TYPES OF NON-KARST CAVES IN POLISH OUTER CARPATHIANS – HISTORICAL REVIEW AND PERSPECTIVES

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Abstract: On the basis of historical review of progress in exploration and scientific studies and categorisation of non-karst, mainly gravitational caves in Polish Outer Carpathians (Beskidy Mountains), new concept of these caves' classifications is proposed. Two classifications are suggested. According to the genetic classification, in which the criterion is the relation to the stages of slope evolution, two main types of caves: *initial caves* and *subsequent caves* can be distinguished, however intermediate forms are also observed. According to the geomechanic classification, which accounts the type of phenomenon-process producing caves, three types of caves can be discriminated: *dilation caves*, *dilatancy caves* and strict *boulder caves*.

Introduction

Polish Outer (Flysch) Carpathians, called also the Beskidy Mountains (BMs), with their Foothills, and constituting the predominant part of the Polish Carpathians are principally built of siliciclastic-clayey rocks. In morphological terms the BMs are medium-high mountains composed of several mountain ranges. Such geological structure and relief determine the nature of caves which are relatively frequent in this region. Among more than 1,200 caves recorded in the BMs., karst caves are practically absent, whereas most of caves are genetically connected with gravitational mass movements. Close relation between caves and processes shaping the mountain relief causes that the accurate and comprehensive genetical description and classification of these caves is crucial problem for interpretation and reconstruction of morphogenesis of the region. Therefore, the question of proper classification of these caves is a matter of this paper.

Settings: geological structures controlling the morphogenesis

The BMs are built of flysch, siliciclastic-clayey rocks of the Cretaceous-Palaeogene, occasionally Early Miocene age (with an except of Upper Jurassic, limestone-marly flysch occurring only in the most western part of this belt). The Outer Carpathians represent Alpine orogenic belt tectonically shaped in the Neogene and consisting of several tectonic-facies units overthrust each other toward the north. The following units are distinguished in the region (from the south): Magura Unit, Dukla Unit (and their equivalents), Silesian Unit, Sub-Silesian Unit and Skole Unit. Folded Lower Miocene deposits form Stebnik Unit and Zgłobice Unit situated in the northeastern and northern part of the Polish Carpathians. Lithological sequences of the mentioned above units comprise alternation of sandstone and sandstone-conglomerate usually thick-bedded series, thin-bedded sandstone-shale (heterolithic) series as well as shale (claystone) series (Żytko et al. 1989; Lexa et al. 2000).

The BMs and their Foothills are divided into many ranges, which stand from several tens metres to 800 m above the river valleys separating them (Starkel 1972). Steep slopes of these mountain ranges have been predominantly shaped by gravitational mass movements mainly during the Holocene. The development of gravitational mass movements, among which landslides are very frequent, has been facilitated by geological structures (described above) favourable for the disturbance of slope equilibrium. The gravitational evolution of slopes is prolonged process started from gradual, slow spreading or toppling of massif and finalised with its rapid failure and formation of landslide. The propagation and then widening of rock discontinuities is basic element of the initial, preparation stage of landslide development. The subsequent relatively rapid mass movement can be generated by external factors: fluvial erosion, water overloading of rocks and earthquakes (e.g. Zabuski et al. 1999; Poprawa and Rączkowski 2003; Margielewski 2006).

Apart from rockfall, which is relatively restricted process in the BMs, the following mass movements are typical in these mountains (Dikau et al. 1996; Margielewski 2006):

1. Lateral spreading and rock flow (Sackung/sagging *sensu* Zischinsky 1966), which are usually regarded as initial forms evolving into more advanced ones. They are connected with propagation and widening of cracks, which are often accessible for people, and if roofed, can be recognised as caves.
2. Topple, which does not form a sliding surface and also represents initial phenomenon for development of landslides. This kind of mass movement is linked to the loss of stability of the upper parts of rock massif, detachment and displacement of their fragments.
3. Translational slide – strict landslide, characterised by gravitational movement along flat sliding surface (usually bedding plane, joint surface or fault).

