Acta Geodyn. Geomater., Vol. 5 (151), 275–296, 2008

SELECTED LANDFORMS AND THEIR SIGNIFICANCE IN THE ANALYSIS OF THE SLOPE ORIGIN IN THE LOSENICE RIVER VALLEY, ŠUMAVA MTS.

Filip HARTVICH [1)]* and Vít VILÍMEK [2)]

[1)] *Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, v.v.i., Prague, Czech Republic*
[2)] *Dpt. of Physical Geography and Geoecology, Faculty of Science, Charles University in Prague, Czech Republic*
**Corresponding author's e-mail:* hartvich@irsm.cas.cz

(*Received* May 2008, *accepted* July 2008)

ABSTRACT
A detailed geomorphological mapping was performed in the valley of the Losenice R., which is situated on the NE slopes of the Šumava Mts. nearby the Kašperské Hory town. The dominant characteristics of the studied area are steep slopes of the deeply incised, narrow valleys, strong fragmentation of the bedrock composed of various types of gneisses and obvious structural influence on the valley network plan. Based on the analysis of the occurrence, parameters and relative position of selected landforms, which have significance for documenting certain processes, as well as other inputs, the relief of the studied area was divided into eight genetic types of relief segments: structural, erosional, erosional-structural, structural-denudational and erosional-denudational slopes, flat denudational ridges and planation surface remnants and finally the valley floors with the floodplain.

KEYWORDS: geomorphological mapping, fluvial landforms, rockslides, slope development, Losenice R., Šumava Mts.

INTRODUCTION

This article summarizes the results of several years of geomorphological mapping in the catchment of the Losenice stream and seeks to analyse the pattern of the landform occurrence in order to understand the development of the studied area. The mapped landforms were analysed in order to understand the development of the valley, situated on the outer slopes of the Šumava Mts. (Fig. 1).

The key-stone of the analysis of the landforms is the geomorphological map, where the mapped elements are classified according to a geomorphological legend. The final legend, which forms the outline axis of this article as well as the graphic legend of the comprehensive geomorphological map (Fig. 2) is a result of a compilation of several geomorphological maps, adjusted to the properties of the relief in the area of interest.

There are several elementary possibilities of classification of the landforms (Vitásek, 1966; Demek, 1987; Buzek, 1986, Strahler and Strahler, 2000):

- by the geomorphological agent, which transports the material with the result of a landform creation, i.e. fluvial activity, wind activity, etc.
- by the mechanical process, which prevails in the shaping of a landform, i.e. material removal (erosion), storage (accumulation), etc.
- by the source, which supplies energy and predisposes the relief shaping, i.e. endogenous, exogenous forces
- by the scale (makro-, meso- and microforms)
- by the material, climatic or other conditions, in which they have developed (for example carst landforms, desert landforms, periglacial landforms)
- various combinations of the attitudes

For the purposes of this work, the combination of the process and force was used, first classification level was based on the process, and second on the agent, to which correspond the structure of the chapters:

- Structurally controlled landforms
- Erosional and denudational landforms
  - Fluvial
  - Slope
  - Cryogenic
- Accumulation landforms
  - Fluvial
  - Slope
  - Cryogenic
- Polygenetic landforms
- Other important relief elements

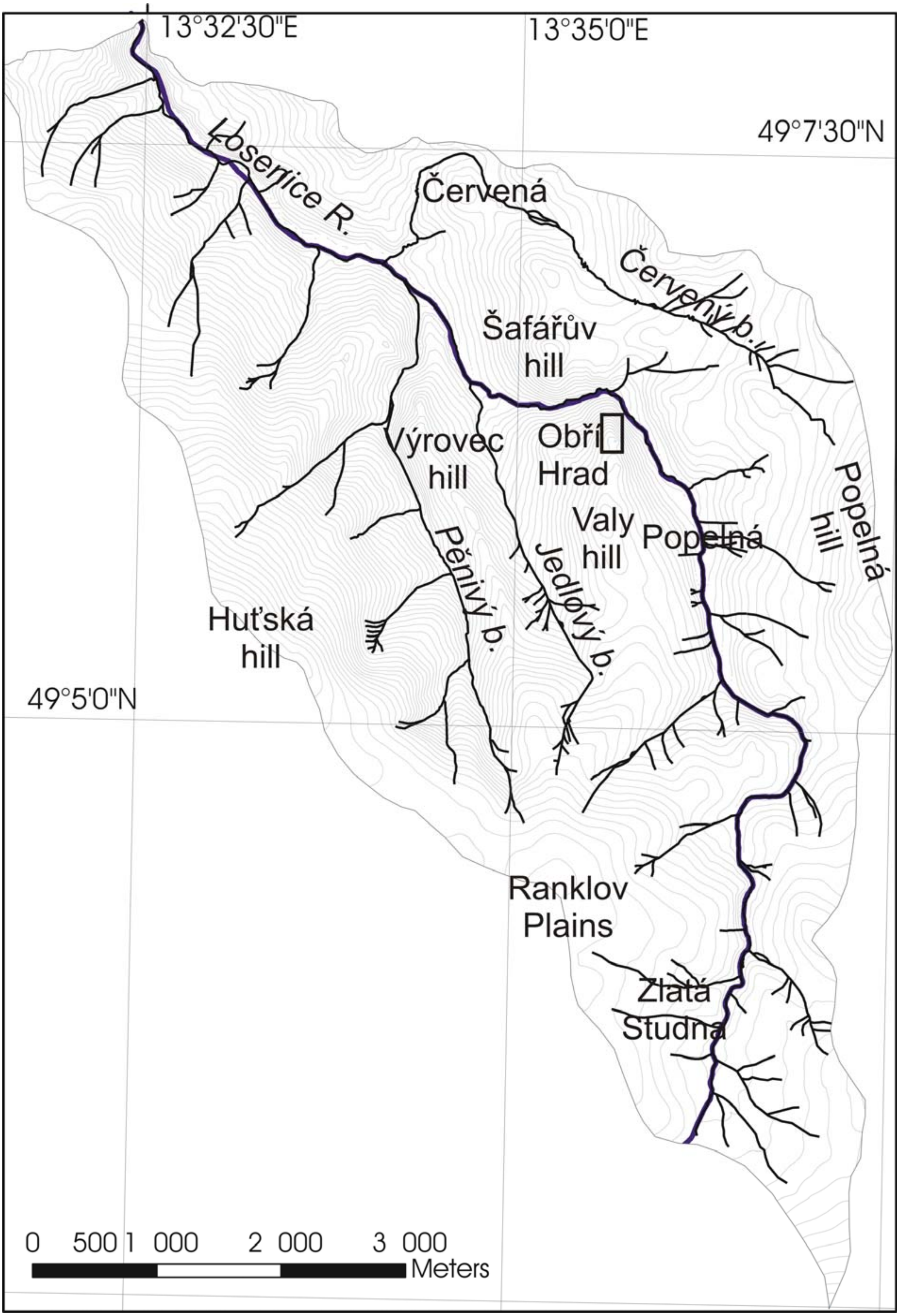

Fig. 1 Overview map of the studied area, showing the topography and reference localities.

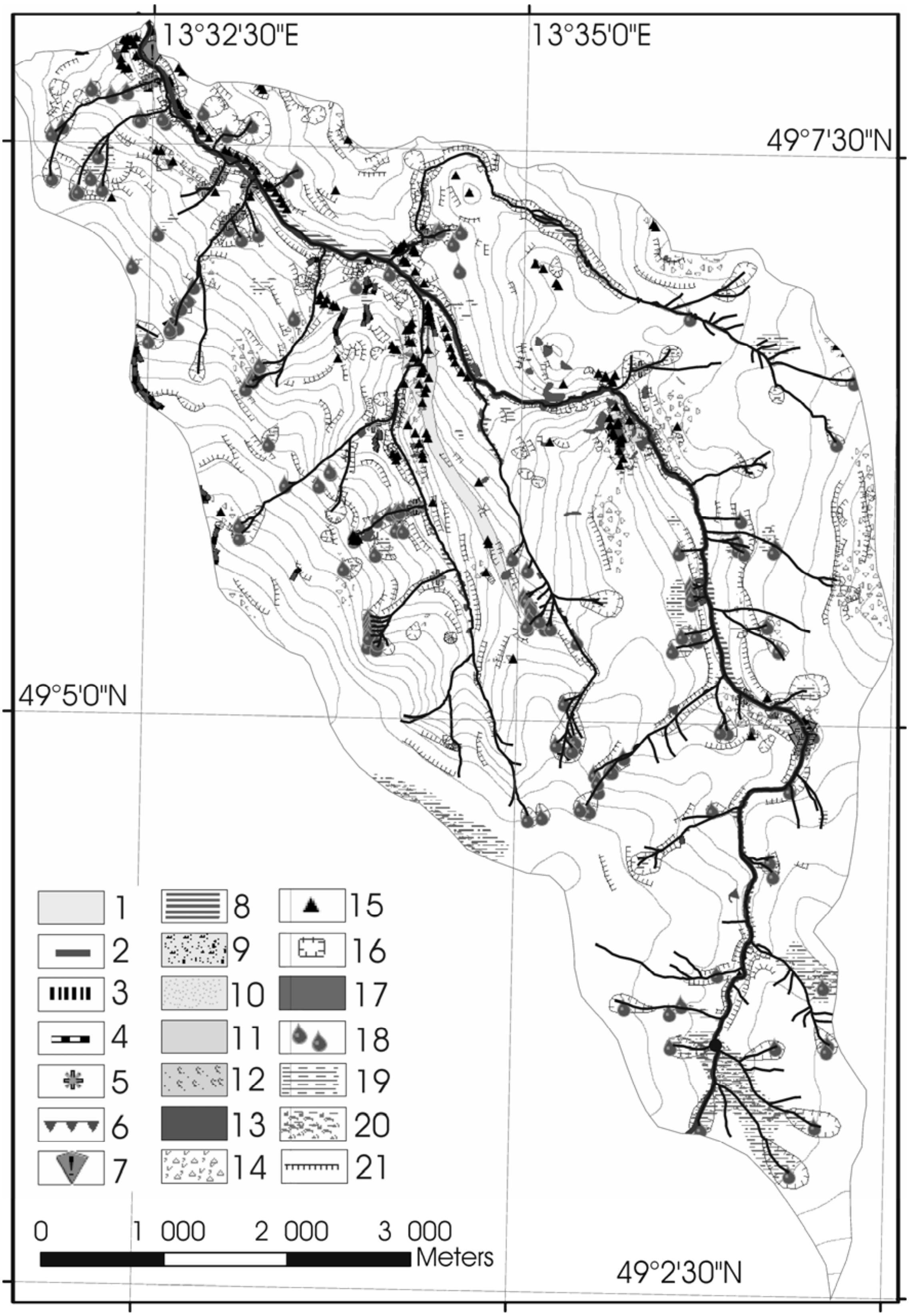

Fig. 2 Comprehensive geomorphological map of the studied area.
Legend: 1 – structural ridge, 2 – bank scour, 3 - multiple channel, 4 – erosion furrow, 5 – rock step, 6 – rock/landslide scarp, 7 – rockfall, 8 – floodplain, 9 – alluvial fan, 10 – fluvial point bar, 11 – rockslide (areal), 12 - land/rockslide accumulation remnant, 13 – dense blockfield, 14 – scattered blocks, 15 – rock outcrop, 16 – dellen, 17 – rock outcrop (area), 18 – spring, 19 – wetland, 20 – peat bog, 21 – relief breakline.

