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Orthogonal jointing in sandstone – possible causes

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1. Introduction

Joints in sedimentary rocks usually have a uniform strike (systematic joints), and mostly bear signs of tensional stress. They are interpreted to form perpendicular to the direction of minimum principal stress (σ_3 axis) of the stress ellipsoid. Orthogonal joint systems, combining two sets of subvertical joints meeting at almost right angles, are relatively common in flat-lying sandstone bodies.

2. Distribution of the phenomenon

Orthogonal joint patterns are frequently met worldwide, especially in platform regions in the proximity of orogenic belts. In sandstone landscapes, they give rise to some of the most complex topographies on Earth. Although classical examples of ruiniform landscapes have been reported from western and central Sahara, they are surpassed by vast areas of sandstone “tower karst” in northern Australia or the Danxia-style landscapes in China. Orthogonal jointing is perfectly developed over large areas of the Colorado Plateau in SE Utah, with rugged relief with pillars, pinnacles and needles locally well developed in Permian and Jurassic sandstones in the Canyonlands National Park and Arches National Park. The Bohemian Cretaceous Basin in the Czech Republic, Germany and Poland displays sandstone “rock cities” of smaller extent but large variety, with both ladder and grid patterns of orthogonal joints well represented.

3. Possible mechanisms of origin

Formation of strictly orthogonal joint systems is problematic because each of the sets should form perpendicular to the minimum horizontal stress. A consecutive growth/opening of the two sets would therefore imply progressive rotation of the stress ellipsoid by 90°. A more plausible scenario is switching of σ_2 and σ_3 axes of the stress ellipsoid with σ_1 orientated vertically, leading to alternate opening of the two joint sets (Dunne and North 1990).

Several models can be suggested for the origin of orthogonal joint systems in sandstone based on a literature review (1–3) and our previous experience (4–5):

1. a switch between σ_2 and σ_3 due to stress release on newly formed fractures (Caputo 1995)
2. a switch between σ_2 and σ_3 due to stress release along a shallow-formed neotectonic normal fault (Stewart and Hancock 1990)
3. repeated rapid switching between σ_2 and σ_3 during waning compression in the foreland of thrust faults (Dunne and North 1990)
4. simultaneous growth of joints of the two sets due to updoming of the sandstone body, resulting from magmatic activity or salt diapirism
5. abutment of flexure-induced fractures parallel to fold axis by transverse fractures during neotectonic uplift

4. Example from the Bohemian Massif: Bludiště Rock City

The Bludiště rock city and its surroundings were subjected to analysis of topographic data and detailed geological mapping, tectonic measurements and paleostress analysis, and surface geomagnetic survey.The Bludiště rock city is a relatively small (150 by 200 m) area in the Jizera Formation sandstone to the NW of Mšeno, with tens of rock pillars 10–20 m in height. One of the sets of subvertical joints strikes 8–20°, and occasionally shows relative subsidence of western blocks by 0.2–1 m. It is subparallel to, and genetically associated with, a fault zone lying immediately to the NW (strike 30°) marking the NW limit of the uplifted Brusné Block (Adamovič and Coubal, 2012). Joints of this set are straight and continuous over tens of metres. The other set of subvertical joints strikes 139–150°, with occasionally subsided NE blocks (by only 0.1–0.2 m). Joints of this set right-laterally offset the joints of the first set but terminate at them at other places, which accounts for a repeated activation of N–S-striking joints. Joints of all strikes are dilated by 1–2 m and show no clear kinematic indicators.

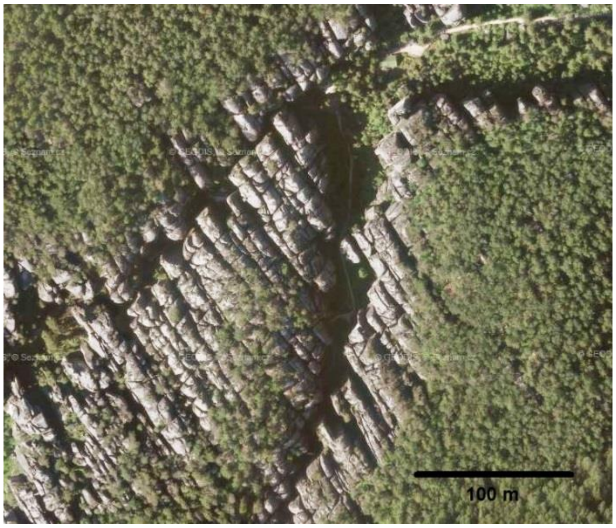

Fig. 1a. An aerial photo of the Skalní ostrov district, Teplice rock city near Adršpach. Source: www.mapy.cz.

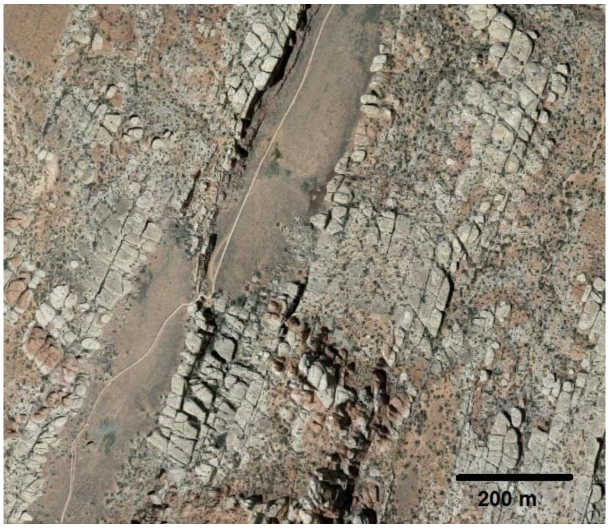

Fig. 1b. A satellite photo of the northern Chesler Park area, Needles District of the Canyonlands NP, Utah. Source: GoogleEarth.

As revealed by tectonic measurements and altitude correlation of a reference conglomerate bed, the rock city lies on the northern slope of a structural dome forming the core of the uplifted Brusné Block. The dome centre coincides with the topographic elevation “Na rovinách” at Romanov where a number of basaltic dykes and small-scale N–S- to NE–SW-elongated grabens were found. In 2010, a phonolitic body was exposed here in a trench for a water-main piping. Updoming by the phonolite body is the best explanation for the multi-direction extension in the overlying sandstone strata including the dilation of joint sets of different strikes and mechanisms of formation.

5. Conclusions

The Bludiště rock city is an example of a ruiniform relief controlled by the presence of two subvertical joint sets meeting at an angle of 60–80°. Joint initiation could have occurred under different paleostress fields. As suggested by strike-slip activation of the NW–SE joints, at least some of the fields had a near-horizontal σ_1 axis. Subsequent joint propagation was probably governed by a different paleostress regime with a near-vertical σ_1, associated with the intrusion of phonolitic magma and updoming. Switches of σ_2 and σ_3 axes allowed for an alternate opening of joints of different orientations, normal faulting and graben formation.

Our study shows that two stages should be distinguished in the evolution of orthogonal fracture systems: 1. formation of incipient (micro)fractures, 2. their further growth and opening. These stages are governed by different physical factors, could have occurred under different stress conditions and could have been separated from each other in time. Updoming of the sandstone body as the process controlling the formation of orthogonal fracture systems, although not given appropriate attention in the literature (cf. Al-Fahmi et al., 2014), may be of particular importance where the sandstone bodies are underlain by massive volcanic intrusions or by salt diapirs. It may be of equal importance as unloading and rapid uplift and erosion in tectonically active areas, as suggested by, e.g., Hancock and Engelder (1989).

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Pseudokarst Caves in Active Tectonic Zone of Mur-Mürz Fault (Eastern Alps)

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Pseudokarst caves in the Eastern Alps are yet rather omitted phenomena, as more attractive ones are numerous and much longer karst caves occurring in large limestone areas. However, during our study of active-tectonic features in caves of the Easter Alps in the frame of the FWF project P25884-N29 SPELEOTECT (http://www.nhm-wien.ac.at/speleotect_EN) we realized that pseudokarst caves are common features in our target area adjacent to the active tectonic zone of Mur-Mürz fault. Some of them have even been interpreted as of only karst origin. In this contribution we exemplify different types of pseudokarst caves in this area, such as the ***Eisenstein Cave*** (2341 m long and 87 m deep, Bad Fischau), the ***Pottschach Crevice*** (61 m long and 14 m deep, Ternitz), ***Bärenkogel Cave I.*** (300 m long and 45 m deep, Langenwang) and crevices at ***Pinkakogel*** (Semmering). By using speleological and structural-geological approaches, analysis of 1-m resolution digital terrain models and infrared thermography, we discuss their evolution with respect to local geology, gravitational slope failures and indirectly also to active-tectonic processes.

Sandstone landforms: Effects of loading stress on spatial distribution and rates of erosion

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Abstract

Weathering and erosion of sandstone produces spectacular landforms such as arches, alcoves, pedestal rocks and pillars. The effect of gravity loading stress has been overlookedor assumed to increase the landform's weathering rate. Here we show by physical and numerical modeling, and field observations of locked sands and sandstones that an increase in stress within the landform reduces weathering and erosion. Material with insufficient loading is rapidly removed by weathering process and the remaining load bearing landform structure is protected by the fabric interlocking mechanism. As the landform evolves the increased stress inhibits erosion from raindrop impact, flowing water and slaking, and retards surface retreat caused by salt and frost weathering. Planar discontinuities in sandstone and negative feedback between stress and weathering/erosion processes are sufficient conditions to create above-mentioned landforms. Our experiments are able to reproduce natural shapes including arches, alcoves, pedestal rocks and pillars using landform material and mimicking natural processes. The proposed negative feedback mechanism is supported by a numerical model of stress pattern in landforms. We conclude that stress field is the primary control of the shape evolution of sandstone landforms.

Study of rapidly recessing sandstone overhang

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Radioisotope dating indicated that walls of the studied sandstone overhangs and caves in the Czech Republic have not retreated more than 1 mm/1000 years during the Holocene. In the town of Plzeň, the sandstone overhang of Čertova Kazatelna was studied where extreme retreat rates of overhang ceiling as large as~ 40 mm/year were reported by a local resident. Sandstone matrix is composed of quartz, kaolinite, illite and K-feldspar based on XRD. Surface of the rock overhang is formed by exfoliation plates several mm to a few cm thick. Unlike its dry and stable surroundings the rock overhang surface is wetted by seeping wastewater. Fallen material from rock overhang was collected on plastic foil for a period of several hours to one day during different seasons of the year. These material contains 0.1-2% gypsum in bulk and 3 – 11 % gypsum in fine matrix base on leaching, XRD and SEM/EDS. Maximum measured deposition of material on plastic foil (214 g/m2/day) occurred during thaw. Wetting weakening, ice wedging and possibly salt weathering are probably responsible for sandstone disintegration. Based on mass balance of sulfates in fallen material we expect long-term retreat rates of sandstone overhang surface between 3 and 12 mm/year. In sharp contrast to this extreme retreat rate, the dry surface of sandstone did not retreat by more than a few mm/97 years based on dated carving. The study demonstrated that sandstone overhangs may potentially develop within a few hundred years in case of favorable conditions.

Speleothems of the non-karstic caves

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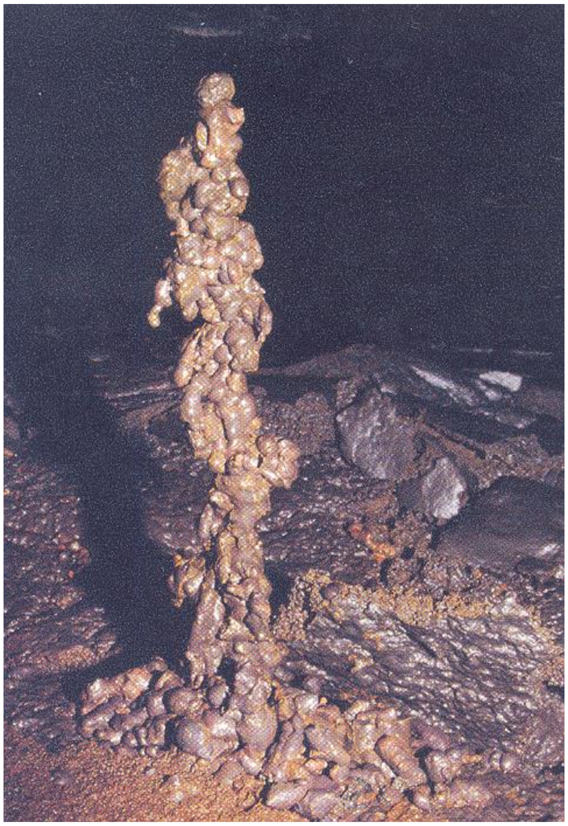
The (features and) speleothems of the karstic and non-karstic caves are different. In the karstic caves are less speleothems, but they appearad in a bigger mass. The speleothems of the non-karstic caves are diverse, but appeared in a smaller quantity. The speleothems of the karstic caves are relatively well-known, but we can not say the same in the ocassion of the non-karstic caves. In this paper, I have 53 kinds of speleothems systemised. I this work I try maybe foremost to sort the (features and) speleothems of the non-karstic caves, which may contains probably some mistakes and incompleteness. Please, let this be brougt up!

Block lava-floor in the Menjanggul Cave /Korea, Jeju

A diaphragme, the cindery hemicylinder in the Leiðarendi Cave / Iceland

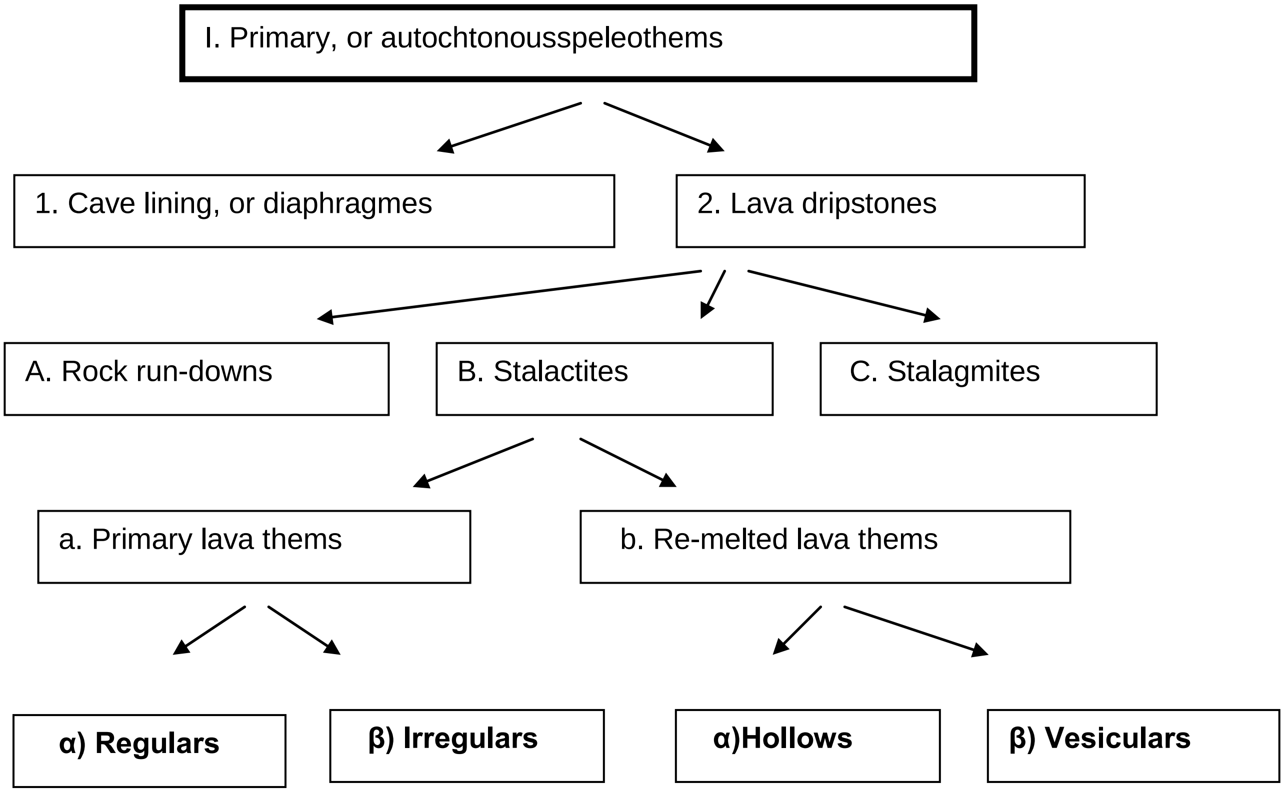
Group of sinuouses in the Verdes Cave / I. Canaries

