Tatry Mts and the Západné Tatry Mts, and in the highest parts of the Nízke Tatry Mts; in the Veľká Fatra Mts, Malá Fatra Mts, Oravské Beskydy Mts and Chočské vrchy Mts there is only subalpine belt. The character of each geoecological belt in individual mountain ranges highly depends on the presence of a higher belt and on the potential occurrence of the allochtonous processes. Therefore, the characteristics of the same geoecological belt may vary considerably between any of the high mountain ranges (e.g. the Veľká Fatra Mts vs. the Tatry Mts).

Describing the high-mountain system of sediment transfer, A. K o t a r b a et al. (1987) identified two basic morphogenetic subsystems, namely slopes and channels. Allochtonous processes can affect lower belts mainly within channel subsystems. The upper timberline, dividing cryonival and temperate forest systems, does not produce an abrupt discontinuity for geomorphic processes (K o t a r b a et al. 1987). This is true especially for the climatic timberline, with the character of a transitive zone, and channel subsystems with active allochtonous processes, where "an avalanche type of timberline" (cf. P l e s n í k 1971) developed. Anthropogenically lowered timberline produces more abrupt discontinuity, the boundary is usually sharp especially in the case of the lower limit of the slope subsystem and mainly slope subsystems are sharply limited towards the forest belt.

According to R. M i d r i a k ' s survey (1999), the mean elevation of present timberline in the Western Carpathians varies from 1,185 m (Kriváň subunit of the Malá Fatra Mts) to almost 1,440 m (the Vysoké Tatry Mts, Kráľova hoľa subunit of the the Nízke Tatry Mts). The averaged anthropogenic lowering of the present timberline reaches 280 m and locally even 350–400 m. The intensity of lowering reached maximum during the Wallachian colonization in the areas with rich soils on calcareous substratum (limestones, calcareous marls) and smooth relief.

Photo 1. Runoff erosion of bare soil. Vegetation together with upper horizon of soil cover were removed by snow avalanches, Malá Fatra Mts

Dwarf pine and forest covers were sporadically destroyed until the 1950s (Janík 1971). Recently, the altitude of the timberline has been increasing. This is associated with the systematic afforestation of selected slopes and natural overgrowing of abandoned pastures. A slow rise in the elevation of climatic timberline is also expected in connection with global warming.

The distribution and rate of present-day geomorphic processes depend on a complex of various conditions such as climate or local geology. Climatic conditions favouring the occurrence of cryogenic processes exist in lower altitudes at least for a part of the year, thus the significance of the other controls becomes more important here. In the upper parts of the cryogenic system, it is the intensity of the processes that is determined by non-climatic controls while in the lower parts it is their spatial distribution. Therefore, the removal of vegetation cover is responsible for the expansion of cryogenic processes to the lower altitudes of subalpine and forest belts (Barka 2005).

Together with the type of vegetation cover and its presence or absence, interactions between processes develop: vegetation can be removed by one process (a primary or initial process) and the other processes (secondary ones) may be induced after the removal of vegetation (Photo 1). Unlike secondary processes, the initial process does not require the absence of vegetation. The higher the number of initial processes, the more intensive morphodynamics can be observed in the area

Photo 2. Fresh accumulation of debris flow in Velická dolina Valley, Tatry Mts

Photo 3. Slopes deforested during the Wallachian colonization, Šútovská dolina Valley in the Malá Fatra Mts. Soil and vegetation covers destroyed by snow avalanches

(Barka 2005). In the lower parts of the cryonival system, the main initial processes are snow avalanches, shallow landslides and anthropogenic activities, in the upper parts cryogenic processes are active regardless of vegetation. In the subalpine belt, the removal of dwarf pine cover and overgrazing has led to the higher frequency of initial processes and the occurrence of cryonival processes since the Wallachian colonization. In the Tatry Mts, the Little Ice Age is mostly associated with more intensive rainfalls and more intensive and frequent gravitational processes. Basing on lichenometric dating A. Kotarba (1992) showed that large debris flows were more frequent during the later parts of the LIA (particularly between the1820s and the1880s), reaching a volume of at least 3,000 m^3. In contrast, within the last 100 years such large events occurred sporadically. A. Kotarba (2004) conducted research in the Zelené pleso Valley in the Slovak part of the Tatry Mts, considering the event of 1813 among the most intensive ones. A review of large debris flow events in Polish Tatry Mts was elaborated by Z. Rączkowska (2006). Within the period of the LIA large debris flows occurred not only in the Tatry Mts. Perhaps the most known has been the event in the Malá Fatra Mts in 1848, which destroyed Štefanová village under Veľký Rozsutec Mt (1,610 m a.s.l.).