A bit aside the others stands the category of structural landforms, which can be considered as "azonal" – the structure-dominated landforms do not fit into a genetically continuous system connected by the energy and material flows (Twidale, 1971). For example, a landslide must have detachment, transport and deposition part (Ondrášik and Rybář, 1991), while a structurally determined kuesta has no or little genetic connection with its surroundings.

Among the most important sources for the construction of the classification legend were works from similar mid-mountain relief of central Europe, including Štěpančíková (2007), Vilímek (1998), Balatka et al. (1963), or universal ones such as Bashenina et al. (1968), Demek (ed. 1972) and finally GIS-based (Létal, 2005; MacMillan et al., 2000).

It is necessary to remark that this article comprises only a selection of landforms, which represent the most important keys to understanding the shaping and development of this part of the relief. During the six years of mapping, several thousands of landforms of various origins were recorded and embedded into the detailed geomorphological map.

A large group of landforms, which was omitted in this article even though it was mapped, is the class of the anthropogenic landforms. It is particularly intriguing and problematic part of geomorphological mapping in the Šumava Mts. The human activity in the area was the strongest, due to historical-political reasons, in the 19th and beginning of 20th century, diminishing significantly after 1940ies. As a result, once strongly human-influenced and changed landscape was in many parts practically left to its natural development for the last 50 - 150 years. It is clear, that the marks of the human activity are after such period of natural development blurred by the geomorphological and biological processes and nowadays it is very difficult to differentiate between the natural and anthropogenic influences.

AREA OF INTEREST

The area of interest (further AOI) is situated in the mid-mountainous relief of the NE slopes of the Šumava (Bohemian Forest) Mts. in the catchment of the Losenice River. It is one of the rivers draining the flat relief of the planation surfaces of Šumavské Pláně and on its 16 km long course towards N and NW steeply descends into deeply incised valley of the main stream, Otava River (Fig. 1).

This area forms one of the most significant outer slopes of the Šumava Mts., where the relief steeply descends from the uplifted plateaus of planation surface of Ranklovské Pláně (1100-1200 m a.s.l.) towards milder relief of the Šumava foothills and Otava valley. At the confluence of Losenice with Otava R. in Rejštejn, the altitude descends to 550 m a.s.l., only 6 km from the highest point.

The most intriguing part of the AOI is a long, approximately northward outspur of the Valy hill, surrounded from east and north by a sharply bent and deeply incised valley of the Losenice R. On the northern end of the ridge are situated remnants of a Celtic fortification of yet unknown purpose (Zvelebil and Slabina, 2002). The otherwise almost continuous, double belt of walls remnants is curiously missing on the eastern slopes.

MAPPING METHODICS

The vast majority of the work performed in order to achieve the results presented in this article has been performed during the fieldwork. Among the basic sources of information for the mapping were the maps - both in paper and digital form, in particular: the 1: 10 000 topographical map (ZABAGED) and the 1:25 000 and 1: 50 000 geological and special maps (Babůrek et al., 2001; Žáček et al., 2007; Müller et al., 1999).

The field maps were embedded into the GIS environment and supplemented by the input data, such as DEM, contours, slope maps, geological maps, etc. and further processed. In the GIS were performed both key tasks, i.e. spatial analyses and correlations as well as preparation of the cartographical outputs.

The balance between including maximum information while keeping the readability of the map is always a difficult work. For example, Gustavsson et al. (2006) have used a new attitude to involve as much information as possible into a general geomorphological map, including – aside from usual geomorphological objectives – age, lithology and activity of the landforms. The resulting map, however, is not very comprehensible and its reading is very difficult. Therefore, it is necessary to follow the objective of the particular map and carefully select the means of visualisation, particularly with the possibilities of the GIS (Létal, 2005).

RESULTS - SELECTED LANDFORMS: PROPERTIES, DISTRIBUTION AND DESCRIPTION

STRUCTURALLY CONTROLLED LANDFORMS

By the structurally controlled landforms are meant those that owe their existence to the influence of rock composition or structure, or tectonic activity, which has significantly contributed to their shape (Twidale, 1971). The only landforms classified as structural in the AOI were structural slopes and structural ridges. Arguably, the inner structure influences many other forms, particularly various rock outcrops, and partly even the block fields and fluvial sediments (Hartvich et al., 2007), but in the shaping of these landforms is dominated by other processes (Vitásek, 1966).

The structural slopes in the AOI occupy very limited area. There are no fault slopes, even though the plan of the valley system is clearly predisposed by the structural conditions including faults. The structural slopes are restricted to steep NE slopes where the foliation planes run approximately parallel with the surface. This configuration causes that the slopes are prone to sliding along these planes

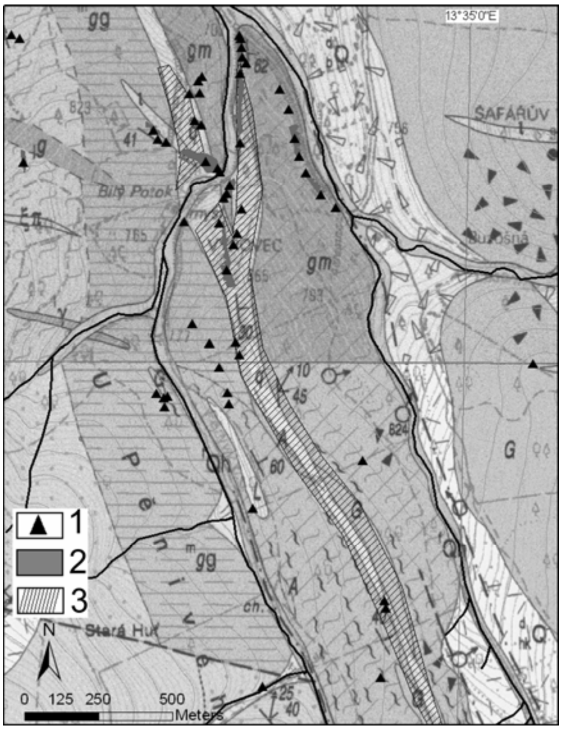

Fig. 3 Crop from a geological map (Babůrek, 2001) showing the position of the Výrovec structural ridge.
Legend: 1 - rock outcrop, 2 - rock outcrop (area), 3 - structural ridges

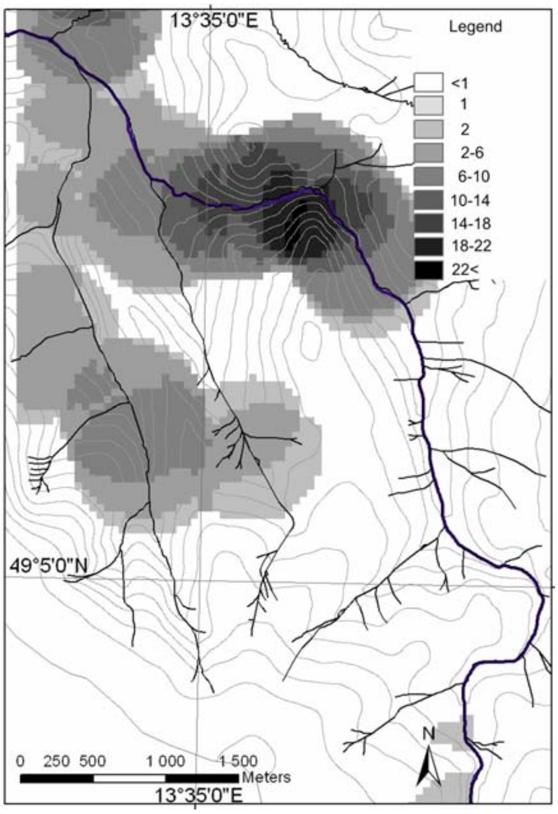

Fig. 4 Map of distribution of the bank scours. The raster hue indicates number of scours in the 500 m neighbourhood.

(Hartvich, 2006). By far the largest and most significant area of the structural slope is situated under the remnants of ancient Celtic fortification Obří Hrad on the NE slopes of the outspur of Valy Hill. Here, the most active slope movements occur, and the slopes reach in accordance with the foliation around 30°-40°.

The category of structural ridges was identified only on the long, sharp ridge of Výrovec (Fig. 3), a belt of hard quartzite (Babůrek, 2000; Žáček, 2006), which, being less prone to weathering, determines the position of the ridge. The quartzite belt crosses the Pěnivý brook, where it has caused the development of narrowest rocky gorge (valley floor is only 10 m wide here) and continues in another ridge on the other side of the brook.

EROSIONAL AND DENUDATIONAL LANDFORMS

Fluvial

Fluvial erosion is currently very active in reshaping the relief, particularly through dynamic flow concentrated in the vicinity of the streams and during higher discharge periods. Very significant consequences occurred during the severe 2002 flood, when the water has in many places filled whole width of the valley floor (Hartvich et al., 2007).

Bank scouring occurs usually on the outer side of curves or meanders, or as a consequence of various obstacles, re-directing the erosive power of the stream into the banks (Hartvich, 2007). The distribution of the bank scours in the AOI is unequal, as is illustrated in Figure 4 – by far densest concentration of bank scours was documented in the narrow valley of Losenice R. under Obří Hrad, where the slope processes interact with the material transported from the slopes, which limits the space in the channel and directs the stream towards the opposite bank (Fig. 5).

The development of multiple and braided channels is connected with the changes in the balance of sediment load and transport power of the stream

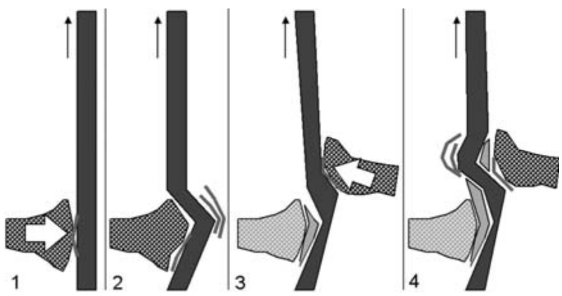

Fig. 5 Scheme showing the interaction between slope and fluvial processes in the narrow valley. Each sketch (1-4) shows a phase of development, from left to right.

(Sklar and Dietrich, 2006). This misbalance is most often caused by several factors (after Montgomery, 1997):

- obstacle in channel – tree, rock block or anthropogenic object/structure
- tributary – change in transport power
- sediment input from the slope – alluvial fan, landslide, rockfall

In the AOI, the presence of braided or multiple channel can is most common, as in the case of the bank scours, under the outspur of Obří Hrad (Fig. 6). Another occurrence coincides with the tributary input, almost under all confluences with major creeks. During the 2002 flood, the secondary channels were reactivated, cleared of sediment and in some cases remained active again for few following years.