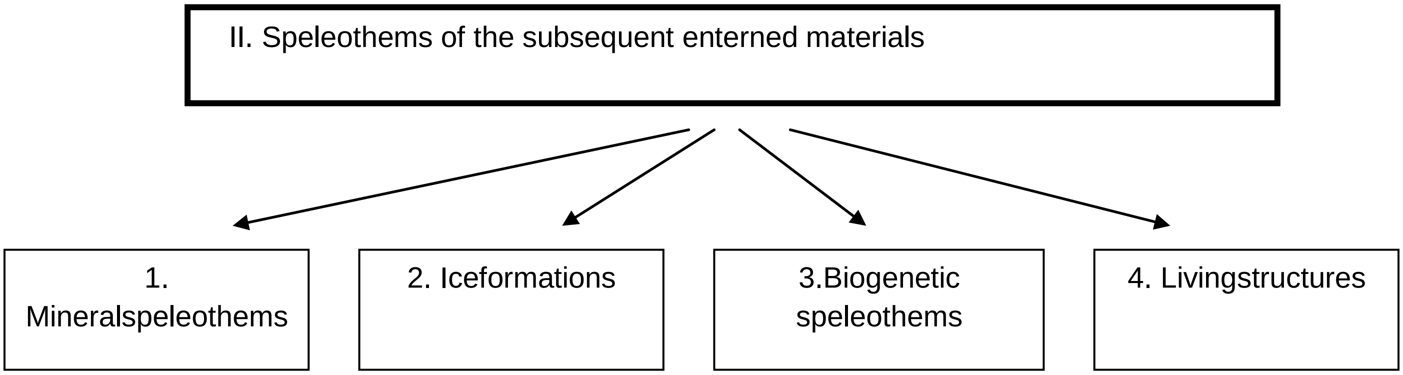


A 40-cm high staphylite in the Fóki Cave / Iceland

A 25-cm high root stalagmite one of the caves of

the Broumov Mountains/ Bohemia





System of the speleothems of the non-karstic caves

Caves formed in the effusive rocks and in their tuffs described in the digital list of the non-karstic caves in Hungary

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Abstract

In Hungary 930 natural non-karstic caves have been listed. Six hundred and sixty of these caves are to be found in effusive rocks, in andesite, basalt, rhyolite and in their tuffaceous formations. Organised research of the non-karstic caves began in 1983 with the launch of the Volcanspeleological Collective. Their comprehensive activities are still ongoing. The organisation, led by István Eszterhás, was admitted and was elected as a substantive section by the Hungarian Speleological Society (MKBT) in 1992. In 2003 the Authors broadened the Digital List of Non-karstic Caves in Hungary and since then the List has been updated every year. In the List the locations of the non-karstic caves have been plotted on detailed and indexed maps, which have been compiled on the basis of GIS elaboration. Beside the maps the List has been supplemented with data tables, cave surveys, cave photographs and area descriptions. In the present study the Authors describe the caves which have formed in effusive rocks and in their tuffaceous formations in Hungary according to where these are shown on the detailed maps in the List. Furthermore, the study has been completed with a geological sketch of the surrounding rocks, the history of cave research and the structure of the Digital List

1 . Geological sketch of the effusive rocks and their tuffs

Effusive rocks and and their tuffs in Hungary occur in the Transdanubian Mountains and in the North Hungarian Mountains as follows (Fig. 1).

Volcanic activity in the *Miocene* produced extensive rhyolite and andesite masses and their tuffaceous formations in the Visegrádi-, Börzsöny-, Mátra- and Tokaji Mountains. The majority of non-karstic caves are to be found in these sequences. Part of the Cserhát Mountains and the Bükk Region are also composed of similar sequences. The *Visegrádi Mountains* have formed from a Miocene stratovolcano which has been intensely denuded and dissected along fault lines. It is composed of andesite agglomerate, andesite tuff and subordinately compacted andesite. The *Börzsöny Mountains* are mainly made up of the denuded residual of a Miocene. stratovolcanic blanket. In the middle section a collapsed caldera can be evidenced. The key horizon in the North Hungarian Mountains is the Lower Miocene *Ottnangian* light grey pumiceous rhyolite tuff, referred to *as Lower Rhyolite Tuff* in geological literature. In the *Carpathian* and *Badenian Stages* significant andesite volcanic activity and tuff deposition occurred. The rhyodacite tuff, referred to as *Middle Rhyolite Tuff*, divides the *Lower* *and Middle Andesite Formations*. The final stage of andesite volcanism is characterised by dark grey piroxene andesite. Andesite volcanism was accompanied by rhyolite intrusions in the Mátra and Tokaji Mountains. The *Mátra Mountains* comprises of a stratovolcanic group with several eruption centres. The eruptions occurred in the Miocene and have resulted in various formations of lava rocks and pyroclastics. Thick tuff and the andesite agglomerate layers have accumulated on the margins of the karstic *Bükk Mountains*, and it is here that several non-karst cave caves have developed. The andesite agglomerate also outcrops on the rim of the *Sajó Basin*. Intense volcanic activity took place in the *Tokaji Mountains* throughout the Miocene. The oldest sequence is composed of andesite, andesite agglomerate and tuff, while the younger formation is of rhyolite, rhyolite tuff and subordinately dacite and dacite tuff.

Basalt occurrences related to non-karstic caves in Hungary are to be found in the Bakony Mountains and the Medves Region. The Upper Pliocene and Lower Pleistocene basalt volcanic activity in the *Bakony Mountains* can be divided into three phases. The first explosion resulted in tuff layers, which are dotted with lapilli and volcanic bombs. The second phase produced lava streams and the liquid basalt lava spread out on the surface. The third explosion phase resulted in toadstone, which is known as „bread stone“ by the locals. Basalt lava layers are to be found in the Western Bakony Mountains, in Mount Kovácsi. Holes filled with calcite crystals and zeolite can be observed in the basalt. The Tapolcai Basin is typical of the landscape of the Bakony Mountains. The region is remarkable for the whiteness buttes. Basalt and basalt tuff have shaped the truncated cones, which overlay the Pannonian sediments. Also noteworthy are Mount Badacsony and the basalt columns of Mount Szent György, although the other cones are also geomorphological curiosities. The Pannonian sediments which lie between 270 m and 290 m a.s.l. are overlain, by 4 m to 5 m thick basalt tuff, the material resulting from the first explosion phase. Forty meter thick basalt covers the tuff formation, which is overlain by toadstone. Basalt tuff also outcrops on the Tihanyi Peninsula. In the South Bakony Mountains, basalt volcanoes overlay the Pannonian sediments, the Triassic limestone and dolomite. The highest peak of the Southern Bakony Mountains, the 601 m high Mount Kab, is composed of basalt. Basalt volcanism also can be seen in the northern part of the mountains. The 435 m high Mount Somló and , some distance away, the Kemenesalja Region is composed of Pannonian clay which is overlain by a tuff ring and basalt lava.The *Medves Region* in North Hungary is composed of basalt, which is the product of the volcanoes at the end of the Pliocene and the beginning of the Pleistocene. The fluid lava reached the surface through vents and spread on the surface. The extended basalt plateaux are the witnesses to this volcanic activity. The 100 km^{2}Medves Plateau is the largest basalt plateau in Europe. The volcanic activity began with an andesite laccolite intrusion, which was followed by tuff deposition and extended basalt lava streams. The 4-5 m thick tuffaceous layers are subordinate to the basalt lava formation. As a consequence of several eruptions the geomorphology of the basalt formation is diverse. There is dark grey thick-bedded basalt and black columnar jointing basalt. Especially spectacular are the basalt columns of Somos-kő, Szilvás-kő and Bagó-kö. The basalt formation extends northward into Slovakia and some interesting and scientifically significant caves are also to be found in the basalt.

2. Number and genetic type of the caves developed in effusive rocks and their tuffs

The digital List describes all non-karstic caves in igneous, sedimentary and metamorphic rock formations in Hungary. The present study only deals with non-karstic caves, which have formed in the effusive rocks and in their tuffaceous formations according their locations (Table I). Twenty eight syngenetic and significantly more, 632 postgenetic caves are to be found in the effusive rocks and in their tuffs.

Two different types of *syngenetic* caves occur in Hungary. The gas and steam blowdowns in the consolidating lava have resulted *exhalation-tube caves*, for example *Kamori Fox Hole, formed in* the andesite agglomerate and the shaft of the *Baglyaskői Basalt Hole*. The accumulated gases blow up spherical holes in the ductile lava, forming the other type of the syngenetic caves, *gas bubble cavities*. These cavities have been exposed either through natural erosion or as a result of quarrying operations. Examples include *Gyula Cave* and *Vidroczky Cave* in the andesite of the Mátra Mountains and in *Explosion Cave of the Castle Hill* which has developed in basalt near the village of Szigliget on the southern rim of the Bakony Mountains.

The main categories of *postgenetic* cave development are mass movement, physical weathering, fragmentation and chemical weathering. The *tectonic caves* have been classified by the trends of constituent faults. There are caves which have formed parallel to the edge of the outcropping rock formation. The (Fig. 6) and the *Hermit Cave* in the basalt of the

Bakony Mountains are examples of this type of cave formation. There are caves which have developed perpendicular to the rim of the outcrop, such as the *Galériás Cave* in the Tokaji Mountains. The formation of *the Basalt Tuff Cave* near the village of Pula follows the bedding planes. The *Iván Cave* (Fig. 11) in the rhyolite of the Tokaji Mountains has formed as a result of combined tectonic effects. *Atectonic caves* are the result of the movement of large boulders.The*Vadlány Hole* in the basalt of the Bakony Mountainsformed as a result of the expansion of cracks as the rock mass was sliding down on the convex slope of the marl and sandstone. The sliding induced cracks in the basalt blocks, which widened into cave size as they slid further. The 428 m long Csörgő *Hole*, the longest non-karstic cave in Hungary (Figs. 9, 10) is an atectonic labyrinth. The development of the cave can be traced back to the continuous sliding of the rhyodacite tuff boulders and the consequent aggradation (Eszterhás 2010). *Break up Caves* form when the roof of a cavity loses its stability and collapses partly or completely due to the lower layers being washed out. The original cavity becomes filled with debris and a new hollow develops in the upper part, the so called break up cave. The most significant break up cave in the Bakony Mountains is the 151 m long *Basalt Cave near the village of Pula.* The *consequence caves* represent an interesting genotype, as they have formed as a result of the collapse of an artificial cavity. In the early 20th Century, below the basalt, a 3 m thick coal seam was mined out in the Medves Region. In May 1917 the mine collapsed. As a consequence of this collapse the 80 m thick basalt layer downfaulted and many consequence caves were created. The largest cave is the 68 m long and 14 m deep *Szilvás-kői Cave* (Eszterhás, Szentes 2010).*Pseudo caves* are holes among the boulders. A leaning pseudocave is the *Devil Cave* in the Tokaji Mountains, where a large boulder stands against the rock wall. Talus cave is a labyrinth among the boulders, as is the*Rókás Pseudocave* in the Tokaji Mountains (Eszterhás 2011a).

Physical weathering has created different types of caves in the tuffaceous formations. Near the town of Bátonyterenye *the Macska Rock Shelter* has been shaped by *evorsion* in rhyodacite tuff below a waterfall. Under the category of the *fragmentation* development process the *Rózsa Sándor Cave*(Fig. 8) which is “pulled away” in origin, is to be found in the pyroxene andesite ofMount Kis-Péter-mennykő in the Tokaji Mountains. There, due to denudation the lower, north western boulder area of the double peaked mountain was weakened laterally and collapsed to such an extent, that accessible cavities were formed. A further cave developing process has resulted from the influence of *temperature and moisture variation*. Examples of such caves are the *cavities between basalt columns.*A cave which has originated from C*hemical weathering* is the *Big Cave on Mount Fuló* in the Tokaji Mountains. The cave has developed through alkaline solution in the siliceous rhyolite tuff. (Eszterhás, Szentes 2009).

3. The history of the research of non-karstic caves through the activities of the Vulcanspeleological Collective

Mention and short descriptions of non–karstic caves are known from the early historic times. The first written reference to a non-karst cave, the Likas-kő near the village of Lovasberény, dates from 1295. The cave has developed in quartzite and it was mentioned in a charter as a border reference point. From the year1600 more and more descriptions of non-karstic caves have turned up. By 1980 119 non-karstic caves had been detected in Hungary.
In 1983 cavers in the Bakony Mountains (István Eszterhás, Imre Gönczöl, István Jákói, Csilla Somlai, Károly Szobonya) began to explore the basalt caves of the region. Later several more cavers joined the group and their activity was extended to research of the the non-kasrstic caves in the whole country. In the year 1992 fifteen researchers officially launched the Volcanspeleological Collective. Increasingly, more non-karstic caves were identified in the course of weekend research trips and the summer volcanspeleological camps. The activities of the Collective were principally to survey, to photograph, to describe and to list the non-karstic caves. By 2013, as a result of the activity of the Volcanspeleological Collective, 930 non-karstic caves were known. It is only possible to navigate oneself around such a large number of caves with the help of a digital list. István Eszterhás and George Szentes have commenced a digital list in 2003, and this is updated every year. Since 2004 the List can be viewed on the website http://geogr.elte.hu/nonkarstic.

The Volcanspeleological Collective has studied the development of non-karstic caves, and has identified several new types of cave development, namely as consequence caves, holes formed by alkaline solution and fumarole cavities.They have discovered, and described, some speleothems previously unknown in Hungary, such as silica stalactites and isingerit discs**.** They have dug and discovered nearly 1000 m of new cave passage in 40 non-karstic caves. The most significant discoveries have been the 140 m long extension in the Csörgő Hole, and the complete exploration of the Pulai Basalt Cave and Arany Cave. On the basis of Hungarian examples they have solved the problem of the reasons for ice development in low elevation basalt caves.They have classified 200 species of animals and 20 species of fungi which are to be found in the non-karstic caves. They have studied the root-stalagmites on the basis of Hungarian, Slovak, Czech and German examples. They have looked at historical aspects of the caves and recorded 30 legends, which are related to the non-karstic caves.

In 1996 they organized a successful International Symosium on Pseudokarst in Galyatető. In the 12th international Congress of Speleology in Switzerland the leader of the Collective was instrument in establishing the Pseudokarst Commission of the IUS. Over 12 years they have launched and edited the international pseudocarst journal, the "Newsletter" or "Nachrichtenbrief". The Collective have received a number of Hungarian and international accolades.

Location	basalt	basalt tuff	andesite	andesite agglom.	andesite tuff	rhyolite	rhyolite tuff	**Total:**
Bakony Mts. and Kemenesalja Region	61	9						70
Visegrádi Mts.			2	71	10			83
Börzsöny Mts.			8	77	5			90
Cserhát Mts.			6	1				7
Mátra Mts.			29	27		3	6	65
Medves Region	35						1	36
Bükk Region and Sajó Basin				12		8	4	24
Tokaji Mts.			200			57	28	285
Sum total:	96	9	245	188	15	68	39	**660**

Table I: Location and number of the non-karstic caves in volcanic rocks and their tuffaceous formations

4. The structure and operation of the Digital List

The List plots the entrances to the non-karstic caves on detailed maps which can also be approached through index maps. The Index map of Hungary summarizes the locations of the non-karstic caves in 20 regions (Fig. 2). Fifteen regions are covered with further index maps (Fig. 4),while five smaller regions are connected directly to the detailed maps. In the various regions the number of the caves varies from one to a large number of caves. The maps of the 20 regions of Hungary can be also be found via a tabular approach. Further tables sort the caves of the 15 larger regions into alphabetical order or according to the pages of the index map, showing the numbers of the detailed map pages on which the caves are to be found. Click on the number and the detailed map opens (Fig. 5). The caves of the five smaller regions are also listed in tables with direct accessibility to the detailed maps (Eszterhás, Szentes 2004)

The maps have been completed with Archview GIS software, using the digital base maps of Hungary. The accuracy of the detailed maps meet the requirements of the scale of 1: 5000 or 1: 25000 maps. The cave entrances have been located through either GPS measurements or topographic surveys. The Archview project maps have been converted into jpg file format. The maps and tables have been incorporated in a website. In addition, the website includes cave photographs (in jpg format) and cave surveys (gif format) from the respective regions. Each region has a short description in Hungarian and English. The most important data and instructions regarding the List are in Hungarian and English. Furthermore the website has been extended through the addition of a preface, statistics and a list of selected literature (Fig. 3). Offline any browser opens the CD of the List, while online the website can be accessed at: http://geogr.elte.hu/nonkarstic (Eszterhás, Szentes 2012).

5. Regions marked in the Digital List where caves in the effusive rocks and their tuffs occur

In the *Bakony Mountains,* and in the nearby smaller *Kemenesalja Region* , the List details the locations of 61 caves developed in basalt and 9 natural caves developed in basalt tuff on 13 of the 25 detailed map pages. For instance, page 16 includes Pokol Hole near the village of Kapolcs. This fifty one metre long cave is a leaning pseudocave The basalt overlays a loose sandstone and the basalt rim has broken away. The basalt blocks have not slid down on the slope, but have fallen back against the bedrock, forming the leaning pseudocave (Eszterhás in press) .