The LIA also influenced the frequency and size of the snow avalanches. Although the reconstruction of snow avalanche activity during the LIA is impossible, as avalanche sediments were buried by later processes, the drop stones in lacustrine sediments suggest higher avalanche intensity during this period (Kotarba 2004).

Nowadays two climatic tendencies can be observed: a progressive temperature rise and an increase in rainfall intensities (Kotarba 1997, 2004; Niedźwiedź 2004). The frequency of gravitational processes (Photo 2) and snow avalanches (Photo 3) is slightly increasing. There has been a rise in avalanche intensity since the winter of 2000, particularly in the forest belt (Hreško et al. 2005). Avalanches were triggered even in dense broadleaf forests, and in the Malá and Veľká Fatra Mts they reached valley bottoms at the elevation below 500 m a.s.l. However, this trend does not reach the scale of the LIA.

GEOMORPHIC PROCESSES IN TEMPERATE FOREST SYSTEM

Nearly all the Slovak Carpathians lie in the temperate forest system except for the parts of high mountains situated above the upper timberline. Thus the system comprises extensive parts of high mountains situated below the upper timberline, middle mountains and intra-mountain depressions. The specific feature of the lower parts of high mountains is the penetration of processes from the higher situated cryonival system, particularly their accumulation component (rock falls, rock slides, debris flows and snow avalanches). A distinctive trait of the temperate forest system is the prevalence of chemical over physical weathering (Kotarba and Starkel 1972). Under natural conditions gravitational and fluvial processes dominated in the temperate forest system although subsurface water processes and organogenic processes also occurred. The situation changed radically with the appearance of humans who gradually settled mountain areas and progressively transformed the forest landscape into the cultural landscape with developed agriculture and other economic activities.

Anthropogenic changes of the natural environment in the Carpathians, especially the transformation of woodland into farmland, resulted in the acceleration of the majority of geomorphic processes but mostly in the emergence of processes that previously had negligible or no influence on the forest landscape. Gradually, the significance of the so-called proper anthropogenic processes i.e. direct interventions of the humans in the relief increased. The rate of these processes is decreasing with the increasing sea level. Devastation of extensive areas of newly obtained farmland by a complex of anthropogenically accelerated geomorphic processes resulted in local afforestation. This in turn distinctly reduced the effects of the processes in these localities, and in terms of relief dynamics essentially re-established the natural conditions.

Chronologically, the development of settlement in the Slovak Carpathians can be divided into three periods with different land use patterns and process dynamics:

— period before the arrival of the first farming communities (minor interventions in the original landscape);

— period between their arrival and the beginnings of the Great colonization — typified by considerable temporal and spatial variability of settlement with the resultant local human interventions in the forest environment and discontinuity in the operation of accelerated processes;

— period between the beginning of the Great colonisation and the present, characterised by distinct transformation of the forest landscape to the cultural, largely farming, landscape, its permanent agricultural exploitation and continuity in the operation of accelerated processes.

As far as the spatial aspect is considered, three below mentioned landscape types with different dynamics of geomorphic processes, based on the specific features of the long-term landscape evolution and the rate of human impact in time and space, can be discerned in the temperate forest system of Slovakia.

GEOMORPHIC PROCESSES IN THE PERMANENTLY FORESTED LANDSCAPE FREE FROM OR ONLY LOCALLY AFFECTED BY HUMAN ACTIVITIES

The characteristic feature of this landscape type is essentially the invariable set of geomorphic processes, with rates changing in time under the influence of environmental (mostly climatic) changes. The dominant processes are gravitational and fluvial, complemented by subsurface water processes and organogenic processes. Uninhibited by the forest cover, both surface and deep creep as well as deep-seated landslides occurring mostly in wetter periods are the principal gravitational processes here. Generally, gravitational processes can be linked to specific features of local geology (cf. Nemčok 1982). Their effects are most evident on the klippen forms of the structurally lithologically controlled relief in core mountains or in the area of the Klippen belt (with very resistant carbonate complexes) and also in volcanic mountains where various processes of falling accompanied by accumulation of debris occur. Construction of linear structures (transportation network) in the forest environment activates gravitational deformations.