The presence of a rocky bottom or steps in the channel indicates an outcropping bedrock, i.e. no sedimentary cover on the valley floor. While normally the valley is partly filled with sediment, outcrops in channel signify on-going incision of the river due to backwards erosion wave or due to harder bedrock in which it takes longer period to incise (Kale, 2005).

Generally, there are two areas of occurrence of the rock steps in the studied area: along the lower course of the Losenice R. and the Pěnivý brook, where the most likely cause is the difference in incision speed between the main course and the weaker tributaries (Hartvich, 2005). The other area is connected with a steeper segment of the upper Losenice R. under Churáňov Hill (Fig. 7). According to geological map, this segment coincides with a amphibole dyke, limited by a fault (Žáček, 2006), which can explain this anomaly.

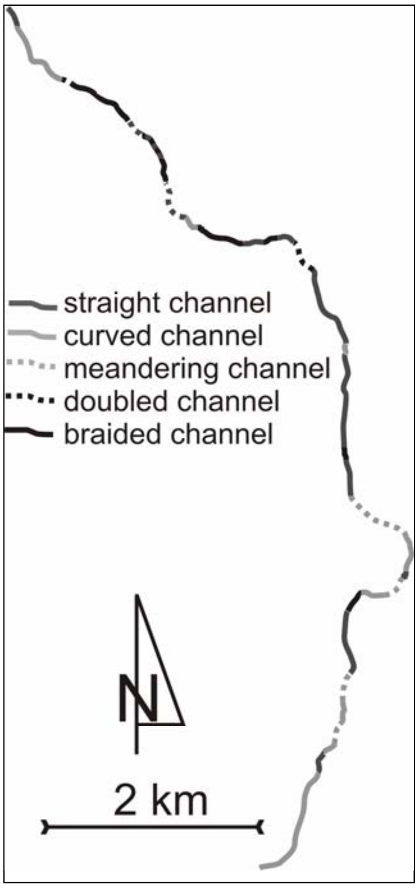

Fig. 6 Scheme of the Losenice R. channel type.

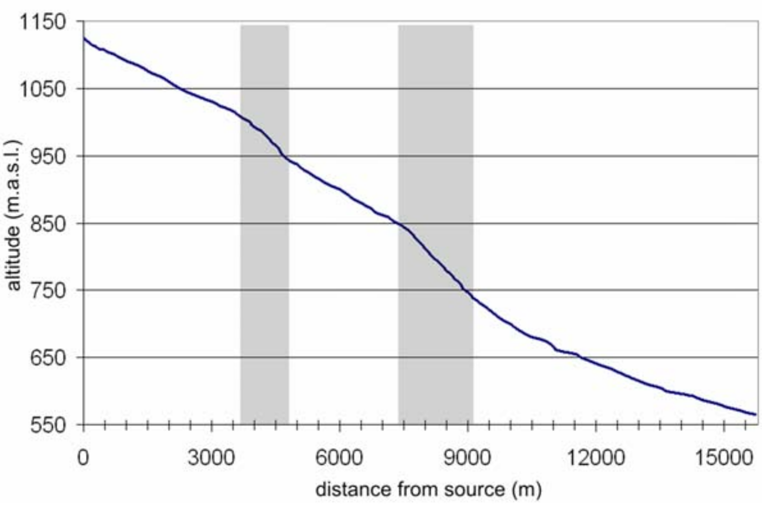

Fig. 7 Longitudinal profile of the Losenice R. The grey bars indicate steeper segments.

Finally, around 40 erosion furrows were identified in the AOI. The erosion furrows, elongated valley-like forms, develop in unconsolidated material (Rubín, Balatka et al., 1986), in the case of the studied area it was in the slope diluvium, which covers most of the slopes. The furrows typically develop on rather gentle slopes, averaging 12°. It is, however, sometimes difficult to distinguish the natural furrows from other linear depressions of anthropogenic origin, such as old forest road cuts or traces of prospecting for the metals.

Slope

The slope erosional forms are not as typical for the mid-mountainous relief of the Šumava Mts. (Záruba and Mencl, 1987) and are restricted to structurally predisposed, steeper slopes. The most prominent among the slope erosional landforms in th AOI are the landslide or rockslide scarps. There are two types of the slope deformations: shallow, small-sized slope deposit sliding and larger, deep-seated rockslides.

The shallow diluvium landslides occur in steep slopes, nearly always in direct connection with lateral erosion of the streams, being thus closely related to the bank scouring. The stream undercuts the steep banks until the stability decreases and shallow (usually 0.5-2 m in depth) layer of the slope deposits slides, often into the river. The distribution of these slope deformations depends mostly on the steepness of the slopes (Fig. 8), reached by the undercutting.

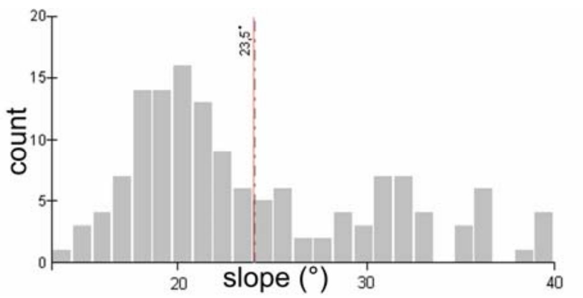

Fig. 8 Distribution of land/rockslide scarps by the slope inclination classes.

The other type of the slope deformation, larger, more deep-seated, structure-conditioned rockslides, occur only on the eastern slopes of the Valy hill outspur. The rockslides developed in several generations, the largest and oldest rockslide with the area reaching almost 200 x 200 m and, according to geophysical research, up to 20-25 m deep (Beneš et al., 2002). The detailed description of these – in the studied area and its neighbourhood rather unique – phenomena was given in Hartvich et al. (2007).

Two sites of rockfalls were found during the mapping. One is situated in the upper valley of the Losenice R. and it was also caused by the river undercutting. Much more interesting is the other site, situated approximately 200 m above the confluence of Losenice and Zlatý brook. This rockfall (Fig. 9) occurred after a long rainy period in the spring of 2006. The weathered, tectonically strongly fractured gneiss rock outcrop collapsed due to decrease of stability caused by the increase in ground water level. The total volume has been estimated to approximately 40-50 m^3, the largest block's dimensions being 3 x 4 x 2 m. The rockfall illustrates well on-going activity in the steep, fractured and weathered rocky slopes.

Cryogenic

Cryogenic forms in the central Europe have been developing mainly during the prevailing periglacial conditions of the Pleistocene (Svobodová et al., 2002; Mentlík, 2006), however, in favourable conditions of higher altitudes the frost action can still take place, albeit in a limited extent (Demek, 1987). In the relatively lower altitude of the AOI, the frost action is even more limited, and the cryogenic landforms can be considered fossil. Votýpka et al. (1999) describe in the Losenice valley numerous frost cliffs, which are in this work, however, classified as polygenetic landforms, because:

- the shape of the cliffs is strongly influenced by the rock structure
- cryoplanation terraces are not or little developed
- the formation of the outcrops is currently influenced by other processes apart from cryogenic

Some of these points were already discussed by Creemens et al. (2005).

There are, however, several outcrops, where the frost formation including the lateral development of the cryoplanation terrace can be traced, for example in the case of a step-like outcrop on a steep SE slope above the narrow gorge of Pěnivý brook (Fig. 10). The photograph clearly shows cutting of the cliff obliquely to the foliation and the small cryoplanation surface.

ACCUMULATION LANDFORMS

Fluvial

Fluvial accumulations develop wherever the transportation power of the stream decreases, which can be caused by various reasons (Montgomery, 1997). Several types of fluvial accumulations were observed, such as point bars, in-channel bars, floodplain sediments and alluvial cones. The fluvial sedimentation is currently by far the most dynamic and active process and quickly changes the valley floor, particularly during the floods. In the AOI, the traces of the severe 2002 flood can still be seen on many places (Hartvich et al., 2007). The vas majority of the mapped sedimentary bodies (and all over 100 m long) is situated in the floodplain of the main stream, the Losenice R.

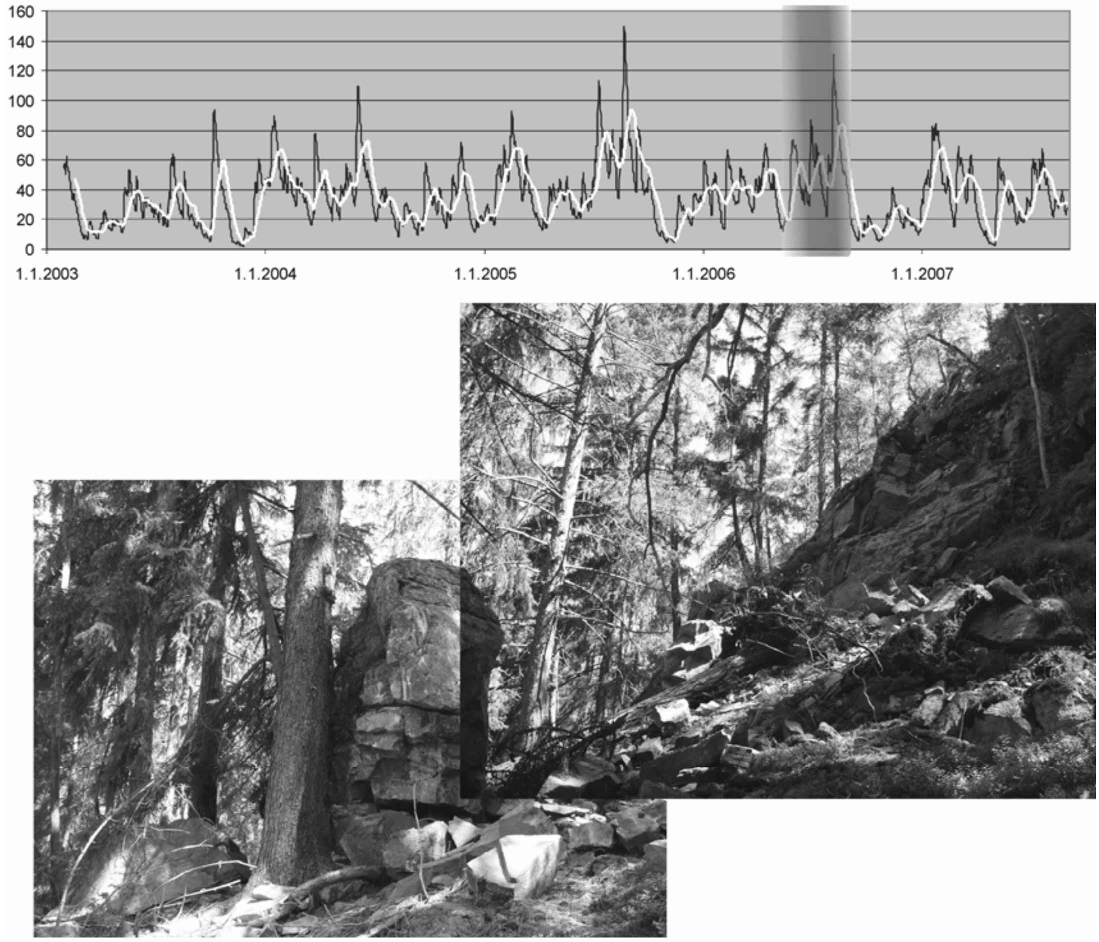

Fig. 9 Top: Chart of cumulative precipitation (PPI 30, previous precipitation index), indicating wet period of the spring 2006. Bottom: Photo of the fresh rockfall in the valley of the Losenice R. (June 2006).

