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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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DYNAMICS OF DEBRIS FLOWS IN THE CULMINATION PARTS OF THE MORAVSKOSLEZSKÉ BESKYDY MTS

Abstract. Debris flows in the Moravskoslezské Beskydy Mts represent a type of slope deformations that so far have been investigated insufficiently. The aim of this study is to contribute to the existing knowledge of debris flows in the context of the morphometry of their source basin. The field geomorphological mapping involved debris flow accumulations that were consequently divided into two groups based on their size and morphology. Further analysis comprised morphometric analysis of longitudinal profiles of accumulations-containing valley floors. On the basis of this analysis the longitudinal profiles were classified as pertaining to the colluvial segment (the predominance of slope processes) or the fluvial segment (the predominance of fluvial processes). The comparison of the boundary point position of both the segments and the reach of fronts of individual accumulations brought very interesting results: voluminous (and probably older) debris flows showed longer reach than the smaller debris flows (mostly originating at present). The assumption of minor dynamics of small flows is also supported by the fact that their material made a stop in positions with a higher gradient than in the case of large flows.

Key words: the Moravskoslezské Beskydy Mts, debris flow, morphometry, large and small accumulations, longitudinal profile

INTRODUCTION

The existence of debris flows in the Moravskoslezské Beskydy Mts has long been neglected. First studies dealing with such a type of slope processes in this area have appeared only recently (Šilhán and Pánek 2006, 2007, 2008a; Rybář et al. 2008). The existing knowledge shows that it concerns a very frequent type of accumulations that occur mainly in valley floors. However, their spatial distribution is almost exclusively limited to culmination parts of the Moravskoslezské Beskydy Mts (Šilhán and Pánek 2008a). The present knowledge comprises detailed information on the spatial distribution of the accumulations (Šilhán and Pánek 2008a; Rybář et al. 2008), their sedimentological properties (Šilhán and Pánek 2007 or the chronology (Šilhán 2008; Šilhán and Pánek 2008b, 2009). Despite the fact that this problematics is contemporarily much discussed all over the world (Fiorillo and Wilson 2004; Rowbotham et al. 2005; Kovanen and Slaymaker 2007; Sterling and Slaymaker 2007), less complex information is available concerning the predisposition factors and the relation between the flows and the relief morphometry (Šilhán and Pánek 2007; Rybář et al. 2008). The aim of this study is to contribute to the existing mosaic of information on debris flows in the Moravskoslezské Beskydy Mts providing an analysis of the position of their accumulations in the context of the morphometry of basins and longitudinal profiles of valley floors.

METHODS

The research was conducted using the methods of field geomorphological mapping and laboratory morphometric analysis of the relief. The analysis included all culmination parts containing debris flow accumulations: Mt Smrk (1,276 m),

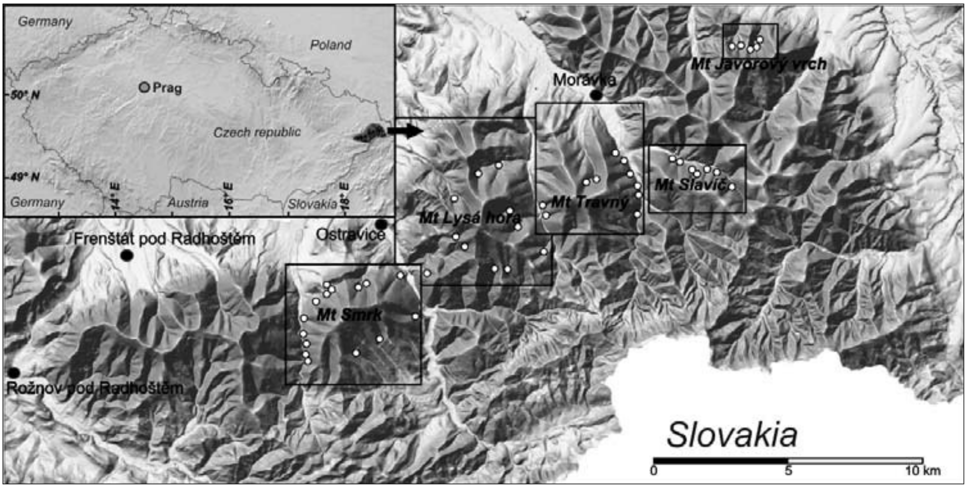

Fig. 1. Location of the studied area and debris flows (white points)