Concerning fluvial processes, erosion prevails over accumulation as the forested slopes do not release sufficient material so as to reduce the erosive activity of streams. Geomorphologically efficient fluvial processes take place only under high water levels caused either by heavy rainfalls or snowmelt with the resulting continuous deepening of the V-shaped valleys or channel incision in flat-bottomed valleys. Fluvial erosion of valleys or undercutting of slopes by lateral erosion provokes slides.

Subsurface water processes operate both mechanically and chemically. Mechanical erosion by subsurface water is mainly caused by suffosion (piping) occurring in permeable layers of the regolith. It is especially typical of glacial and glaciofluvial accumulation bodies. In areas prone to sliding, suffosion favours landslide formation. Corrosion is active in soluble rock complexes primarily in karst areas. In the case of subterranean karst streams, it is accompanied by corrasion. Subsurface water which moves in fissures also operates outside the karst areas, for instance in fissured flysch calcareous sandstones (cf. Stankoviansky 1994); in places of subsurface water resurgence calcareous tufa deposits form (Stankoviansky 1977). Deep water circulation in weathered material and Quaternary sediments (regardless of their position but respecting their thickness) causes leaching and subsequent transport of mineral substances in solution. This mechanism may be responsible for the distinctly higher chemical denudation values compared to the cryonival system (cf. Kotarba 1971).

Organogenic processes are associated with morphogenetic activity of plants and animals. The pressure of growing roots results in what is referred to as biogenic weathering. Considerable amounts of material are transported within the root systems at uprooting of trees mostly during wind calamities which mostly strike the Slovenské rudohorie, the Vysoké and the Nízke Tatry Mts, geomorphic units of the Beskydy Mts, Spišská Magura Mts and Levočské vrchy Mts. Significant wind calamities took place in 1897–1898 while that in 1941 struck forests in almost entire Slovakia. Other large events occurred in 1947, 1948, 1949, 1964 and 1976 (*Encyklopédia Slovenska* 1979; p. 336).

The effect of runoff processes under natural conditions is practically negligible. However, any human intervention in the forest landscape markedly changes the situation. The significance of anti-erosion function of woods is often weakened by large--scale clearcuts, inappropriate technology of log skidding, construction of unmetalled roads, ski tracks, ski lifts, etc. (Midriak 1988). Research has revealed that considerably greater values of soil loss occur under the influence of linear erosion linked to tractor wheel tracks, log skidding tracks or to forest roads. R. Midriak (1995) found out in the flysch area of the Bukovské vrchy Mts that the values of soil loss caused by linear erosion equal nearly 100-fold loss caused by sheetwash.

GEOMORPHIC PROCESSES IN DEFORESTED LANDSCAPE TRANSITIONALLY USED IN AGRICULTURE AND SUBSEQUENTLY AFFORESTED

This landscape type is characterized by a double change in the operation of geomorphic processes. The first change is linked to deforestation, the second is connected with afforestation. Before deforestation, the series of processes and their effects were the same as in case of the first landscape type. After deforestation, the effects of the processes which previously operated under natural conditions were accelerated or altered, and more importantly, new processes such as runoff, aeolian or tillage processes were triggered. Original conditions were then largely restored as a result of afforestation. Deforestation of extensive areas in the Carpathians under farming or pastoral colonizations and the development of mining and metallurgy (and related logging and charcoal production) and the resultant progressive extension of the cultural landscape proceeded in stages. Large scale deforestation only took place from the 13th century and it was connected with the beginning of the Great colonization. The last stage of more significant interventions in the forest were associated with the “kopanitse” colonization which finished in the mid-19th century. Local deforestation still occurred even in the 20th century (Podolák 1966).

