# Proposal for a Method for Colluvisol Delineation in Chernozem Region

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**Abstract**: Erosion, which is one of the most important exogenous processes forming the landscape, has become a main degradation factor affecting agroecosystems. One of the direct erosion effects is a change in the soil cover structure. Colluvisols, originating in the material accumulated in depressions and foot part of slopes, represent a significant element in such a segmented soil mosaic. In the Chernozem loess area of Žďánický les, a method of areal delimitation of Colluvisols was proposed. Considering the homogeneity of the relative soil properties, the terrain morfometric characteristics (slope, profile curvature, and plan curvature) were applied as the main criteria. The final map reflects specifically the general zones of potential Colluvisol formation, such as lateral valleys and slope bases – floodplain interfaces. In the locality under study (size 3 ha), the microrelief evaluation of the colluvial process was proceeded particularly in a colluvial-alluvial zone. The results showed a significant difference between the soil properties of adjacent Colluvisol and Fluvisol resulting mainly from the distinct character of sedimentation.

**Keywords**: soil erosion; terrain modelling; soil cover structure; soil mapping

The soil loss caused by water erosion is one of main degradation processes influencing agroecosystems. Soil developing from loess parent material is extremely susceptible to this phenomenon. In addition to the influence of the early deforestation and intensive agricultural use, it is especially its physical character (high silt fraction content) which is of concern (Terhorst 2000, Janeček 2002). As a result of accelerated erosion, a diversified soil mosaic comprising various degradation and accumulation phases of the original soil types is formed on the cultivated land. Colluvisol, which is formed mainly from the humic material transported from the exposed parts of the slope, is one of thus originated soils.

The Chernozem loess region of south Moravia offers ideal conditions for the research of colluviation.

– Regarding the soil texture dominated by silt, Chernozems are highly predisposed to erosion, which results in deep colluvial horizons formation.
– Clear colour distinction of calcareous and mollic horizons allows a remote sensing-based monitoring of the soil loss and soil deposit areas when the exceptional colour contrast between the erosion and accumulation parts of the slope is well demonstrated by aerial photographs.
– Long periods of human activity in the area facilitated a practically continuous development of Colluvisols.

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– A highly segmented terrain (in terms of mezorelief slope parameters and parcel detail) implicates a wide range of positions, where the transported material can be sedimented. Consequently, Colluvisols are not located exclusively in the bases of slopes but also, and often better developed, in lateral dry valleys and behind the terrain obstacles.

There are several problematic points that must be considered when studying the areal determination of Colluvisols and their delimitation against the neighbouring soil types. First of all, we must remember that the Colluvisols are morphologically indistinctive and the minimal colluvial horizon thickness of 0.25 m (when not counting the typical terrain position) is the only diagnostic criterion. The considerable variability of colluvial horizon forms, resulting mainly from a strong dependence on the source material, makes the identification of Colluvisoils rather difficult in many cases.

The fuzzy character is another typical feature of colluvial soils (Mitra *et al.* 1998), meaning that the colluvial area (if it is not related to any terrain obstacle) merges in the floodplain continuously and is gradually dissolved in steeper parts of the slope. The boundary between Colluvisols and adjacent soils is relatively difficult to determine, which applies primarily to the Colluvisol/Fluvisol contact areas. Because of the fact that both Colluvisols and Fluvisols are young soils with a low morphologic distinctiveness, with an irregular distribution of organic matter and often a stratified character (Němeček *et al.* 2001), their differentiation can be difficult in many cases.

When the sedimentation capacity of the concave parts of the slope has been exhausted or reveals a sudden increase of the erosion potential, the floodplain (mainly the zone adjacent to the foothill) is gradually filled with erosion sediments and a broad belt of sedimentary material of different characters is formed (Lang 2003). In addition, both sedimentation events can take place at the same time: a heavy rainfall event can cause both a flood sediment accumulation and an elevated soil wash out on slopes. The properties of the so formed depositions correspond to the local (colluvial) and regional (fluvial) material characters (Houben *et al.* 2006).

