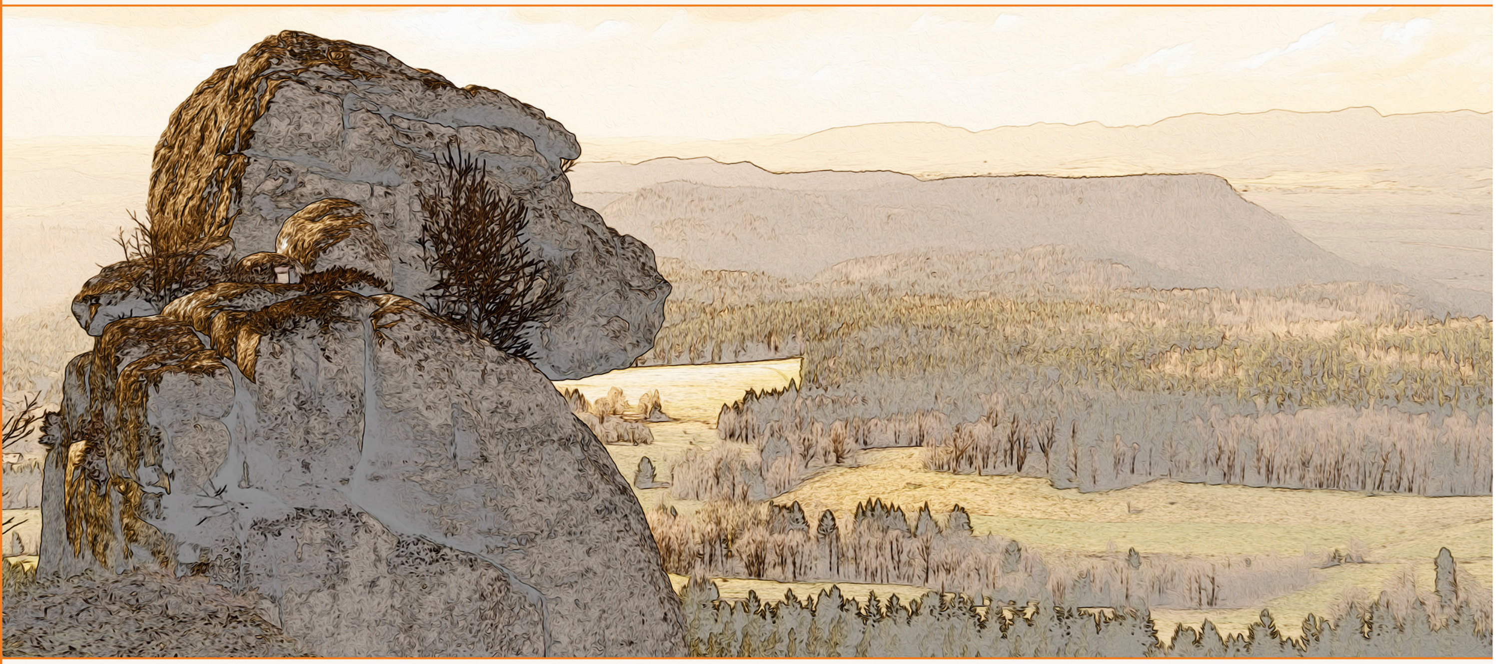
Union Internationale de Spéléologie

14th International Symposium on Pseudokarst

Sudetes, Southwestern Poland, Karłów 24–27th May 2023

ABSTRACTS



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Preface

Although the term "pseudokarst" has not been precisely and convincingly defined, the need of its usage seems obvious, because caves of non-karst or problematic genesis, as well as polygenetic caves are very frequent. They represent a great number of caves discovered, explored and studied currently and in the past. And there are much more superficial landforms and phenomena (as swallow holes etc.) similar to karst but not of karst origin. However, they are still undervalued in publications, presentations and media reports dedicated to cave and karst exploration and research. Even in the International Year of Caves and Karst celebrated in 2021-2022, "karst" was clearly called in its name, but we know that many caves are not karstic, or only partly karstic. Our contribution to the celebration of this Year was the 30th issue of the Pseudokarst Commission Newsletter (http://www.pseudokarst.com/ : Newsletter) that presented numerous examples of such caves occurring all over the world.

The 14. International Symposium of Pseudokarst held in the Sudetes, SW Poland, is an excellent proof that the genetic research and other scientific studies of non-karst caves and pseudokarst landscapes are commonly conducted. The diversity of rocks and landforms analysed in the speeches, and then papers in this volume, are very large – from sandstones deposited in different sedimentary basins, through volcanics, up to limestones and igneous rocks that occur in uplands, mountainous areas but also sea-shore zones. Not less numerous is the richness of phenomena and processes discussed during the Symposium – from gravitational and erosive processes, through complex chemical weathering and specific karstification conditioned by specific or changeable environmental factors, up to volcanic or human activities. Among the caves and other landforms described in the papers are, therefore, unique and very specific ones. These features are characterised using wide spectrum of methods: from simple observations and cave explorations (but sometimes advanced as e.g. scanning), through various geophysical methods, recently very useful and popular, up to laboratory analyses. Can you imagine such a rich list of topics in a symposium dedicated to karst issues? No, this is only possible during the pseudokarst symposium!

We waited long time for the 14th International Symposium on Pseudokarst, because the 13th Symposium was held in Kunčice pod Ondřejnikem, Czech Republic, in 2015. As you know very well, the reason of this prolonged waiting was the pandemic situation, because the first attempt to organise such a meeting took place in the Świętokrzyskie Mountains, central Poland, in 2020. And this attempt was repeated in 2021 but without success. The appropriate conditions for the implementation of this idea appeared in 2022-2023 with the joining of the Pseudokarst Commission by new, young members from the Wrocław scientific centre, which conduct their studies in the Sudetes, mainly Stołowe Mountains. Therefore, I am very grateful to these members for their such active involvement in the activities of the Commission. But above all, I am very pleased that the issue of pseudokarst has gathered such a large group of scientists and cave explorers in this Symposium. I am sure that our meeting will bring an interesting exchange of views, will inspire profitable cooperation, and consequently will lead to significant scientific results.

Jan Urban
President of the UIS Pseudokarst Commission

Geological controls on the formation of caves in sandstone, Kokořín area, Czech Republic

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The Kokořín area lies on the right bank of the Elbe River north of Mělník in north-central Bohemia, forming the southern part of the Kokořínsko Protected Landscape Area. Several levels of structural plateaus combine with the valleys of the Pšovka and Liběchovka streams and their tributaries, forming canyons, gorges, sharp ridges with isolated rock pillars, as well as areally limited rock labyrinths. All outcrops are formed by quartzose sandstones of the Jizera Formation arranged into upwards-coarsening cycles, with only rare calcareous intercalations (Adamovič 1994). Fractures strike NNE–SSW or E–W, mostly represented by dilated joints, occasionally injected by Paleogene–Neogene volcanics. Major faults in the area show vertical displacement not exceeding 40 m (Fig. 1).