Most of the caves in the *Visegrádi Mountains* , 71 caves to be precise, have formed in andesite agglomerate. Only 10 caves are to be found in andesite tuff and 2 caves are in compact andesite. The List marks cave entrances on 10 pages of detailed maps. Particularly interesting is page 10, which describes the caves of the Vasas Chasm. There, the andesite agglomerate has slid down the clayey andesite tuff, due to erosion deepening the nearby Cseresznyés Creek . As a result of this a 250 m dilatation fault has evolved, the Vasas Chasm, in which five caves open. The most extensive cave is No.1 Cave (Fig. 7). The cave can be reached along a 38 m long, 10 m. deep crevice which is 3 – 4 m wide. The cave passage is 2-3 m high and 70 cm wide and contains some huge boulders The total length of the cave is 50.2 m, its horizontal extension is 40.2 m and its deepest point is 20.4 m (Eszterhás , Gönczöl , Szenti 1997). In the *Börzsöny Mountains* 90 non-karstic caves have been listed. Similar to the neighbouring Visegradi Mountains most of the 77 caves, have formed in andesite agglomerate. Only eight caves are to be found in compact andesite and five caves open in andesite tuff. The List plots the caves on ten pages of detailed maps. The largest number of caves, 17 and 24 caves, are to be found on pages 8 and 9 respectively. On page 9 the *Holló-kői Lámpás Cave* is a 18 m long talus cave in andesite agglomerate. On page 5 the artificially widened caves on Mount Szemt Mihály occur in andesite agglomerate. The longest is the 29 m long Hermit Cave or Rock Chape (Eszterhás 2011b).

The extensive *Cserhát Mountains* have various geological structures. As a consequence of this different karstic and non-karstic caves occur in the region. From the 24 non-karstic caves six caves are to be found in compact andesite and one cave has developed in andesite agglomerate. Eleven pages of detailed maps summarize all the non-karstic caves, while two pages show the caves in compact andesite and on page 10 is to be found the 21 m long *Erdőkürti Andesite Cave*. This appears to be a syngenetic cave. On the swampy moorland falling hot volcanic gravel heated up the swamp water, and pressure of the steam which was generated as a result of this caused a hollow to form in the andesitic gravel (Eszterhás 2011c). Four *syngenetic cavities* on the page *5* have been formed by a volcanic steam explosion.

The *Medves Region* is composed of basalt, which is the product of the volcanoes which erupted at the end of the Pliocene and at the beginning of the Pleistocene. There is both dark grey thick-bedded basalt and black columnar jointing basalt. The List presents on three pages, 35 basalt caves and on page 9 describes one cave which has formed in rhyolite tuff on edge of the region . On page 2, in Szilvás-kő there are 31 caves. These are *consequence caves*, as has already been mentioned, as they have formed as a result of the collapse of the abandoned coal mines beneath the region. After the longest cave, *Szilváskői Cave* , there is mention of the 51 m long and 16 m deep *Sárkánytorok Cave.* The syngenetic 30 m long *Kis-kői Basalt Cave* is described on page 3.

In the *Mátra Mountains* 29 caves have developed in compact andesite, 27 caves occur in andesite agglomerate. Three caves are to be found in rhyolite and 6 caves have formed in rhyolite tuff. Ten pages of the list show the caves. On page 4 the longest non-karstic cave, the 428 m long atectonic originated *Csörgő Hole* has been described (Figs. 9, 10). The cave has formed in rhyodacite tuff. On page 7 are described caves which have formed in rhyolite. There the biggest cave is the133 long partly artificial, partly consequence cave, *Csák-kői Big Cave*.

Thick tuff and the andesite agglomerate layers have accumulated on the margins of the karstic Bükk Mountains, and it is here that several non-karst cave caves have developed. The andesite agglomerate also outcropson the rim of the *Sajó Basin,* in which the *Cavity of the Big Stone* opens. This 2.9 m long and 1 m high cave has developed as a result of tectonic movement in an adesite agglomerate cliff, which rises from its tufaceous environment. Five pages show the 12 caves formed in andesite agglomerate, 8 in rhyolite and 4 in rhyolite tuff in the *Bükk Region.* Particularly interesting are the 10 caves of Damsa Chasm on page 1. These are atectonic caves, where the formation is the result of a landslide in the andesite agglomerate. The longest cave is the 58 m long *Dancing Saloon – Butterfly Passage System* (Eszterhás, Szabó 2005).

The *Tokaji Mountains* are the largest non-karstic cave region in Hungary. Two hundred and eighty five non-karstic caves have developed in the andesite, andesite agglomerate, rhyolite and rhyolite tuff of the mountains. The large number of the caves are plotted on thirty nine detailed pages of maps. Several significant caves – the *Rózsa Sándor Cave* (Fig. 8), the *Big Cave of in the Mount Fuló,* the *Devil Cave* ,the *Rókás Pseudocave,* the *Galériás Cave and* the *Iván Cave* (Fig. 11), have already been described in the chapter of the cave developments.

6. Summary

In Hungary in the Miocene extended volcanic activity produced rhyolite, andesite and their various tuffs. In the late Pliocene and in the early Pleistocene basalt volcanism occurred. Significant parts of the caves which had developed concurrently with the volcanic activity, in other words syngenetic caves, were destroyed by erosion. Due to mass movement and physical and chemical weathering many postgenetic caves have developed in the volcanic formations. Structured research in these caves began 30 years ago with the launch of the Volcanspeleological Collective**.** They have listed 660 caves in the volcanic rocks and in their tuffaceous formations. In order to know one's way around such a large number of caves it was felt necessary to create a digital list, which describes the caves according to their locations and includes the size, details of the surrounding rock, a survey and a photograph of each cave.

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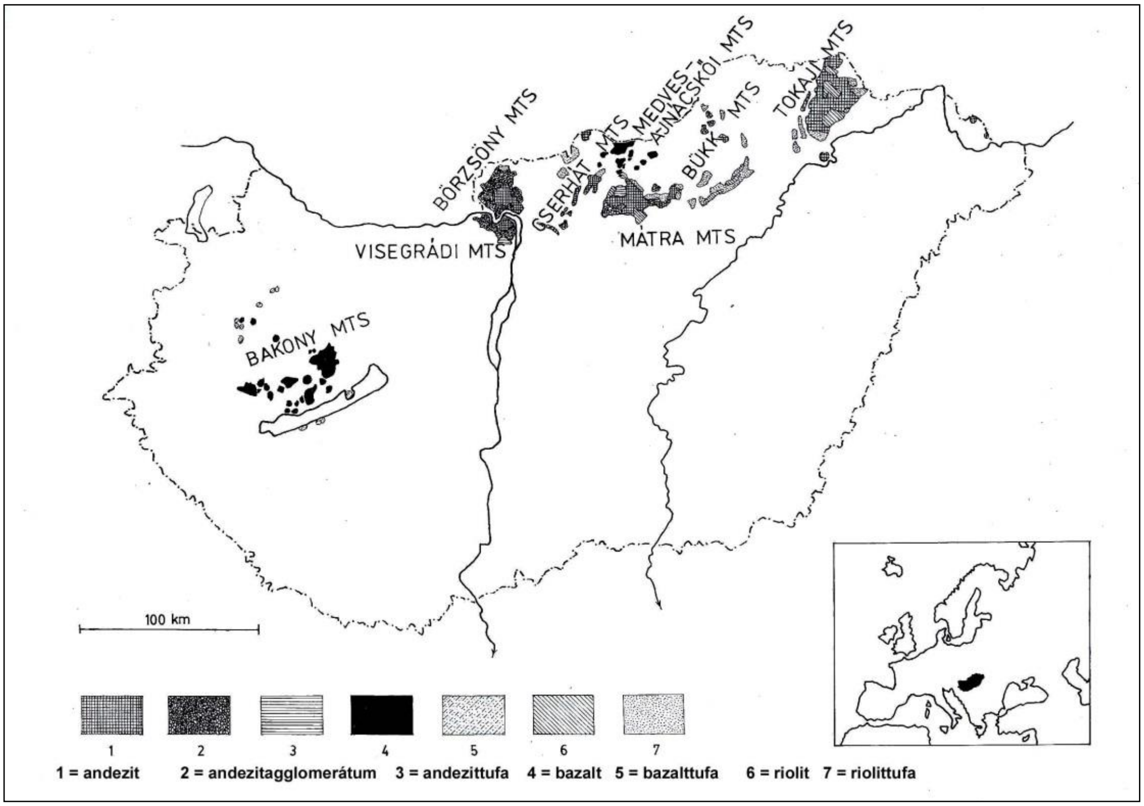


Figure 1 :Occurence of basalt andesite, rhyolite and their tuffs in Hungary

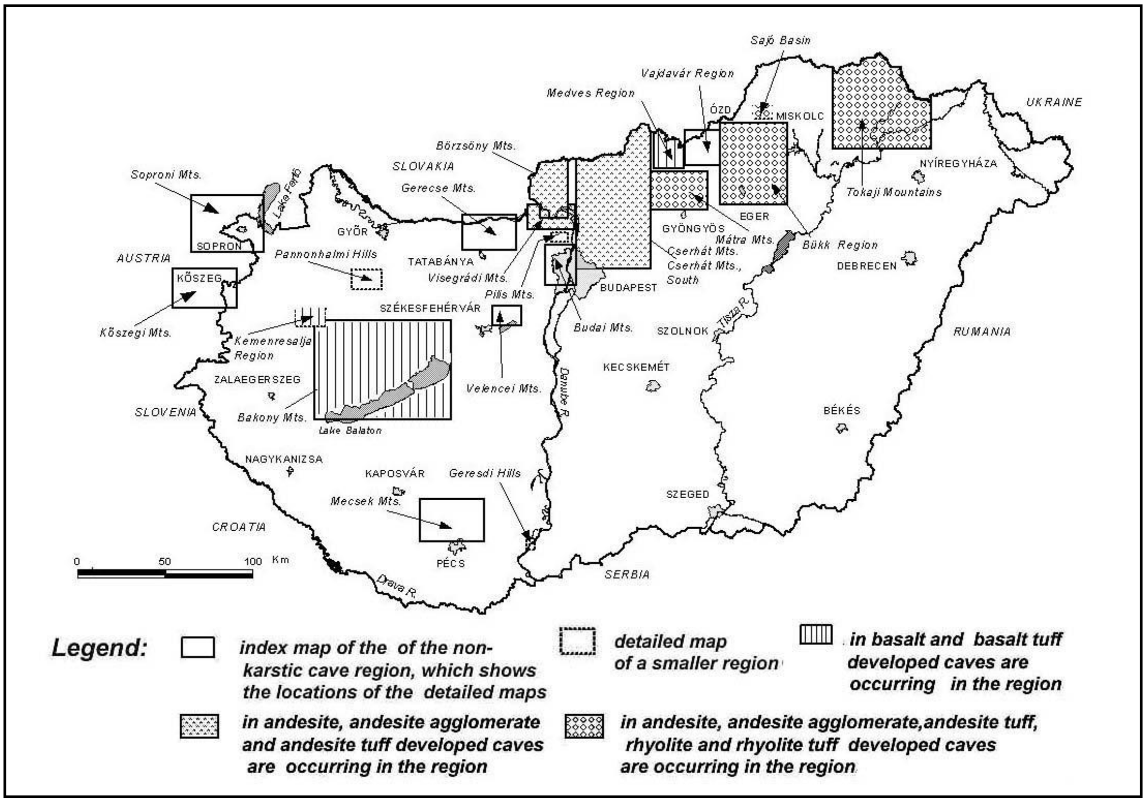
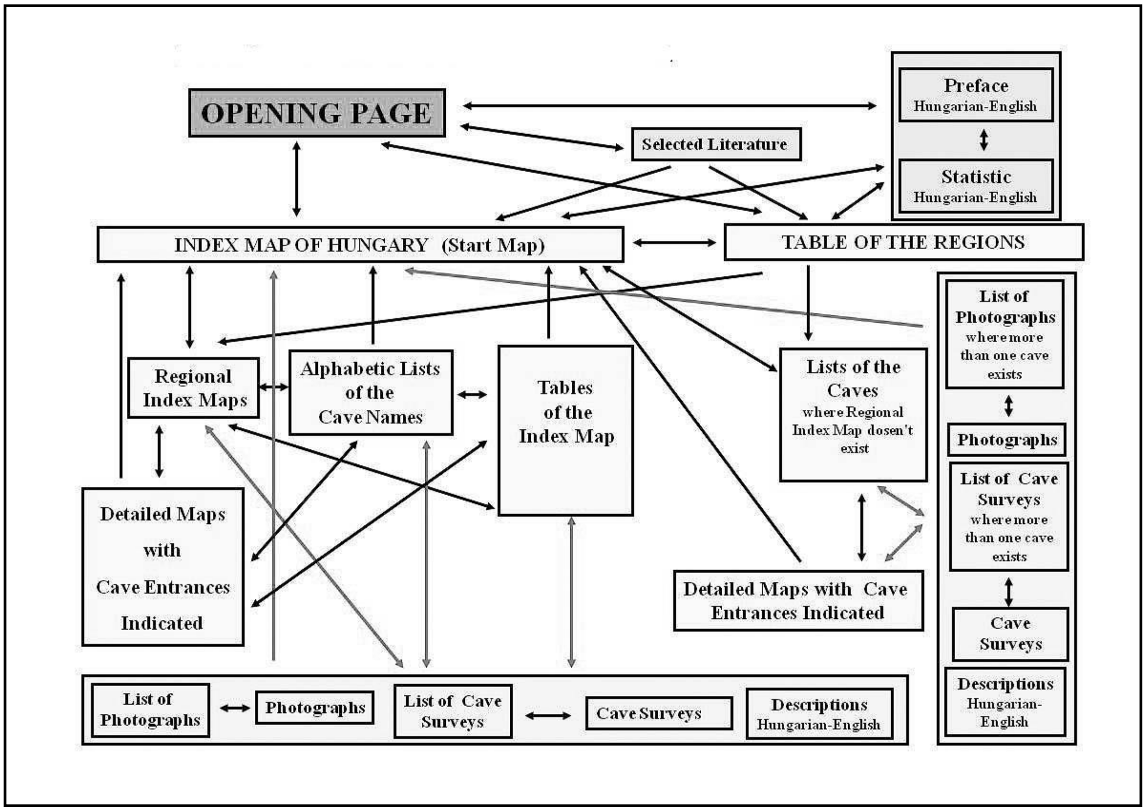