Fig. 10 Photo of a most likely genuine frost cliff with a cryoplanation terrace near the Pěnivý brook.

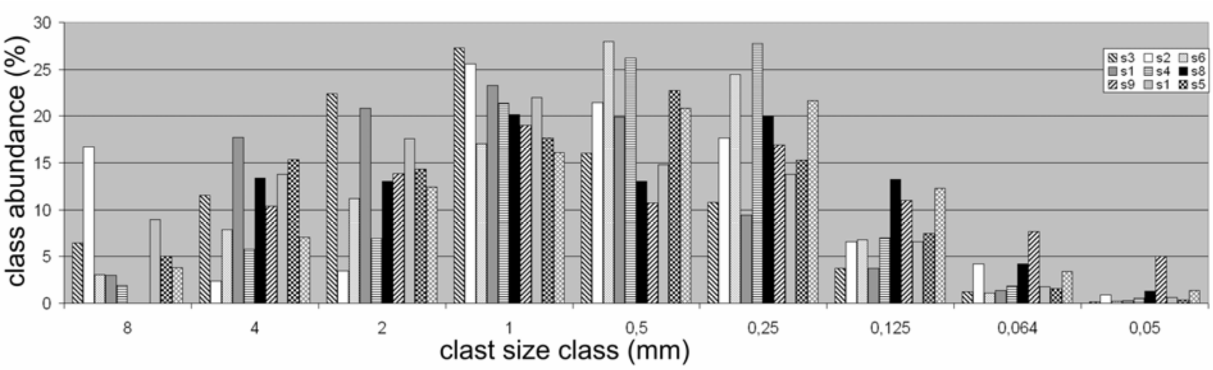

Fig. 11 Distribution of the fluvial sedimentary material from the probes in the floodplain of the Losenice R.

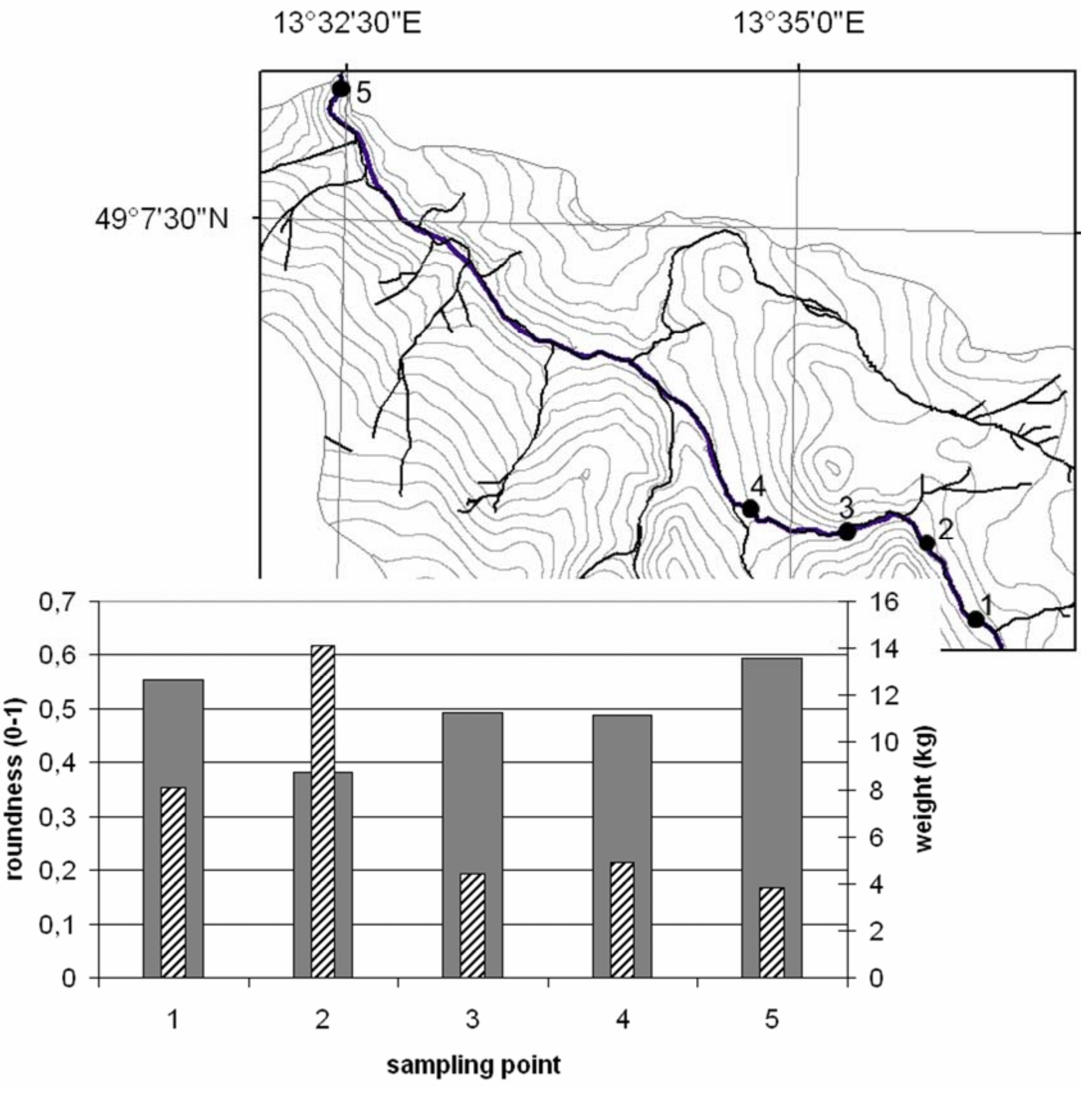

Fig. 12 Top: Position of the sampling sites for the coarse gravel/boulders. Bottom: Roundness (hashed columns) and weight distribution (full grey columns) of the coarse gravel/boulders on each sampled site.

Generally, the material of fluvial accumulations in the Losenice valley varies from coarse gravel to fine sand, very small part of the sediment falls into the silt and clay category (Fig. 11). The analysis was performed by dry sieving using the standard sediment classes (Casagli et al., 2003; Bunte and Abt, 2001) on 9 samples from various floodplain sediment accumulations. Clearly, for most of the samples the most typical material is the coarse to medium coarse sand.

During the floods, even much larger clasts / blocks are transported, as was observed during the mapping of the 2002 flood consequences (Hartvich et al., 2007) and during the analysis of the probes in the floodplain. It was found that particularly the lower parts of the floodplain sediment profile contain large, angular to semi-angular boulders up to 50 cm, even though the probe was located approximately 20 m from the channel.

The grain size and clast shape of the fluvial sediments depends on several factors, including source material, length of transportation or stream size and steepness (Sklar and Dietrich, 2006). Abrupt changes in the observed clast parameters, i.e. roundness, clast size and clast shape, along the stream course may indicate an input of fresh, angular slope material (Hradecký and Přibyla, 2007). This could be seen in the preliminary analysis of the sediments in several profiles along the Losenice R. Using a technique described by Bunte and Abt (2006), applied on five sites, 50 gravel / boulder clasts were measured on each site. The result (Fig. 12) indicates possible source area of the angular, slope origin material in the vicinity of Obří Hrad slope deformation.

As concerns the morphological and spatial properties of the sediment accumulations, most of the bars were of rather small size (Fig. 13), there are, however, few exceptions: large and wide (approx. 300 x 20 m, the depth according to probing up to 1.5 m) sandy-gravely accumulation in the segment of Losenice R. with wide floodplain above the narrow part, blocked by slope activity. Another large sedimentary bar has – at least partly – accumulated during the 2002 flood above the confluence of Losenice and Zlatý brook in the length of almost 200. It is necessary to mention a large gravely/sandy accumulation, which is above Rejštejn village, i.e. outside the AOI. It is, nevertheless, by far the largest and thickest fluvial accumulation in the whole catchment, very likely a product of repeated sedimentation during multiple flood events.

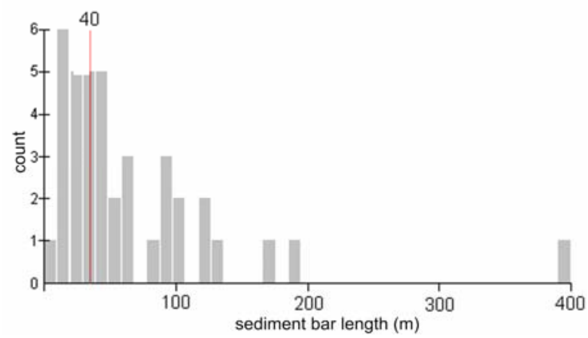

Fig. 13 Distribution of the length of the point bar accumulations.

The alluvial fans are a special class of fluvial sediments. Mechanically, their evolution is bound, as in the case of other fluvial accumulation types, to the decrease of the transportation power of the running water; their position is, however, specific as the fans develop in the mountain fronts or at major valley junctions (Gomez-Villar and Garcia-Ruiz, 2000). In the AOI, the fans develop typically on the floodplain / valley floor of the main course at the entrance of a side valley (Fig. 14) and do not reach large sizes: the largest do not exceed 70 x 70m. Their composition corresponds to the transportation power of the small tributaries, which can even in the high discharge periods carry only finer, usually sand-size clasts.

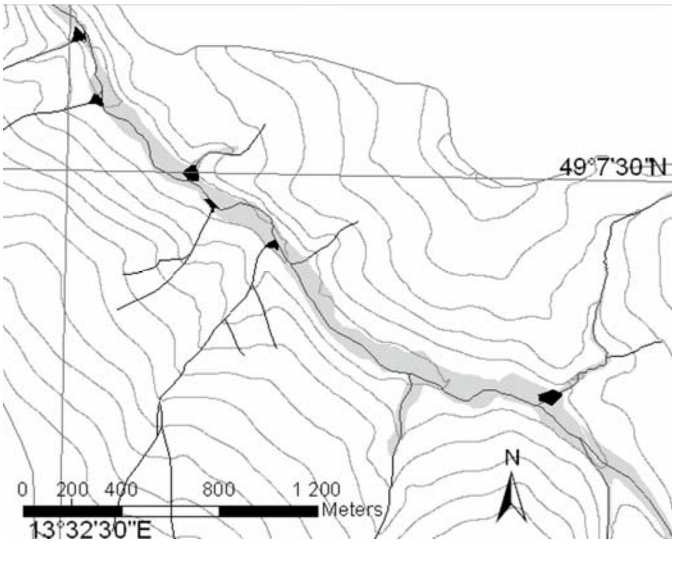

Fig. 14 Map of the position and size of the largest alluvial fans in the lower Losenice R. valley. Light grey indicates the floodplain.

