1. Introduction

The Slovak Karst is situated in the eastern part of southern Slovakia, representing the largest and most typical karst area of Slovakia (over 800 km²). The area extends to the northern Hungarian Aggtelek Karst. Canyon- and gorge-like valleys divide the area into several plateaus: Koníar, Plešivec, Silica, Hornývrch, Dolný vrch, Bôrka, Zádiel and Jasov. The altitude difference between the valley and the plateau surfaces is ~400 m.

The easternmost plateaus of this area are Jasov and Zádiel Plateau and, due to their proximity to Košice (the second largest city of Slovakia), they have been the subject of numerous geological, geomorphological, hydrological and speleological research (e.g. Gaál, 2008; Hochmuth, 2013; Hochmuth & Petrvalská, 2010; Lešinský, 2002; Petrvalská, 2014). The plateaus are unique not only from geomorphological and speleological perspectives, but also due to the relationship of people to the karst relief and its exploitation. The geomorphological boundary is also not as clear as the border of other plateaus. These plateaus are of irregular shape over an area of 9.5 × 6.5 km and 4.0 × 2.5 km. They are divided by a well-defined geological fault into two parts of different sizes. This fault strikes from SE to NW and is a non-karstic feature. The highest points of the surface reach 744 m a.s.l. (Jasov Plateau) and 891 m a.s.l. (Grečov vrch, Zádiel Plateau). From a geological perspective (according to Mello et al., 1997), the area is a complex of Mesozoic rocks/Wetterstein limestone. The greatest area of the plateau is situated between 500 and 700 m (circa 60%) and the mean surface inclination is 9° E–SE. As much as 70% of the area falls into this category. The direction of inclination is identical to the general inclination of the whole Slovak Karst. The surface of the plateau is well-karstified but has undergone anthropogenic modification. The present doline density is 6 dolines/km², but according to historical literature and interviews with inhabitants, many were filled by deposited rock and other material (especially in meadows and arable land to achieve flat relief). The same anthropogenic influence affected karren, they were dugout and used for burning lime. More than 50 speleological objects were mapped in this area. The deepest and longest cave of the Slovak karst is situated here, having developed in Waxenec limestone and is over 8 km long (Skalistý Potok, Rocky Brook Cave).

Both plateaus were well-known in the past because of the historical concentration of inhabitants (Turňa Castle, Jasov Monastery or Neolithic humans in caves). Based on classical geomorphological mapping, two partial geomorphological maps cover the area. The geomorphological study of Slovak Paradise is detailed, with partial geomorphological maps of all karst plateaus (Novotný & Tulis, 2005). Jakál (1975) mapped four fragments of the karst surface of the Silica plateau in the west part of the Slovak karst. However, only one detailed geomorphological map of the whole Slovak Karst exists at a scale of 1:50,000 (Liška, 1994), but the position of landforms is not precise and many are absent. Therefore no detailed geomorphological mapping has been conducted in the study area as many authors consider these plateaus less developed and so less interesting in the Slovak Karst. This partial mapping was the
main motivation to undertake the presented geomorphological mapping.

2. Methods

Our geomorphological mapping in the field has resulted in the creation of a detailed geomorphological map at a scale of 1:10,000. The map is based on mapping inside 1 × 1 km² and the identification of all visible geomorphological forms. For mapping geomorphological forms, we used 1:10,000 topographical maps, a global positioning system receiver, laser distance meter and clinometer; small forms were measured using a 5-m long measuring tape. We also used LIDAR scans from this part of the Slovak Karst.

With the help of these scans, we chose geomorphologically interesting areas for more detailed research and the identification of both natural karst depressions (dolines) and other forms probably of anthropogenic origin. We cannot interpret all depressions as dolines as it is necessary to verify the character of them. We also used the ‘Mapy orientačného behu’ at a scale of 1:20,000 (http://www.orienteering.sk). The maps cover small areas of Slovakia, including the karst plateaus. These areas are complicated for a runner’s orientation because of the flat plateau relief and forestation with numerous dolines. There are many details on these maps (karren fields, dolines, buildings and anthropogenic forms) and we used them for our orientation in the area during field mapping. They are more precise than topographical maps, but only small areas are covered.