Afforestation also varied in time and space. The first references to afforestation of the Carpathian part of Slovakia, particularly in the environs of Banská Bystrica are from the 16th century. After 1770, the artificial restoration expanded to the majority of the exploited forests. Extensive afforestation took place in the region of Horehronie in 1809–1830 (3,942 ha), and in the region of Orava in 1868–1878 (7,010 ha). Stabilisation and afforestation of gullies and barren land started in 1885. Forestation increased significantly after the World War 2, when over 130,000 ha of land and nearly all formerly stripped parts were forested. Much attention was given to afforestation of the barren land in the Brezovské Karpaty Mts and the Slovenský kras Mts (*Encyklopédia Slovenska* 1982; p. 492–493). While in 1895 the total area of forest in Slovakia was 1,683,220 ha (34.4%), in 1961 it was 1,793,769 ha (36.6%) (Mazúr 1974) and in 1980 it was even 1,911,870 ha (39.0%) (*Encyklopédia Slovenska* 1982; p. 493) length of time during which the deforested area was exposed to the activity of accelerated geomorphic processes and its land use pattern (meadow, pasture, arable land) were spatially variable. The impact of deforestation was smaller on the processes which had already been active in the forest landscape, such as deep creep, falling or deep-seated slides (cf. Kotarba and Starkel 1972).

However, removal of forest significantly increased the frequency of gravitational processes striking the regolith such as shallow slides, earthflows, and mudflows. The nature of fluvial processes has changed considerably in deforested areas. Increased sediment supply from deforested slopes reduced the erosive power of streams resulting in increased accumulation. In the basins of smaller streams reduction in the area of forest cover and occurrence of extreme rainfalls resulted in the increased frequency of flash floods. More important, however, was the triggering of the formerly insignificant or inactive processes (runoff and aeolian processes respectively). Deforested areas were then used for agricultural production followed by extreme grazing after the soil had been impoverished. Herds grazed on poor pastures and destroyed the remaining vegetation. Beside deforestation itself, also forest fires and wind calamities locally played a negative role (Midriak 1969); following increased activity of runoff and aeolian processes led to the total destruction of the surface and the development of the so called secondary barren lands (Janečko et al. 1955; p. 12).

In areas with more resistant rocks and shallow regolith practically the whole layer of soil was removed and substratum was denuded. In places with thicker regolith, especially in areas built of less resistant rocks, the soil was thinned by sheet erosion and a dense network of permanent gullies was formed by linear erosion. Suffosion significantly contributed to the formation of gullies. The nature of barren land of this type locally resembles that of badlands. Gullies in the Carpathian part of Slovakia occur chiefly in flysch and volcanic areas. Barren lands with the combined effect of sheet erosion and gully erosion are typical for the areas built of carbonate rocks (Midriak 1969; Zachar 1970; p. 357).

Beside pastures, the dense gully networks have also formed on arable land which is indicated by their linkage to artificial linear elements such as access roads, field boundaries or lynchets remaining from the former farming landscape (Stankoviansky 2003d). The greatest effect of runoff processes is observable in places where the land use and climatic effects met, as in the area of the Myjavská pahorkatina. It is where the large-scale deforestation linked to the “kopanitse” and Wallachian colonizations coincided with the cooler and wetter fluctuations of the LIA. Between 1550 and 1850 at least two stages of disastrous gullying produced a dense network of permanent gullies (Stankoviansky 2003a). Gully erosion was accompanied by muddy floods, which left thick bodies of colluvial cones prograding onto the floodplains of the valleys in which the gullies mouthed (Stankoviansky 2002). The Myjavská pahorkatina, the geomorphic units in regions of Kysuce, Orava and Šariš, the Nízke Beskydy Mts, southern part of the Slovenské stredohorie and the Juhoslovenská kotlina were are the areas that stricken by the most intensive gullying (Bučko and Mazúrová 1958).

Continuous tillage erosion, accompanied by sheet erosion in the middle and lower reaches of slopes, took place in deforested areas that were changed into arable land and led to the lowering of convexities and increase of concavities of the surface. Up-and-down tillage resulted locally in such soil loss that the farmers stopped ploughing the land and used it as poor pastures (Lobotka 1958). Contour tillage gradually led to an unintentional formation of terraced fields. Sometimes, when the fertility of such terraces diminished, they were also changed into pastures. A vast area of the former fields was even afforested. However, old terraces hidden among trees reveal the original function of such slopes now coated by forest (cf. Stankoviansky 2003d; p. 60).