Figure 2: The regions of the non-karstic caves in Hungary according to the List



Fgure.3.: The structure of the List of Non-karstic caves in Hungary

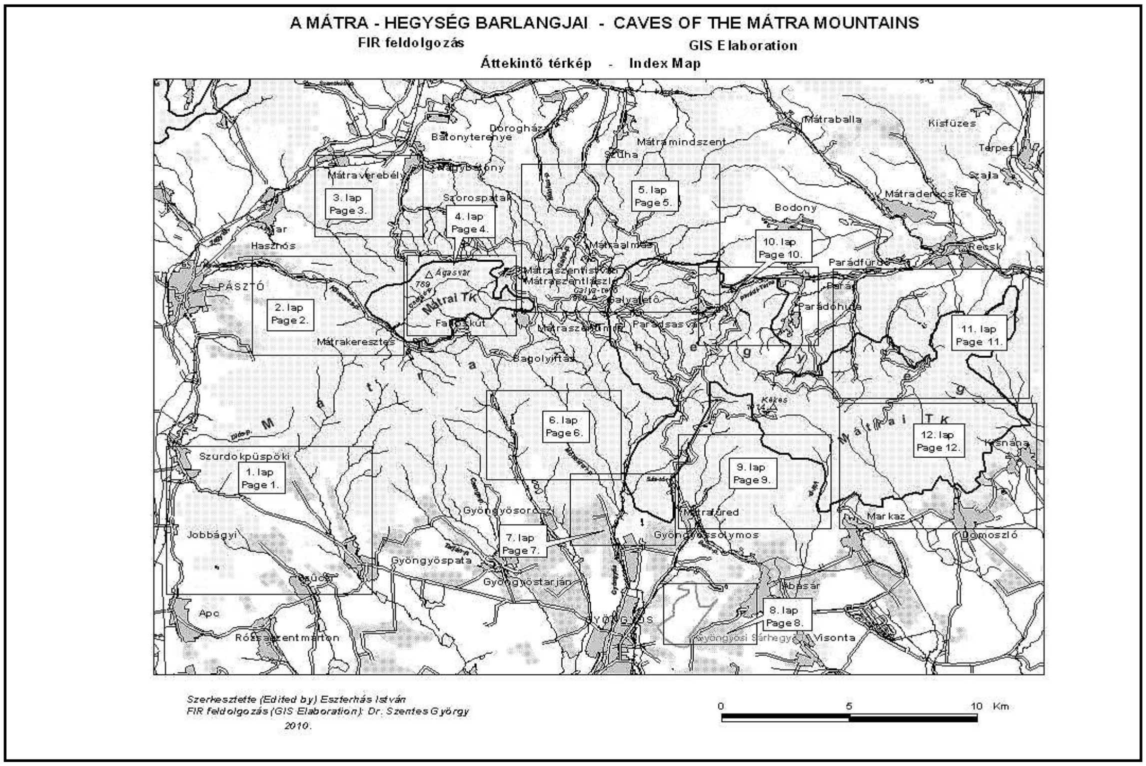


Figure 4.: Example of the index map, Matra Mountais

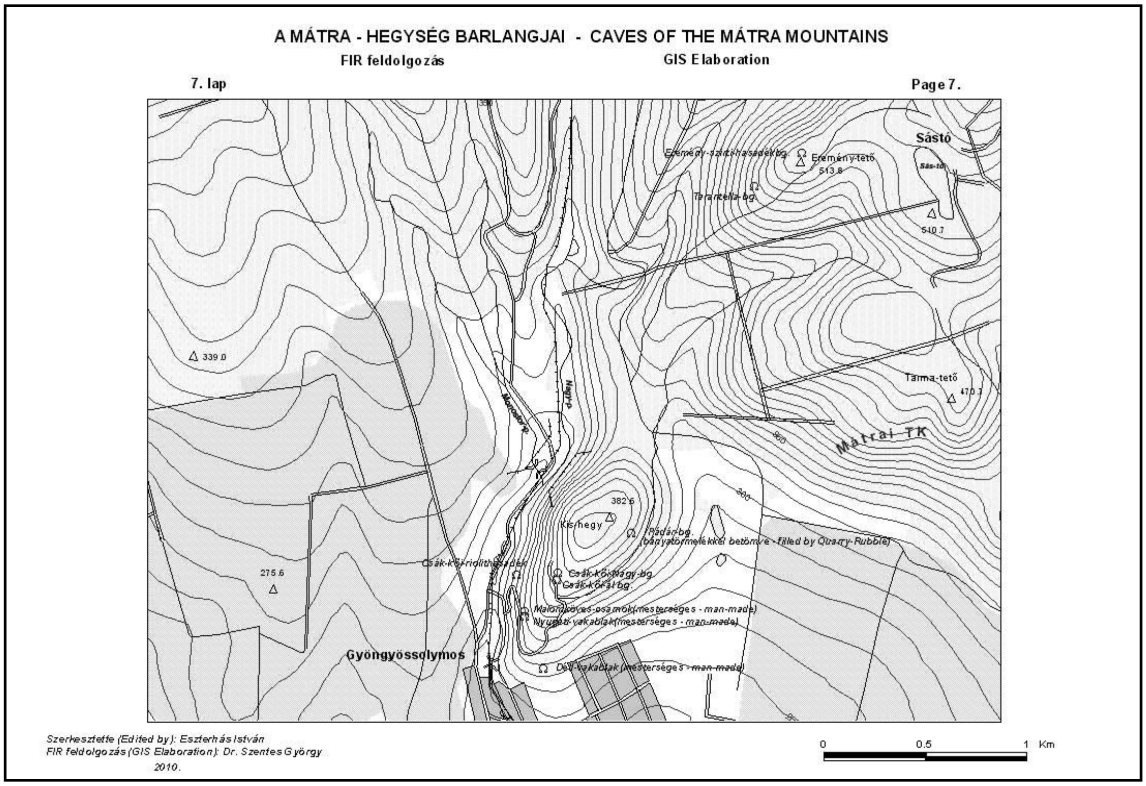


Figure 5 Example of the detailed map, Márta Moutains, Page 7.

Figure 6.:The Pokol Hole developed in basalt in the Bakony Mountains

Figure 7: Vasas Chasm Nr 1. Cave in the andesite agglomerate of the Visegrádi Mountains

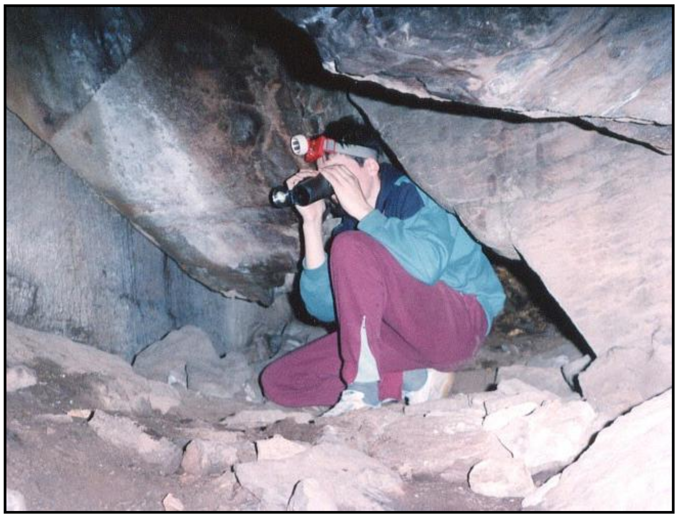


Figure 8. Rózsa Sándor Cave in the andesite of the Tokaji Mountains

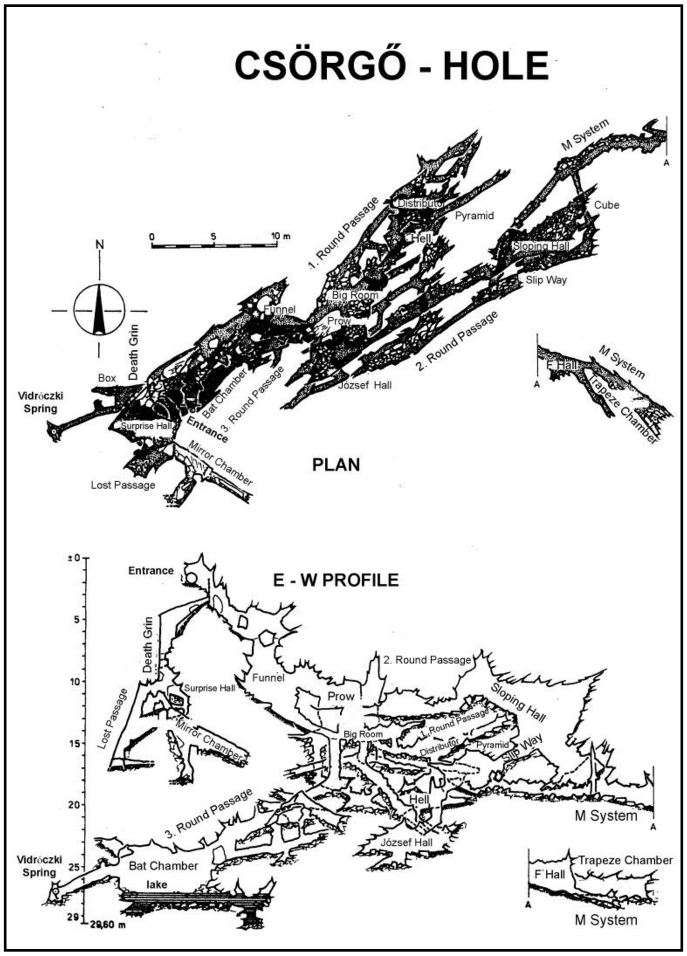


Figure 9: Survey of the Csörgő Hole the longest non-karstic cave of Hungary in the rhyodacite tuff of the Mátra Mountains

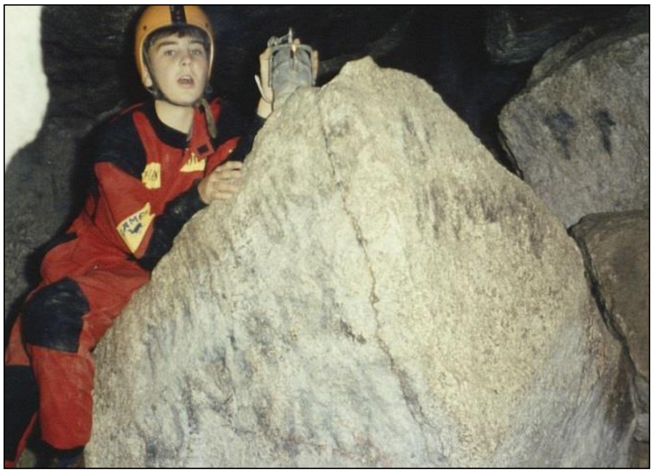


Figure 10: The Prow a spectacular boulder in the Csörgő Hole

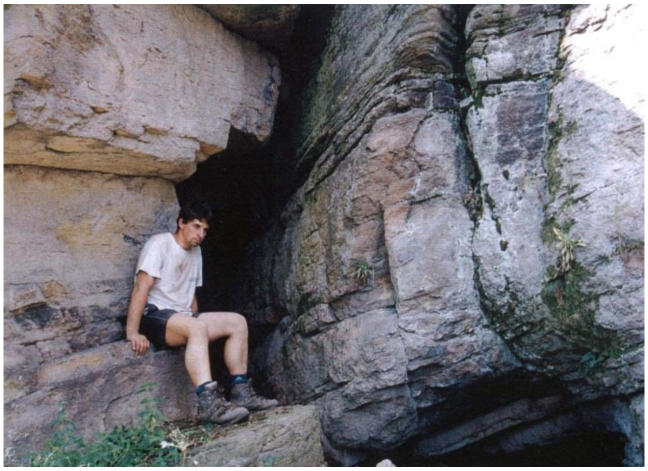


Figure 11: Iván Cave have formed in rhyolite

Cave airflow mechanism of the Velká Ondrášova jeskyně Cave

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Ventilation and cave airflow represent significant microclimate factors determining both physical and chemical basement of cave atmosphere. These variables are used as input into a variaty of models that solve spatiotemporal distribution of microclimate parameters in caves. Unfortunately, in crevice-type caves these models are rare. Crevice-type abyss in Moravskoslezské Beskydy Mountains Velká Ondrášova jeskyně Cave have been the subject of this paper. Ventilation mechanism and its driving forces have been studied via ambulatory measurements of temperature, cave airflow and external wind in the cave's environment. Measured time series of cave airflow have been analyzed from the point of view of their oscillations. Basic outline of mechanism of the cave ventilation in Velká Ondrášova jeskyně Cave have been provided by quantification of volumetric cave airflow in short-term periods together with some statistical approach. Results of the work have shown ventilation is partly nonlinear function of temperature gradient, i.e. temperature difference between cave and its outdoor environment. However, there is significant influence of external wind on the cave airflow despite this effect is often questioned in caves. Precise mechanism of how the external wind influnces the cave airflow is still unknown and it will be the subject of the next research. Key role is probably played by cave morphological predisposition determining quite intense energetic and material trasfer between inner and external cave environment. Unfortunately, due to lack of similar studies in crevice-type caves it is only possible to compare outputs of this paper to results of research managed in caves which have been created by diverse processes and are morphologically absolutely different. There is a presumption that many crevice-type caves could be very similar from the point of view of the cave microclimate due to analogous morphology and genesis. However, this is still only a guess which would have to been confirmed.

Keywords:
cave climate, airflow, ventilation, temperature, oscillations, crevice-type caves, Velká Ondrášova jeskyně Cave

Progress in exploration and registration of the caves in Polish Outer Carpathians in 1999-2014

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In geological terms the Outer Carpathians are formed almost exclusively of flysch rocks of the Cretaceous and Palaeogene age. These rocks are represented by sandstone-conglomerate, sandstone-siltstone-claystone or siltstone-claystone series, however, the most common are sequences of sandstone, siltstone and claystone interbeddings. The flysch rocks are strongly tectonically modified, forming several units that thrust one over another in a northward direction. The principal tectonic units of Polish Outer Carpathians are as follow: Skole nappe, Sub-Silesian nappe, Silesian nappe, Dukla nappe and Magura nappe.

The Outer Carpathians within the Polish territory are ca 330 km long and cover ca 18,500 km^2. In the principal regional division within Polish part of the Outer Carpathian province, the following sub-provinces are distinguished:

1. Western Outer Carpathians with two macro-regions:
   - Western Beskidy Mountains, intermediate mountains with the highest summit of Mt Babia Góra (1725 m a.s.l.;
   - Carpathian Foredeep, ca 400-500 m a.s.l high;
2. Eastern Outer Carpathians, with macro-region of the Bieszczady Mountains with the highest summit of Mt Tarnica (1346 m a.s.l).

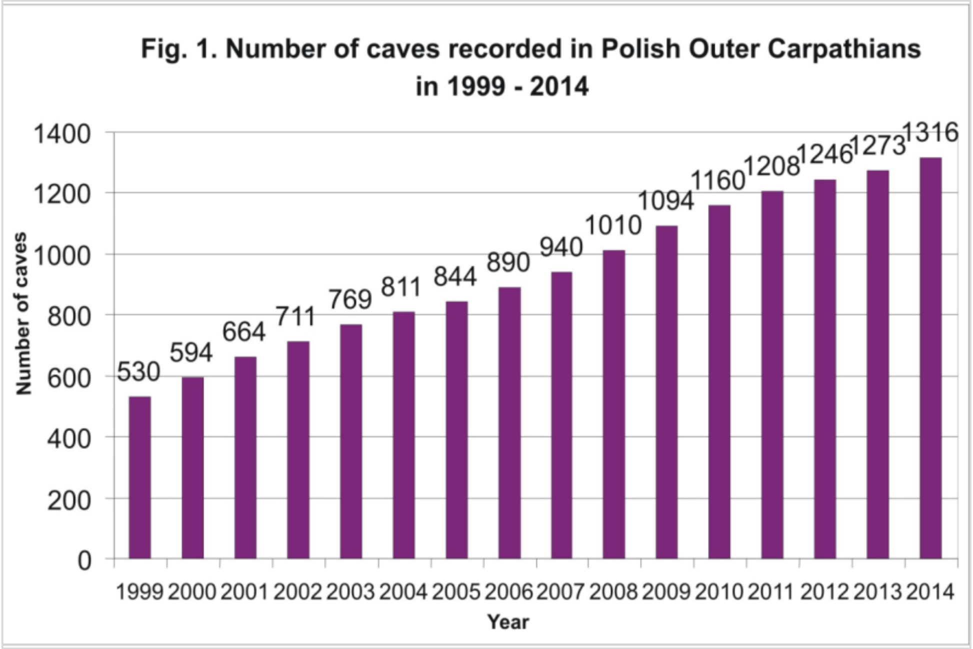
The non–karst caves of the Western Carpathians are represented mainly by crevice type caves, whose origin and development are connected with gravitational mass movements, producing failures of mountain slopes. Propagation of systems of cracks (which are caves, if they are accessible for people) precedes the development of landslides in the mountain slopes. However, the caves are formed also directly as results of the landslide development, within the slide zone and main scarp, as well as within the packet landslide bodies (Kowalski 1954, Janiga 1974, Klassek, Mikuszewski 1997, Margielewski, Urban 2003, Urban, Margielewski 2013). Moreover, the interaction of processes of mechanical and chemical weathering as well as water erosion and piping generated formation of cave niches and bedding type caves in the Outer Carpathians.

In 1969 the cavers from the KTJ Bielsko-Biała Speleoclub undertook a complex exploration and inventory of the caves in Polish Outer Carpathians. The initiators of this project were G. Klassek and Z. Ładygin, subsequently also J. Ganszer and J. Pukowski from the Bielsko-Biała Speleoclub as well as T. Mleczek from the Beskidy Caving Club.

The first phase of the realisation of this project was finalised with the publication of three volumes of the inventory "Jaskinie polskich Karpat fliszowych" (Caves of the Polish Flysch Carpathians – Pulina 1997a, b, 1998) by the Polish Society of the Supporters of the Earth Sciences in 1997-1998. In this monograph 471 caves have been described.

The second phase of the project, realised in 1999-2014 (this last year is the year of completing of the second edition of the inventory) was very profitable for the exploration and registration of "new" caves in the Outer Carpathians (Fig. 1). This exploration covered the areas which had not been penetrated by cavers, yet, and was finalized with the total number of 851 "new" caves , among which three ones, Jaskinia Wiślańska, Jaskinia Miecharska and Jaskinia w Trzech Kopcach are longer than 1000 m, and the deepest Jaskinia Ostra-Rolling Stones cave system reaches the depth of 60 m. New cave portions have been penetrated also in "old" (previously discovered) caves.

Such effective results were possible owing to the activity of wider than before group of enthusiasts of exploration of non-karst caves in flysch rocks. The initiators of the project in 1969 and members of the Bielsko-Biała Speleoclub and the Beskidy Caving Club have been followed by members of the Association for the Cave Conservation "Malinka Group" led by Cz. Szura, Geographers' Club of the Jagiellonian University under the initiative of P. Franczak, Dąbrowa Górnicza Speleoclub, Nowy Sącz Caving Club, Alpinist Club of the Beskidy Mountain Safety Group and people not affiliated to any organisations.