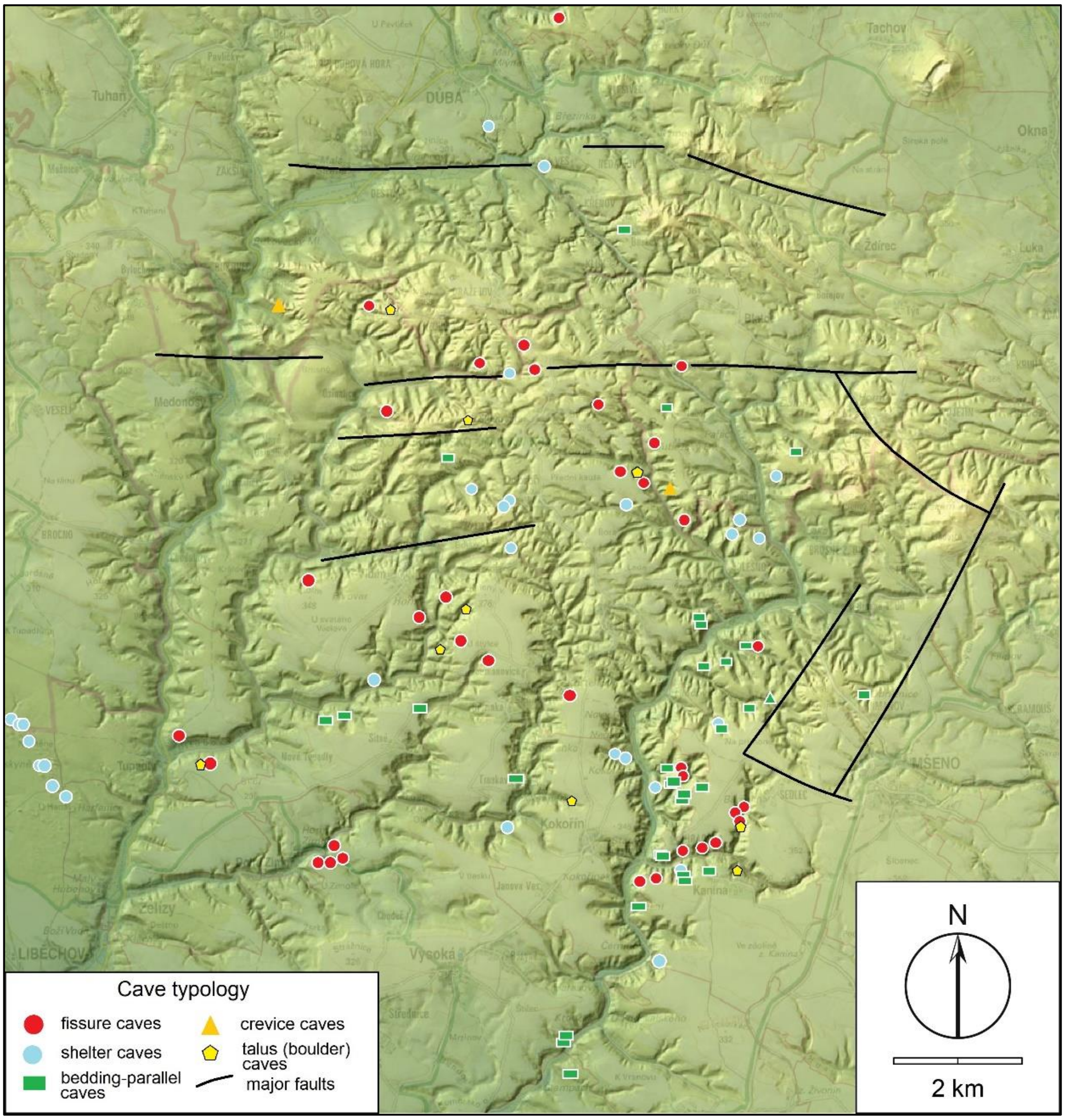

Fig. 1. A shaded-relief map of the Kokořín area with courses of major faults and indicated positions of caves of different types. Courses of faults adapted from Adamovič (2016). DMR after https://ags.cuzk.cz/av/ .

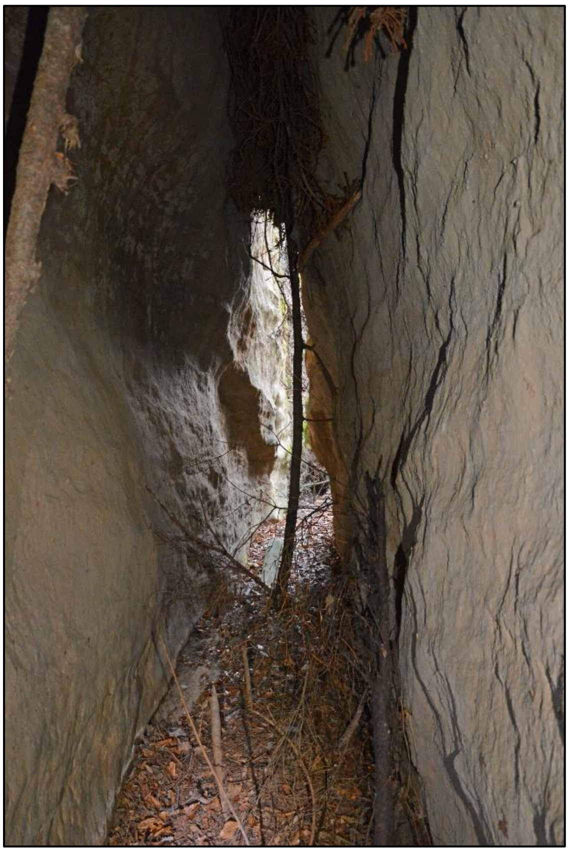

Fig. 2. Fissure cave the ceiling of which is formed by fallen boulders and soil. The upper reach of the Štylec Gorge near Šemanovice (photo J. Adamovič).

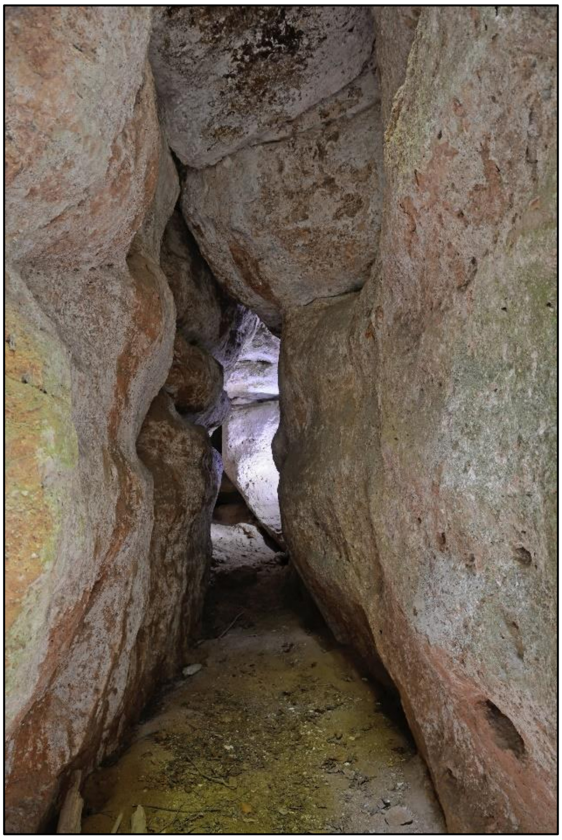

Fig. 3. A side passage in the fissure cave of Dominův sklep near Dolní Zimoř (photo J. Adamovič).

Although the reconnaissance of the Kokořín area has not been completed yet, 110 caves of various types are registered by the authors between the towns of Dubá and Lhotka u Mělníka. Most of the caves are less than 10 m in length, although some bedding-parallel caves or fissure caves exceed 30 m in total length (Zimerman, Piller 2004, Mertlík et al. 2009, Piller, Adamovič 2019). Strictly taken, almost all caves are combined caves or transitional caves between two types.

Fissure caves were formed by erosional widening of subvertical joints and usually display narrow triangular profiles, often several metres high. Their floors are covered with sand or talus of variable size, including boulders. Their ceilings are formed by massive rock or by boulders fallen into the cave. A specific feature of the Kokořín area is the presence of ceilings formed by beds of resistant ferruginous sandstone (Fig. 2). Examples of them can be: Dominův sklep (Fig. 3), Sluj u Micky, Plší jeskyně, Jeskyně pod Shnilým mostem.

Crevice caves are rare and of small size, restricted only to steep slopes with dynamic topography, favourable for gravitational sliding of blocks separated from the massif by basal undercutting or jointing – examples: Močidla Gorge, Planý důl Valley, edges of the Rač Plateau.

Shelter caves *sensu* Palmer (2009), equivalent to cave niches of Vítek (1983), are perhaps the most numerous caves in the Kokořín area. By definition, they are formed by removal of a weakened part of the rock. They have roughly isometric shapes and vary between 3 and 10 m in length (Fig. 4). Two processes are involved in their formation: 1) rapid weathering of sandstone occupying stress shadows in the rock massif (Filippi et al. 2018), 2) evacuation of sand within the limits of former carbonate concretions, later arenized due to cement dissolution (Adamovič et al. 2015). Due to basal undercutting, common in the Kokořín area, rock shelters are related forms but rarely meet the definition of a cave. Examples of shelter caves are the Pod Kaninou, Margareta, Zimermanka caves and the cave in a rocky step on the bottom of the Janošíkova rokle.

Fig. 4. An ellipsoidal shelter cave (cave niche) beneath the village of Hradsko (photo J. Adamovič).

Bedding-parallel caves follow sedimentary strata prone to weathering and erosion. They mostly represent deep notches following major bedding planes or coalesced shelter caves of various geneses. Total lengths of around 10 m are common, and some caves include relatively spacious halls. As examples, the following caves can be mentioned: Pecková (Fig. 5), Hlídky, Uriášova and the cave in the Štylec Gorge. Much like shelter caves, they are associated with certain stratigraphic levels.

Fig. 5. Arcades developed along a specific bedding plane tend to merge to form a bedding-parallel cave. Pecková Cave in the V kříži Gorge near Kokořín (photo J. Adamovič)

Talus caves, or boulder caves, are mostly restricted to areas where sandstone is hardened by near basaltic or phonolitic intrusions. Boulders tend to accumulate on bottoms of narrow, dry gorges, and some of the spaces among them are passable for a short distance – examples: Kočičina Gorge, Sitenský důl Valley, Planý důl Valley, Supí hora and Nedvězí hills.