Composition of geomorphic processes, their course and rate have substantially changed after the afforestation of the areas once deforested and later used in a different manner. Tillage erosion disappeared from former arable land, followed by aeolian processes and areal runoff erosion. The latter also disappeared from former pastures. Gully erosion, once active on old pastures and arable land, has diminished substantially but is observable even in forests during extreme rains or abrupt snowmelt. Uprooting of trees caused by wind calamities can be noticed again in exposed localities within the secondary forests. The calamity of November 19, 2004 that affected the foothills and foreland of the Vysoké Tatry Mts has remained a memorable event. Within the stricken area — a belt of about 120 km^2 stretching along 30 km from Podbanské to Tatranská Kotlina — uproots prevailed over fallen trees. Spruce monocultures (*Piceetum Culti*) were the ones most frequently uprooted for their shallow root system.

GEOMORPHIC PROCESSES IN PERMANENTLY CULTURALLY USED LANDSCAPE

A major part of the Slovak mountains remained deforested until the present despite historical changes in land use patterns. Here the course of geomorphic processes has been similar to the one described for the pervious type. However, the intensity of the processes has continued to increase and is further enhanced with increasing anthropogenic pressure. With the progressive intensification of human interventions in the landscape, the probability of occurrence of gravitational processes, mainly shallow slides, earthflows and mudflows affecting the regolith, has increased. In wetter periods the processes also affect the substratum. Reactivation of older slides under the human impact was also frequent. For instance, 90% of all landslides which occurred in populated areas within the last decades and which caused the greatest damage were brought about fully or partly by human intervention in the areas of old landslides (Malgot 1980). Such landslides are either artificially loaded or undercut. They were activated due to the construction of civil or industrial structures, bridges, roads, tunnels, pipe-lines and water reservoirs. Numerous landslides were induced by deforestation, incorrect agricultural melioration works, intensification of the surface and subsurface runoff and failures of underground pipe-lines (Malgot and Baliak 2002a).

The changed landscape also determined the effects of fluvial processes during frequent floods. For instance, floods on the Váh River occurred in 1602, 1625, 1652, 1683, 1710, 1714, 1736, 1748, 1794, 1813, 1854, 1864, 1876, 1880, 1889, 1894, 1903, 1925, 1948, 1958, 1960, 1974, 1997 (Kunsch et al. 1998; Bitara 1998). The largest known flood on the Váh River, with recurrence interval of 500–1000 years, occurred in 1813 and caused 243 deaths. Between Žilina and Sereď over 50 communes lost the majority of their houses. The spa of Piešťany was utterly damaged except for six houses (Bitara 1998). According to E. Bitara (1998) and J. Minár et al. (2006), recent floods are significantly smaller and do not reach the levels of floods which occurred before 1960.

A substantial part of the deforested areas is still agriculturally used (see Fig. 1). After M. Stankoviansky (2005a), the period of functioning of the cultural landscape can be divided into two unequally long intervals with considerably different course of geomorphic processes, especially runoff ones: the period between the primary deforestation and the start of agricultural use until collectivisation and the period after the collectivisation. Within the earlier and longer of the two periods, two types of relief evolution were distinguished on the basis of the predominant processes and their geomorphic effects. The first type was dominated by linear runoff (gully) erosion and its geomorphic effect was represented by the formation of permanent gullies. Gully erosion, in the period of the transformation of the woodland into farmland and later, resulted in the creation of a dense network of gullies on slopes and along bottoms of dry valleys and dells. As the gullies have been almost completely afforested, these processes and their effects in those areas are described above.

The second type of relief evolution within the earlier period is characterised by the predominance of a combined operation of areal runoff erosion and tillage erosion. The areal runoff erosion occurred irregularly during extreme hydrometeorological events while tillage erosion occurred regularly in the course of the temporally fixed tillage operations. The geomorphic effect of these processes, complementing each other, consisted in the lowering of the surface of slopes and ridges where ploughed along the gradient and in the creation of cultivation terraces (steps of terraced fields) in parts ploughed along contours. In terms of landform transformation the main role was played by tillage erosion.

The second, later and shorter of the two identified periods of relief evolution in the farmland, started by large-scale land use changes associated with the collectivisation in agriculture after the World War 2. The mosaic of original small private parcels vanished in favour of the vast collectivised land units. The most inconvenient terrain adjustment was levelling of the former cultivation terraces resulting in the reacquisition of smoothly shaped slope relief similar to the one inherited from the period of periglacial morphogenesis.