Up to 2014 in Polish Outer Carpathians 1316 caves of the total length of 23407 m have been discovered (distribution in regions – Table 1). 35 caves are longer than 100 m, among which four are 500-1000 m long and three – more than 1000 m long. 27 caves range the depth 15 m or larger, among them two caves are deeper than 50 m (Tables 2 and 3).

Table 1. Distribution of caves in Polish Outer Carpathians

Region	Number of caves	Total cave length [m]
Beskid Śląski	415	12275,64
Kotlina Żywiecka	2	23,5
Beskid Żywiecki	95	1183,1
Beskid Mały	71	958
Beskid Makowski	37	489,7
Beskid Wyspowy	71	1508,5
Gorce	48	442,5
Beskid Sądecki	79	1281,8
Beskid Niski	253	3153,4
Bieszczady	30	284,5
Góry Sanocko-Turczańskie	14	71,5
Pogórze Śląskie	4	28
Pogórze Wielickie	15	97
Pogórze Wiśnickie	19	92,6
Pogórze Rożnowskie	79	1010
Pogórze Ciężkowickie	38	221,8
Pogórze Strzyżowskie	16	79,5
Pogórze Dynowskie	30	206,4
Totally	**1316**	**23407,44**

Table 2. The longest caves in Polish Outer Carpathians

No.	Cave name	Region	Length [m]
1.	Jaskinia Wiślańska	Beskid Śląski	2275,0
2.	Jaskinia Miecharska	Beskid Śląski	1838,0
3.	Jaskinia w Trzech Kopcach	Beskid Śląski	1250,0
4.	System Ostra – Rolling Stones	Beskid Śląski	855,5
5.	Jaskinia Słowiańska-Drwali	Beskid Niski	601,0
6.	Jaskinia Dująca	Beskid Śląski	582,0
7.	Jaskinia Głęboka w Stołowie	Beskid Śląski	554,0
8	Jaskinia Oblica	Beskid Żywiecki	436,0
9.	Jaskinia Zbójecka w Łopieniu	Beskid Wyspowy	433,0
10.	Diabla Dziura w Bukowcu	Pogórze Rożnowskie	365,0

Table 3. The deepest caves in Polish Outer Carpathians

No.	Cave name	Region	Depth [m]
1.	System Ostra-Rolling Stones	Beskid Śląski	60,0
2.	Jaskinia Miecharska	Beskid Śląski	55,8
3.	Diabla Dziura w Bukowcu	Pogórze Rożnowskie	42,5
4.	Jaskinia Wiślańska	Beskid Śląski	41,0
5.	Jaskinia w Trzech Kopcach	Beskid Śląski	32,6
6.	Jaskinia Niedźwiedzia	Beskid Sądecki	28,0
7.	Jaskinia Głęboka w Stołowie	Beskid Śląski	25,0
8.	Jaskinia Ali-Baby w Klimczoku	Beskid Śląski	25,0
9.	Jaskinia Słowiańska-Drwali	Beskid Niski	23,8
10.	Jaskinia Malinowska	Beskid Śląski	23,2

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History of caves in the Ledové sluje (Ice Caves) locality, Podyjí National Park, Czechia

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1. Introduction

Pseudokarst caves Ledové sluje belong to the most valuable natural localities of the Podyjí National Park. This locality was made accessible already in 1859, when the construction of the access path going across steep north-west slope to the top of the ridge had been finished. This north-west slope was affected by massive rock falls, which created an extensive pseudokarst cave system with unusual arrangement of fallen rocks. Beside the unique relief, the historical interest in this locality was provoked by long-lasting ice decoration inside the caves, which can be maintained by cold microclimate up to summer months.

Shortly after the opening of the footpath to the caves, Roth (1863) published the first scientific paper regarding this locality. This publication was later followed by several other German studies (Jarz, 1882 & 1884, Filek, 1895) and Czech texts (Špalek, 1935; Skutil, 1950). The amount of descriptive information, however, was hardly ever recorded cartographically. Many authors referred to the first situation plan (Jarz, 1882), whose usefulness was significantly limited by relatively coarse scale, large generalization as well as shortcomings in the description of the caves. Absence of historical maps affected also modern speleological mapping in the 90s of the 20th century, when the researchers concluded, that the caves can be hardly identified based on historical documents particularly due to extensive geomorphological changes (Wagner, 2001). Progress in mapping of the caves was reached thanks to publication of the facsimile of the map "EISLEUTHEN. Zaisaer im Revier" (Hallamassek, 1859), historical photographs and digitalization the original speleological map. Thanks to these fundamental materials we were able to create the map of the Ice Caves (Fig. 1) with all their historical names.

2. History of discoveries and speleological mapping in Ledové sluje locality

The historical documentation and speleological materials contain altogether seven different nomenclature systems of the Ice Caves, however, three of them play the key role. The oldest nomenclature is based on studies of ROTH-JARZ and consists of Roman numerals I – VII for caves (VIII is rest area) and four word-names derived from the table of temperature measurements. The second nomenclature consists of numbers of nails at the entrances to the caves that were established during the geodetic survey between 1986 and 1987. This survey provided the data for the map at the scale of 1: 200 (Počta & Schönbeková, 1991). Numerical naming of caves was adopted also by speleologists during the speleological mapping from 1991 to 2000. However, they also established new names which consist of abbreviation "ZO ČSS", order number and alternatively new word-name. The speleological survey was conducted by five Basic ČSS organizations with abbreviations: 'Br' for 5-03 Broumov (J. Kopecký), 'Bo' for 7-01 Orcus Bohumín (J. Wagner), 'Li' for 4-01 Liberec (L. Tomáš), 'Brno' for 6-12 Speleological Club Brno later 6-25 Pustý žleb (F. Musil, ml.) and group 6-27 Znojmo (T. Andrejkovič). Revision of nails and cave names was done in 2000 by employees of the National Park Podyjí who assigned new names to unnamed prominent sites. This third system of names, which consists of the number of nail and the word-name, is the most comprehensive because it contains all prominent sites in this area.

Beside these nomenclature systems, reputedly conspicuous designation of three caves by numerals 1 – 3 (Špalek, 1935) is worth mentioning. This designation was established by the Club of Czechoslovakian Tourists in 1918, however, it does not correspond to the original Roman numerals I – III by ROTH-JARZ. According to photographs and the description in the original paper (Fig. 2) it does not correspond to names Grotte I – Grotte III, which were written on the walls of the caves. For the two prominent caves, the name "Grotte" was preserved even in modern speleological documentation. Another, time being incomplete, system of cave names is represented by a nation-wide cave database JESO. However, only small number of known caves of this locality is registered in this database. Complete list of names assigned to the caves in the Ledové sluje locality can be found in the following table (Tab. 1).

The history of Ice Caves' naming is full of historical misunderstandings which were caused by wrong identification of caves and subsequent shifts in numbering of caves. Considerable confusion can be found in identification of caves in the II. Pillar according to original work of Roth and later studies. During the exploration of this locality, Roth left paved footpath and, according to the context, he got to the longest cave system J27 Brněnská. However, probably due to high similarity of pseudokarst relief forms, his followers did not leave the footpath, therefore, they incorrectly identified the caves and assigned original names introduced by Roth-Jartz to wrong caves. Shifts in the numbering of caves thus caused that Jarz's number VIII (originaly assigned to the rest area) was assigned to not existing cave in the southern slope. This cave is mentioned in historical literature just due to erroneous transcription of scientific texts.

3. Conclusion

Knowledge of the historical perception and naming of Ice Caves provides an important link between historical and new surveys. After the completion of current projects of terrestrial laser scanning (Kuda et al., 2013) and structural measurements of crevices by geological compass (Lenart, J.; ZO CSS 7-01 Orcus Bohumín), complete map of this locality including all 23 caves will be available.

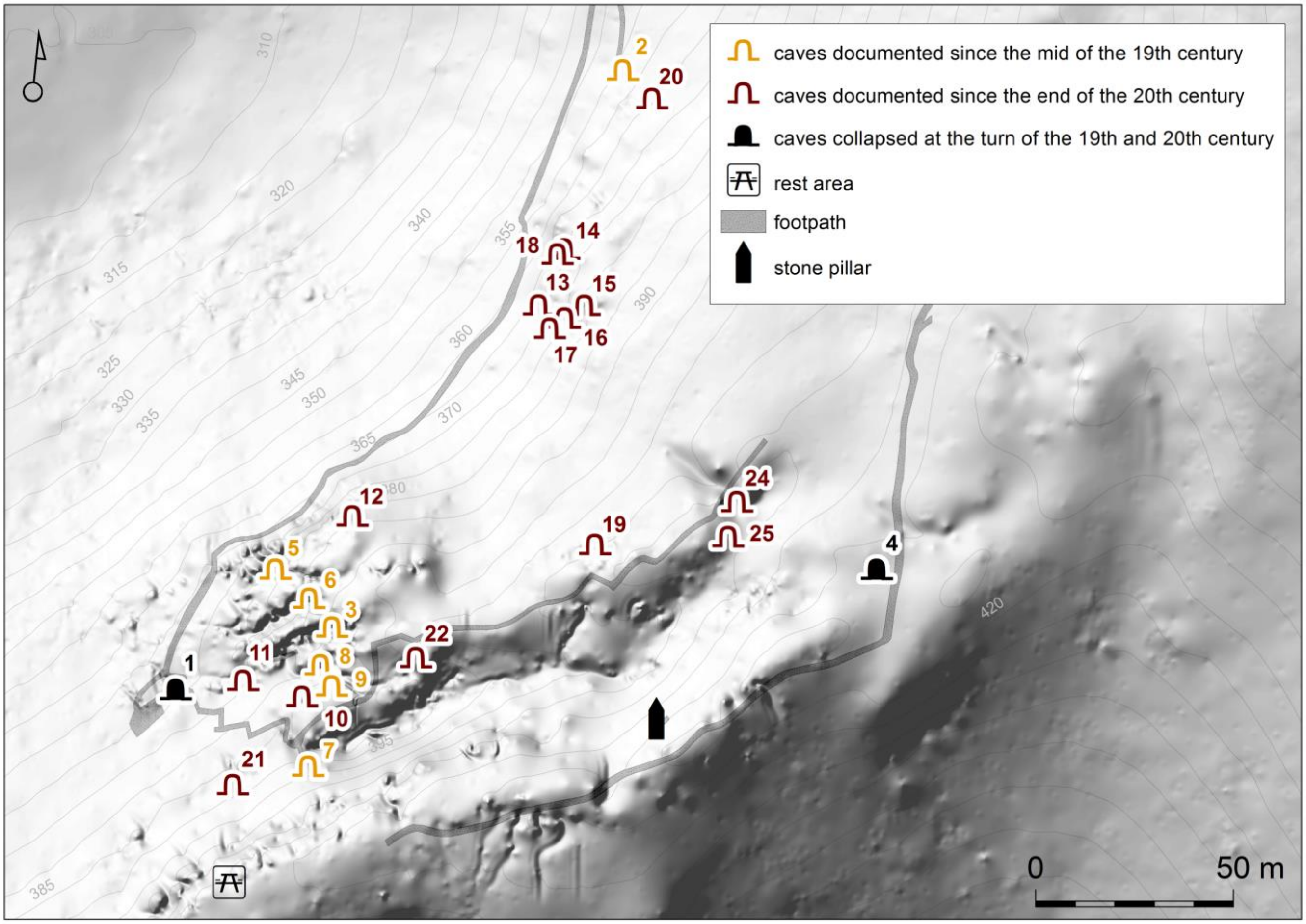

Fig. 1: Locality Ledové sluje (Ice Caves) with all known caves. Number of cave corresponsd to designation in the first column of the Tab. 1 (Kuda & Divíšek, 2015).

Tab. 1: Timeline of the cave names in the Ledové sluje (Ice Caves) locality according to Hallamassek (1859); Roth (1863); Jarz (1882); Club of Czechoslovakian Tourists / Špalek (1918/1935); Počta (1991); ZO ČSS caving clubs (1991 -2000); Podyjí National Park, Plaček & Mahr (2000); Kuda & Divíšek (2015).

2015	**1859**	**1863**	**1882**	**1918 / 1935**	**1991**	**1991-2000**	**2000**
1	Eisgrube	I. Alte Grube		*no longer accessible*			
2	Eisgrube. Endekt im Juli 1858	II. Neue Grube			29	Bo 7.	Ledový sklep
3		III. Eishöhle		Grotte II / 1	8	Br 1.	Suchá "Grotte II"
4		Höhle am Bergrücken	IV	*no longer accessible*			
5			V		23	Brno 1.	Brněnská
6			VI	Grotte I /unmarked	7	Li 1.	Grotte I
7	Alberts Ruhe		VII	/ 3	16	Br II	Hlavní zlom
8				Grotte III / 2	14	Br IV	Netopýří
9					14a	Br III	Sintrová
10					13	Br V.	Průrva
11					4	Li 2.	Pod Čtyřkou "Ledová"
12					25	UPG25	Pod převisem Brno
13					35		Propadliště
14					38	Bo 5.	Ledová sluj "Dyje 2"
15					39	Bo 2.	Kaple
16					40	Bo 3. Tunelová	Brána do propasti
17					41	Bo 4.	Východ z pekla
18					46	Bo 1.	Orcus portál
19					48	Nová	Nová
20						Bo 6. (29b)	
21					15		Ananas
22					17		Pod schodištěm
24					31		U vstupu
25					32		Štěrbina pod kleny
	Enkels-Sitz am 1 Oktober 1858		VIII				

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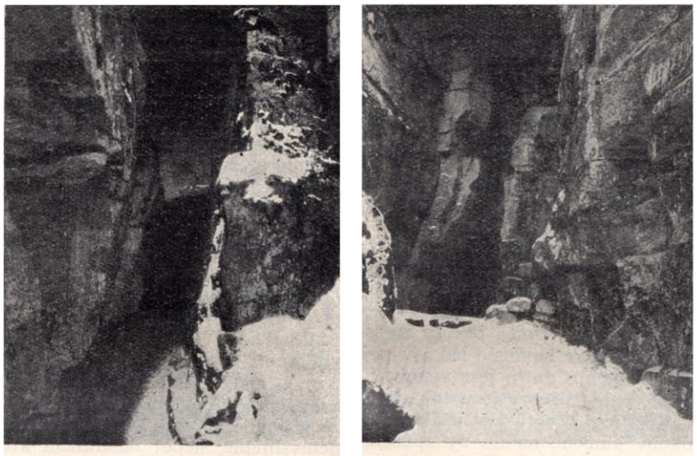
Obr. 4. Ledová sluj č. VI. podle Rotha (dnes neoznačená).

Obr. 3. Ledová sluj č. V. podle Rotha (dnes č. 1.).

Mistaken identify of Roth's caves according Špalek (1935).Špalek's photos do not correspond to Roth's description of cave and his number-identification.It is almost certainly, that Roth's measurements of temperature were done in one of two dominant caves (apparently Grotte II i.e. Roth's No. III).However, Špalek attributed these dominant caves Roth's No. VI. and V.


J7 Grotte I.

J8 Suchá Grotte II.

J14 Netopýří

Fig. 2: Comparison of historical and recent appearance of cave (top: postcard from unknown year; middle: photo in Špalek (1935); bottom: photo 2015, J. Kudová)

The Cyrilka cave - longest crevice-type cave in Czechia

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The Cyrilka cave is the second-longest pseudokarst cave and the longest crevice-type cave in Czechia. It is developed within the headscarp area of a deep-seated landslide. The cave became the object of scientific research in recent years when new passages were discovered. Geophysical measurements revealed the possibility of further discoveries. We first used 3-D ERT measurements in flysch rocks. These measurements, together with a detailed survey of the cave, reveal the predisposition of the slope deformation by a normal fault. It also reveals unknown crevices above the existing headscarp, which indicate the retrograde evolution of the landslide. Based on the evaluation of the previous studies, we discuss the problems associated with determining the age of the cave, which could theoretically reach the Pleistocene. We performed a faunistic survey in the cave for the first time. We found 11 invertebrates and 5 vertebrates. The locality is threatened by many visitors and by contamination by rubbish. We recommend the protection of the cave as a national monument.

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Key words:*Pseudokarst, Crevice-type caves, Mass movements, Outer Western Carpathians, Cyrilka cave, Crumomyia parentela*

Pseudokarst of the Moravskoslezské Beskydy Mts.

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Moravian-Silesian Beskydy Mts. (Figs. 1, 2, 3) belong to the Carpathian Mountain Range. It is a part of the Outer Western Carpathians which consists of the Mesozoic-Paleogene sedimentary flysch rocks – sandstones, siltstones and claystones. In the Neogene the strata were folded and disrupted by joints and faults which pervade the rocks tens of meters into the massif. In the Quaternary, the deep valleys were formed and steeply dipping slopes started to be unstable. The slope deformations became the main geomorphic factor shaping the landscape. Due to the gravity driven slope processes the jointswere widened and the crevice-type caves were formed(see front cover). This type of speleogenesis has been continued up to the present.