Geological data cannot be fully used for the delimitation of Colluvisols. As it is known in Quaternary geology, the concept of colluvium is wider in comparison with its understanding in pedology (colluvial sediments originated from Pleistocene solifluction and other periglacial processes; Růžičková & Růžička 2001).

The most appropriate technique for the potential colluvial area delineation seems to be a mathematical algorithm calculated upon the morphometric terrain properties (slope inclination, slope length, deposition area...) with limit values delimiting the colluvial zone (Wilkinson & Humphreys 2006). Possible limitations of this method result mainly from an insufficient resolution of the digital terrain model (DTM). In addition, various types of source material must be considered: in loess regions, a thick colluvial horizon is formed even in areas with lower slopes, whereas on sand- and clay-rich soils the accumulation is less intensive (Schmitt & Rodzik 2006). As mentioned above, not only a detailed terrain research but also an exact determination of the role of each factor in the genesis of Colluvisols is required for geographical delimitation of the area, where this soil type can be potentially found.

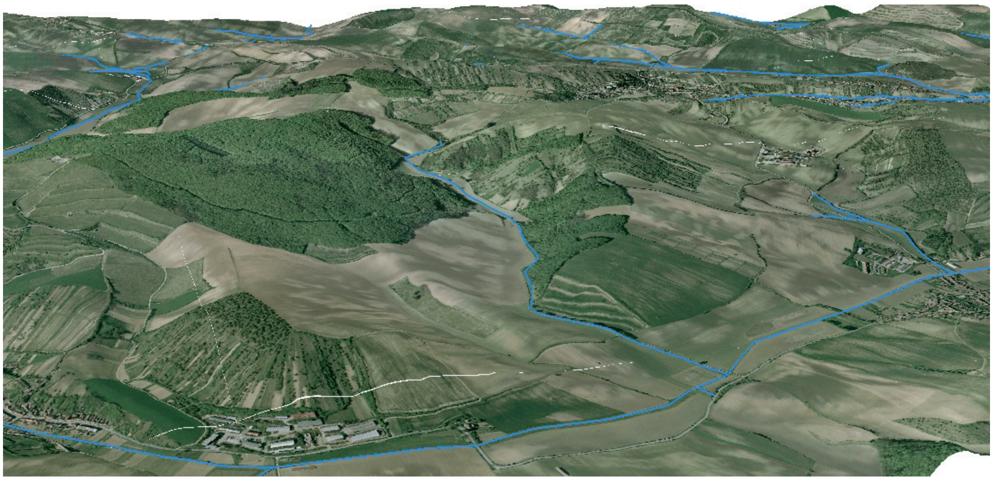

Figure 1. Larger study area

## MATERIAL AND METHODS

### Study area

For the study, the loess region in Southern Moravia (southern extremity of Žďánický les, lower part of the Haraska river watershed) has been chosen (Figure 1). On the study plot in Boleradice cadaster (size 3 ha), a detailed research including soil sampling has been carried out. The locality main slope (up to 19° in height) is fragmented by a system of small dry valleys and terrain undulations, so that many potential sedimentary places have been created. The slope foot merges into a floodplain of a smaller tributary of the Haraska river. Haplic Chernozem, significantly eroded on steeper slopes, is a dominant soil type in the wider area. The area is underlaid by upper Eocene molasses facies and Oligocene sandstones covered by a Pleistocene loess layer (Chlupáč *et al.* 2002).