The only secondary minerals registered in the caves are moonmilk coatings. They are found in fissure or shelter caves whose dripwaters pass through Pleistocene loess covers deposited on plateau tops. Many caves were adapted for shelter, refuge or temporary living in historical times, ranging from the Middle Ages to World War II.

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Contrasting speleothems in sandstone crevice and boulder caves of the Elbe River canyon (northern Bohemia, Czech Republic) – a factor of age?

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The Elbe River canyon in northern Czech Republic, lined by steep slopes up to 300 m high with vast outcrops of quartzose sandstones of the Upper Cretaceous age, features a variety of crevice and boulder caves. Entrances of the largest caves lie 80–240 m above the Elbe River level, in geological terms being positioned in the uppermost part of the Bílá hora Formation or the base of the Jizera Formation (Fig. 1A). Besides ordinary clay and moonmilk (calcite) coatings, two morphological types of coralloids are common: 1) cauliflower-shaped calcite- and silica-dominated coralloids, and 2) silica- and kaolinite-dominated knob coralloids with smooth surfaces and distinctly layered internal structure, also containing phosphate-rich laminae (Fig. 1B, C). These two types of coralloids occur at near sites, often within a single cave. While calcitic coralloids have been reported from this area by Marwan (2000), silica coralloids remained unnoticed for a long time before their description by Adamovič et al. (2022). The coralloids mostly cover steep cave walls and edges, and were clearly deposited in subaerial conditions. Active dripping in the caves is limited to only a few places, not coinciding with the coralloid occurrences.

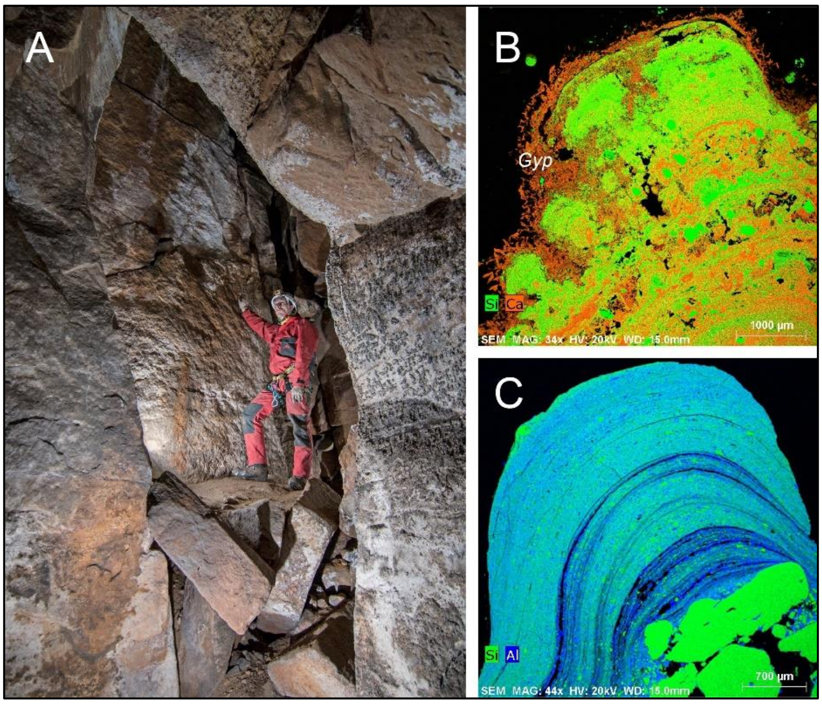

Fig. 1. A – The main shaft of the Loupežnická Cave with cauliflower-shaped coralloids covering the joint plane on the right. B – The distribution of Ca (calcite) and Si (quartz and opal) in a section of the apical part of a cauliflower-shaped coralloid. The top is covered with gypsum crystals (Gyp). Sample 112, Loupežnická Cave, SEM-EDS data. C – The distribution of Si (quartz and opal) and Al (kaolinite) in a section of a knob coralloid. Sample 113, Přesýpací svět Cave, SEM-EDS data (photo A by J. Kukla, photos B–C by N. Mészárosová).

The contrast in mineral composition of coralloids lying closely apart (calcite- *vs.* silica-dominated) is somewhat puzzling and can be explained by deposition from pore waters of different chemistries, possibly at different times. Calcite-dominated coralloids are spatially related to moonmilk coatings and are presumably still active, as suggested by gypsum crystals precipitation both during and after their formation: gypsum is a typical mineral of present salt efflorescences in most Czech sandstone areas. By contrast, silica-dominated coralloids were probably deposited in pre-Holocene times (possibly a warmer period in the Pleistocene) as suggested by their dark brown shiny surfaces rich in organic carbon and their incomplete chemical compatibility with the waters sampled in the caves.

Chemistry of dripwaters from the caves was compared with the compositions of bulk and throughfall precipitations at Kuní vrch Hill, 13 km east of the Elbe River Canyon (monthly monitoring by Navrátil and Dobešová 2018, 2019) and literature data on shallow percolates from overhangs (Navrátil et al. 2013). The dripwaters were modelled for chemical equilibria with MINEQL ver. 4.5.

Dripwater(1), taken from the Loupežnická Cave, is of a semi-neutral pH (6.1), with low Al concentrations, comparable to those in bulk precipitation, elevated Si concentrations, but strongly elevated Ca, Mg and SO_4^{2-} concentrations compared to bulk or throughfall precipitation. The water is saturated with respect to quartz and chalcedony, slightly undersaturated with respect to amorphous SiO_2, and almost saturated with respect to gypsum. The present dripwater(1) is compatible with the composition of cauliflower-shaped coralloids and can be also made directly responsible for the origin of moonmilk. Only modest microbial mediation of silica precipitation was observed in cauliflower-shaped coralloids.

Dripwaters(2) from the Ledová Cave and Přesýpací svět Cave are characterized by high acidity (pH ~3.8 compared to 4.5–6 in bulk precipitation) and strongly elevated concentrations of Si and Al when compared to atmospheric and throughfall waters. Si concentrations clearly exceed even those in dripwaters from rock overhangs. Saturation with respect to quartz, chalcedony and amorphous SiO_2 is the same as for dripwater(1). This prevents opal precipitation, while a direct precipitation of quartz to produce knob coralloids would be possible if supported by evaporation or microbial action. Although no microbial mediation could be confirmed by SEM, the presence of wind-guided forms of knob coralloids and their preferred formation along vertical shafts argues for their origin from pore waters similar to present dripwaters(2) under the effect of draught.

Table 1. Basic chemical parameters of dripwaters from the Elbe river Canyon caves. Average values from Adamovič et al. (2022).

	Dripwater(1) (n = 1)	Dripwater(2) (n = 2)
pH	6.1	3.8
Ca (ppb)	46,170	3,390
Mg (ppb)	10,740	910
Al (ppb)	20	5,150
Si (ppb)	7,020	12,560
SO_4^{2-} (ppb)	137,280	16,020

All dripwaters are highly undersaturated with respect to boehmite, gibbsite and other Al oxides and sulphates. This suggests that kaolinite, forming an important component of knob coralloids, was rather transported through the pore space in the form of clay particles before the deposition on cave walls. The formation of Si-Al speleothems was favoured by the specific lithology of the Elbe River sandstones (prevalence of quartz with kaolinite admixture), which explains the scarcity of similar forms in sandstone caves elsewhere in the temperate zone.

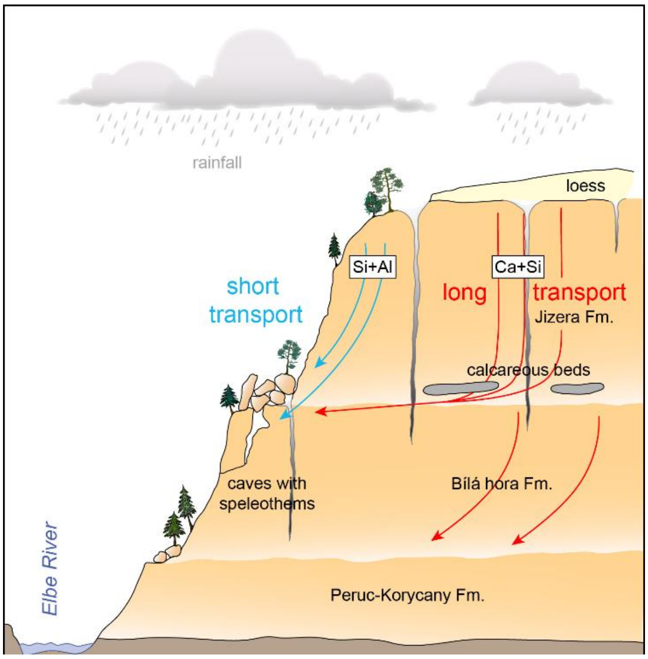

Fig. 2. A scheme of the presumed different seepage paths of waters of deeper circulation producing cauliflower-shaped coralloids (Ca+Si) and waters of shallow circulation producing knob coralloids (Si+Al). Alternatively, acidic waters producing knob coralloids were not buffered by loess because they by-passed loess deposits or preceded loess deposition.