Mt Lysá hora (1,323 m), Mt Travný (1,203 m), Mt Slavíč (1,054 m) and Mt Javorový vrch (1,023 m). The whole area is built by alternating layers of Godula sandstones and claystones of various thickness, slightly inclined (up to 10°) towards the SE. The first-phase mapping at a scale of 1 : 5,000 covering the valley floors and slopes of all the studied localities included the specification of the position of all debris flow accumulations. The laboratory part involved morphometric analysis of the longitudinal profiles of valley floors. In this perspective, the essential relation is as follows:

$$S = k_s A_C^{-\theta}$$

where:

S is the local channel slope,

k is the steepness index,
A_C is the upstream drainage basin area
and θ is the concavity index (D u v a l et al. 2004; K o r u p 2006).

If we evaluate the relation between the local channel slope and the upstream drainage basin area within the whole longitudinal profile on logarithmic paper, we are able to determine a point that represents a theoretical boundary between the part of valley that is predisposed to slope processes and the part of valley that is predisposed to fluvial processes (S t o c k and D i e t r i c h 2003). In this way, we can speak about colluvial and fluvial valley segments (M o n t g o m e r y and D i e t r i c h 1988). The upper (colluvial) segment shows insignificant changes in the gradient of the longitudinal valley profile with the increase in the drainage basin area. On the contrary, the valley floor gradient decreases exponentially with gradual increase in the drainage basin area within the lower fluvial segment. Examples of the boundary point derivation are given in Figure 2. The debris flow dynamics was analysed comparing the reach of individual accumulations with the position of these points in the valley floor longitudinal profiles. The morphometric analysis was carried out in the ArcGis 9.2 Spatial Analysis software using the ZABAGED source data and the pixel size of the drainage basin gradient grid of 5 m.

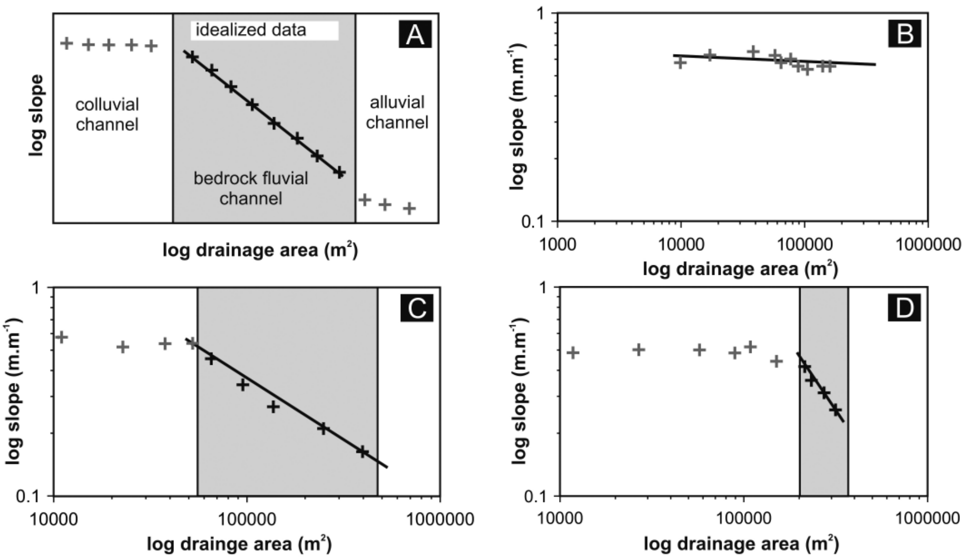

Fig. 2. Determination of the boundary between the colluvial and fluvial valley segments on the basis of the ratio of gradient/area: A – idealised model, B – valley with 100% dominance of the colluvial segment C – valley with the dominance of the fluvial segment D – valley with the balanced ratio of both the segments

RESULTS

POSITIONS OF DEBRIS FLOWS

Field mapping proved the occurrence of debris flows in all studied localities. All identified accumulations were divided into two groups varying in a few properties.

Accumulations of the first group are relics of large accumulations represented by up to 20-m-high levees similar to fluvial terraces or by large fans at the mouth of gullies and smaller valleys. Some of them even exceed the height of 20 m and the volume of the largest ones reaches 1,000,000 m^3. They are formed by weathered material; the grain size analysis showed more than 30% share of aleurite-lutaceous fraction (<20 µm) (Silhán and Pánek 2008a). At present, debris flows of such dimensions are not found in the area of interest. These indicators point to high age of the accumulations (maybe as old as of the Pleistocene).