4. Rotational landslide with circular slip surface, developed in homogeneous material, but also typical of deep-seated mass movements developed in anisotropic rocks. In the case of this type of movements influence of natural discontinuities (joints) is reduced due to deep-seated slip surface along which large volume of material is displaces.
5. Compound landslide, understood as form intermediate between translational and rotational types of movements (Dikau et al. 1996).

The caves can be associated with each mentioned above types of mass movements.

State of art as a motivation for the discussion

The caves in the Beskidy Mts. have been mentioned in historical sources for several last centuries, however the first explorations of these caves were reported in 19th and first half of the 20th century (Klassek and Mleczek 2008). In the first modern inventory of caves in Poland 23 caves in the Outer Carpathians were described and mapped. Their non-karst, gravitational origin was stated, but not considered in details (Kowalski 1954). The vigorous exploration of the caves in the Carpathians started in 70-ties of 20th century and has been performed by members of the Speleoclub Bielsko-Biała (SBB) founded in that time as well as members of the Beskidy Caving Club active since the 80-ies of 20th century and Association for the Caves Conservation "Malinka Group" founded at the beginning of the 21st century. It has resulted in discovering and mapping of several tens of caves each year. The work of the cavers was recapitulated in three volumes of the inventory published at the end of the 20th century (Pulina 1997 a, b, 1998), and has been reported during yearly national speleological meetings. According to the last report (Klassek and Mleczek 2012), up to August 2012, 1,246 caves of total length yielding 22,580 m have been recorded in the Beskidy Mts. The longest cave, Jaskinia Wiślańska Cave, is 2,275 m long and 41 m deep; 33 other caves are longer than 100 m. The largest vertical distance between uppermost and lowermost cave parts was measured in the Jaskinia Ostra Cave and yields 60 m, but the deepest cave (measured as the vertical distance between the lowermost part and ground surface directly above) is Diabla Dziura w Bukowcu Cave, 42.5 m deep. 26 caves are deeper than 15 m.

Along the exploration, morphological-genetic features of the caves have been recognised. The scientific studies of the caves started by J. Janiga and J. Mikuszewski in 70-ties years, were continued by L. Zawierucha (1986), W Puchejda (1989) and J. Waga (1993) in the 80-ties and 90-ties of the 20th century (Klassek 2004; Klassek and Mleczek 2008). The work of these authors was recapitulated by Klassek (1989, 1994) as well as Klassek and Mikuszewski (1997), who proposed genetic-morphological categorisation of non-karst caves in Polish Outer Carpathians (BMs). Two general genetic groups of caves occur in the BMs: A. *gravitational caves* and B. *erosional-weathering caves*. Three types of gravitational caves were distinguished by Klassek (1989, English terms after Klassek 1994): A.1. *Landslide caves* – the most common, connected with various elements of landslides and disintegrated (prepared to landslide) slopes; A.2. *Slacking caves* – similar in genesis to the first type, but occurring at the rock outcrops. A.3. *Stone-falling caves* – directly related to rock falls. *Erosional-weathering caves* (type B) have developed on the rock outcrops and usually represent very small cavities.

According to morphological classification proposed by Klassek (1989, 1994; Klassek and Mikuszewski 1997) three general groups of caves occur in the BMs (English terms after Klassek 1994). The first group, *fissured caves*, represents single crevice or systems of crevices, somewhere of maze character. In this group the authors of classification distinguish four types: (a) *grooved-ridged type*, situated in parallel trenches and ramparts within landslide type failures of slopes; (b) *rubbled type*, situated within packet-type landslide colluvia; (c) *cracked caves*, situated upslope of landslide main scarps and (d) *divided caves* occurring in the rock outcrops and connected with initial stages of slope disintegration. The second morphological group is represented by *rock niches* – small forms spatially related to the natural rock forms (crags, cliffs). To the third group belong rare *bedding-type caves*, characterised by horizontal sizes much larger than vertical size (height).