### Methods

The soil erosion and Colluvisol extension on the study plot were estimated by combining the terrain mapping and sampling methods. The locality was first investigated by soil mapping based on an irregular network (depending on the terrain shape) of borings (depth 1 m) from which the humus horizon depth and profile stratigraphy were determined. In the representative slope positions, the soil was cored down up to a depth of 3.8 m with Eijlkekamp engine corer (Figure 2). From each core, soil samples were taken (each 0.25 m) for analysis. Samples were analysed for the grain size distribution, organic C content, carbonates content, cation exchange capacity, pH in calcium chloride, and for other complementary characteristics. For the wider area, aerial photographs (spectral reflectance classification) and terrain modelling techniques were used. For the derivation of the characteristics representing an auxiliary criterion for Colluvisol delimitation according to their typical position in pedogeomorphic catena, a digital elevation model (DEM) derived from contour lines of ZABAGED (ZM 1:10 000, pixel size 10 × 10 m) was applied. The derived characteristics were calculated using integrated algorithms in the software ArcGIS 9.1 (slope, plan curvature, profile curvature, flow direction, flow accumulation).

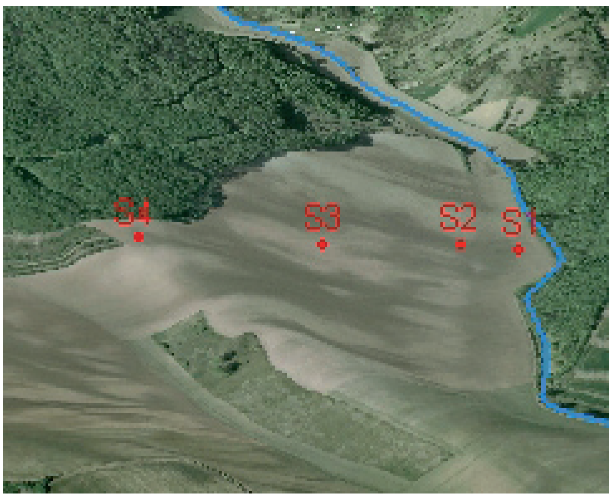


Figure 2. Cores location on the study plot

## RESULTS AND DISCUSSION

### Soil cover structure in the study area

The essential objective in the terrain mapping is to distinguish Colluvisol from other soil types present in the study area. The erosion activity led to an extraordinary increase of soil unit diversity (Figure 3). On the basis of the terrain survey and soil samples analysis, several soil types were identified on the locality where Chernozem originally dominated. The watersheds with minimal slopes are covered mainly by Haplic Chernozem (Figure 4d). The increasing slope is presented by its eroded forms with soils characterised by minimal $C_{ox}$ content in the plough layer in the steepest parts of the slopes (Figure 4c). These soils can be clas-

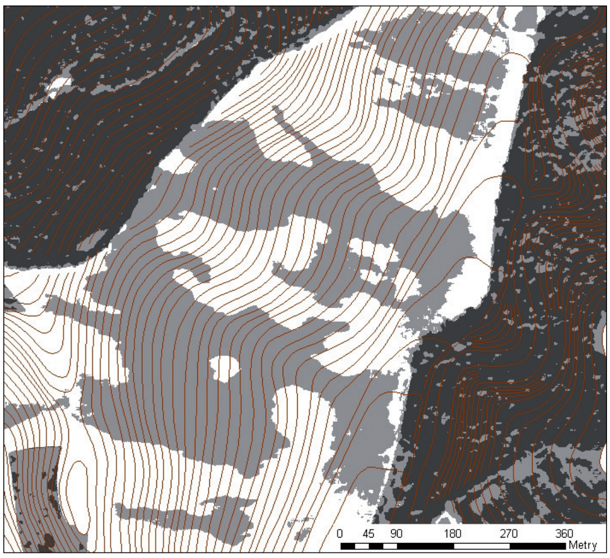


Figure 3. Colour diversity of soil cover structure based on spectral soil reflectivity