However, the present-day surface is markedly lowered; it was estimated that in the area of the Myjavská pahorkatina the thickness of the removed layer within the whole cultural period frequently exceeds 1 m (Stankoviansky 2003d; p. 151).

Large-scale changes in land use resulted in a distinct acceleration of runoff processes during extreme rainfalls or sudden snowmelts. The formation of large blocks of cooperative fields and removal of a dense network of artificial linear landscape elements caused a shift from the predominance of linear erosion to the prevalence of areal erosion, manifested by a marked increase in the area affected by repeated intense sheet wash, rill and inter-rill erosion (Photo 4). As to the linear erosion, almost exclusively topographically controlled ephemeral gullies are formed under the new conditions. Usually they are some meters wide, shallow and deepened only in the cultivation layer. The gullies are regularly erased by the subsequent tillage operation.

The increased intensity of runoff processes after collectivisation is also confirmed by thick beds of correlative deposits. The maximum amount of the total post-collectivisation deposits in the form of the vertical accretion of colluvium, as well as of the aggradation in the valley bottoms, reaches approximately 1 m. The thickness of the fill in some narrow valley cuts or gullies reaches and locally even exceeds 2 m, (cf. Stankoviansky 2005b).

Erosion, intensified due to extreme hydrometeorological events, is accompanied by muddy floods. It was found that the present landscape is characterized not only by a significantly more frequent flooding of this type but also by an increase in its destructive power. Muddy floods in lateral dry valleys represent a significant environmental issue and natural hazard for local inhabitants (Stankoviansky 2002). Perhaps the most terrifying event so far was that of May 1, 1996 in Ivanka pri Nitre where 175 houses were flooded including 4 that crushed down seriously threatening human lives. The geomorphic effect of muddy floods is manifested only outside build-up areas as the layers of mud within the communes are removed.

However, extreme local rainfall events can have significantly greater geomorphic effect than muddy floods. The so-called flash floods of local streams occur regularly and their number even increased within the last 10–15 years. In 1998, a flash flood on the Malá Svinka Brook killed 44 people in the village of Jarovnice, Eastern Slovakia (Minár et al. 2006). During this event precipitation totals exceeded 100 mm in two hours within a restricted area. The destructive effect of the flood partly resulted from an insufficient risk assessment in relation to the floodplain characteristics and partly from the lack of urban planning regulations. The scope of the damage is also attributed to the character of the present landscape.

Photo 4. Contemporary farmland in the eastern part of the Myjavská pahorkatina Hill Land, modeled since the 14th century by tillage and runoff erosion that was intensified after collectivization. In the background the Malé Karpaty Mts

A smaller part of the material supplied by runoff processes during extreme events from fields, permanent or ephemeral gullies and field roads enters the river network and is transported by streams, along with the material eroded from the bed and banks. Part of this material remains in the numerous reservoirs in the Carpathian area. According to K. Holubová (1997) suspended load plays a decisive role in reservoir silting. Annual sedimentation of suspended load in Slovak reservoirs is 8–10 times higher than sedimentation of bed load. The problem of intensive reservoir silting is characteristic mainly for the middle and upper reaches of the Váh River cascade. This is connected with the high rate of erosion processes in rocks of medium to low resistance. Measurements in 1955–1972 showed that silting is responsible for the loss of 58% (Krpeľany), 25% (Hričov) and 22% (Nosice) of the original volume of these reservoirs. The total amount of the material accumulated in these reservoirs during the period from their construction till 1992 represents more than 12.7 million m^3 of sediments equalling, on average, approximately 35% reduction in their original volume (Holubová and Lukáč 1997).

The permanently used arable land in the Carpathian part of Slovakia is also stricken by aeolian processes but their effectiveness is negligible in comparison with lowland areas. According to A. Klukanová et al. (2002) fairly frequent dust storms occur only in the valley of the Váh River in its reach between Púchov and Nové Mesto nad Váhom, in the Cerová vrchovina Mts and the south-eastern part of the Košická kotlina.