The classification of caves proposed by Klassek (1989, 1994; Klassek and Mikuszewski 1997) is not sufficiently precise. Especially the morphological categorisation is somewhere not clear, combining shape of caves, their spatial situation within the slope (its inner and surface structures) and even genetic features, e.g. in a case of type (d): *divided caves*. But also the genetic categorisation does not determine clear margins between the types of gravitational caves, e.g. *landslide caves* (A.1) and *slacking caves* (A.2). Such impreciseness is at least partly caused by the real complexity of the nature, occurrence of many intermediate forms and phenomena. This supports the tendency to simplify such categorisation. Therefore the Carpathian caves have been also classified applying simpler categorisation, which in this region was introduced by Vitek (1983). According to this author the gravitationally induced caves can be divided into two types: *crevice type* and *talus type*. Following this author – the *crevice type caves* are the caves "produced by the movements of large blocks … as cracks … widened along tectonic contacts … and clefts (not of tectonic nature), by the breakdown of blocks and rock. In their initial stage the openings are narrow and high …". In turn, the *talus type caves* are "free spaces formed between boulders and rock block debris distributed … in stone fields and piles of boulders" (Vitek 1983). The quoted above description of *crevice type caves* is generally in accordance with common understanding of this term (e.g. Halliday 2004a, 2007) or with the term of *fracture caves* (Kastning 2005), whereas *talus type caves*, named also *boulder caves*, represent widely described type of these objects (Halliday 2004b, 2007, Kastning 2005; Bella and Gaál 2010, 2011). According to these materials, both the terms and types represent rather morphologic than genetic categories, however, especially in the case of *crevice type caves* gravitational context and relation to stage of slope evolution has been emphasized by mentioned authors. In turn, the *talus type caves* are strictly related to their morphological/spatial situation (on the slope), whereas the same objects named *boulder type caves* have been distinguished owing to their shape and relation to boulder agglomerations (the problem was discussed by Bella and Gaál 2010, who prefer the term *boulder caves*).

Materials and methods

The materials used for our analysis are maps and descriptions of caves published in the volumes of cave inventory (Pulina 1997a, b, 1998) and –in a case of recently found caves – papers published in speleological journals for several last years. We analysed in details about 15 caves distributed in various parts of the BMs, particularly in the Beskid Śląski Mts., Beskid Wyspowy Mts., Beskid Sądecki Mts., Beskid Niski Mts and Pogórze Ciężkowickie (Ciężkowice Foothill). The basic method of analysis is, apart from deduction from maps and field observations, mapping of surface landforms (landslides) spatially related to caves as well as measurements of spatial orientation of the surface and underground elements in order to assessment of nature and stage of slope disintegration (some of such studies have been already published: Margielewski, Urban 2002, 2003a, b, Margielewski et al. 2007, 2008). Recently, also the geophysical method, electrical resistivity tomography (ERT), was used to reconstruct inner slope structures (Pánek et al. 2010; Urban et al. 2011).

Discussion and proposals

Despite the problems described above, the classification applied by Vitek (1983), as simpler than proposed by Klassek (1989, 1994), was used by us in papers discussing the slope structures (failures) and, generally, morphogenesis of the BMs (Margielewski and Urban 2002, 2003a,b, Margielewski 2006). In these papers the *crevice type caves* were interpreted as cracks preceding the landslide formation and preparing a slope to such mass movements, while the *talus type caves* were understood as caves produced within colluvial body of landslide after its formation. However, such interpretation was in some cases misunderstanding due to unclear and combined (morphological and genetic) criteria of discrimination of both these types of caves (see the chapter "State of art …"). For example within the typical landslide body we observed the caves comprising single cracks and fitting the description of *crevice type caves*. Such situations motivated us to discuss the problem of classification and definition of caves and to display our proposals hereafter.