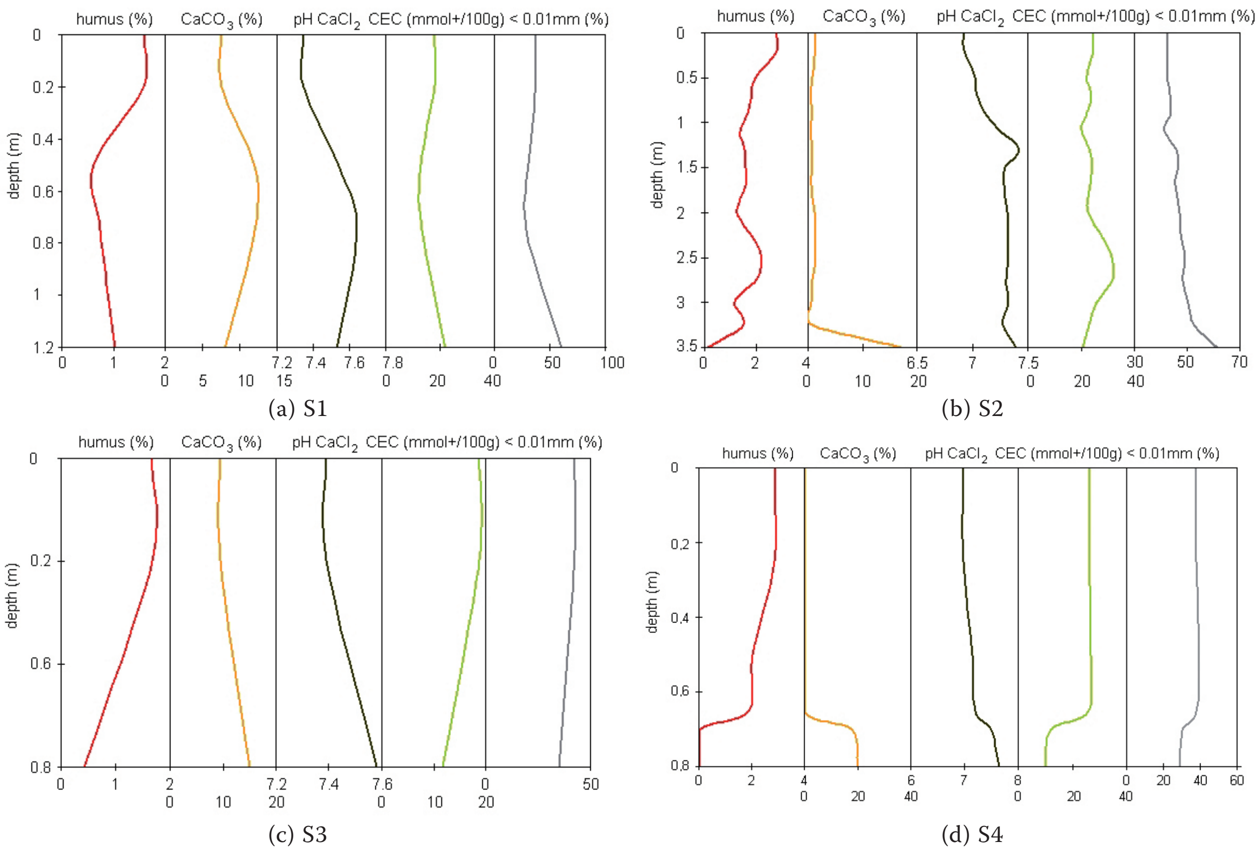


Figure 4. Soil characteristics changing with depth

sified as Haplic or calcareous Regosols according to the parent material character. Loess itself can be exposed in extreme cases. The eroded material is transported, however, the transport distance can vary considerably; it is sedimented first in the concave slope depressions and on the slope base or directly in the floodplain when those are filled up. A significant amount of material is washed out into the watercourse. In these accumulation positions, the original Chernozem is buried by allochtone humic or mineral (when humic matter is exhausted) materials. According to colluvial horizon thickness, soils in different phases of colluviation are distinguished (from colluvial subtypes to Haplic Colluvisol) (Novák *et al.* 2006). The colluvial horizon reaches up to 3.8 m in extreme cases. In