The absolute number and density of dolines (number of dolines and karst area ratio) allows us to compare this area with others in the Slovak Karst or other karst areas worldwide. Dolines had not previously been mapped so we decided to map and measure their morphometric parameters using methods by Bondesan, Meneghèl, and Sauro (1992) and Castiglioni (1991). Each doline on the map has its own identification number which links to the table listing the main morphometric parameters (Table 1). For detailed morphometric results, see Petrvalská (2012). The karstification index (density of caves and sinkholes) is described in Shofner, Mills, and Duke (2001). Florea and Paylor (2002) and Huang and Cai (2009) describes different methods for karst mapping using remote sensing.

3. Geomorphological forms of the Zádiel and Jasov Plateau

In the following text we present all the categories of geomorphological forms mapped in this area (Main Map). Structurally conditioned forms such as cuestas, inselbergs, ridges and saddles were identified. The latter three are not typical structural forms but in this area are conditioned by different rock resistance. The most significant cuesta on the Jasov Plateau is Vysoká peak (706 m). The slopes of these plateaus can be divided into two main categories: tectonic (south facing slopes along inferred faults) and erosional (fluvial erosion of the Háj and Blatnica streams). The north, west and south facing slopes show a typical inclination of more than 45°, and abundant vertical rock walls.

Surface and subsurface karst features are usual for these plateaus. Their dimensions and density are different from other western plateaus of the Slovak karst; they are much smaller in depth and diameter. Karren are typical features for plateau areas which were used as pasture as the landscape was deforested due to seepage of water and eolian erosion. Here all morphological types of karren are widespread (rillenkarren, cavernous, tubular, fissure, etc.), but the size is not as large as on the other karren fields in the west part of the Slovak karst. The best developed karren field is located on the south slope of the Zádiel Plateau and is related to the position of Turňa Castle which has historically exploited this area. Other karren fields are situated in different areas, but at present we have observed slow forestation.

The main points of interest for our research were dolines and other karst depressions as indicators of karst plateau development. Dolines are situated on plateau surfaces, valley bottoms, plateau slopes and uvala bottoms in the study area. The depth of dolines ranges between 3 and 20 m and there are visible changes between the different localities. In the north of both plateaus dolines are shallower, affected by human activity. The density of dolines is 6/km² whilst in the western part of the Slovak karst, density is around 45–55/km². Table 1 shows the results of some geomorphological research on the density and number of dolines for all plateaus of the Slovak karst.

There are depressions mainly of corrosion and alluvial origin, and it is likely that buried and suffosion-types are also present. Only 8% of all dolines have a typical bowl shape, with the remainder of plate-like shape in profile. 91% of dolines occur within Wetterstein limestone and 9% developed within Waxenec limestone. In terms of planar morphology, elliptical are more typical than circular and asymmetrical dolines. Orientation is defined as the direction of the longest axis. 35% of all dolines are oriented in a NW–SE direction, which corresponds to the general direction of slope, 16.5% have a NE–SW orientation, 14% W–E, 12% N–S, 10% NNW–SSE, 10% NNE–SSW and 2.5% NW–SEE orientation. Doline alignment is related to the strike direction of the main faults dissecting the plateaus and the longitudinal direction of dry valleys.