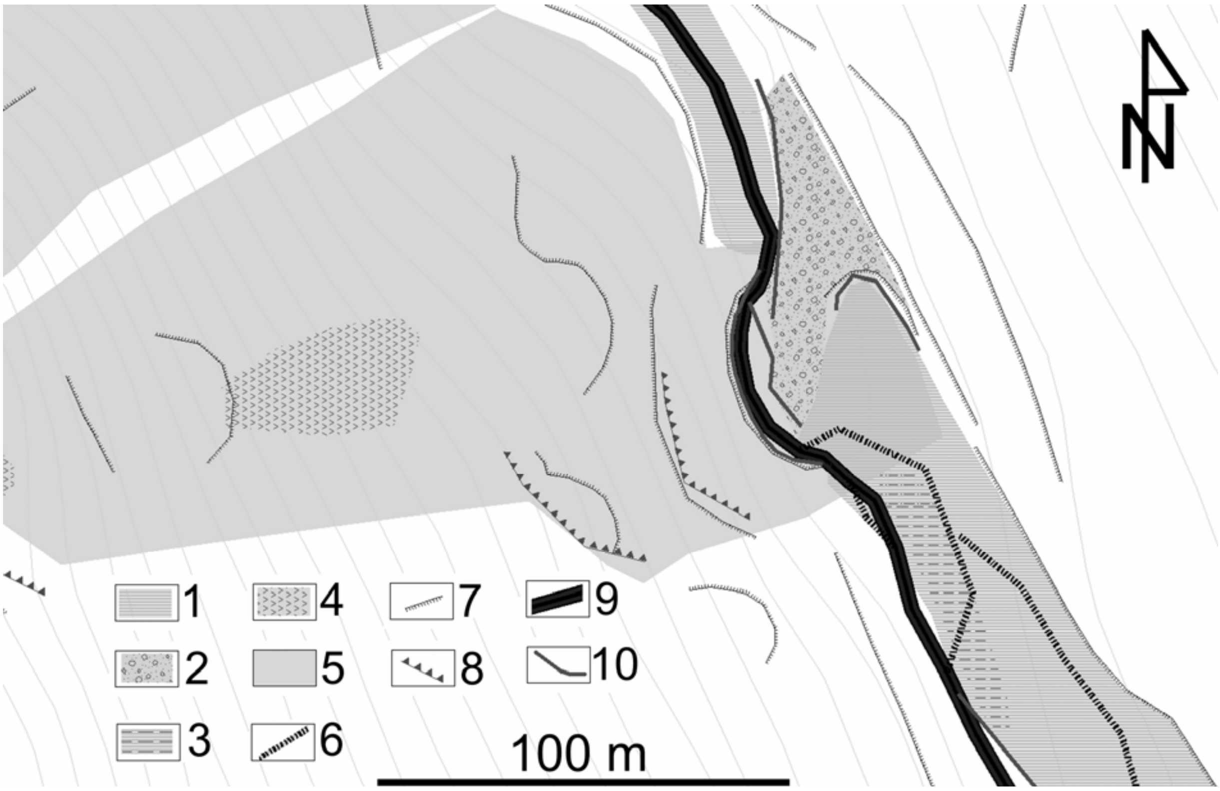

Fig. 15 Situation of the youngest rockslide/debris slide SE from Obří Hrad.
Legend: 1 – floodplain, 2 – remnant of the slide accumulation, 3 – wetland, 4 – debris creep, 5 - landslide/rockslide (area), 6 - multichannel, 7 - relief breakline, 8 – scarp, 9 – Losenice R., 10 - bank scour.

Slope

Landslide accumulations are usually the most important source of information on the mechanics, phases and particularly chronology of a slope deformation (Ondrášik and Rybář, 1991), as the accumulation may block the valley or a bar a sedimentation basin and thus provide datable material (Baroň et al., 2004).

The remnants of slope deposit accumulations are very limited in the valley of Losenice and their occurrence is restricted to the narrow, gorge-like segment under the Obří Hrad outspur. Due to morphology of the narrow valley floor, which is during flood events completely flooded, and due to high erosive and transportation power of the steep flooding stream, the accumulations of the slope deformation on the valley floor are soon removed by the fluvial erosion. There are several small block/ debris accumulations of slope origin in the westward oriented segment of Losenice, probably remnants of episodic activisations of the block streams higher on the slope during the wetter periods. The age of these forms is difficult to assess, they cannot be, however, too old as the intensive fluvial erosion has not removed them completely yet.

The larger, multigenerational rockslides, described above, are, unfortunately too old to have the accumulations preserved. The only exception might be the accumulation of the youngest (and smallest) generation, which affected only lower part of the slope (Hartvich et al., 2008), and which has probably crossed the stream. The remnant of this accumulation, though partly removed and re-shaped, is still perceivable (Fig. 15). The slope processes, forms and history in this area are described in detail in Hartvich et al. (2007) and yet another paper is in preparation.

Cryogenic

Various block accumulations are very common in the studied area, in particular blockfields, block streams, and scattered block debris. Rubín, Balatka et al. (1986) further differentiate the blockfields depending on their position on the slope profile and whether they are autochthonous or alochthonous.

These accumulations are explained as a result of frost shattering of massive well-jointed bedrock during the periglacial conditions of Pleistocene (Goehring et al., 2008; Rubín, Balatka et al., 1986). There have been many debates on the actual age of these landforms (Goehring et al., 2008), for example Rea et al. (1996) argue on the example of blockfields on the uplands in Norway, which were found to contain clay minerals, that they must have experienced intensive chemical weathering and

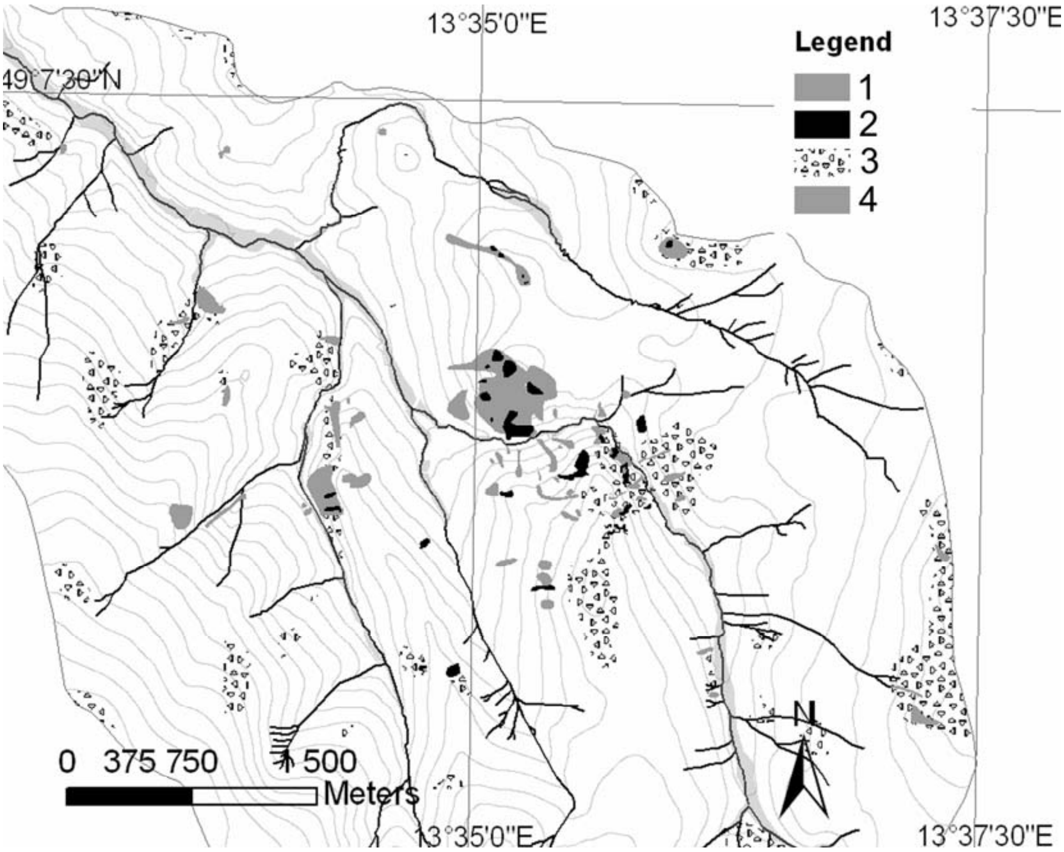

Fig. 16 Map of the distribution of the block accumulations.
Legend: 1 – covered blockfield, 2 - open, dense blockfield, 3 – scattered blocks, 4 – floodplain.

therefore must be of rather old age, possibly even pre-Pleistocene. Even if this may be considered extreme, however, the parallels from the flat relief of high latitudes may not apply to the steep slopes of central European mid-mountains. In fact, the blockfields in the AOI seem to be highly active, instable and delicate, to the extent that it is difficult to imagine that they would be in current state for a long period. To resolve this contradiction, a system of extensometric monitoring was established on two opposite blockfields in the Losenice valley in 2006.

The blockfields and block streams are the most remarkable cryogenic accumulations in the Losenice catchment. They are generally situated on rather steep valley slopes, mostly in the narrowest part of the valley around Obří Hrad site (Figs. 2 and 16). The majority of the blockfields is not very large, there are, however, few exceptions. As concerns the distribution of orientation, there are two not too strong clusters around ENE-E and SW-NW (Fig. 17). The inclination distribution has its peak value around 23°, and the largest blockfields are usually on slopes between 25°-30°, significantly more than is given by Rubín, Balatka et al., 1986.

The largest blockfield (2.3 ha) is situated on the border of the AOI on the Popelná hill, the biggest

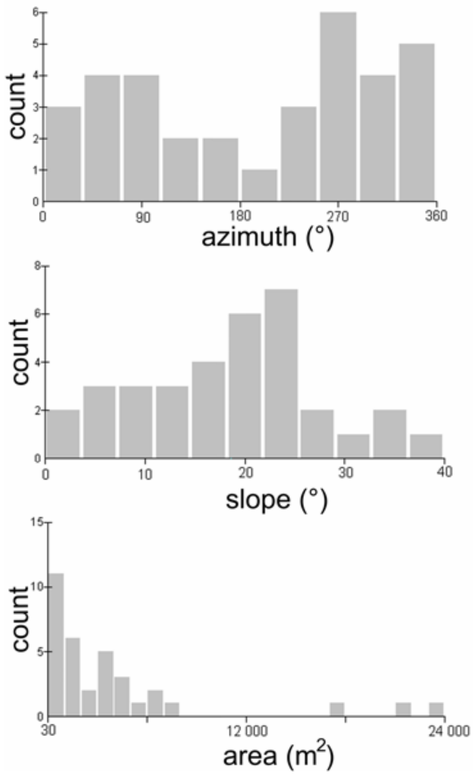

Fig. 17 Distribution of the blockfields by: slope azimuth (top), slope inclination (middle) and area (bottom).