Some approaches to categorisation of non-karst, gravitational caves – or, widely, cracks or irregular voids (if not accessible for man) in the BMs – can be considered. Two the most important for scientific studies are:

- genetic approach, in which the criterion is the relation to the stages of slope evolution,
- geomechanic approach, taking into account phenomena (processes).

Regarding the genetic criterion, two general types of caves can be distinguished: 1. caves preceding formation of typical landslide, which we name *initial caves (cracks)* and 2. caves developed within these structures/landforms named by us *subsequent caves (cracks)* (Figs. 1, 2, 3). Since the predominant stress producing the *initial caves* is tension, these caves are connected with spreading-translation or topple type of movements, however vertical movements and slight rotation are also observed (Fig. 2 C – diagrams show slight toppling). The same types of displacements occur in the case of the *subsequent caves*, but range of topple (tilting) as well as back rotation and rotation around vertical axis (very frequent in the case of translational slide) is usually much higher (Fig. 3 D – diagrams show rotation around vertical axis). Referring to the "classic" Vitek's (1983) classification, *initial cracks* represent exclusively *crevice type caves* (e.g. Fig. 2 B), whereas *subsequent caves* can be both *crevice* and *talus type caves*. Intermediate forms (combining features of both types) are rare caves situated in the zone of landslide main scarp (comprising yielded by tension surfaces). Such cracks are formed before landslide development and they are modified by the main gravitational displacement (slope failure). In this moment their upper parts are transformed to landslide head scarps, while deeper parts are propagated as cracks down the rock massif.

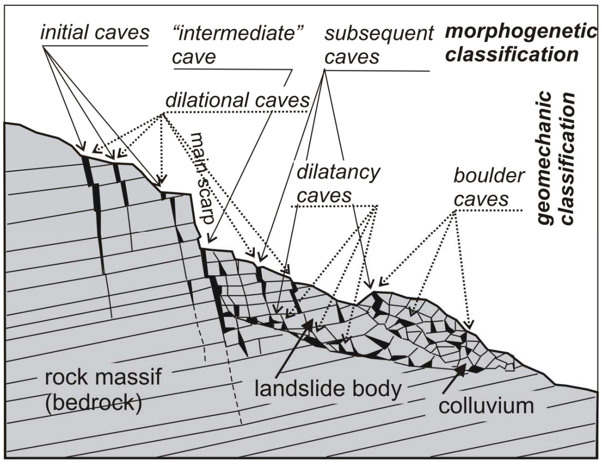

Fig. 1. Model illustrating the types of caves (in broader sense: cracks or systems of cracks) in classifications proposed by authors and their situation in the slope.

The geomechanic classification (criterion) considers the type of phenomena (processes) causing modification or destruction of slope. In this case two principal phenomena should be accounted: dilation (dilatation) and dilatancy. The dilation is defined as change (of rock massifs) in volume but not in shape. In turn, the dilatancy consists in alteration from "close-packed structure" to "open-packed structure", in other words: it generates growth of rocks volume and change in its shape (Dadlez and Jaroszewski 1994). In slope scale the dilation causes propagation and widening of cracks along natural discontinuities (joints, faults) in the initial stage of slope disintegration, as well as during and after the main stage of slope failure (e.g. within landslide body), whereas the dilatancy produces voids within the shear zone (next to slip surface) of landslides during the main stage of slope failure. If such voids are formed along natural discontinuities existing in the massif, the phenomenon is called fissure macrodilatancy (Kwaśniewski 1986). As effects of both types of phenomena two types of caves are distinguished: *dilational caves* and *dilatancy caves* (Figs. 1, 2, 3). The principal feature differing these cave types is their position in relation to shearing zone (slip surface) of landslide: *dilatancy caves* are situated always close to this zone, between stable bedrock and displaced material (Fig. 3 B), whereas *dilation caves* are usually situated in extensional zones close to the surface' It is apparently visible on ERT profiles (e.g. Fig 3 C), where *dilatancy voids* are marked by high and low resistivity bodies distributed close to the sliding surface (A), while the *dilation cracks* are marked by wedge shaped high resistivity anomalies close to the ground surface (B). Although the *initial caves* in morphogenetic classification represent *dilation caves*, the *dilation caves* cannot be automatically identified with *initial caves*, because some of them form in the landside body during the stage of main slope failure. The *dilation caves* are produced principally due to extensional stresses, while shearing strains are initial stresses controlling the development of *dilatancy caves*. However, the size and shape of caves is not decisive feature, the *dilation caves* comprise usually simple widened cracks, *crevice caves* according to Vitek's (1983) classification, whereas *dilatancy caves*, represent more complex, maze systems of passages – *crevice* or *talus type caves* according to Vitek (1983).