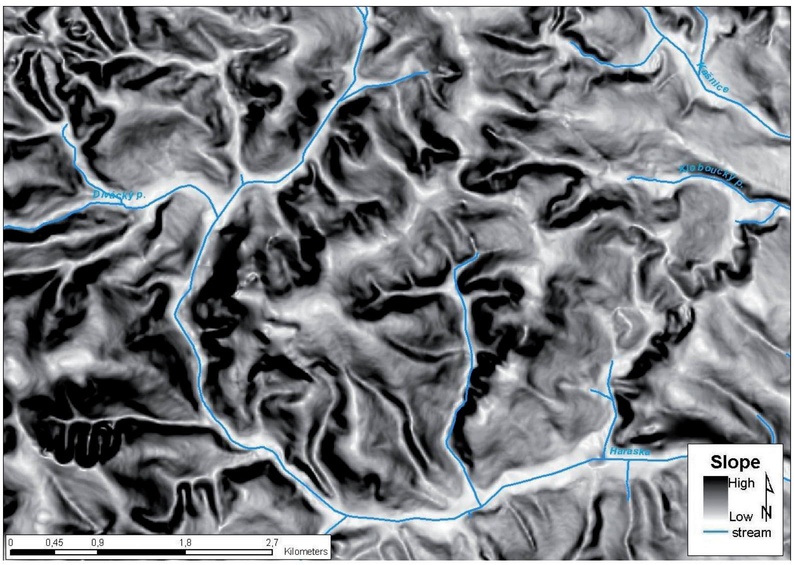


Figure 5. Terrain slope

the south of Poland, Colluvisol with A horizons exceeding 4 m was found (Schmitt & Rodzik 2006). The bright coloured spots occurring on the base of the slope do not indicate soil loss but rather the accumulation of mineral loess material (slightly increased carbonate content in the plough layer of Colluvisol; Figure 4b). Terhorst (2000) identifies similar calcareous colluvial layers on the valley floors in the south-west Germany loess region. This means that the Colluvisol itself is covered by non-humic material in some parts of the slope, which results in subfosilisation of the soil profile and retrograded soil development.

### Potential area of colluviation based on digital terrain model

On the basis of the terrain model, the potential areas of soil loss and accumulation were evaluated. Contours from ZABAGED in the scale 1:10 000 were provided as the data source.

The DTM was used to detect the areas of concentrated runoff and the places of accumulated material with reduced drainage and particles retransportation possibility, particularly the slope positions with minimal profile and plan curvature (Figures 5–8). The key task in colluvial position identification is the location of inflection points on the convex-concave shape transition, where the eroded material is accumulated. These sites can be indicated as potential places of Colluvisol formation.

For the final map of colluvial zones (Figure 9), the following criteria, based on primary terrain attributes (Penížek & Borůvka 2006), were chosen. The areas of a high probability of running colluviation process and therefore with a high potential of Colluvisol development were defined in terms of these conditions: slope inclination 2° or