CONCLUSIONS

The Slovak Carpathians are situated in two vertical climatic-morphogenetic systems, namely the cryonival and temperate forest systems characterized by different sets of geomorphic processes. According to A. Kotarba and L. Starkel (1972), the border separating the two systems is the upper timberline which oscillates around the altitude of 1,500 m. The occurrence and dynamics of geomorphic processes have also been to some extent influenced by the variability of relief and geological substratum. The main differentiating factor of the occurrence and operation of geomorphic processes in the Slovak Carpathians is vegetation, mainly the forest cover. Damage or even total removal of the originally almost continuous forest cover is associated with human interventions in the mountain landscape which took place on a more massive scale only during the so-called Great colonization in the 13th and 14th centuries. Gradual forest clearance enlarged the area of land attacked by accelerated processes. The most intense, spatially extensive and from the human viewpoint damaging activity of the processes occurred in periods when anthropogenic interventions overlapped with climatic fluctuations, mostly during the Little Ice Age.

The most important human intervention in the operation of geomorphic processes in the cryonival system was represented by the Wallachian (shepherd) colonization associated with the lowering of the upper timberline (up to 300 m on some places). This resulted in the penetration of cryogenic and nival processes into lower positions, namely on slopes situated below the natural upper timberline. However, runoff processes remained predominant. Climatic fluctuations during the Little Ice Age were manifested by the increased occurrence of debris flows and snow avalanches.

Temperate forest system was significantly more affected by human interventions than the cryonival system. Farmers, shepherds, miners and smelterers gradually reduced the extent of forest areas and their quality. Naturally, the scale of the anthropogenic transformation of this system was changing in time and space. It is possible to distinguish three landscape types with different dynamics of geomorphic processes since the beginnings of human impact until now, especially in the period of the last eight centuries, namely:

a) Permanently forested landscape free from or only locally affected by human activities;
b) Deforested landscape transitionally used in agriculture and subsequently afforested;
c) Deforested and then permanently culturally used landscape.

The characteristic feature of the first landscape type is essentially the invariable set of geomorphic processes, only their rate was changing over time under the influence of environmental, mostly climatic, changes. The dominant processes are gravitational and fluvial, complemented by subsurface water processes and also organogenic processes.

The second landscape type is characterized by a double change in the operation of geomorphic processes. The first change is linked to deforestation, the second is connected with afforestation. Before deforestation, the set of processes and their effects were the same as in the case of the preceding landscape type. After deforestation, the effects of the processes which previously operated under natural conditions were aggravated and more importantly, some processes such as runoff, aeolian or tillage processes, negligible in terms of effectiveness before deforestation, emerged. The most distinct manifestation of the operation of accelerated processes was the formation of dense network of permanent gullies which were later afforested.

The third landscape type represents areas that have never been afforested, although over time they underwent local land use changes. A similar course of processes to that in the second type is characteristic for these areas. The only difference is that the acceleration of processes is not limited in time and continues into the present, increasing with the growing anthropogenic pressure. This is typical of the increasing utilization of farmland that culminated with large scale land use changes associated with collectivisation after World War 2.

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STRESZCZENIE

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REAKCJA GEOMORFOLOGICZNA NA ZMIANY ŚRODOWISKOWE W SŁOWACKICH KARPATACH

Artykuł omawia geomorfologiczne procesy i ich skutki w środowisku przyrodniczym słowackich Karpat wywołane zmianami klimatycznymi i działalnością człowieka. Opisano zmiany zachodzące w dziedzinie krioniwalnej i umiarkowanej leśnej. Podkreślono zmiany gospodarki człowieka w ujęciu historycznym, ze szczególnym uwzględnieniem ostatnich ośmiu stuleci, oceniono przebieg i tempo procesów rzeźbotwórczych i ich wpływ na środowisko przyrodnicze. Autorzy przedstawiają tezę, że głównym czynnikiem różnicującym występowanie procesów rzeźbotwórczych w słowackich Karpatach jest roślinność, a w szczególności obecność lub brak pokrywy leśnej. Usuwaniu pierwotnie zwartej pokrywy leśnej towarzyszyło oddziaływanie człowieka na krajobraz górski, najwyraźniej zaznaczone w okresie wielkiej kolonizacji w XIII i XIV stuleciu. Stopniowe karczowanie lasów skutkowało występowaniem antropogenicznie przyspieszonych procesów. Najbardziej intensywne, rozległe i groźne zniszczenia miały miejsce w okresach, gdy na ingerencję człowieka w środowisku nakładały się wahania klimatyczne, zwłaszcza podczas małej epoki lodowej.