Accumulations of the second group are characterized by smaller volumes (up to 10,000 m^3) and a shape of prolonged levees of the height of up to 3 m. The content of the aleurite-lutaceous fraction is smaller than 20%. Debris flows of such parameters are presently common. Some of them were dated by dendrochrolonogical methods (max. 70 years old) (Šilhán and Pánek 2008b).

Most accumulations (of the total of 21) were identified in Mt Lysá hora. This area is also occupied by the longest debris flows (longer than 1,500 m) in the whole studied area. Fifteen accumulations of dissimilar length (some of them exceed 1,000 m) were discovered in the massif of Mt Smrk. Ten debris flows of an average length of 640 m were found in the massif of Mt Travný. The shortest accumulation was mapped on the northern slope of Mt Javorový vrch (average length of 580 m; 8 accumulations in total). The massif of Mt Slavíč shows 6 debris flows of an average length of 650 m also only on the northern slope. The number and length of debris flows in individual localities are given in Figure 3. The proportion of debris flows lying on slopes and in valley floors is indicated in Table 1.

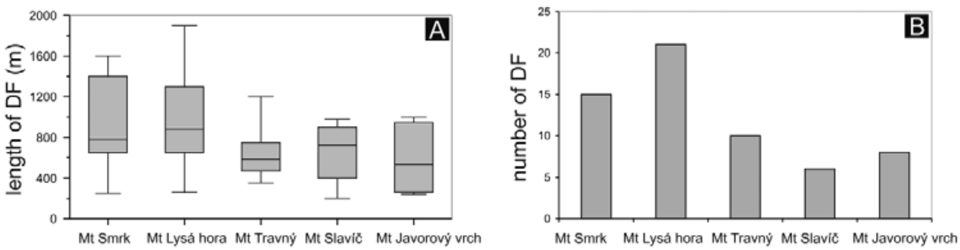

Fig. 3. Debris flow accumulations in individual localities: A – accumulation lengths, B – the number of accumulations occupying positions on valley floors

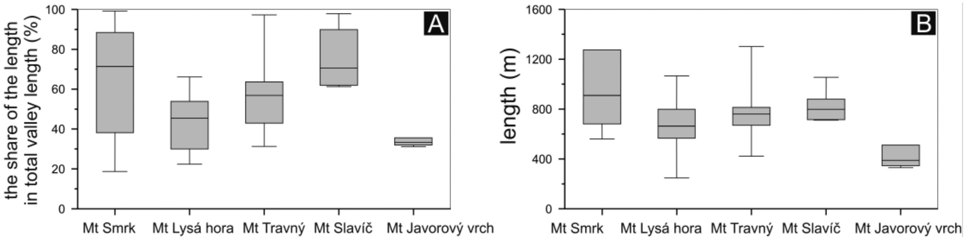

Fig. 4. Colluvial valley segments: A — the share of the lengths of colluvial segments in total valley lengths as far as the beginning of the alluvial segment, B — lengths of colluvial segments

Table 1

The number of debris flow accumulations in individual localities

	Mt Smrk	Mt Lysá hora	Mt Travný	Mt Slavíc	Mt Javorový vrch
No. of DF	15	21	10	6	8
Valley floor	12	12	10	6	5
Valley gradient	3	9	0	0	3

BOUNDARY POINTS POSITION AND LENGTH OF INDIVIDUAL SEGMENTS

In the evaluation of the colluvial segment morphometry it is important to consider not only the length of individual segments but also their proportion in the whole valley length before the passage into the alluvial channel (Fig. 3A). Analysis of this type involved all the valleys with evidenced occurrence of debris flow accumulations. The analysis results are shown in Figure 6.

The longest colluvial segments, the average length of which exceeds 900 m, have been identified on the slopes of Mt Smrk. A significantly different situation has been documented in Mt Lysá hora. In comparison with Mt Smrk, the boundary points between the colluvial and fluvial segments lie considerably nearer the source zones. In the case of Mt Travný, a majority of the boundary points occur likewise in the vicinity of the source zones, however, some of them lie almost at the foot of the slopes. The average length of colluvial segments in these two areas is comparable. As for Mt Slavíč massif, the boundary points occur especially in central and lower sections of the travel and they are rather distant from the source zones. Some of them reach as far as the main valley floor of the Slavíč stream and their average length exceeds 800 m. The shortest and very little varied segments as for the length are colluvial segments on the northern slope of Mt Javorový vrch. Their average length barely reaches 400 m. The boundary points of the segments occur approximately in the upper third of the longitudinal profiles, beneath the steepest parts of the slopes.