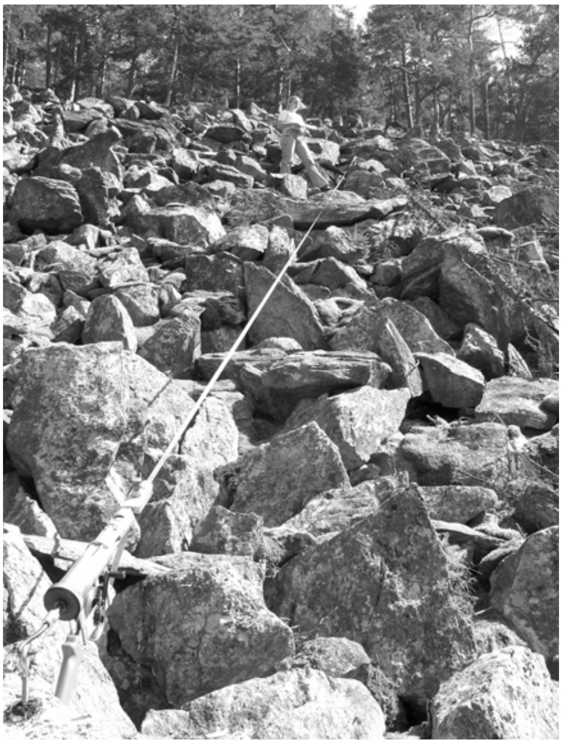

Fig. 18 Photo of the blockfield at the Šafářův hill, showing the extensometric measurement.

Fig. 19 Photo of a 40 m high rock face with a fresh rockfall.

cluster of large blockfields is, however, on the SW slopes of Šafářův hill and the opposite NE slopes of Valy hill. These blockfields are currently being studied in detail; the research includes also monitoring of the current dynamics of the block movement using an extensometric measurement network (Fig. 18).

Polygenetic landforms

There are landforms left to be described as polygenetic, as more than one geomorphological process has taken significant part in their formation. From these, various types of rock outcrops were selected as significant markers for the relief development.

The rock outcrops in the mountainous areas are often classified as frost cliffs, however, for the reasons given above (in the chapter "erosional cryogenic forms"), vast majority of the rock forms were classified as outcrops, on formation of which several processes including frost action, thermal volume changes, mechanical and chemical weathering, slope creep, activity plants and rock falling.

In the studied area, 188 rock outcrops of all types were identified. Wherever it was possible, the joint system, foliation parameters and traces of tectonic dislocations (shearing) were investigated. Altogether, more than 2500 structural measurements were performed and analysed within the scope of the morphostructural analysis in order to assess the tectonic influence on the current relief formation (see Hartvich, 2005).

The size of the outcrops is highly variable – from few meters to almost 2 kilometres long rock defile above the left bank of lower Losenice or almost 1 km long lithologically predisposed ridge of Výrovec hill. The highest rock walls in the lower Losenice valley reach almost 50 m (Fig. 19), whereas most of the outcrops do not exceed 5-7 m. The shape properties are equally variable. In few cases, it is possible to recognize traces of sideward development of the cliffs by cryoplanation (see above), the shape of most of the outcrops, however, is strongly influenced by the structure of the rock, particularly the joint systems.

Distribution of the rock outcrops is shown in Figure 20. There are three main areas of dense outcrop occurrence: structurally and lithologically controlled area around confluence of Losenice and Pěnivý p. with quartzite dyke, deeply incised lower Losenice valley, and structurally strongly influenced area of Obří Hrad.

Other important relief elements

Into this class were gathered the most important elements, which were found during the mapping and cannot be classified exactly as landforms, and which, however, represent an important source of information on the relief-shaping processes or development.

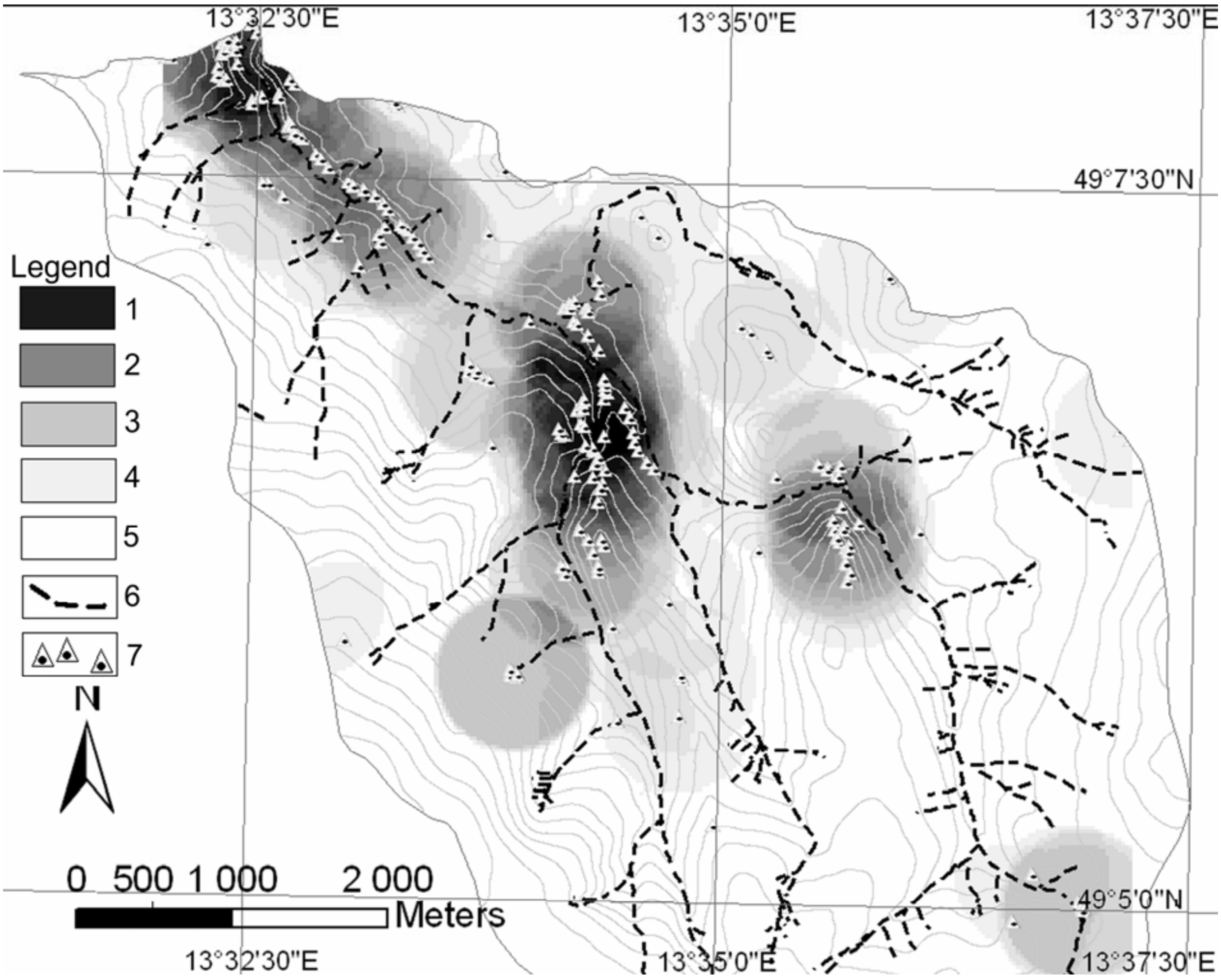

Fig. 20 Map of the distribution of the rock outcrops.
Legend: raster density indicates number of the outcrops in the 500 m neighbourhood (1 – 30 and more, 2 – 15-30, 3 – 5-15, 4 – 1-5, 5 – none), 6 – streams, 7 – rock outcrops.

Firstly, the water bodies and courses, in particular springs and wetlands / peat bogs were observed. The springs are not only important as the source of water and beginnings of the streams, but their position and character may well inform about the inner structures of the bedrock. For example, a linear pattern of the springs may indicate a fault (Demek, 1987).

In the case of the Losenice catchment, the position of the springs well correlates with the relation between the foliation structure and the relief. As can be seen from the Fig. 21, the density of springs is much higher on the structurally conditioned slopes. In particular, the best example of this influence can be seen in middle valleys of Pstružný and Jedlový creeks (Fig. 21), where all the springs are concentrated in the cataclinal slopes (see Meentenmeyer and Moody, 2000; Hartvich, 2006), while on anaclinal not a single one was found.

The wetlands and peat bogs are not as common feature on the steep slopes of Šumava rim as up on the plains. There are two types of wetlands: large, roundish swamps with peat, which are only found in the upper, flat part of the AOI, particularly on the brink of the Šumava plains near the spring of Losenice and Pstružný creek. Much more common are the small-sized wetlands in the vicinity of the springs, in dells and in the floodplain along bigger streams. These have similar significance as the springs, as they occur much more often on the slopes in accordance with the inner structure. Also, larger wetland areas in the floodplain indicate an obstacle in the stream, either above a fluvial accumulation, or a narrower channel segment due to, for example, a slope deposit slide.

Finally, it is necessary to mention the relief breaklines, which were observed and recorded during the mapping. Being among the most common mapped elements (almost 450), the breaklines are important for distinguishing the slope segments, which correspond to a change in the prevailing process and thus can be used in the landform delineation (Mentlík, 2006; Minár and Evans, 2008).