Fig. 1. The Beskydy Mts from the top of Lysá hora Mt.(photo J. Lenart).

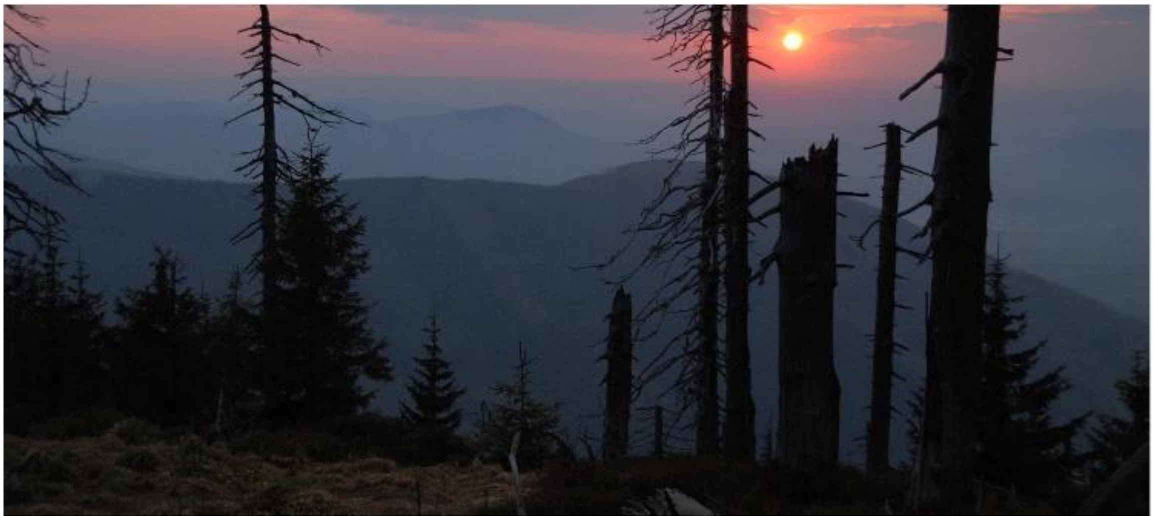

Fig. 2. The Beskydy Mts. – the ridge of Radhošť(photo J. Wagner).

Short history of the speleological research

The history of the cave exploration in the Beskydy Mts. was connected with the first inhabitants of this region. The first information about the caves derived from ancient Slavonic fables. The caves were connected with the cult of the pagan God Radegast. His statue was situated at the Radhošť ridge (1106 m a.s.l.) just close to the longest crevice-type cave Cyrilka (535 m long). The historical wooden houses at the Pustevny settlement were built in the 19th century at the place where old Wallachian shepherds stored a milk in the cold cave entrances. The oldest written mention about the caves comes from 1639, while the speleological exploration started in the 18th century, when some adventurers tried to describe several caves. The scientific research of the caves has been performed since the middle of 20th century. The members of the Speleological Club Orcus (Czech Speleological Society) have been investigating the non-karst caves in the Beskidy Mts. since 1969 up till now.

The longest and the deepest caves

The longest crevice-type cave in the area is the Cyrilka cave with 535 m long passages. It is also the 2nd longest non-karst cave in the Czechia. The Kněhyňská cave (Fig. 4) reaches the depth of 57,5 m under the surface, this cave is the 2nd deepest crevice-type cave in the flysch Carpathian Mountain Range. The most spacious passages in this cave are characterized by respectable dimensions: 12x15x4 m.

Fig. 3. The morphological forms on top of a mountain Čertův mlýn (photo J. Wagner).

Fig. 4. The Kněhyňská cave, the Big Abyss (photo J. Wagner).

Spring tufa caves in Austria

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1. Introduction

Caves developed in spring tufa and travertine deposits are not restricted to karst areas. Occuring in karst areas as well as non karstic rocks - as long as these contain carbonates – the formation of the cavity is not directly connected to the dissolution of rocks. The same applies to the abundant speleothems in spring tufa caves – some of them are formed similar to those in karst caves, others are closely connected with plants, comparable to those in subaerial tufa deposits (Taboroši & Hirakawa, 2004). In Austria just a handful of spring tufa caves of minor size have been discovered so far, none of them exceeding a lenght of 25 meters. In contrast to this, in Austria's neighbouring countries there are three comparativley large show caves in (cold water) spring tufa, namely *Niederaltdorfer Tropfsteinhöhle* in Saarland and *Olgahöhle* in Baden-Württemberg, both Germany, and *Höllgrotten* near Zurich, Switzerland, all of them with lenghts of 200 to 300 m. As with other spring tufa spots in the alpine area it seems that both caves and spring deposits did not survive the erosional force of the pleistocene. So far none of the formations already dated are older than the Holocene in Austria. To our opinion the caves may bear a distinct potential for high resolution climatic studies of the Holocene due to the high deposition rates.

2. Formation of spring tufa caves

Spring tufa developes where waters with elevated contents of carbonates emerge and encounter steeper gradients of terrains. Due to the increased water movement equilibrium-CO_2 is lost, sometimes (but not always) probably with support of certain plants like mosses and algae. This results in massive and fast precipitation of predominantly $CaCO_3$. Mg is co-precipitated to a certain extent, reflecting the hydrochemistry of the water at least faintly. Where the terrain is very steep to overhanging, the chance of cavity-forming is increased. However, a long term stability of the caves is rare as the cavities are endangered by the same process that accounts for the formation – limestone precipitation. Only in those cases where the supply of water is terminated in time, there is a chance that the tufa cave is conserved. Within the cave both biogenic and common speleothems - like in karst caves - occur. The most comprehensive monography for tufa and travertines (Pentecost, 2005)compares the different types of speleothems with those of common limestone caves.

3. Examples from Austria

The oldest report about a spring tufa cave (Weiss, 1963) in Austria describes a still existing, small but remarkable cave, partly misused as „campsite" by visitors (Fig. 2) near the impounded Drau River in Carinthia. Its overall length does not exceed 25 meters, however its passages are full of speleothems, both biogenic and common karst-like types are abundant.

The limestone-precipitating waters emerge from non-karstic clastic rocks containing limestone components, whereas crystalline rocks form the bedrock in this area. Is is important that Weiss (1963) mentioned an inflow of waters and a rapid growth of speleothems whereas the cave is dry at the moment (Fig. 1 – red „X"). The so far unnamed cave lies adjacent to the *Draugrotte*, a huge rock shelter developed in spring tufa too, close to the river level (No. 2728/1 in the Austrian cave inventory) but is more difficult to reach. Both can be approached by boat only.

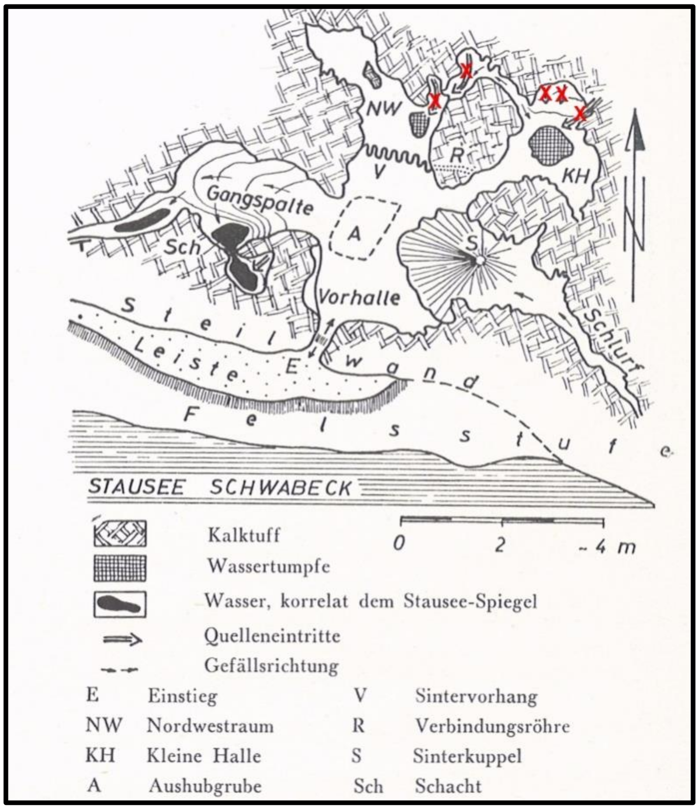

Fig. 1: Scetch of the tufa cave near the Draugrotte (from Weiss, 1963, p94, slightly modified).

Fig. 2: Speleothems and human interference inside the tufa cave near the Draugrotte (Photo: Rudolf Pavuza)

Some twenty years later another example of a tufa spring cave was described from the prealpine mountains of western Lower Austria (Ilming, 1983), subsequently named *Tuffsteinhöhle* (1827/19). This spacious chamber, overall extending some 13 m also decorated with predominantely biogenic speleothems but – contrary to the tufa cave in Carinthia – is still hydrologically quite active (Fig. 3). Cavers recorded certain changes of the entrance of this cave fearing that it might be sealed due to tufa accretion some day.

Fig. 3: Inside Tuffsteinhöhle (Photo: Heiner Thaler)

Another example from Lower Austria is the *Eibenmühlenhöhle* (1836/182), a 22-m-long cave with three entrances a few meters above the river Erlauf and thus severely overformed by high waters (sediments, driftwood). On the other hand older driftwood inclusions might be advantageous for easy ^{14}C-dating in order to obtain a minimal age of this cave.

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The Slámova sluj cave – pseudokarst in limestones

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The research deals with the genesis and evolution of the Slámova sluj crevice-type cave which is situated on Zámecký vrch hill in Štramberk town (Štramberský karst area, North Moravia, Czechia). The cave is around 55 m deep abyss. The research was based on structural measurement within the cave by using a geological compass. The outputs were used to understand the slope processes which formed the crevice cave in Jurrasic limestones. According the results, the Slámova sluj cave was formed by simple widening of joints in upper and lower level and by rotational movement in the middle part of the cave. The following research was focused on the tectonic faults of the bedrock and on the superficial geomorphology of the Zámecký vrch hill by using of geophysical measurements (electrical resistivity tomography) and geomorphological mapping. The geophysical measurement revealed the distinct fault zone passing through the investigated hill. It can by closely connected with the original evolution of the cave.

Effect of lichen cover on sandstone surfaces quantitative study of hydraulic and mechanical properties and erosion

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Keywords: sandstone, weathering, lichen, strength, erosion

Over recent years, the effect of microorganisms on weathering of sandstone surfaces has been discussed. Some authors claim that the weathering of rocks can be accelerated by the growth of lichen species (see e.g. Brehm et al. 2005). On the other hand, some studies show that lichen cover may protect the surface of various types of rock from weathering (see e.g. Carter and Viles 2005).

Our study is focused on the effect of lichens on hydraulic and mechanical properties of locked sand (weak sandstone) of upper Turonian and Coniacan age from Střeleč Quarry (Český ráj). Several studies characterizing the original material (Bruthans et al. 2012, Bruthans et al. 2014) and preliminarily describing the effects of organic crust (Schweigstillová et al. 2013) were carried out. According to our first observation, presence of lichens protects the surface from erosion. However, the effect of lichen cover on mechanical and hydraulic properties is not well-understood.

Locked sand is characterized by low tensile strength and high erodibility, therefore the effect of lichens on mechanical properties is likely well measurable. The objective of our study was to quantify differences in mechanical and hydraulic properties between surface crust of locked sand colonized by microorganisms and underlying locked sand with no evident presence of organisms.

Saturated hydraulic conductivity was measured at cores under constant head flow conditions. Samples with the organic surface crust show values between$2.2*10^{-6}$ m/s and $5.9*10^{-5}$ m/s. It appears that samples with no evident organic colonization (underlying material) are little more permeable with values ranging from $5.8*10^{-5}$ m/s to $1.2*10^{-4}$ m/s.

Capillary water absorption was measured at cores hanged on a tensiometer recording the weight of the sample in 0.1 second interval. Studied material is classified as medium or highly absorbing material with water absorption coefficient between 1.7 $kg.m^{-2}.h$ and 18.9 $kg.m^{-2}.h$. Rate of capillary water absorption is considerably reduced by surface crust.

Water vapor permeability of Střeleč Quarry locked sand was measured using method of wet cups. Our results indicate that the existence of surface crust has no measurable effect on water vapor permeability with values of water vapor diffusion coefficient varying from $1.4*10^{-11}$ s to $8.7*10^{-11}$ s.

Tensile strength of Střeleč Quarry locked sand was measured on 20 x 20 mm block samples. Using a tensiometer, the strength necessary to the sample failure due to tensile stress parallel with surface was detected. Based on our first results, material with organic crust has 2.6 – 4.8 times higher tensile strength (5 – 70 kPa) than underlying material with no lichen coverage.

Measuring of drilling resistance was used as proxy for compressive strength (Pamplona et al. 2007). Surface with the organic cover is found to be 3 - 15 times more resistant to drilling than underlying material, accordingly, presence of surface crust increases compressive strength of material.

Observing the effect of lichen cover on cores left on natural rain revealed that material with surface crust is far more resistant to erosion by flowing or dripping water than underlying material. While erosion rate of the surface with no lichen cover was over 2 mm per year, there was no measurable erosion of the same material with developed organic surface crust.

To sum up, the presence of organic crust only affects some hydraulic and mechanical properties of Střeleč Quarry locked sand. Based on our results, existence of lichen cover causes slight reduction of saturated conductivity, considerably slows capillary water absorption and increases compressive and tensile strength of the investigated material. On the other hand, there is no measurable impact of lichen coverage to water vapor permeability.

Lichen cover, which may develop in few years, considerably slows erosion of locked sand. This fact, together with a higher compressive and tensile strength, can be the reason why stonemasons waited until a protecting cover developed before using material as a building stone.

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Structural and tectonic control of the sandstone mesa as revealed by ERT: preliminary results from Ostaš and Hejda Mts.

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Abstract

The investigated area consist of three main parts – two table mountains Ostaš and Hejda, and a rock ridge Kočičí skály (“Cat Rocks“) including a small plateau with an apt name Rovný (“Flat“) in its northern part. The area is situated in the north-eastern part of the Czech Republic and belongs to the Broumovská vrchovina uplands, the part of the Sudety subprovince - Orlická oblast (region) of the Czech highlands. In terms of geology, the area is located in the easternmost part of the Bohemian

Cretaceous Basin (Czech massif). The top parts of all studied mountains are formed by the Cretaceous quartz sandstones of Teplice formation – the facie of thick-bedded block sandstones, which is underlain by the rhythmically interbedding Cretaceous layers of marls (marlstones) with limestones.

Geophysical surveying using a DC resistivity imaging (electrical resistivity tomography, ERT) was performed in 2014 and 2015 in order to reveal the thickness of block sandstones, which form platforms (table mountains) and rocky ridge of top areas, and to confirm the hypotheses of the tectonic control of its development. The ERT measurements revealed different thickness of the block sandstones at each individual mesa, ranging from 20 to 50 m (Fig. 1). However, the difference between maximum altitudes of each mesa reaches nearly 100 m, thus mere thickness of sandstones does not sufficiently explain this altitude variance. One of the possible explanations could be vertical movements controlled by tectonics. This is supported by revealing several vertical, low-resistivity structures limiting the marginal parts of the sandstone platforms. Therefore, another ERT profiles were carried out among individual studied parts (across the valleys) in order to confirm this hypothesis (also suggested by geological map – as the Police fault zone). Fault zones of considerable width (~ 50 to 100 m) were discovered. That supports the hypotheses of breaking (disintegration) of an original platform into individual blocks and their (probably gradual) vertical movements along these faults (Police fault zone intersected by the westernmost branch of the Bělá fault system). This survey (focused on tectonics-related features) also confirms the theory of the origin of the Zlomová rokle ("Fault gully"). The Zlomová rokle gully seems to be really predisposed by one of the branches of the Police fault system. The morphology of the top platforms (namely local depression forms) corresponds with ERT results and suggests a vertical subsidence (sackung) of rock blocks, on both Ostaš and Hejda mesas. That could be explained as a result of deep-seated creep of the block sandstones along the underlying plastic marlstones and limestones. Block movements were also confirmed by precise dilatometric measurements provided by TM-71 optical-mechanical crack gauges, namely on Hejda site. Dynamics of the sandstone mesas development on the studied sites can be described in two levels: (i) dilatometric measurements of the separate rock towers on the very margin of the platforms does not confirm current movements and margins thus seem to be stable (no toppling confirmed); (ii) measurements inside the rock massif in the central parts of the Hejda mesa confirm vertical block movements what is in agreements with our findings from the ERT measurements.

To summarize, the ERT surveying reveals different thickness of the block sandstones within individual blocks (platforms) as wells as its local disruptions. The ERT also confirmed hypotheses of the breaking of the original sandstone platform along the complex fault system consisting of the Police fault and the part of the Bělský fault zone. It seems that long-term development of the Ostaš and Hejda mesas, as well as Kočičí skály rock ridge, is predisposed and further controlled by tectonics. The research was performed thanks to the financial support of the project CzechGeo LM2010008.