With respect to the ratio of colluvial segments to the total valley length up to the alluvial segment, the situation within all the localities corresponds relatively well with the length of individual segments (Fig. 6A). Although showing high variability (>70%), the highest proportion of colluvial segments is observed on Mt Smrk. Some valleys are practically formed exclusively by the colluvial segment. In this respect, similar characteristics can be observed on the northern slope of Mt Slavíč. Colluvial segments here reach very high proportions as well, however, with much lower variability. The localities of Mt Lysá hora and Mt Travný are relatively comparable, nevertheless, the proportions of colluvial segments in the case of Mt Travný are slightly higher and of higher maxima. On the contrary, the lowest proportions of colluvial segments are identified in valleys on the northern slope of Mt Javorový vrch. They show very low variability and hardly reach 40%.

REACH OF DEBRIS FLOWS IN LONGITUDINAL PROFILES

The comparison of theoretical boundary between the colluvial and fluvial segments and the real reach of individual debris flow generations on the slopes of Mt Smrk show that the accumulations of the 1st group (of the volume of up to 10^5–10^6 m^3) reach far into the fluvial valley segments, whereas the fronts of recent accumulations of the volume of 10^2–10^4 m^3 usually correlate with the position of inflection points between the colluvial and fluvial valley segments (Fig. 5A). The same comparison made within Mt Lysá hora reveals that practically no debris flow accumulation has been preserved above the boundary point. The 2nd group of debris flow can sporadically be observed in the colluvial valley segment, whereas the 1st group of accumulations occupies the most distant positions from the boundary (Fig. 5B). Mt Travný bears similarities to the situation of Mt Lysá hora. The accumulations there, particularly smaller ones (the 2nd group), reach far beyond the boundary point only sporadically. The 1st group of forms is limited to lower sections of the drainage basin (Fig. 5C). No accumulation of the first group reaches the colluvial segment of the valley floors on the northern slope of Mt Slavíč. On the contrary, the 2nd group of accumulations abounds in this valley segment as well as in the fluvial segment (Fig. 5D). All accumulations of the valley floors of the northern slope of Mt Javorový vrch occur exclusively below this point (Fig. 5E).

The study area is, therefore, characterized by the difference in the reach of both the 1st group and the 2nd group of debris flows with respect to the position of the boundary point between the colluvial and fluvial segments, as well as by the difference in these parameters within individual localities. A majority of the 2nd group of accumulations lie below the boundary point (70.3%) or slightly above (29.7%). On the contrary, although reaching farther from the boundary point (620 m) (Fig. 6B, Tab. 2, 3), the 1st group of accumulations occupy positions almost exclusively below the point (94.3%). Mt Smrk represents an exception