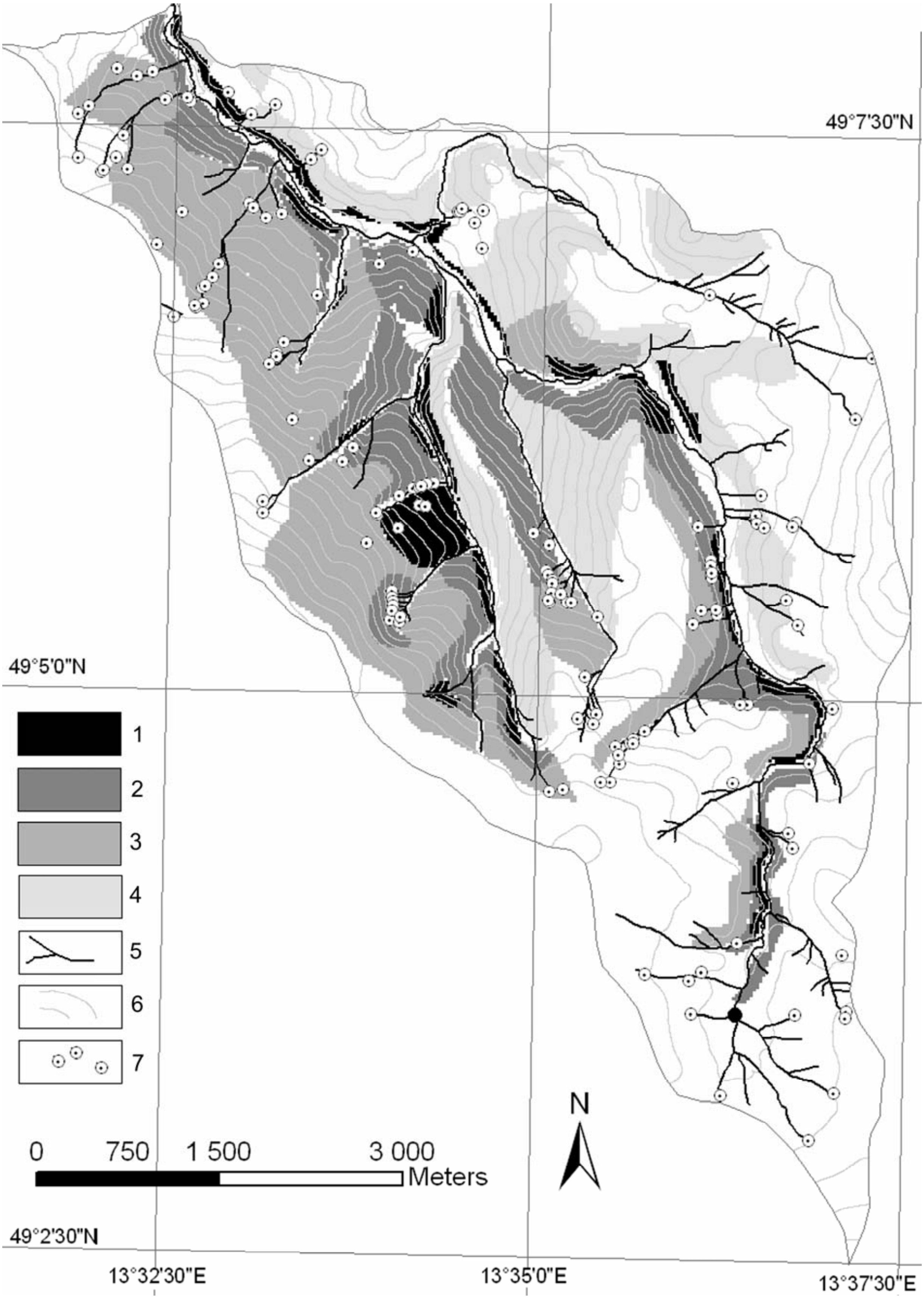

Fig. 21 Map of the distribution of the springs by the genetic slope types.
Legend: 1 erosional slopes, 2 – erosional-structural slopes, 3 – structural-denudational slopes, 4 – erosional-denudational slopes, 5 – streams, 6 – contours (25 m interval), 7 – springs

DISCUSSION: THE SIGNIFICANCE OF THE DISTRIBUTION AND CHARACTER OF THE LANDFORMS

The balance between including maximum information while keeping the readability of the map is always a difficult work. For example, Gustavsson et al. (2006) have used a new attitude to involve as much information as possible into a general geomorphological map, including – aside from usual geomorphological objectives – age, lithology and activity of the landforms. The resulting map, however, is not very comprehensible and its reading is very difficult. Therefore, it is necessary to follow the objective of the particular map and carefully select the means of visualisation, particularly with the possibilities of the GIS (Létal, 2005).

Genetic types of relief segments

A synthetic map of the slope segments was created as a synthesis of the detailed mapping. The significance of the particular landforms was analysed and, together with other data sources, used as an input into genetic classification of the slopes or, to be accurate, the relief segments.

Each segment was defined on the basis following inputs:

- morphology – slope, aspect and curvature
- dynamics – evidence of changing of the relief, monitoring
- structural properties of the bedrock – joint systems, foliation structure
- lithology – fluvial sediments, outcrops
- occurrence of specific landforms – scours, landslides, shear planes, etc.

The morphological properties of the relief are tied with their development. This observation was used in definition of "elementary forms of relief", which have always certain describable geometrical properties (Minár and Evans, 2008). By aggregation of these elements into more complex units are defined the landforms, which are already genetically homogenous. Even without such subtle and complicated techniques, the morphology of the relief has always been essential for geomorphological synthesis as each type of relief-shaping process creates a characteristic landscape (Vitásek, 1966).

The last point, analysis of selected landforms and their significance for the relief development, is the main objective of this article. The selected significant landforms can either:

- occur only in one particular relief segment type
- be more numerous/typical in particular relief segment type
- have different form/size/other characteristics in each relief segment type

For relative similarity of the studied areas, similar technique of mapping and character and types of observed landforms, the genetic slope types used by Vilímek (1998) and Štěpančíková (2007) were taken as a basis for the classification and adjusted for the purposes of this work. Altogether, eight relief segment types were distinguished in the AOI:

- structural slopes
- erosional slopes
- erosional-structural slopes
- structural-denudational slopes
- erosional-denudational slopes
- flat denudational ridges and planation surface remnants
- valley floor with the floodplain

Structural slopes

Structural slopes are relief segments where the inner bedrock structure, such as fault plane, bedding or foliation plane is directly projected into the relief surface (Montgomery, 1997) or where the morphology is perceivable as a direct consequence of some rock properties (Twidale, 1971), for instance significantly high resistance to weathering. Such parts of the relief can be regarded as somewhat azonal, because their location is not controlled by a continuous system as in the case of the other factors (Selby, 1993).

In the AOI, the true structural slopes are represented by a few small enclaves with approximately dip-parallel cataclinal slopes (sensu Meentenmeyer and Moody, 2000). As this slope structure implies (Selby, 1993), these are – together with steep erosional slopes – among the most active parts of the relief. These include the observed slope under the Obří Hrad (Fig. 22), a part of the slope in the area of Bílý potok, which is also observed by the dilatometric network, and few smaller patches along Losenice and Pěnivý creek.

Erosional slopes

The erosional slopes can be in the AOI considered currently most active slope segment (Hartvich and Mentlík, in prep.). These slopes are within the reach of current erosional phase of the streams, which means that they are either being currently undercut by the streams, or were only recently. The freshness of the erosional slope can be observed particularly well on the morphology of the transversal profiles – these slopes usually form a lower part of the slope, and have either no significant vertical curvature or are convex (see Fig. 23). Generally, the erosional slopes in the conditions of the AOI are among the steepest, usually exceeding 25°, and in some places up to 50°. These slopes are, with the exception of the valley floor, genetically the youngest segment of the relief in the area.

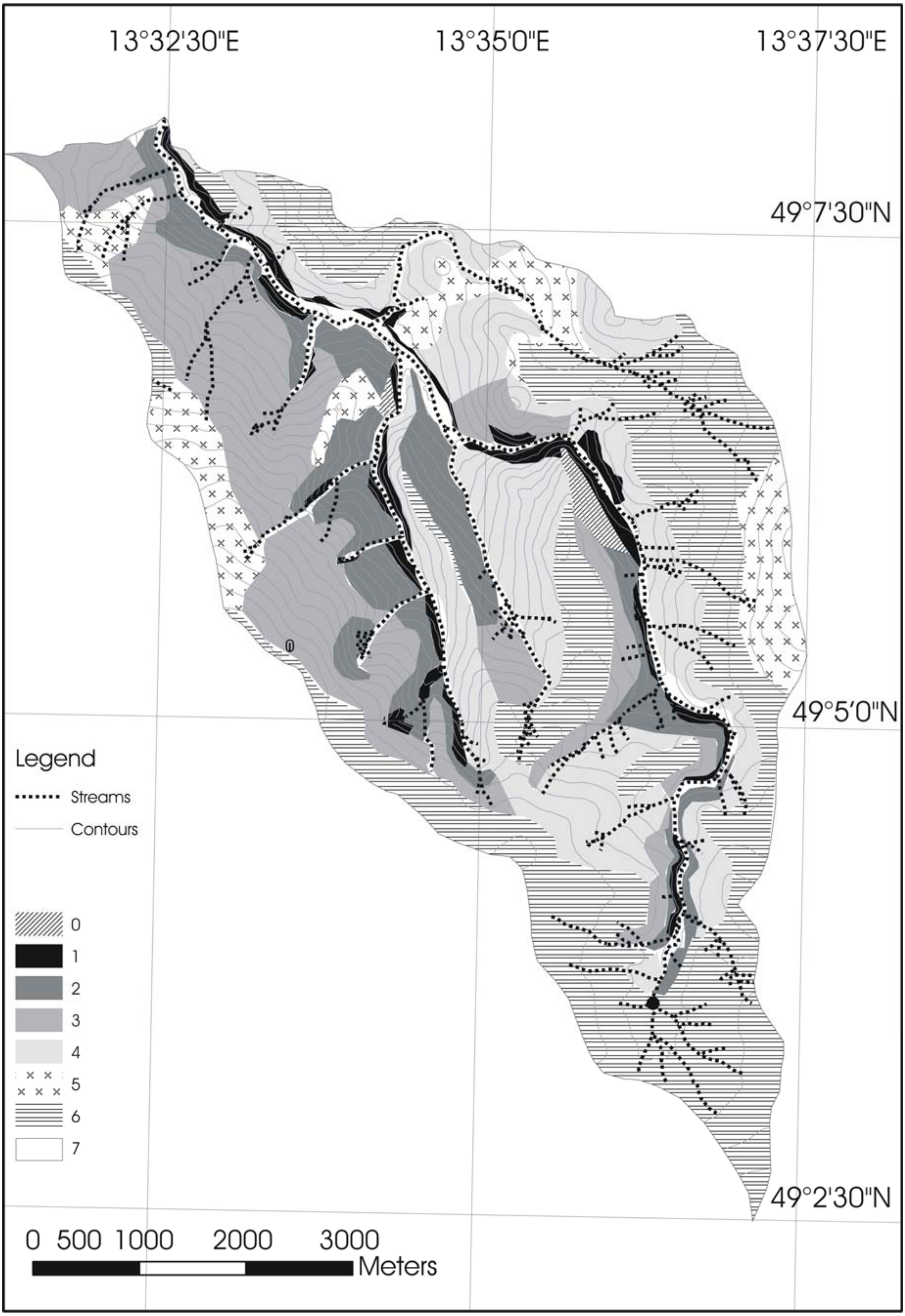

Fig. 22 Genetic types of the slopes in the catchment of the Losenice R.
Legend: 0 – structural slopes, 1 - erosional slopes, 2 - erosional-structural slopes, 3 - structural-denudational slopes, 4 - erosional-denudational slopes, 5 - flat denudational ridges, 6 - planation surface remnants, 7 – floodplain

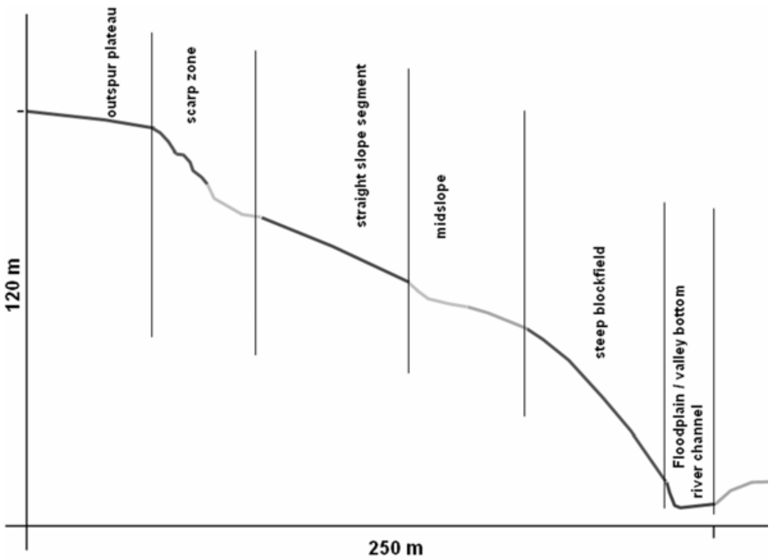

Fig. 23 Profile across the active slope under the Obří Hrad site indicating the curvature of each slope segment.