Keywords: block sandstones, mesa, tectonic predisposition, fault zone, electrical resistivity tomography, TM-71 crack gauge

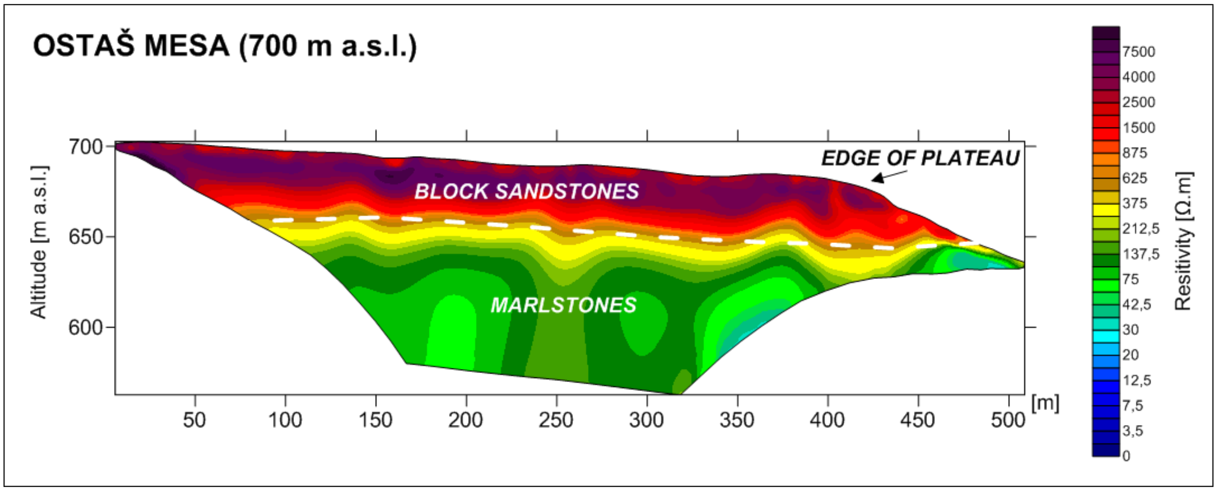

Fig. 1: ERT section of the Ostaš mesa – rigid block sandstones (high resistivity) underlain by plastic rocks – marlstones and limestones (lower resistivity).

Gravitationally induced caves in the Outer Carpathians - their genesis, classification and age

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Non-karst caves, frequent in flysch massifs of the Outer Carpathians are connected with various stages of development of mass movements (Margielewski and Urban, 2003, 2005, Margielewski, 2006; Lenart et al., 2014). They form during the initial stage of mass movements as extension crevices, as well as during landslide development within the landslide body and in the packet colluvium (*sensu* Dikau et al., 1996). Their classifications used up to now, were referred to their shapes and genesis (e.g. categorisation of Viték, 1983, distinguishing crevice type caves – crevices widened along joints or faults, and talus type caves – voids among large rock blocks within the landslide bodies or packet colluvia) or directly to the categorisation of mass movements (*sensu* Varnes, 1978), e.g. caves of V, H and A types attributed respectively to movements of topple, translation and backward rotation character (Lenart et al., 2014).

Crevice-type caves develop due to the unloading of sheer stresses in the rock massifs generated by external factors. The relaxation of these stresses along the discontinuities produces crevices, which are widened owing to the following stages of the relaxation of these stresses (Margielewski, Urban, 2003). The formation of the extensional crevices (which can be accessible for humans as caves) proceeds up to the moment when part of the massif separated by these crevices is gravitationally moved. The phenomenon of crevice widening occurs also within the landslide bodies, transported *en masse* as relatively integrated rock packets (Margielewski and Urban, 2005).

From the geomechanic point of view the opening of extensional crevices is connected with the phenomenon of dilation (dilatation), which is defined as a change of a medium (as e.g. rock massifs) in volume but not in shape (Dadlez, Jaroszewski, 1994). In mountain slopes it is a process of fragmentation of the rock massifs along the crevices into the segments which individually keep the dynamic equilibrium. The second phenomenon resulting in non-karst cave formation within the flysch massifs is the dilatancy, which comprises growth of medium (rock) volume (bulk volume) and change in its shape (Kranz and Sholz, 1977; Kwaśniewski 1986), i.e. alteration from “close-packed structure” to “open-packed structure”. The increase in volume of granular medium is called granular dilatancy, whereas similar process developed in fissured medium, i.e. propagation of crevices is called fissure dilatancy or – if it develops in the relatively large scale (e. g. in the zone of slope failure) - fissure macrodilatancy (Kwaśniewski, 1986). Slope failure developed owing to fissure macrodilatancy can produce the system of crevices (caves) along the shear zones of landslides (Margielewski et al., 2007; Panek et al., 2010).

The proposed hereafter new classification of the gravitationally induced caves is based on two criteria:
- morphogenetic criterion regarding the relation between cave formation and slope development;
- geomechanic criterion, determining the process producing the cave (Fig. 1).

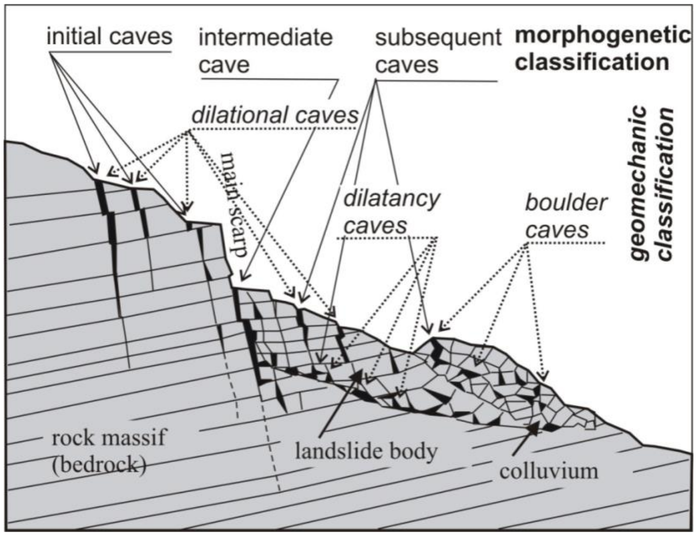

Fig. 1. Proposed classification of caves based on morphogenetic and geomechanic criteria (a model after Urban and Margielewski, 2013).

In the morphogenetic categorisation the following cave types are distinguished (Urban, Margielewski 2013):

a) Initial caves, whose formation precedes significant mass movements; most crevice type caves in Viték's (1983) categorisation belong to this type.
b) Subsequent caves, forming within the landslide bodies or packet colluvia; according to Viték's (1983) classification they represent mainly talus-type caves, however some crevice-type ones belong to this group, too.
c) Intermediate caves, which occur in the cutting surface between the *in situ* massif and landslide bodies; their upslope walls are usually continuations of landslide main scarps.

In the geomechanic categorisation the following cave types are distinguished:

a) Dilational caves, formed owing to the dilation process; this group is represented by crevices widened both before the landslide formation (as initial caves) and during the significant slope failure (landslide formation); in the Viték's (1983) classification they represent the crevice-type caves.
b) Dilatancy caves, formed owing to the fissure macrodilatancy *sensu* Kwaśniewski (1986). They are located usually within the slide zones of landslides, along the boundary between the untouched substratum and disintegrated, gravitationally moved fragment of massif.
c) Boulder caves, produced by chaotic movements of rock blocks usually within the colluvia and in Viték's (1983) classification representing the talus type caves.

The presented above classification makes possible clear and unequivocal determination of nature of caves genetically related to gravitational processes in mountain slopes.

The datings of carbonate, occasionally organic speleothems occurring in some (slightly more than ten) non-karst caves in Polish Outer Carpathians by the radiocarbon method (also by U-series method and palynological analysis) proves that the oldest such caves were "opened" in the Late Glacial (caves: Jaskinia Słowiańska-Drwali in the Beskid Niski Mts. and Jaskinia Miecharska in the Beskid Śląski Mts.) (Urban et al., 2015). Principally the beginning of the formation of these carbonate speleothems or their distorted/de-concentric growth (indicating the gravitational rotation of rock blocks) fell on the phases of precipitation increase in the Late Glacial and the Holocene, during which the intensification of mass movements were also recorded.

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Variability of caves conditioned by morphogenesis and lithology - Homole Gorge (Polish Carpathians) case study

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1. Homole Gorge – geological and geomorphological settings

The Homole Gorge is situated in the eastern part of the Pieniny Mts, a specific mountain range in the central part of the Polish Carpathians. In the geological terms the Pieniny Mts. represent the principal part of the Pieniny Klippen Belt (PKB) – narrow tectonic zone separating the Inner Carpathians from the Outer Carpathians and being a flower structure with tectonic melange (Plašenka and Mikuš, 2010; Jankowski, 2012). PKB is built by various Jurassic and Cretaceous sedimentary rocks: bioclastic limestones, micritic limestones (massive and bedded), marly limestones, marls, radiolarites (a type of hornstones) and claystones (Birkenmajer, 1971; Oszczypko and Oszczypko-Clowes, 2014).

The Homole Gorge is situated just below the highest summit of the Pieniny Mts, Mt Wysoka (1050 m a.s.l.) within the geological unit called Homole slab, slightly dipping to the north and formed mainly of limestones overlying plastic clays and claystones. Consequently, the slab is partly dissected by tectonic discontinuities (faults and even overthrusts) of the Alpine (Paleogene or Neogene) age, which recently (in the Late Neogene and the Quaternary) have developed as dip-slip, normal gravitational faults (of the dislocations reaching even 200 m) framing the slab. According to Birkenmajer (1971), the Homole Gorge has developed probably along the zone of tensional splitting of this slab during several stages of the slap uplift since the Late Neogene (see also Zuchiewicz 1984).

Consequently, the Homole Gorge is a valley of the S-N direction, 100-150 m deep and 100-400 m wide. In the lower section it is V-shaped and framed from the west with rock wall and from the east with rock crest several tens of meters high (Fig. 1). In the upper section the valley is U-shaped and partly filled by landslide bodies and lacustrine sediments of the paleo-lake dumped by landslide body at the beginning of the Holocene (Alexandrowicz, 1993).

2. Caves of the Homole Gorge

In the Homole Gorge 32 caves of the total length 271 m have been recorded (Gubała, 2006, Gubała and Urban, 2007). The longest cave, Jameriskowa Jama is 57.5 mlong, three other ones are relatively long (19.5-26.0 m), while 53% caves are not longer than 5 m. However, the recorded caves represent several different morphological and genetic types, which are connected with the stages of the gorge development.

2.1. Karst caves

The karst caves are concentrated in the boundary zone between the crinoid and micritic limestone series, within the rock crest, that separates the gorge from the fault zone framing the Homole slab from the northeast (NEE) (Fig. 1). They are tubular or lenticular conduits of the length ranging from several to ca 20 m (Jaskinia z Filarkami – 26.0 m long), dipping to the northeast or aggregations of cupolas (Schron z Oknami – 5.5 m). Their shape, spatial orientation and occurrence suggest that they were genetically connected with underground water flow from the central part of the Homole slab to its eastern tectonic margins. Consequently, they represent relic, paleokarst systems formed relatively deep (in freatic zone?) and preceding the split of the Homole slab, which triggered the development of the gorge, because this splitting and subsequent morphological cut of the slab completely changed system of water circulation (Gubała and Urban, 2007). Their occurrence confirms the hypothesis of Birkenmajer (1971) stating that the development of the Homole Gorge was triggered by the tectonic break of the Homole slab.

2.2. Non-karst caves

The other groups of caves in the Homole Gorge represent non-karst (or partly-karst) forms which are spatially and chronologically related to the morphogenesis of the gorge. Most them formed due to the gravitational movements of rock massifs – slides or other slow movements of competent rocks, such as limestones, radiolarites, generated by plastic deformations of the clay-claystone substratum – a process called cambering and gulling (Hutchinson, 1991). The gravitational movements shaping the upper section of the Homole Gorge (Fig. 1) occurred in various phases of the Holocene or the Late Pleistocene, because they preceded and postdated the deposition of the sediments of the landslide lake in the upper section of the gorge, dated by Alexandrowicz (1993) at the Early Holocene. Consequently, the formation of the gravitational caves can be attributed to the Early Holocene or the Late Pleistocene, when the plastic deformation of the clay-claystone substratum could have been stimulated by permafrost deterioration (see Hutchinson, 1991). Two characteristic morphological types of non-karst caves (Viték, 1983; Bella and Gaál, 2011) occur in the Homole Gorge: crevice type and talus (boulder) type. Majority of this first group represent the initial and dilational caves in the lights of new morphogenetic and geomechanic classification proposed by Urban and Margielewski (2013). These caves formed in the massive limestones, occasionally also in bedded limestones and radiolarites, due to the slow and spatially limited movements of individual massifs, usually spreading (e.g. Szczelina koło Sadu – 20,0 m, formed along the fault surface), toppling (Jaskinia z Obrączką – 9,0 m) or backward rotation (e.g. Czerwony Most – 9,0 m). The largest cave in the Homole Gorge – Jameriskowa Jama – represents talus (boulder) type. This cave and some caves in its vicinity of the crevice and talus types, are very specific objects genetically connected with slow plastic deformation of the clay-claystone substratum and slip of the rigid limestone blocks (massifs). The third group of caves and rock shelters is represented by concavities, niches and short fissures formed owing to mechanical and chemical weathering (partly karstification, e.g. Okap nad Przepływami I – 2.5 m) combined with gravitational rock fall. They have been formed in (sub)vertical limestone cliffs and are usually the youngest forms among the caves.

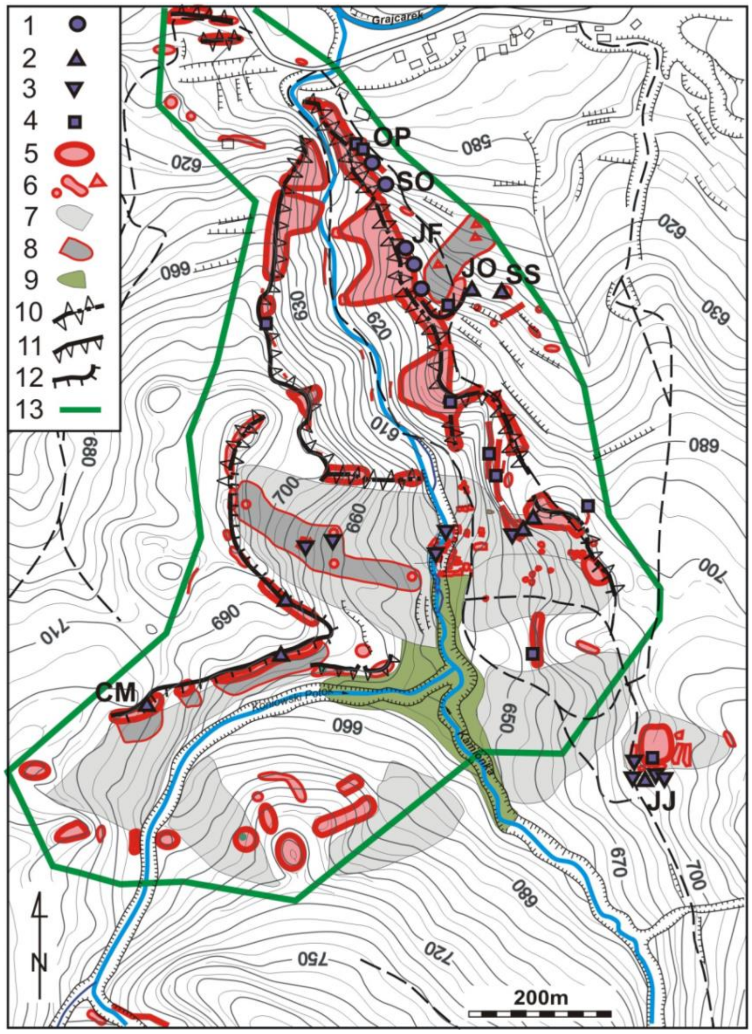

Fig. 1: Map of the Homole Gorge with caves, rock forms and landslides. Explanation of symbols: 1 – karst cave, 2 – crevice type cave, 3 – talus (boulder) type cave, 4 – weathering-gravitational cave (rock shelter), 5 – large rock form, 6 – small rock forms, boulder, 7 – landslide, 8 – blockfield, 9 – lacustrine sediments, 10 - rock crest, 11 – rock cliff, 12 – landslide scarp, 13 – boundary of Homole nature reserve. The caves mentioned in the text: CM – Czerwony Most, JF – Jaskinia z Filarkami, JJ – Jameriskowa Jama, JO – Jaskinia z Obrączką, OP – Okap nad Przepływami I, SO – Schron z Oknami, SS - Szczelina przy Sadzie.