Present dripwaters(1) represent precipitation waters buffered by Ca-rich rocks along the trajectory of their movement through the rock massif: either by calcareous intercalations in quartzose sandstone, previously reported from basal Jizera Fm. by Klein et al. (1967), or by Pleistocene (Würm) loess which covers the top of the plateau above the Elbe River Canyon. Present dripwaters(2) are shallow-circulation waters whose acidity was further enhanced by humic substances leached from the soil (Fig. 2). Formation of knob coralloids from acidic pore waters of chemistry similar to dripwater(2) can be possibly explained by their old age – prior to the deposition of the loess cover.

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Tafoni on rock surfaces in the Ukrainian Beskydy Mountains: morphological observations

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The study of tafoni as predominantly negative microforms of the walls of rock formations has a long history. The authors consider the issues of their morphology, genesis and evolution. Tafoni microforms have been studied in different regions of the world: Central Europe (Adamovič et al. 2015), Świętokrzyskie (Holy Cross) Mts. in Poland (Urban, Górnik 2017), USA (Turkington, Phillips 2004; Paradise 2015), China (Chen et al. 2019), South Africa (Mol, Viles 2012) and others.

Turkington and Phillips (2004) describe tafoni as mesomicroforms 2–10 cm in size in the classification of cavernous forms. Tafoni develop in various rocks, also the most common, such as sandstones, granites, conglomerates, and limestones. The main factors of their development include climate, lithological changes, weathering and erosion processes. Filippi et al. (2018) identify such tafoni formation factors as the influence of raindrops, capillary water effect, frost and salt weathering, and the influence of biota. Occasionally, runoff moisture also has certain effect (Mol, Viles 2012). Paradise (2002) investigated the dependence of tafoni frequency, location, and size on exposure and pointed out that insolation and temperature are important factors of their occurrence. He also found that southern walls tend to exhibit the largest cavities in arid climates, because that is where the wetting-drying and/or heating-cooling cycles are increased. Some tafoni are considered to be relicts of carbonate-cemented concretions that were weathered and decomposed (Adamovič et al. 2015).

Paradise (2015) distinguishes the following morphological varieties of tafoni: honeycomb, sidewall tafoni, basal tafoni, nested tafoni, iconic tafoni, which can bear a resemblance to an animal's head, face, mushrooms, structures, and writing. By default, they are elliptical or rounded in shape – this is the minimum volume that a certain body can occupy. Regarding the issue of tafoni evolution in morphological terms, the criteria of change in shape, change in the width-depth and height-depth ratio are used. The tafoni evolve from cavity initiation and development, to enlargement, then coalescence, and sometimes back to cavity initiation (Paradise 2015).

The history of the tafoni study in the Carpathian region as dynamic microforms on rocks is several decades old (Alexandrowicz, 2008 – Polish Carpathians; Zinko 2008; Ridush, 2012; Bayrak, 2019 – Ukrainian Carpathians). In these studies, tafoni were not the main subject of research, but appeared as one of the features in the characterization of rock forms.

The purpose of the presented research is to analyze the morphology of tafoni on sandstone rocks of the Ukrainian Beskydy, their typification to establish the factors of development and stages of evolution. The researchers implement the following tasks: description of the tafoni morphology and their spatial structures, analysis of the influence of various factors on their formation, in particular, lithological diversity, fracturing, and exposure. The following research methods are used: morphographic and morphometric inventory, relationships between morphological types of tafoni groups with lithological and climate-exposure factors, comparative-geographical, comparative-ecological, and spatial structure analysis.

There are about ten crag groups in the Ukrainian Beskydy, in particular, west to east: Urytskyi, Yamelnytskyi, Komarnytskyi, Kniazhi Rocks, Kliucha-Kamianky, Rozhirche, Bubnyskyi, Tserkovianskyi (Bayrak, Teodorovych 2020) (Fig. 1). In terms of morphology, crag groups in the Beskydy are classified into the following types: rock towers (pinnacles, spurs, mushrooms), elongated and chain-shaped (walls, blocks, slabs), arched and combined forms; natural rock outcrops are also classified into three other types: cliffs (bluffs), canyons (trenches), and triangular prisms (Bayrak 2019). Most of the crags are formed of sandstones of the Yamna Formation of the Lower Paleogene age, while the crags of the Rozhirche are built of sandstones of the Vyhoda Formation of the Eocene age. Sandstones are massive thick-bedded, light grey and yellowish with interlayers and lenses of gritstone and fine-grained conglomerates. Single sandstone layers are separated by thin interlayers of grey or greenish grey argillites. Occasionally, the lower part of the sandstone contains cobs of black-colored quartzite, which is probably a product of the destruction of metamorphic complexes. The lithological composition of the sandstones is represented by quartz (85-95%) and feldspar (5-15%), which allows us to classify them as typical feldspar-quartz sandstones. Clay substance acts as cement and its amount in the rock does not exceed 10% (Gavryshkiv 2008).

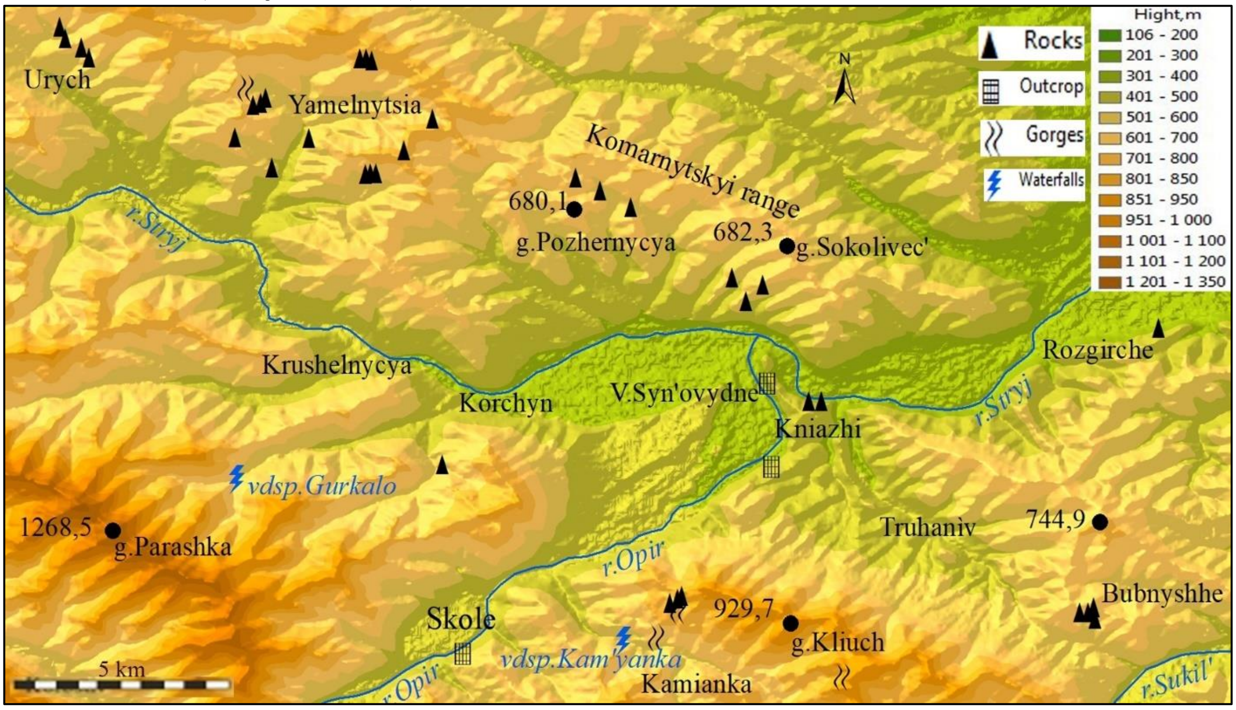

Fig. 1. The location of the crag groups in the Ukrainian Beskydy.

Rocks are significantly dissected by cracks of different genesis and degree of opening: vertical tectonic, weathering, biogenic and lithological, perpendicular to stratification. The rock surfaces are covered by traces of selective weathering of sandstone layers of different composition, areas of tafoni weathering, various anthropogenic signs – from ancient, prehistoric ones to marks made during the Christian era (Zinko 2008). Typical of most rock surfaces are rounded contours and smoothed shapes, which are the results of weathering, flaking and grinding of sandstones during past cold geological periods due to frost and salt weathering as well as aeolian and water (raindrop) erosion, but also in the present-day temperate climate.

The increased lithologic heterogeneity of rocks, especially gritstone and conglomeratic sandstones, contributes to the formation of an original tafoni (cellular or honeycomb) weathering structures on their surfaces.