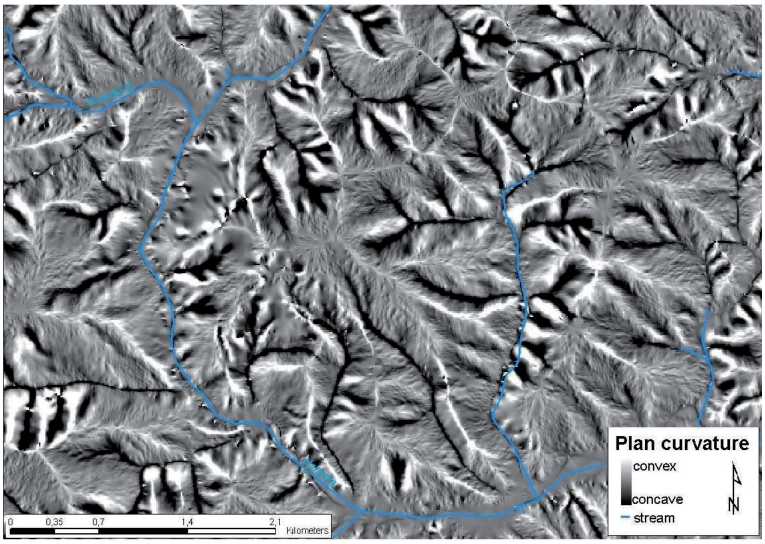


Figure 6. Plan curvature

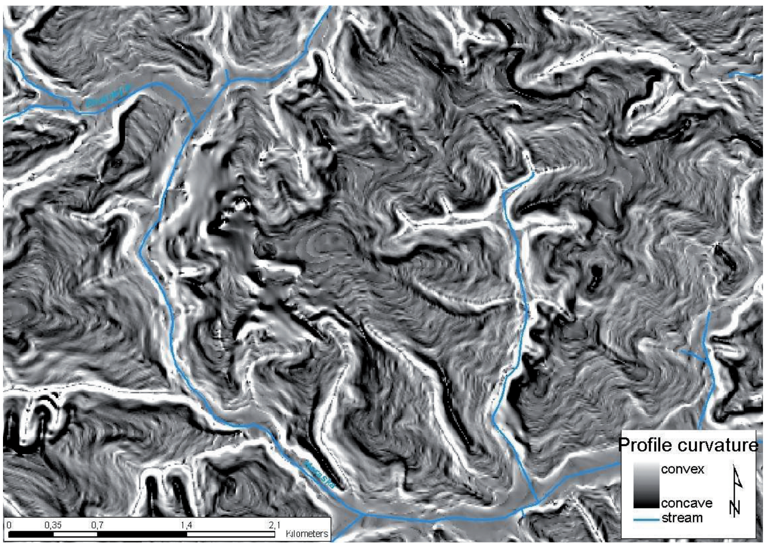


Figure 7. Profile curvature

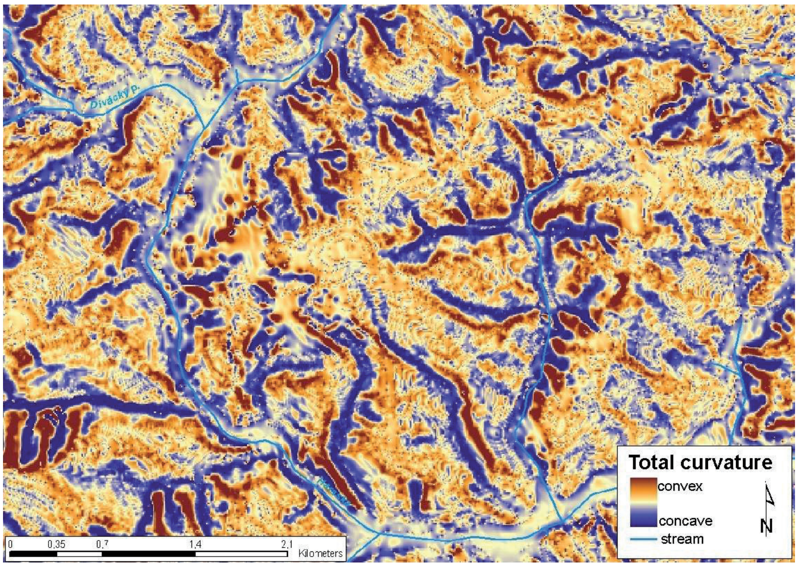


Figure 8. Total curvature

less and concave plan curvature or concave profile curvature (Seidel & Mäckel 2007). In this case, the intersection of morphometric characteristics favourable for an increased sedimentation is achieved. Due to a lower resolution of the input data, only main zones of potential Colluvisols formation were delimited. The model does not consider the microrelief sedimentation processes (soil deposition behind particular terrain undulations or within small dry valleys).

### Characteristics of soils within colluvial-alluvial zone

As shown in Figure 9, relatively large part of delimited areas fall within the transection zone between the slope foot and floodplain. According to main acting processes, this sector can be called colluvial-alluvial belt (Rommens *et al.* 2006).