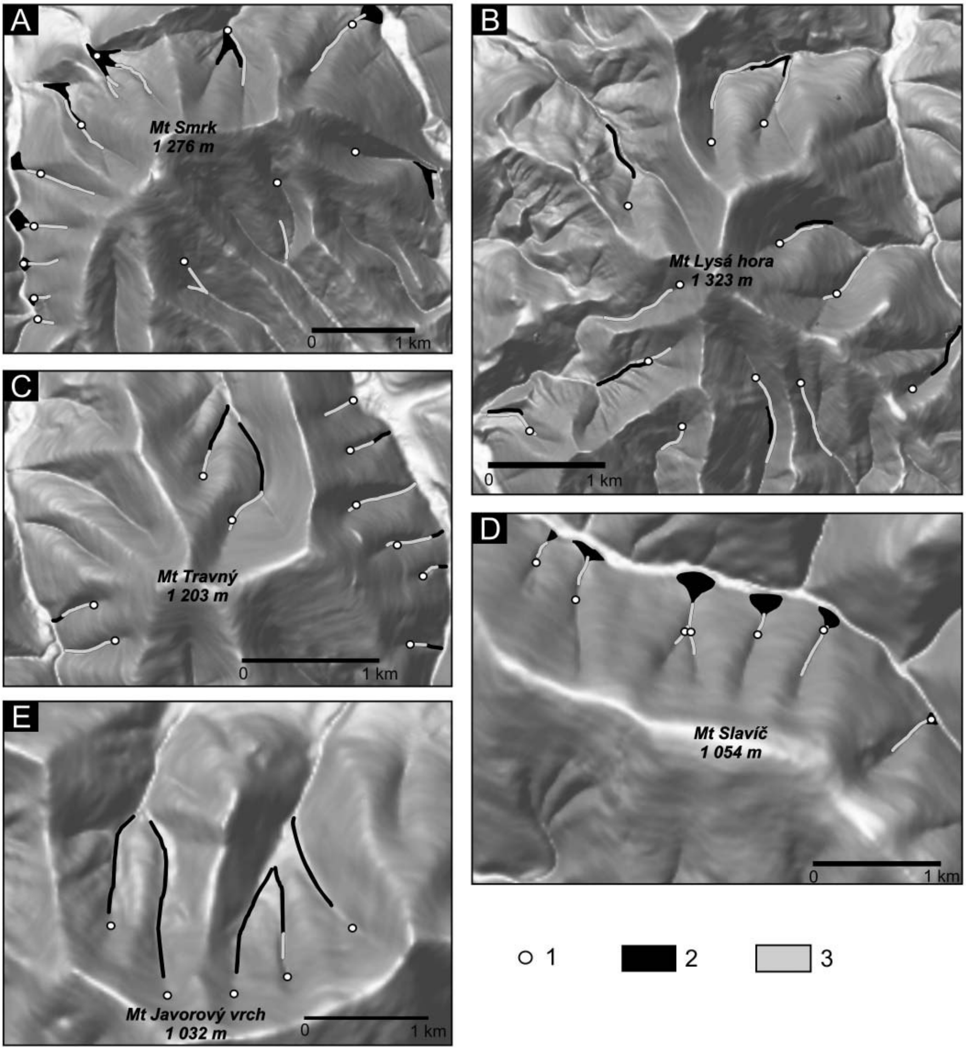

Fig. 5. Maps demonstrating the boundary point position of the valley floor colluvial and fluvial segments: 1 – boundary point, 2 – accumulations of the 1st group, 3 – accumulations of the 2nd group,

with the 1st group of accumulations occurring independently of the boundary point between the colluvial and fluvial valley segments. An interesting aspect has been observed comparing the local slope gradient in most distant parts (fronts) of individual debris flows (Fig. 6A, Tab. 3). In comparison with the 1st group of debris flows, the fronts of the 2nd group of debris flows came to a halt in positions, whose gradient is, on average, of much higher values, both in the colluvial and the fluvial segments.

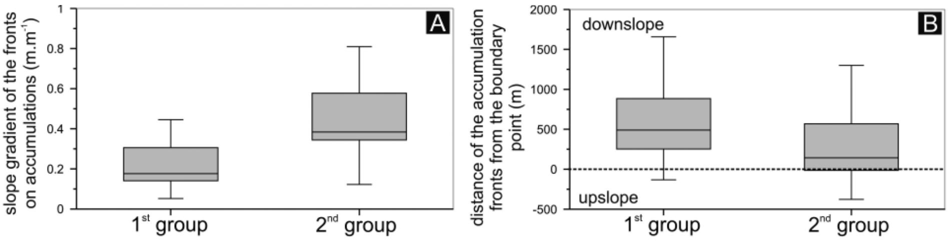

Fig. 6. A – Slope gradient of the fronts on individual debris flow accumulations, B – Distance of the debris flow accumulation fronts from the boundary point of the colluvial (counter-slope) and fluvial (down the slope) segments

Table 2

The number of DF accumulations in colluvial and fluvial segments

		Colluvial segment		Fluvial segment	
	Number	Number	[%]	Number	[%]
1st group of DF	35	2	5.7	33	94.3
2nd group of DF	37	11	29.7	26	70.3
Total	72	13		59	

Table 3

Medium distance of accumulations from the boundary point and medium slope gradient on the fronts of individual accumulations

	Medium distance from boundary point [m]		Medium slope gradient [$m \cdot m^{-1}$]	
	Colluvial segment	Fluvial segment	Colluvial segment	Fluvial segment
1st group of DF	87	620	0.40	0.20
2nd group of DF	99	464	0.61	0.35

DISCUSSION

Geomorphological mapping proved the presence of a multitude of debris flow accumulations in all the selected culmination localities. They are situated both on slopes and in valley floors. With regard to relatively little extreme morphometric parameters of the slopes and different climatic characteristics of the Moravskoslezské Beskydy Mts, individual accumulations were identified as surprisingly long. They can thus be compared to the debris flows in the Giant

Mts (P i l o u s 1973, 1975, 1977). What is more, the largest accumulations are even comparable with length of debris flows of the Tatra Mts (K o t a r b a 1989, 1991).