We have studied the forms of tafoni themselves, which are found in the crags in the Ukrainian Beskydy. In this region tafoni are distributed on rock surfaces in two ways: locally in small areas or covering large areas e.g. whole crag surfaces of particular aspect. In the first case, the forms are located in small groups of 10-30 pieces in separate parts of a rock wall. In the second case, they occupy the entire plane of the rock surface or half of the surface of particular exposure. Local groups of tafoni can be divided into three shape varieties: 1) vertical bands, 2) horizontal bands, and 3) lenticular bands. Tafoni concentrations that occupy the entire one plane of the rock can be located on it: a) chaotically, b) in a chain-like manner (Fig. 2).

The following forms of particular tafone cavities can be distinguished in the Ukrainian Beskydy: 1) rounded, 2) ellipsoid, and 3) vertically elongated. According to the nature of the walls between them, we distinguish: a) with all four edges clear, b) with three clear and one levelled wall, c) with all unclear walls. In the Beskydy, the first type of forms – with distinct edges – prevails.

The size of the tafoni cavities was also evaluated during the research. In ellipsoid and vertically elongated forms, the following parameters were investigated: length, width and depth, and in rounded ones – diameter and depth. The largest length is 20-30 cm, while the diameter reaches 10 cm, and the largest depth ranges 15 cm. Holes of large sizes are not common in the Beskydy, they are found only in the Komarnytski crag group and on the Mala (Small) crag of the Urytskyi complex. Medium and small-sized tafoni are more common. There are isolated large forms up to 30 cm across, as well as small, closely spaced ones.

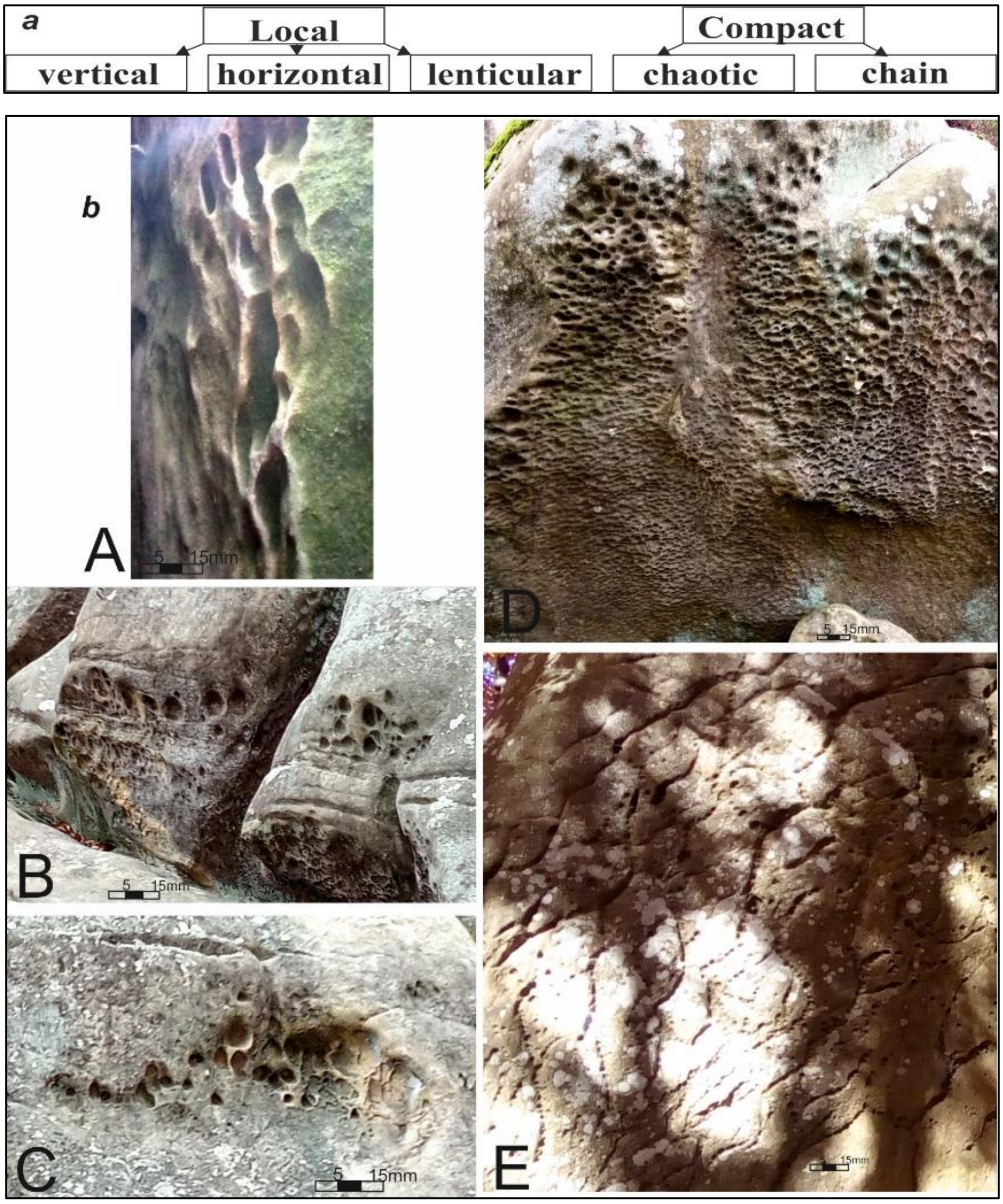

Fig. 2. Types of tafoni groups: a – scheme; b – photographs: A – vertical, B – horizontal, C – lenticular; D – chaotic, E – chain.

In each morphological crag groups different tafoni occur. In the vertical local groupings, vertically elongated and rounded tafoni with distinct four walls or three distinct walls and a lower blurred edge are common. Medium to large sizes prevail. In horizontal and lenticular local groups, ellipsoid tafoni with distinct edges are widespread. The sizes are medium and small. In local groups, tafoni are densely located next to each other and resemble ripples on the shallow seabed.

Rounded, somewhere vertically elongated forms with indistinct blurred edges are common in chaotic groupings of tafoni. They are mostly small in size and deep, occupy rock wall. Chain-like continuous groupings are unique, found on the Sokolivets crags groups in the Komarnytskyi complex and on the crags in the Tserkovianskyi complex. Rounded small forms of tafoni are common here, arranged in elongated grooves resembling chains. The depth of the grooves varies from 1–2 cm on the western side of the rock wall to 10-13 cm on the eastern side.

Each morphological type of tafoni was influenced by its formation factors. There is no doubt that the general process that led to the formation of tafoni is peculiar weathering of concretions (typical of sandstone) formed during the formation of rocks. However, in each case, weathering was influenced by additional factors, such as runoff water – for vertical formations, widening of stratification cracks –

for horizontally formed formations, moisture retention and steam condensation – for lenticular formations. For continuous or semi-continuous tafoni groupings, long-term wetting of the rock surface could have been the driving force of formation. Somewhere, biochemical weathering due to the spread of lichens on the surface influenced their formation. According to our research, the formation of all types of tafoni is largely influenced by the shading of their locations. In shaded areas, aggressive atmospheric moisture stays longer in the near-surface pores of unevenly cemented sandstones, causing the dissolution of minerals.

We also observe that on walls not covered by weathering crusts, tafoni are more widespread and densely arranged than on mineralized surfaces. Tafoni are also often found in niches under horizontal ledges and rock ledges.

The relationship between morphology and climatic factors was also investigated. Studies were conducted on the number and expression of forms on vertical walls of different exposures/aspects. It was found that on "warm exposures", i.e. walls exposed toward southeast, south, southwest and west the total number of cavities and expression of microforms is greater and better than on "cold exposures" of north, northeast, east and northwest aspects. In temperate latitudes climatic conditions (temperature and humidity fluctuations) are important factors in intensifying the degradation of rock walls, including the formation of tafoni type forms. Typical salt weathering – salt precipitation due to alternative moisture supply and sunlight stimulated drying – seems to be important process of various kinds of indentations form on the surface. The intensity of the processes is enhanced by the primary unevenness of the rock surface, such as depressions, niches, protrusions and steps. Cold exposures act more as "conservators" of micro-relief evolution, while warm exposures act as "stimulators" of active microforms development. Therefore, they are concentrated on unweathered surfaces of shaded, overmoistened walls, but of warm, southern exposures.

So, the studies have shown that in the Ukrainian Beskydy, tafoni of various morphology are common. Local groups of tafoni are the most widespread; among them vertical groups have the largest areas. There are also quite a lot of chaotic tafoni groups. There have more rounded shapes than elongated ones among particular tafone cavities. And we also observe greater number of cavities with distinct edges than with blurred ones, which indicates the relative young age of these forms. Our further research will be aimed at establishing relationships between morphology and the genesis of tafoni.