### Uninterrupted topographic catena

When the floodplain and slope foot are fluently contacted (the soil catena is not interrupted by any terrain obstacle), as in the case of the Boleradice study plot, a colluvial-alluvial belt is formed between these two elements. The accumulation has two source mechanisms – water course transport and slope runoff. Neither DTM application nor aerial photograph analysis seems to be efficient in this case. The first reason is due to the fact that the morphometrical transition from the alluvial plane to the slope is difficult to measure. The second reason is a low colour distinction in aerial photographs. In addition, there no significant differences were found in the soil depth and profile stratigraphy (core S1 – slope base/floodplain transition, core S2 – floodplain). As Leigh and Webb (2005) showed, the whole alluvial plane can

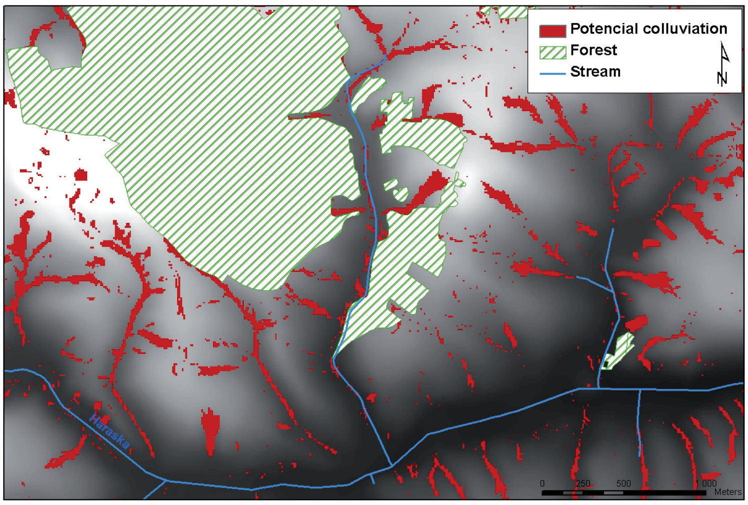


Figure 9. Map of potential Colluvisol areas

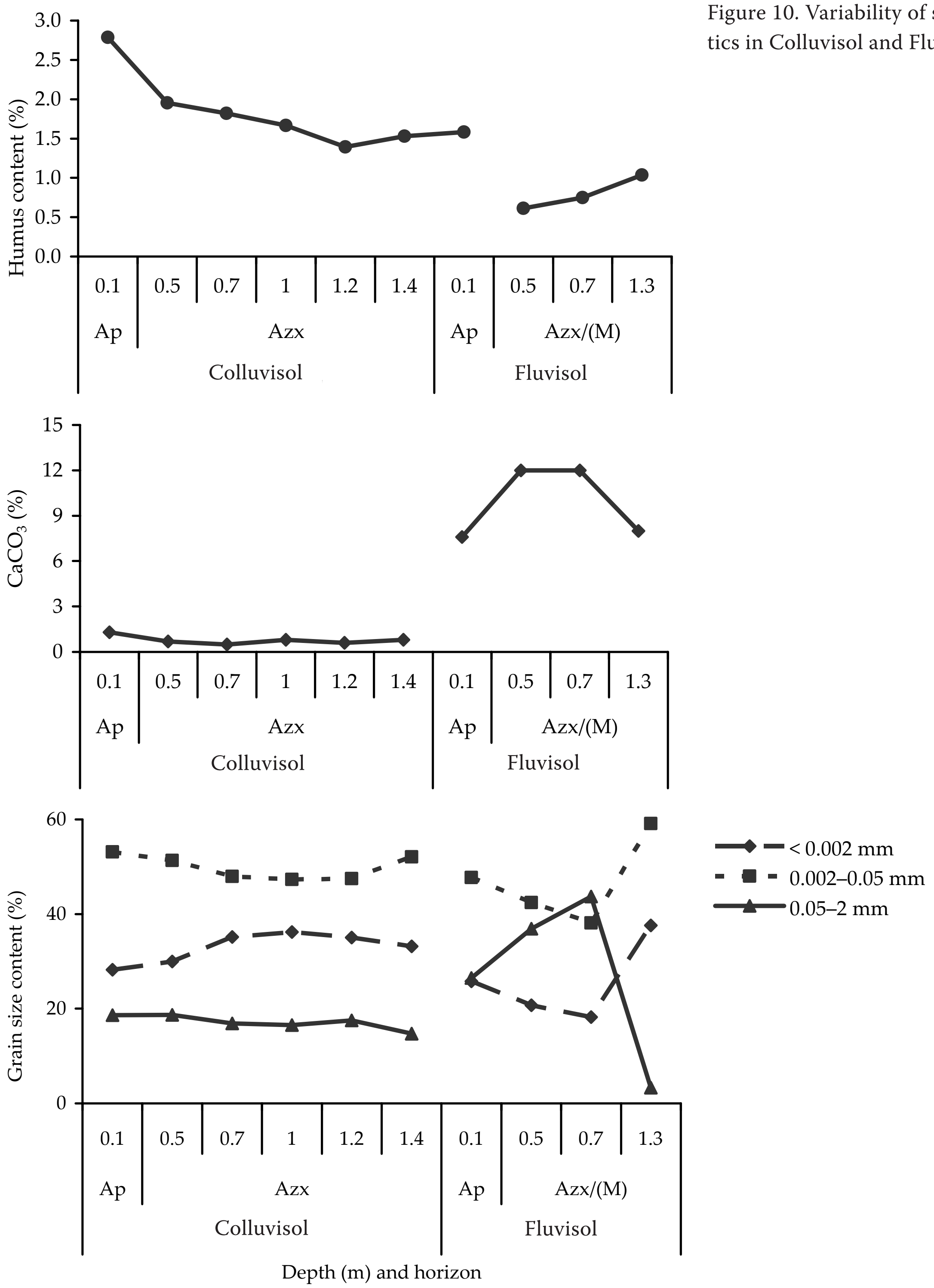


Figure 10. Variability of soil characteristics in Colluvisol and Fluvisol

be covered with soil sediments and a temporary or a permanent burial of Fluvisols can succeed. On the contrary, the analyse of the samples collected from both cores showed significant differences in the of soil properties (Figure 10). It is mostly a different character of the sedimentation process and accumulated material type (locally in erosion sediments, regionally in fluvial sediments) which causes the variability in chemical and physical characteristics of these neighbouring soils (Houben *et al.* 2006). Therefore, the terrain survey completed by soil analysis is proposed as the most reliable method for the identification of soil units limits in the fuzzy zone of the colluvial-alluvial belt.

## CONCLUSIONS

In the south Moravian Chernozem region, fundamental and large-scale changes have occurred in the soil cover character due to long term agricultural use. Chernozem, the originally dominant soil unit, was progressively transformed along with intensive soil erosion. An extremely varied soil cover structure is one of the results of these processes. On the watersheds with minimal slope inclination, Chernozem was conserved. Continuous soil material movement which leads to both humus horizon degradation and aggradation formations can be recognised on the slopes. Colluvisol, formed in the areas of increased accumulation, represents an important element in the landscape and soil mosaic, whose development is still in progress. For the proposed method of their mapping, a relative similarity of the soil characteristics (texture, structure, $C_{ox}$ content) in larger areas was used and several morphometric properties were selected as determining the delineation factor. The final map represents mostly areas of potential colluvial processes in the mesorelief scale and identifies the areas of potential colluvisol formation, without reflecting particular accumulated spots recognisable only in landscape detail. The map illustrates that the main part of the whole Colluvisol area occurrs in lateral dry valleys and slope foot/floodplain interface. Here, a colluvial-alluvial belt with the slope and water sediments has been developed. According to minimal slope inclination, the areal differentiation of these two soil types is rather difficult, thus the detailed terrain survey and soil analysis are necessary to be carried out.

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