A detailed analysis of longitudinal valley profiles containing debris flow accumulations proved that the colluvial segments can have various lengths and conditions in relation to the total valley length. This points to the predisposition of individual localities to the debris flows occurrence. Long colluvial segments recording a high share in the total valley length of Mt Smrk prove high exposedness of this locality (Š i l h á n and P á n e k 2007). On the contrary, short segments with a lower share in the total valley length of Mt Lysá hora indicate lower exposedness of this locality. In comparison with Mt Lysá hora, the massif of Mt Travný is characterized by a higher share of colluvial segments and therefore by higher theoretical predisposition to debris flows. The northern slope of Mt Slavíč represents a relatively dynamic environment with a high share of colluvial segments. In this respect, the northern slopes of Mt Javorový vrch with relatively short colluvial segments appear to be least predisposed to the occurrence of debris flows. This assumption is supported by the presence of the smallest number of accumulations and a sole accumulation of the 2nd group.

The evaluation of the reach of both types of accumulations in comparison with the position of the boundary point between the colluvial and fluvial segments brought very interesting knowledge. The boundary point in the massif of Mt Smrk represents the outermost boundary of recent accumulations that originate even at present. On the contrary, the 1st group of forms lies independently of this point, which can be revealed on the basis of their volume and dynamics, thanks to which they have reached much bigger distance from the source area than smaller-size debris flows. Practically no debris flow accumulation has been preserved above the boundary point in the area of Mt Lysá hora. The 2nd group of debris flow can be identified at few positions of the colluvial segment, while the 1st group of accumulations then occupies the most distant positions from the boundary point. Despite a very short colluvial segment, debris flows of this locality, being extremely dynamic, have reached deep in the fluvial segment. The situation in the massif of Mt Travný resembles the situation of Mt Lysá hora. The accumulations there reach above the boundary point only sporadically and if so, it concerns exclusively 2nd group of accumulations. The 1st group of forms has been identified solely in the lower sections of the drainage basin. Although the boundary points in the massif of Mt Slavíč lie relatively far from the source zones, half of the debris flow travels lack accumulations. The locality dynamics is so high that the majority of the accumulations passes the boundary point easily and stops as far as the mouth of the travels into the main valley. In the case of some of the travels, however, the valley floor has been filled with 2nd group of accumulations high above the boundary point. All the 1st group of accumulations, for the most part cone-shaped, occurs below this point. Despite the fact that the boundary point on the northern slope of Mt Javorový vrch occupies a relatively low position, the debris flow dynamics has been very high there. This fact is supported by the presence of almost purely the 1st group of accumulations whose high dynamics can also be supposed in connection with their voluminousness which is greater if compared with the 2nd group of accumulations.

Generally, longer reach of the 1st group of debris flows in valley floors and their halt in positions with smaller inclination point to greater movement dynamics. This fact is probably connected with bigger motive power and velocity of the material moving in big quantities (Iverson 1997). In this respect, the 2nd group of debris flows of smaller volumes logically reaches a shorter distance in longitudinal profiles and come to a halt at positions of a higher gradient, as proved by the analysis.

The question remains unanswered over how it is possible that such voluminous debris flows do not come to appear at present as well. The origin of the 1st group of debris flows can to be estimated as falling in the Pleistocene period (Šilhán and Pánek in press) characterized by specific climatic conditions (Czudek 1997) that enabled the existence of thick weathered layers on slopes, forest-free areas in culmination parts of mountain ranges, or permafrost degradation at the end of glacials (Ložek 1973).

CONCLUSION

The knowledge on debris flows in the Moravskoslezské Beskydy Mts obtained in the geomorphological mapping and morphometric analysis of longitudinal profiles of the source drainage basins can be summarised in the following points:

- The number of the accumulations is very high and their dimensions are surprisingly big and comparable with debris flows in neighbouring, but morphometrically more exposed, mountain ranges (e.g. the Giant Mts or the Tatra Mts). From the morphological point of view, two groups of accumulations can be distinguished that differ, among others, in sedimenthology and probably in age.
- In a majority of the studied localities the high number and volume of the debris flows are also given by a high share of valley sections prone to slope processes.
- Unlike small (the 2nd group) debris flows that come to a halt at positions with a higher slope gradient, large debris flows reach a longer distance in valley floors. These debris flows were thus of much higher dynamics due to greater amount of material and its motive power. The main reason for this is possibly the fact that they originated in different climatic conditions.

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