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Volcanic pneumatogenic caves – morphology and genetic typology

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Syngenetic (primary) volcanic caves are formed simultaneously with the formation and consolidation of volcanic rocks during active volcanic activity. The more significant, longer and best studied of these are the lava tubes (pyroducts), the so-called rheogenetic caves (Montoriol-Pous 1973, Licitra 1993). The products of volcanic activity are also gaseous exhalations that create pneumatogenic caves, which include exhalation-explosive and expansion caves (Licitra 1993). Exhalation-explosive caves are usually formed in volcanic cones by eruptions or subsurface explosions of volcanic gases and vapours (Gaál, Eszterhás 1990; Galvánek, Gaál 1995; Eszterhás 2004 and others) or in cones formed by erupting lava (Ollier 1964; Wood 1976a, b; Skinner 1993; Webb et al. 1993). Expansion caves form under the crust of a lava flow (Wentworth, Macdonald 1953; Ollier 1962; Montoriol-Pous, DeMier 1970; Gibson 1974; Grimes 2008), more rarely within it (Bleahu 1982), but also at the contact of hot lava with moist subsoil (Waters 1960; Azizbekjan et al. 1987; Pošteková 2011; Gregorová, Lexa 2017). Exhalation-explosive and expansion caves occur in several subtypes, which are distinguished by differences in their morphology and genetic features.

1. Exhalation-explosive caves. These caves are related to chimneys and side vents in cinder volcanic cones, or to chimneys in smaller cinder cones formed by explosively spattered lava as a result of releasing gases or vapours accumulating beneath solidified lava crust (Licitra 1993).

<u>1.1. Central simple or complex vertical chimneys (primary unfilled volcanic vents) and side inclined branch conduits (secondary volcanic vents)</u>. They formed mostly in cinder (scoria) cones when emerging gases and vapours rise to the surface or explode just below the Earth's surface, especially in agglomerates of lava fragments and bombs (Burbank 1956; Gaál, Eszterhás 1990; Licitra 1993; Galvánek, Gaál 1995; Noskova, Dubljanskaja 2004). Some of them are or completely closed cavities, which were revealed only when the volcanic structure is denuded. Longitudinally, the size of such underground spaces varies, alternating between narrower and wider sections of chimneys, sometimes with chamber-like hollows (with irregular side cavities and rock protrusions, exhalation minerals and coatings often formed in closed explosive cavities).

Lava chimneys in cinder cones are usually a few metres to several tens of metres deep, sometimes more than 100 m, e.g. in the Azores (Borges et al. 1992; Forjaz et al. 2008), and occasionally more than 200 m, e.g. in Iceland (Stefánson 1992; Fig 1A). Lava chimneys in cinder cones differ in their origin from volcanic chimneys and other effusive chimney-like cavities, which are formed by the widening of fissures by lava during an effusive eruption (sufficiently permeable magma allows the expulsion of gas bubbles, which suppresses the fragmentation of the magma) and its subsequent subsidence (Gadányi 2010 and others). Shaft-like cavities in the effusive volcanoes of the Hawaiian Islands exceed 300 m in depth (White 2005; Kempe 2012a, b, 2019). The formation and filling of vents is a dynamic and intermittently recurring process that causes changes in volcano morphology over periods of hours, days, decades to centuries (Harris 2009; Siebert et al. 2010).

<u>1.2. Bottle-shaped chimneys or pits inside spatter cones and hornitos.</u> Spatter cones are formed by the accumulation and solidification of lava explosively ejected from a fissure or vent connected to a deep magma source – a spatter-roofed fissure vent (Wolff, Sumner 2000; Sumner et al. 2005; Fodor, Németh 2015). Their vents (spatter cone vents or spatter cone pits) are tens of metres deep. While the diameter of the surface vents is mostly around 1 m to 2 m, the lower part of the chimneys widens like a bottle (Russell 1902, 1903; Ollier 1964; Taylor 1965; Nieland 1970; Macdonald 1972; Wood 1976a; Skinner 1993; Webb et al. 1993; Boreham et al. 2018; Fig. 1B on the left). The base of some of the chimneys is at a greater depth than the lower edge of the cones spattered above the surrounding terrain (Ollier, Joyce 1973).

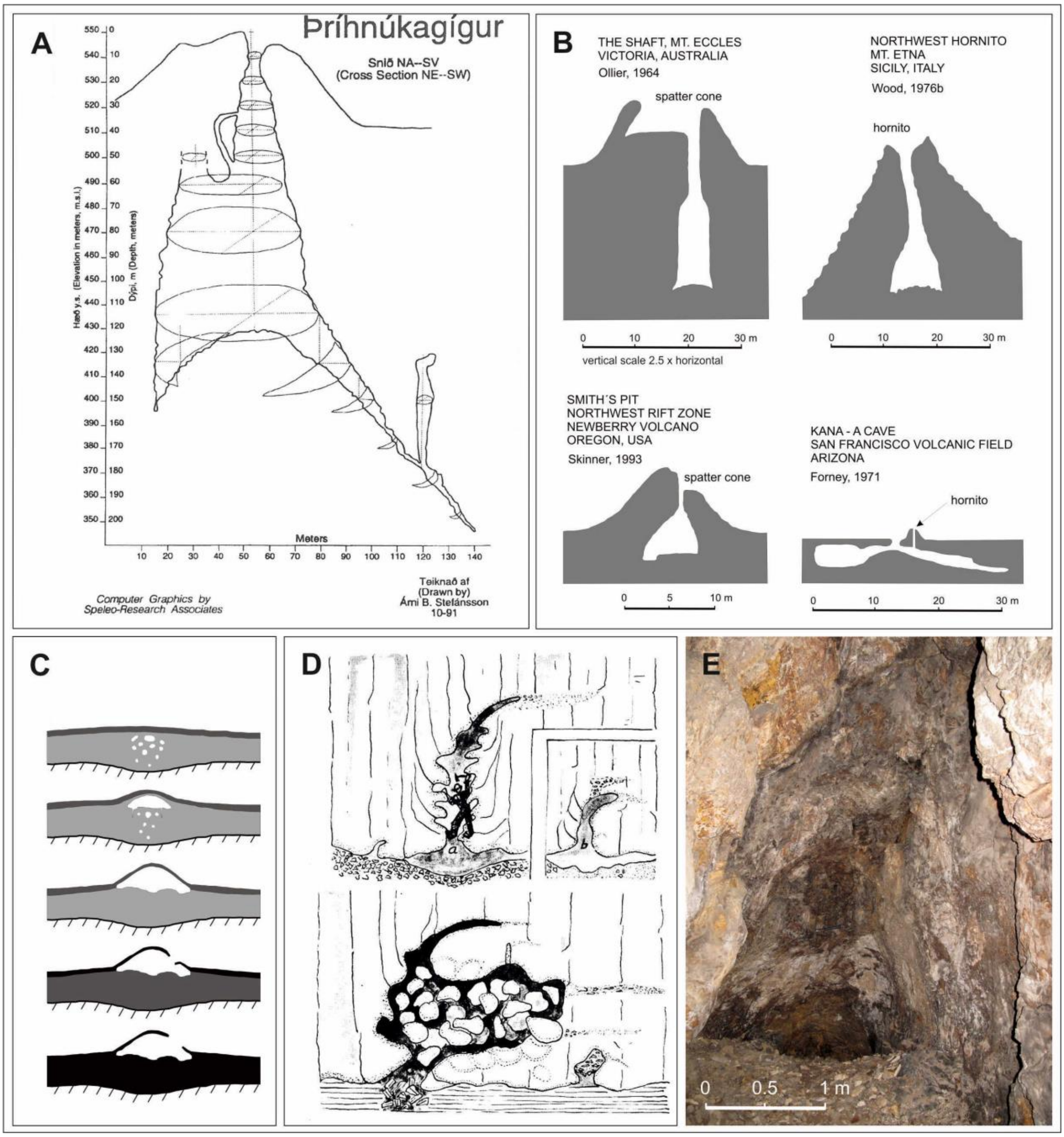

Fig. 1. A – Crater shaft of the Thríhnúkagígur volcano, Iceland (after Stefánson 1992). B – Examples of volcanic chimneys inside spatter cones and hornitos (after Skinner 1993). C – Main stages in the development of lava blister caves (Gadányi 2008). D – Large spiracles in the Columbia River basalt, USA: a) large spiracle with lobate walls rising from a thick mass of aa clinker, Moses Couklee, Washington; b) spiracle, with tongue-like clusters of vesicles, rising from a pit in the underlying pahoehoe flow top, near Olex, Oregon; c) large spiracle rising from beds of water-laid tuff, and expanding into a cavity filled with pillows, Clackamas River, Oregon (Waters 1960). E – Delta Cave, Štiavnické vrchy Mountains, Slovakia, the end part at the base of a rhyolite lava flow (Photo P. Bella).