Fluvial forms are well developed and occur on the foothills of the plateau. Steep slope valleys (couloirs)
Table 1. Dolines and their density on the Slovak karst plateaus according to different authors.

| Plateau | Dolines density (dolines/km²) | Number of dolines |
|---------|-------------------------------|-------------------|
|         | Jakál (1975)                  | Telbíz, Móga, and Kósik (2009) | Petrvská (2014) | Petrvská and Kučárová (2012) |
| Silica  | 50                            | 730               | 204 (6/km²)     |
| Plešivec| 20–30                         | 55                |                  |
| Koniar  | 35                            | 15                |                  |
| Dolný vrch | 45                        | 4                 |                  |
| Horný vrch | 35                        | 8.7               |                  |
| Borka   | 27                            | 1.2               |                  |
| Zádiel  | 5                             | 1.8               |                  |

are also visible on the south slope of the Jasov Plateau and are cut 20–40 m deep into the plateau. They are likely affected by a tectonic line in a N-S direction, and their relief is formed primarily by erosion and corrosion. There are no permanent streams situated at the bottom of these valleys and they have a typical ‘V’ shape, with many bare rock walls and talus. On the foothills of these plateaus, Holocene talus cones have developed from this material.

Anthropogenic action has been affecting the area for many years. The result of this activity is very significant on the surface although most of these forms are not maintained at present (only roads). We identified old paths and roads, mining forms, buildings and relief treatment, rock walls of pasture boundaries, lime pits, limestone and travertine quarries in the Háj valley and Teplica River and old arable areas near Hačava village. Travertine was mined here along the Háj stream and used for building houses in the region. The results of this activity are several travertine steps forming waterfalls. Lime pits are anthropogenic depressions 1.5–2 m deep and 3–5 m in diameter. They were used for burning lime and can subsequently develop as dolines. We distinguish these lime pits from other small depressions spalls of burned limestone within the form.

Denuded systems can help us better understand the development and origin of this area. They represent the planation surfaces of the plateau. We divided the whole area into a denuded higher surface (pre-Neogene, Neogene), midmountain level (Late Miocene), lower midmountain level (Mesin/Zankl) and river level (Late Pliocene; near Debra village, outside the study area). For the denuded higher system, we note the cone-shaped hills on the north edge of the plateau have a similar height, just 50–100 m above midmountain level located between 500 and 550 m. One part of this surface is represented by a relief of 5–10° inclination (designated a heterogeneous surface). All surface karst forms are well developed at the midmountain level, with dolines and fractures filled with terra rossa. The lower midmountain level is situated to the east of the higher surface, around St. Ladislav spring and the Koncovoš košiar to the east of the study area. This surface is between 400 and 425 m and 10° inclination. Dells are well developed in the area, at the bottom within deep dolines. Dells are bowl-profiled valleys without fluvial incision formed mainly by slow mass movement processes.

4. Conclusions

Due to their geomorphological and geological evolution, both of the studied plateaus are specific areas of the Slovak karst. Our geomorphological map contributes to better knowledge of this speleologically and now also geomorphologically well-known area.

Academic discussion about the low karstification of the eastern part of the Slovak karst is limited. Jakál (1975) described this as dolomitisation of the limestone with poor quality of the rock body. However, chemical analyses of the limestone from different localities on these plateaus show that the limestone has no disturbance and is of a good quality similar to the western part of the karst area. Our mapping results show that this plateau is also well-karstified, although karst form dimensions are less than on the western-situated plateaus (east 6 dolines/km², west 45–55 dolines/km²). The known length of the subsurface cave passages (around 18 km) indicate a well-developed karst body with probable different surface evolution. Faint karst depressions could be filled by sediments coming from the north, non-karstic area or filled manually by farmers working here in the past. The relief was anthropogenically planted for easier cultivation. Analyses of the cave sediments document (Bónová, Hochmuth, & Derco, 2008) that the catchment area was situated in the non-karstic Slovenské Rudohorie Mts. (to the north of the Slovak karst). Karren and karren fields are also situated in the areas with significant land use (south slopes).

This map aims to provide ground work for further scientific studies of this area that are necessary for understanding the character and evolution of the Slovak karst. It depicts one of the most detailed geomorphological maps of Slovakia using classical methods, supplemented with LIDAR data and orienteering maps.

Software

We used Corel Draw X6 for the drafting of the map as it allows the bespoke production of symbols (including
asymmetrical forms). Esri ArcGIS 10.1 was used for topographic visualisation and the calculation of slope and aspect of the LIDAR data.

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