3. Conclusions

Despite usually small sizes of the caves recorded in the Homole Gorge, their genetic and morphological variability is relatively high. It is conditioned by morphogenesis of the gorge, lithological variability of rocks as well as the local relief. The particular types of caves are accurately connected with various stages of the geological-morphological evolution of the area. The following genetic cave types have been distinguished:

- the karst caves, which document the early stage of the geological evolution, preceding the initiation and incision of the Homole Gorge,
- the non-karst gravitational caves formed owing to the slow or fast (landslide) deformations of plastic substratum of competent rocks (mainly limestones) during the Holocene or the Late Pleistocene,
- the weathering-gravitational rock shelters representing the youngest group of such forms and related to direct weathering of rock walls and rock fall.

The morphological and genetic variability of caves is significant value of the geological heritage of the Homole Nature Reserve.

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Crevice-type caves of the Moravskoslezské Beskydy Mts as important part of bats habitat

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Microclimate of crevice-type caves (CRCs) of the Moravskoslezské Beskydy Mts predisposed to wintering of bats. Long-term temperature and humidity observations demonstrate habitat conditions suitability to bats occurrence. Dynamic thermal regime is observed in parts related close to the outside e.g. by narrow crevices or close to the entrance. Temperature in these parts is influenced by outside conditions. Deeper parts of caves or parts with greater distance from the entrance have static microclimatic conditions (especially by static temperature regime). This static microclimatic regime is characterised by temperature about +6 °C and relative humidity from 90 to 100%. These conditions are very favourable for bats hibernation especially for the *Myotis myotis* and *Rhinolophus hipposideros* which are the most abundant species of chiroptera (bats) in the caves of the Moravskoslezské Beskydy Mts. The numbers of bats were monthly monitored from the years 2012 and 2015. This monitoring shows that the numbers of the observed bats is very variable. E.g. in the Kněhyňská Cave, especially in the end of the hibernation period a large number of bats is observed in comparison with first half of the hibernation period. It is therefore questionable where the bats are founding. Generally know that the *Myotis myotis* is wintering individually in the larger e.g. underground space. In fact, the bats are probably occurred in the unknown large parts e.g. of the Kněhyňská Cave.

The Mroczna Cave in Magura Wątkowska mountain range - stages of development based on the joints morphotectonic analysis

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The Mroczna Cave is one of the longest caves in the Beskid Niski Mts., located on the south-western slopes of Mt Kornuty. It is situated directly in the zone of the landslide main scarp, which is composed of several cutting surfaces. The cave is formed within the set of crevices that are directly connected with the rock scarp and developed due to the disintegration of this zone. The shape and direction of the cave passages indicate the dilatational nature of its development along a cutting surface that separates the downslope part of the massif from the main part of the mountain massif. The Mroczna Cave was formed during the secondary movements following the main phase of landslide formation, which led to the disintegration of the main scarp and the formation of the currently existing scarp. Its passages were formed (as widened, expanded joint crevices) during subsequent disturbances of the slope stability (as has been determined for other landslides and caves in the Outer Carpathians - e.g., Janiga 1974, Puchejda 1989, Margielewski 1998, 2002, Margielewski, Urban 2003).

On the basis of the morphology of the cave passages, four parts were distinguished in the cave. The comparison of the spatial orientation of the upper and lower sides of the cave passages allows me to reconstruct several stages of cave development (Fig. 1) expressed in the different gravitational movements of rock blocks. Several types of movements were specified: toppling, backward rotation, and rotation around the vertical axis. The spatial situation of the entrance section of the cave (I) suggests that it is directly related to the movements along the current landslide scarp (Fig. 1). The cave passages perpendicular to this scarp seem to be also genetically associated with the upper part of the cave. During counter-clockwise rotation of upper part cave (downslope walls), perpendicular passages was clamped by compression. The main movements which led to the formation of these parts were toppling and rotation around the vertical axis. The next stage of cave development consisted in the formation of the passage of the second (II) part of the cave, which can be identified by the new cutting surface (Fig. 1). The strong disintegration of the massif observed in the deepest part (IV) of the cave suggests that the cutting surfaces observed within the cave and at the ground surface come together in the deep-seated part of the massif and contribute to the formation of the landslide shear zone (Zatorski in print).

Consequently, in accordance with Urban and Margielewski’s (2013) morphogenetic classification, the parts close to the cave entrance and transverse to it (I and III) represent the intermediate type, whereas the part oriented similarly to the predominant direction in the landslide scarp (II) belongs to the initial type. According to the geomechanic criteria of this classification, most cave passages represent the dilational type, but the deepest part (probably associated with a shear zone) can be of the dilatancy type.

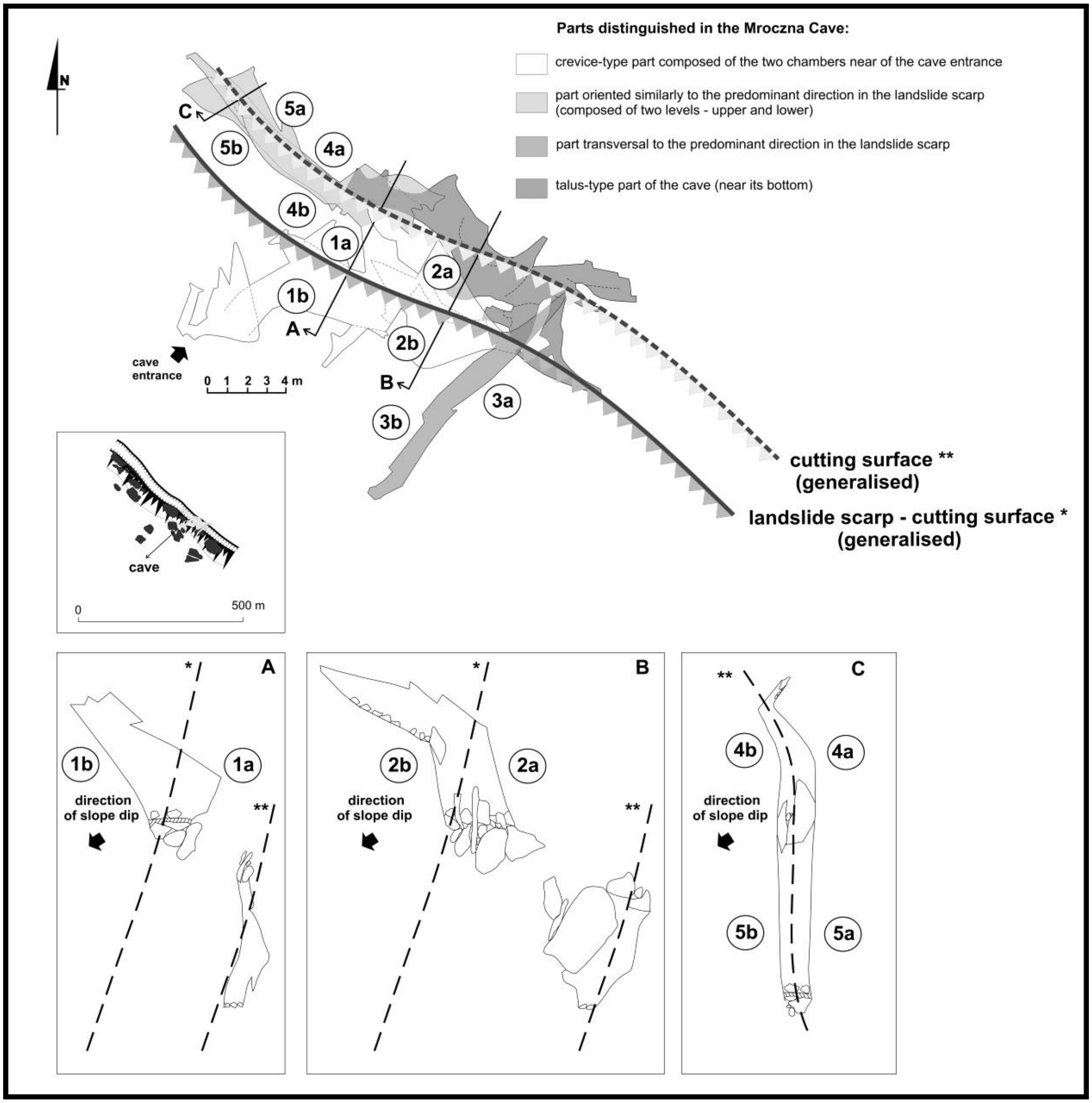

Fig. 1: The Mroczna Cave map with location of the main landslide scarp and cutting surface of the rock massif. Four parts of the cave are marked in different grey colors. A, B, and C—cross-sections of the cave passages. Numbers "1"–"5" indicate places of spatial orienatation measurements in the cave, while the letters "a" and "b" indicate location of the walls in the upper sides („a") and lower sides („b") of cave passages (chambers).

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Water in the caves of Polish Outer (Flysch) Carpathians (Beskidy Mountains)

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In the Outer Carpathians, called in the Polish segment Beskidy Mts. and Bieszczady Mts., built of flysch, siliciclastic-clay rocks, more than 1250 caves with a total length of more than 22.5 km have been recorded up till now (Klassek, Mleczek 2012). All caves are of non-karst origin, most of them have been formed due to gravity-driven slope failures (Urban, Margielewski 2013). In about 30 of these caves (Fig. 1) the larger amounts of water has been observed. There are permanent, perennial or periodic streams and ponds/pools as well as relatively long-lasting ice bodies to be found (Franczak 2012). Historically, the first cave in which such phenomena were described was Jaskinia Malinowska, in which pools occur at the bottom (Klassek 1997a). A drained pond was found in the Jaskinia Wodna w Piotrusiu cave near Dukla (Suski 2001), while undrained ones were described in the Schronisko w Marklowicach (Kasprowska 2010), Jaskinia w Suchej Górze II (Mleczek 1998), Jaskinia Mokra and in the Dolny Waserszlog caves (Figs. 1) (Franczak et al. 2013). Most of these ponds are of small size. A relatively larger pond occurs in the Sala z Jeziorkiem of the Jaskinia Miecharska cave. Apart from this pond, in the same cave the second, smaller pond was found in the Korytarz za Wodą (Gallery behind Water) (Szura 2010). In the following Carpathian caves the periodic, usually seasonal ponds and pools have been recorded (Fig. 1): Mysiorowa Jama w Zagórzu (Klassek 1997b), Szczelina w Klimczoku I (Suski 2001), Jaskinia Wesoła (Mleczek 1998) and Jaskinia w Miecharskiej 2 (Franczak et al. 2013).

Apart from ponds, in the Jaskinia Miecharska cave a permanent stream flows through nearly the whole main gallery system forming a waterfall of about 3 m height (Margielewski et al. 2007; Szura 2010). The permanent water streams (although often small) were observed also in much smaller caves, such as: Jaskinia Wodna w Piotrusiu, Mokra Dziura w Ciężkowicach, Mokra Izdebka II, Schronisko w Polichtach III and Śmietnik (Franczak 2012). Moreover, the seasonal and ephemeral streams, active after the spring thaws and heavy rainfalls occur in the Jaskinia Salmopolska (Ganszer 1998; Urban 1998), Jaskinia Wiślańska and in the Jaskinia Mokra (Fig. 1).

The hydrologic objects can be also connected with anthropogenic transformations. The pool in the small Staw cave (rock shelter) is situated in a hole (trench) dug by man. The lower parts of Jaskinia Rybia cave (Fig. 1), situated on the bank of artificial Jezioro Rożnowskie (Rożnów Lake) were filled up by water owing to artificial dumping of the valley, when the lake was formed (Franczak 2012). The superficial streams occur also in the direct proximity of some caves, which caused their occasional intensive influence on the cave environment. For example during floods water of the Skawica Górna stream fills the Zalewowy Schron cave (rock shelter), which is indicated by the character of cave sediments (Franczak 2012). Occasionally also the Schronisko w Przełomie Skawicy and Szczelina Rzeczna w Szczyrku are overflowed. In turn, over the entrances of the Jaskinia Komonieckiego cave and Schron pod Uporowym Wodospadem rock shelter waterfalls are situated (Fig. 1) (Franczak et al. 2013).

The other form of the water occurrence in the caves is ice, which occurs in the caves usually in the autumn-winter season. However, under convenient conditions such ice bodies can last during spring and even the whole year. The optimal microclimatic conditions for the occurrence of ice bodies exist in the caves within deep ridge trenches and intercolluvial depressions (within rock landslides). In the caves situated in such places thick ice bodies develop, covering their bottoms and walls or even filling whole caverns. In the transitional periods (autumn-winter and winter-spring), when the temperature differences between the deep and near-entrance parts of caves are the largest, icicles and ice ribs are formed. Among the caves with relatively large ice bodies formed in the autumn-winter season the following ones should be mentioned (Fig. 1): Jaskinia Lodowa w Szczyrku, System RI w Okrąglicy, Jaskinia Lodowa w Czarnych Działach, Nora w Kościelcu ze Śniegiem (Ganszer 2004), Jaskinia Lodowych Stalaktytów. Jaskinia Lodowa w Zamczysku is an example of a cave, in which the ice body can remain during the whole summer (Szura 2004). In regard to the specific environmental conditions favourable for the occurrence of long lasting ice bodies, the caves situated in the south-eastern slopes of Mt Kilanowska near Dukla in the Beskid Niski mountain group belong to the most interesting ones. In this area 69 non-karst caves of a total length of 1755 m have been recorded so far (database: http://jkf.m3.net.pl/index.php).

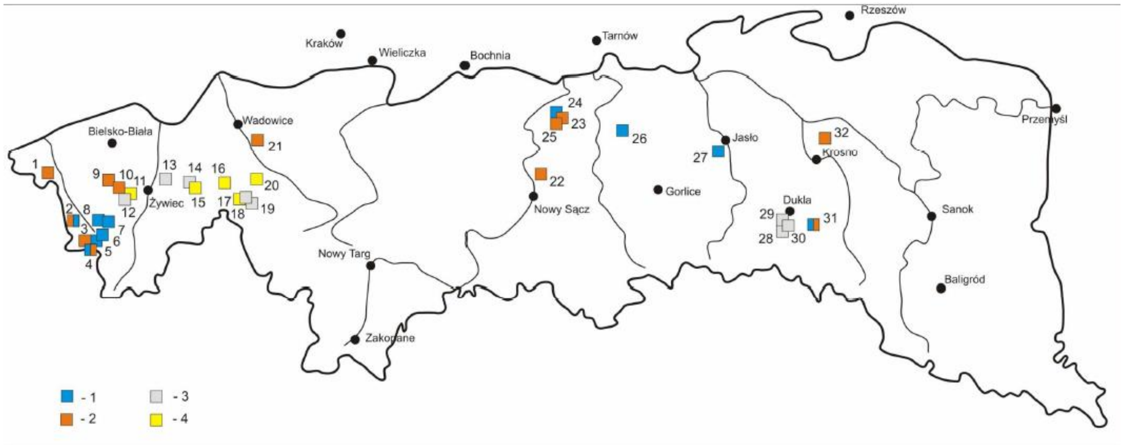

Fig. 1: The distribution of caves with water and ice in Polish Outer Carpathians; 1 – cave with permanent or periodic stream, 2 – cave with periodic or permanent pond/pool, 3 – cave with long-lasting ice, 4 – cave periodically flowed with stream water. The caves mentioned in the text: 1 – Schronisko w Marklowicach, 2 – Jaskinia Mokra, 3 – Jaskinia Malinowska, 4 – Jaskinia Miecharska, 5 – Jaskinia w Miecharskiej 2, 6 – Dolny Waserszlog, 7 – Nora w Kościelcu ze Śniegiem, 8 – Jaskinia Wiślańska, 9 – Jaskinia Salmopolska, 10 –Śmietnik, 11 – Szczelina w Klimczoku I, 12 – Szczelina Rzeczna w Szczyrku, 13 – Jaskinia Lodowa w Szczyrku, 14 – Jaskinia Lodowa w Zamczysku, 15 – Jaskinia Lodowa Czarne Działy, 16 – Jaskinia Komonieckiego, 17 – Schron pod Uporowym Wodospadem, 18 – Zalewowy Schron, 19 – Jaskinia Lodowych Stalaktytów, 20 – System RI w Okrąglicy, 21 – Schronisko w Przełomie Skawicy, 22 – Mysiorowa Jama w Zagórzu, 23 – Jaskinia Rybia, 24 – Schronisko Staw, 25 – Schronisko w Polichtach III, 26 – Jaskinia w Suchej Górze II, 27 – Mokra Dziura w Ciężkowicach, 28 – Mokra Izdebka II, 29 – Jaskinia Słowiańska-Drwali, 30 – Jaskinia Lodowa, 31 – Gangusiowa Jama, 32 – Jaskinia Wodna w Piotrusiu, 33 – Jaskinia Wesoła

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The Čertova díra cave (photo by Jan Lenart

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