Smaller cone-shaped mounds, hornitos (tubular mounds), were formed by lava extruded or explosively ejected from a lava tube through a crack in the solidified crust above a pulsating lava flow, usually in places over water-fed sediments (Macdonald 1967; Cas, Wright 1988; Kauahikaua et al. 2003; Gao et al. 2010; Németh 2015; Boreham et al. 2018; Rader et al. 2018; Fig. 1B on the right). They are therefore referred to as rootless lava spatter cones. They are predominantly formed on the surface of basaltic pahoehoe lava flows. Chimneys in hornitos have been studied in Arizona, Oregon and the Hawaiian Islands (USA), Mt. Etna (Sicily, Italy), the Canary Islands (Lanzarote), Iceland, Mexico and China – reaching depths of 10 to 30 m (Wentworth, Macdonald 1953; Forney 1971; Wood 1976b;

Licitra 1993; Skinner 1993; Webb et al. 1993; Gadányi 2007, 2008b, 2010; Seibe et al. 2009; Wood, Zhang 2010; Sauro et al. 2019). Compared to chimneys within spattered cones, they generally do not increase conically towards the bottom, but rather have a tubular shape from top to bottom (Gates, Ritchie 2007). In Iceland, however, Gadányi (2010) describes hornito caves that increase conically from the upper opening to the surface (with a diameter of 0.5 to 1.5 m) downwards (with a diameter of up to 5 m at the bottom). Their bottom is 0.5 m to 1 m lower than the surrounding terrain. The lower flared part of the chimney usually represents the remnant or domed elevation of a lava tunnel over which the bedrock itself was formed (Wood 1976b; Halliday 2004a; see also Skinner 1993).

2. Expansion caves. Expansion caves formed by the pneumatic expansion of releasing volcanic gases, which, by exceeding the lithostatic pressure in the lava, form bubbles until the pressure in the bubble equals the lithostatic pressure in the consolidating lava (not only in the underlying lava flows). The formation of pneumogenic expansion caves is conditioned by large amounts of gases, which, by expansion pressure, dislocate the overlying part of volcanic products with sufficiently high viscosity and plasticity. The high viscosity will not allow the accumulating gases to escape, the plasticity will allow shape deformation before solidification of the body (Licitra 1993). Kempe (2012a, b, 2019) refers to volcanic pneumatogenic expansion caves by the term "partings", considering that along gas bubbles in a lava body, its upper part may detach horizontally and bulge due to lateral pressure. In English terminology they are usually referred to as bubble or blister caves, in German terminology as Blasenhöhlen (Kyrle 1923; Trimmel 1968; Bögli 1978).

2.1. Subcrustal lava blister caves (lava blisters). These caves developed beneath the solidifying viscoelastic lava crust, mainly in basaltic lava (pahoehoe lava) due to the accumulation and pneumatic expansion of released volcanic gases that could not overcome the litostatic pressure of consolidating lava (Skeats, James 1937; Wentworth, Macdonald 1953; Ollier 1962; Gibson 1974; Wood 1976a; Larson 1993; Webb et al. 1993; White 2005; Gadányi 2007, 2008a; Fig. 1C). Grimes (2008) refers to them as gas blisters – terminologically distinguishing them from the subcrustal lava blisters, which were formed by the inflation of liquid lava that later subsided and drained beneath the uplifted and solidified lava crust (tumulus caves after Gadányi 2008a, and Bella 2011).

Blister caves are low and relatively wide near-surface cavities (beneath slightly bulging lava crust) with an oval plan, usually about 1 m in diameter, sometimes larger (Larson 1992 and others). The exceptionally large Abo Dome Cave in southern Idaho (USA) reaches 4 to 5 m in diameter (Larson 1993). The largest and most numerous blister caves in the world are in the Fentale-Metehara area on the main Ethiopian rift, with 639 documented blisters and blister caves in an area of 80 km^2 between the southern foot of Fentale volcano and the northern shore of Lake Beseka (Belay, Asrat 2021). They were formed by the dome-shaped bulging of fluid pyroclastic flows due to the pressure of gases trapped in the advancing flow and the subsequent rupture of some of the hollow domes (Gibson 1974).

2.2. Spherical cavities (geode-like and simple bubble caves). Spherical cavities enlarged due to the accumulation and pneumatic expansion of volcanic gases inside the solidifying lava flows. Simple geode-like cavities were described also in the magma body, possibly also in basalt dikes (Gadányi 2010) – magmatic pneumatogenic caves. The Pestera de Opal Cave (Gurghiu Mountains, Romania) is considered to be a geode cavity with opal mineralization (Bleahu 1982), probably formed by the pneumatic expansion of gases (Tulucan 1984 in Eszterhás et al.1997). Caves similar in shape to giant geodes were formed mainly in igneous crystalline rocks (Dubljansky, Andreychuk 1989; Holler 2019).

2.3. Basal cavities originated at the contact of lava flows with the wet underlying rock basement. They are known from basaltic lava flows, as well as from short and thick rhyolite lava flows (*coulées*), when a large amount of released water vapour accumulated and expanded in their lower part after contact with wet underlying rocks (Waters 1960; Azizbekjan et al. 1987; Pošteková 2011; Gregorová, Lexa, 2017; Fig. 1D). Similar to geode-like caves within lava flows, these caves represent a less common and less well-known group of volcanic pneumatogenic expansion caves. In the existing genetic classifications of volcanic or pseudokarst caves (Maximovič 1974; Wood 1976a; Gaál, Bella 1994; Halliday 2004b; White 2005; Gadányi 2008c; Kempe 2012a, b, 2019; Bella, Gaál 2013; Holler 2019 and others), as well as in the classification of volcanic pneumatogenic caves (Licitra 1993), the expansion caves formed on the basis of lava flows in contact with wet rock basement are not mentioned.

The Delta Cave (Štiavnické vrchy Mountains, Slovakia), formed in Middle Miocene rhyolite lava, 9.5 m long and almost 7 m high, is probably a megabubble or megavesicle after released gas, mainly water vapour (Pošteková 2011; Gregorová, Lexa 2017; Fig. 1E). Bubble-shaped cavities are one of the basic structural features of short and thick rhyolite lava flows (*coulées*) and morphologically representing upwardly directed tongue-like clusters of vesicles (cf. Waters 1960). The rounded walls and teardrop shape of Delta Cave, with its glassy surface and parallel detachment, indicate the expansion of the cavity as the gas bubble expands and rises. Azizbekian et al. (1987) describe syngenetic lava balloon (spherical) cavities in southeastern Armenia, formed at the contact of the lava flow with the underlying rocks, with diameter of up to 10 to 12 m. On the surface they are exposed in ravines and similar depressions deepened by streams.

Table 1. Types of volcanic exhalation-explosive and expansion caves.

Type/genesis and morphology		**Position**	**Morphological features**
pneumatogenic exhalation-explosive caves	simple or complex funnel-shaped chimneys (primary vents)	central part of cinder cones	simple downward extending chimneys (bottle-, pear- or bell-shaped) or irregular vertical chimneys with different diameters
	sloping, usually chimney-like caves (branching from funnel-shaped chimneys, secondary vents)	lateral parts of cinder cones	inclined vent tubes with irregular cavities and rock protrusions
	simple tube-, bottle- or bell-shaped chimneys formed by spattered lava	inside the lava spatter-roofed cones	simple, downward conically expanding vertical chimney-like cavities
		inside hornitos (rootless lava spatter cones)	simple tubular or downward conically expanding vertical chimney-like cavities
pneumatogenic expansion caves	blister caves	just below the thin crust of the lava flows	upwardly curved hemispherical cavities with a more or less flat floor
	geode-shaped or bubble caves	inside lava flows	simple spherical or ellipsoidal cavities
	bubble-like cavities connecting upwards, tear caves narrowing upwards	the basal (lower) part of the lava flows at the contact with the wet rock basement	caves consisting of small spherical cavities, mostly elongated upwards (tongue-like clusters of vesicles leading upwards – Waters 1960)

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Pseudokarst caves in New Zealand's North Island according to their development

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Non-karst caves in New Zealand have been formed genetically by the influence of external and internal forces. The surrounding rocks are Tertiary and Quaternary basalt, ignimbrite and sandstone. The authors studied the pseudokarst caves of the inner area of North Island (Fig. 1). Coastal sea caves, considered to have partly pseudokarst origin, are the subject of a separate study. The study, on the other hand, includes Whatipu's fossil abrasion caves separated by the costal sand movement from the sea. Through typical examples, they describe the origin and surrounding of the most characteristic pseudokarst caves in the North Island. The caves were formed under the influence of mass movements as fissure caves, caves developed along bedding plains, atectonic boulder caves, breakdown caves and plastic lava sheets movement originated caves. The physical weathering forms caves by lateral (Fig. 2) and turbulent erosion, fragmentation, and wave erosion. Cavities in the thermal regions result from chemical weathering (Fig. 3). Tafoni is a separate group of the pseudokarst cave development. Their specification within the non-karstic cave development is strongly disputed (Turner 1974; Cody. 1978; Hickson 1978; Crosley 1979, 1995, 2014; Wood 1994; Szentes 2007, 2011; Crossley, Szentes 2017).