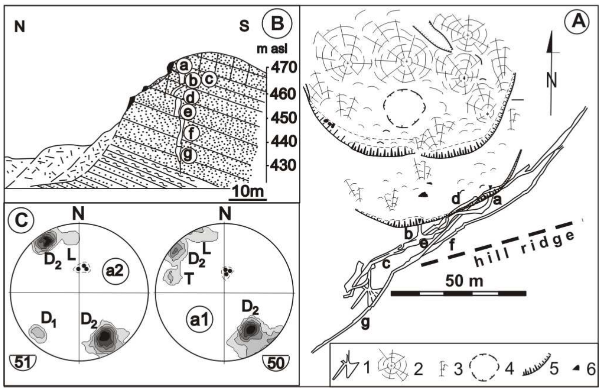

Fig. 2. Diabla Dziura w Bukowcu Cave, as an example of initial cave and dilational cave (after Margielewski and Urban 2003b). A – map; B – cross-section (the letters on map and cross-section mark the same parts of cave); C – orientation of joints on contour diagrams and bedding planes on pole point diagrams (equal area plot, projection of normals on the lower hemisphere) in the upslope (a1) and downslope (a2) walls of the upper (a) part of the cave (joint sets: L – longitudinal, T – transversal, D_1 and D_2 – diagonal) . Explanations: 1 – cave's outline, 2 – colluvial swells, 3 – colluvial material, 4 – morphological depression, 5 – rocky or soil scarp, 6 – rock form.

The geomechanic classification includes also the third type of caves, developed within chaotic agglomeration of rock blocks (boulders) within totally disintegrated rock masses of landslide colluvia. Such caves are characterized by irregular structure (framework), not related to original directions of discontinuities in rock massif, (joints, faults etc.) and irregular or rather pyramidal than prismatic shape of chambers. These caves accurately fulfil conditions of *boulder caves*, as they were characterised by Bella and Gaál (2010, 2011), so they can be named *boulder caves*.