Fig. 24 Photo of a small, shallow slope debris landslide, triggered during the 2002 floods by the scouring in the middle part of the Losenice R. valley.

Among the most typical landforms on erosional slopes are the rock outcrops, exposed by the lateral erosion, and various types of the block debris and blockfields, eventually transported downslope. Also, bank scouring and minor sliding of the slope sediments and the debris occurs frequently (Fig. 24), in one case even rockfall.

The distribution of the erosional slopes is restricted to the lower parts of the valleys along the main courses. Shallower valley of Jedlový creek is not incised enough yet to develop an erosional cut similar to gorge-like valley of the Losenice R. a and Pěnivý creek.

Structural-erosional slopes

Structural-erosional slopes are still among the very active parts of the relief, due to the combination of reach of the erosion fluvial and structural predisposition, favourable for slope movements. Also these slopes are cataclinal (Meentenmeyer and Moody, 2000), usually steep to medium steep (Fig. 25d) and slightly convex or straight.

Among the markers of the structural-erosional slopes are the rocky steps in the channels, which occur in the favourable structural conditions or in the harder outcrops. In the slope debris covered parts of the slopes, erosional furrows often develop, particularly in the consequent direction (NE) as can be observed near the confluence of Losenice and Pěnivý brook or on left valley side of Losenice above Popelná.

Structural-denudational and erosional-denudational slopes

Milder slopes, usually situated in higher parts on the valley cross-sections, are already above the influence of the current stream erosion and are loosing their original shape by gradual denudation (Vilímek, 1998). These slopes were divided into two subtypes: structural-denudational and erosional-denudational.

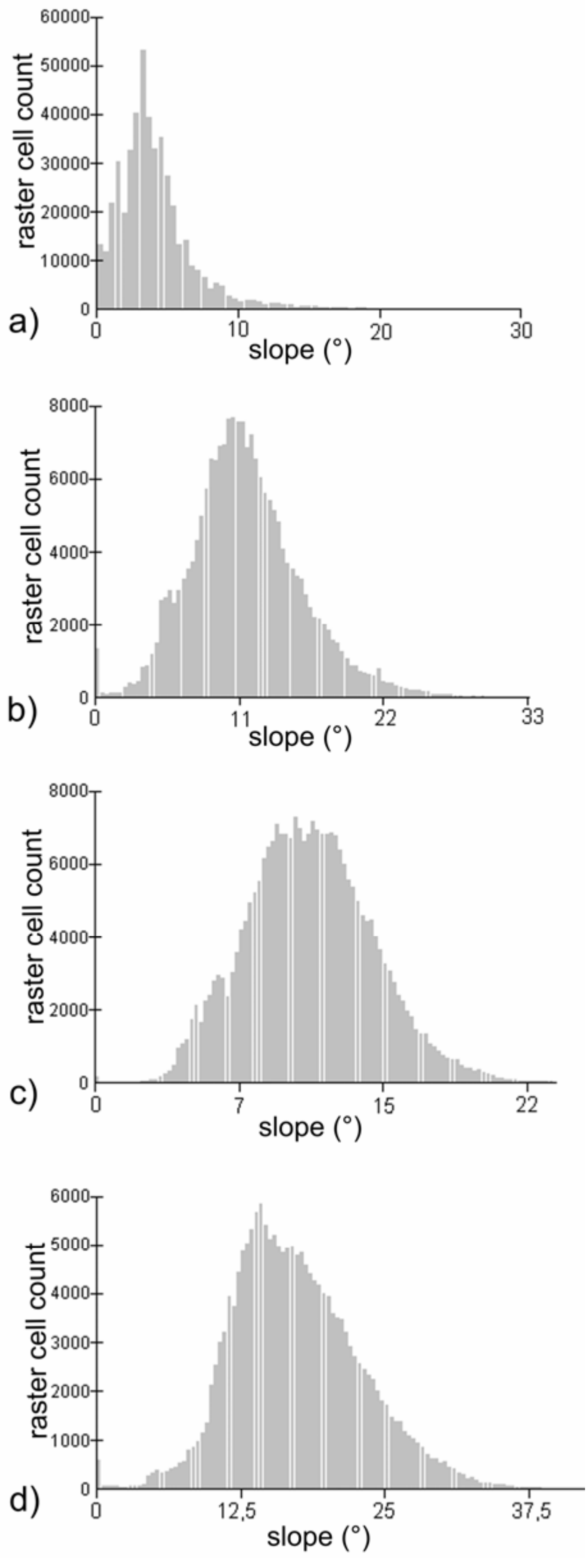

Fig. 25 Distribution of the genetic slope types by the slope inclination.
a) denudational ridges and planation surface remnants,
b) erosional-denudational,
c) structural-denudational,
d) structural-erosional

The structural-denudational slopes pass directly into structural-erosional slopes below and into flat ridges and plateaus above. They would originally correspond to the structural slopes, but the denudation and surrounding relief development has changed their face. This class would approximately correspond to the underdip cataclinal slopes as defined by Meentenmeyer and Moody (2000). Morphologically, the structural-denudational slopes tend to be straight or slightly convex and their slope does not exceed 20°, averaging 10°-12° (Fig. 25c). These slopes are typical source areas of the streams: due to favourable structural conditions, even though structural-denudational slopes represent only 10% of the AOI area, more than 30% of springs is situated here.

The other subtype, erosional-denudational slopes, fall into similar range of morphological properties (Fig. 25b), their relation to the underlying rock structure, is, however, different. According to this relation, they would belong to anaclinal slopes in Meentenmeyer and Moody (2000) classification. The difference can be clearly seen on the spring occurrence, as mentioned above, or on the drainage pattern (Strahler and Strahler, 2000) For example, Pěnivý brook has no right-side tributaries (from erosional-denudational slopes), but it has 4 water-rich tributaries from the left-side structural-denudational slopes.

Denudational ridges and planation surface remnants

Denudational ridges and planation surface remnants are flat areas, situated above the incised valleys, and presenting remnants of old surfaces, levelling the original rock structure (Demek, 1987). These plateaus were later uplifted into current position and following development has dissected the once monotonous plain and isolated its remnants in the position of residual hills (butte, Twidale, 1971). In the AOI, the flat ridges and remnants of planation surfaces are situated around the perimeter of the Losenice catchment, in particular in the southern part, where the backwards erosion of Losenice and its tributaries has reached almost to the planation surface of Ranklovské Pláně. The slope in this category is very low, averaging under 4° (Fig. 25a).

As the relief energy in these flat areas is low, there are very few perceivable micro- and mesoforms (sensu Rubín, Balatka et al., 1986), which were objective of the mapping. From the mapped landforms, the most common were the wetlands and particularly peat bogs, all of which are situated on the flat plateaus.

Valley floor

As a slightly special category among the genetic relief types can be viewed the valley floor. Compared to the delimitation of the other relief units, there is practically no ambiguity with its definition, either in the morphology or by the significant landforms, particularly in this mountainous relief. The valley floor, as a morphological unit, coincides frequently in the conditions of narrow mountainous valley with the floodplain as genetic unit (Křížek et al., 2006).

As the fluvial activity, concentrated on the valley floors, is currently the most active process in the study area (Hartvich, 2007a), and the slope deformations (as well as the tributaries) from the valley sides move material into the valley floor, it is clear that it is the most dynamic, fast-changing part of the relief.

Therefore, there are many erosional and accumulation landforms, particularly fluvial, to be found on the valley floor, such as bank scours, braided channels or remnants of slope accumulations, proving the lasting - and often violent - re-shaping of the valley floor. For example, the youngest slope movement accumulation is still partly blocking the valley. Here, a hypothesis on the presence of a temporal lake has been tested by a probing the floodplain for remnants of lacustrine sediments. Even though none were found – either because the lake lasted too short or because they were removed after dam breach – the coarse, semi-angular floodplain material illustrates the transportation power of the stream.

The presence of the alluvial fans illustrates the current fluvial sedimentation, as the weaker, but steep tributaries follow the incision of the main stream and carve their valleys. Also these landforms are probably rather recent; for their sandy material is easily carried by the main streams during sever floods, as can be seen on partly eroded fan of the third left tributary of Pěnivý brook.

CONCLUSION

The detailed systematic mapping of the catchment of the Losenice River, performed in the AOI during last several years, yielded plenty of new information on the development of the area. The occurrence, position and properties of selected landforms, tell-tale milestones of the relief development, were analysed and the gathered information was used together with other data sources in reconstruction of the genetic types of the relief segments.

The selected significant landforms can either:

- occur only in one particular relief segment type
- be more numerous/typical in particular relief segment type
- have different form/size/other characteristics in each relief segment type

The relief segments represent genetically related parts of the AOI, which together form a jigsaw, documenting the development of the area. As was partly argued earlier based the morphological and structural data (Hartvich 2005, 2006), the new information on the landform and slope genesis confirm that the development is dominated by the structurally controlled backwards erosion and incision of the Losenice R. (and Otava R. in wider neighbourhood), which cuts into rims of flat planation surfaces and steepens the outer slopes of central Šumava.

The overall conclusion from the observed landforms is a rather surprising activity some of recent and current geomorphological processes, albeit limited to the “hot spots”, i.e. particularly active parts of the relief. These highly active areas are predisposed by following factors:

- favourable structural conditions, i.e. direction of foliation dip-parallel or over-dip of the slopes
- deep and dense fragmentation of the bedrock by old tectonics
- lasting fluvial incision and lateral erosion, undercutting the slopes
- steep slopes, securing enough potential energy for the slope processes

ACKNOWLEDGEMENTS

The work on this article was supported by the the projects KJB300460803, VOZ30460519 and MSM 0021620831, which authors gratefully acknowledge.

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