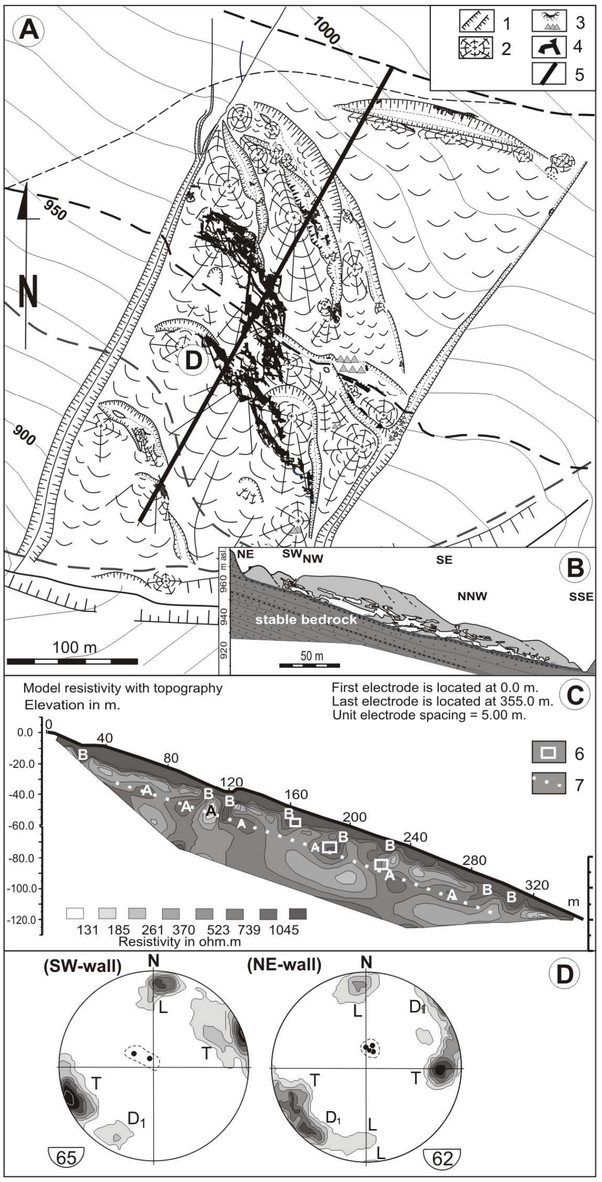

Fig. 3. Jaskinia Miecharska Cave (as subsequent and dilatancy cave) and other small caves within the landslide surrounding this cave. A – map (after Margielewski et al. 2007); B – cross-section (after Margielewski et al. 2007); C – ERT profile (after Pánek at al. 2010); D - orientation of joints on contour diagrams and bedding planes on pole point diagrams (equal area plot, projection of normals on the lower hemisphere) in the Sala Grzelaka chamber (letter D in map) in the cave (joint sets: L – longitudinal, T – transversal, D_1 and D_2 – diagonal) (after Margielewski et al. 2007 . Explanations: 1 – rocky or soil scarp, 2 – colluvial swell, 3 – rock forms, 4 – cave's outline, 5 – ERT profile showed in part C, 6 – element of the cave (passage, chamber) crossed by ERT profile, 7 – landslide sliding zone.

Conclusions

Although Polish Outer Carpathians (BMs) are formed of non-karstified rocks, the caves (among which are large ones) are very frequent in this region. Their intensive and efficient exploration has been performed along the scientific study of these objects. However, classifications of the caves proposed up till now have not been based on clear criteria. The criteria of Klassek‘s (1989, 1994; Klassek and Mikuszewski 1997) classification combine shape of caves, their spatial situation within the slope and even genetic features. Also classification proposed by Vitek (1983) does not allow unequivocal categorisation of caves and determination of their genetical features. Clearly defined criteria are the crucial problem of proper classification.

Therefore two classifications: genetic and geomechanic, are proposed. The criterion of genetic classification is relation of caves to slope development. It allows to distinguish two main types of caves: *initial caves* and *subsequent caves*, however intermediate forms are also observed. Formation of the *initial caves* precedes main slope failure, whereas the *subsequent caves* develop within the landslide body, during the main mass movements (landslide formation). According to the second, geomechanic classification, considering the type of phenomenon-process producing the caves, three types of caves can be discriminated: *dilation caves*, *dilatancy caves* and strict *boulder caves*. The *dilation caves* are connected with the change in volume (but not in shape) of rock massif, usually with extensional dissection of rocks, whereas *dilatancy caves* are produced by change in shape and growth of volume of rock massif and they are related to the formation of shearing zone during the main mass movements. *Boulder caves* comprise irregular voids within the chaotic agglomeration of boulders in landslide colluvia.

These two classifications could help in scientific description of caves connected with gravitational mass movements, because application of them (i.e. identification of cave according to their criteria) makes possible clear determination of geomorphologic situation of cave and its genesis.

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