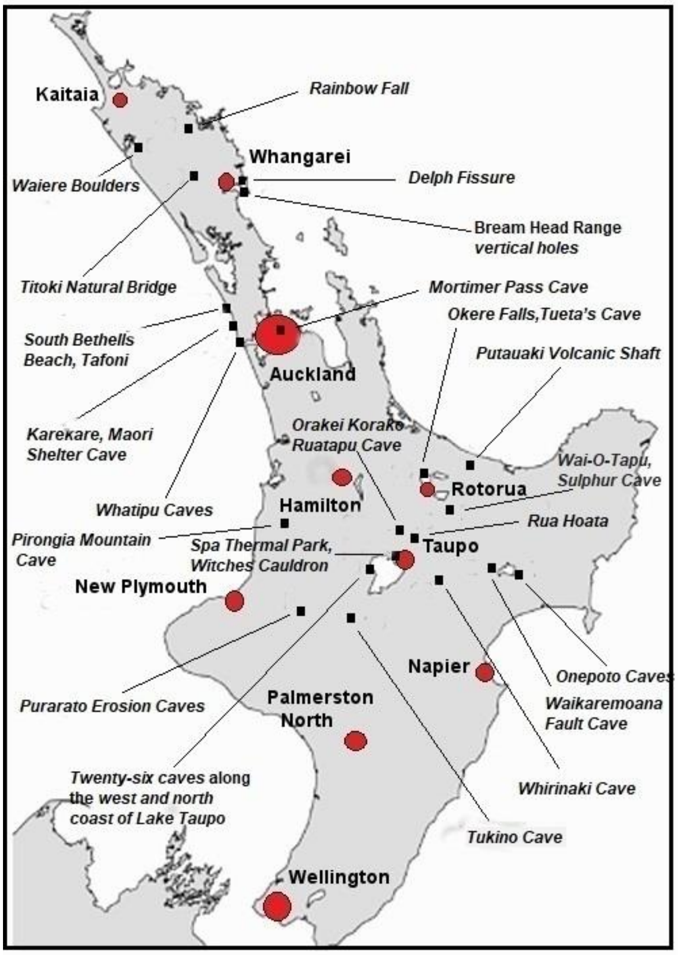

Fig. 1. Location of the investigated caves.

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Fig. 2. Linear fluvial erosion formed the Titoki Natural Bridge (photo P. Crossley).

Fig. 3. Thermal water dissolved the Ruatapu Cave in Orakei Korako thermal area (photo G. Szentes).

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New insights into tectonic structures of the Ostaš Table Mountain and its surroundings

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The area of the Police basin, the easternmost part of the Bohemian Cretaceous Basin, and in particular its most prominent part of table mountains Ostaš and Hejda, is strongly influenced by tectonic structures. Two large tectonic systems, Polický and Skalský faults, cross in vicinity and leave distinct traces in both formation and morphology of the relief.

While the passive effect of these tectonic faults is well acknowledged, the possible active role in the form of creep movements on the faults remained unsuspected. In this study we collect current knowledge and supplement it with new geophysical, morphometric and structural data to formulate revised hypothesis on the structural development of the table mountains and their surroundings.

The studied table mountains are formed by the Cretaceous quartz sandstones of the Teplice Formation, and underlain by Cretaceous layers of marls with limestones (Fig. 1). Geophysical surveying revealed the thickness of block sandstones, which form the platforms (table mountains), and confirmed the hypotheses of the tectonic control of their development. Electrical resistivity tomography (ERT) profiling revealed different thicknesses of the block sandstones of individual mesas, ranging from 20 m

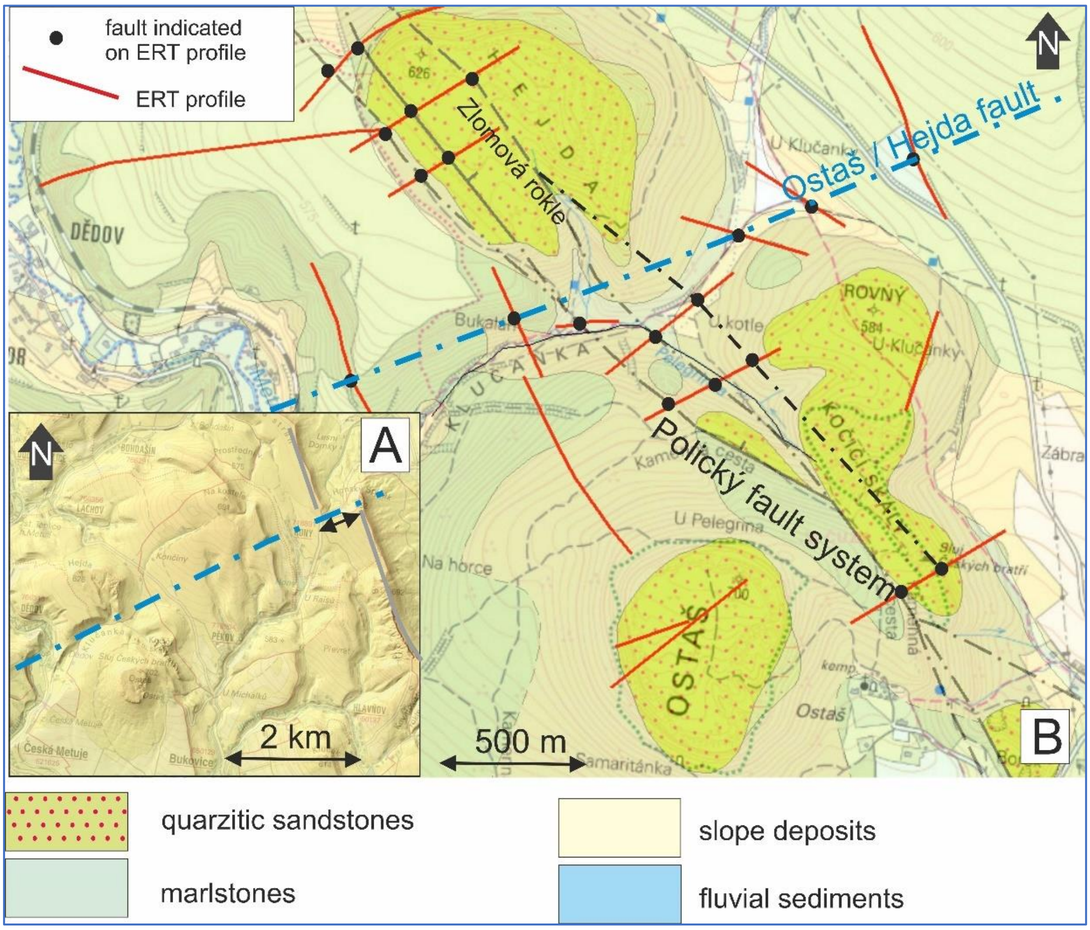

Fig. 1. A – Map (strictly DTM) illustrating the sidestep of the Broumovské stěny kuesta frontline at the Ostaš/Hejda fault line. B – Topographical and geological situation of fault systems and ERT profiles (2015-2021) in the study area.

to 50 m. However, the difference between maximum altitudes of each mesas reaches nearly 100 m. Because mere thickness of sandstones did not sufficiently explain this altitude variance, another explanation had to be found. Vertical movements controlled by tectonics seemed to be a possible answer.

The ERT tomography has also proved the existence and direction of several branches of the Polický fault system (Fig. 1) and indicated existence and course of a new fault structure running between the Ostaš and Hejda mesas (therefore called Hejda/Ostaš fault) with direction approximately parallel to Skalský fault. The biggest support for this hypothesis was large difference of the sandstone blocks altitude and lithological bases positions, which cannot be explained by denudation and erosion only. The survey also confirmed the origin of the Zlomová rokle, which seemed to be predisposed by one of the branches of the Police fault system.

Measured joint systems at outcrop sites corelate with the nearby faults. Measurement and analysis of the morpholineaments in the further neighbourhood also yields directions similar to the main faults in the vicinity (Polický fault SE-NW, Skalský fault WSW-ENE). Moreover, the morphology of the top platforms on both Ostaš and Hejda mesas suggests a vertical subsidence of rock blocks, which is very likely a result of deep-seated creep of the block sandstones along the underlying plastic marlstones. Block movements were further confirmed by precise dilatometric measurements using TM-71 3D dilatometers.

Based on the above evidence we can formulate a hypothesis that the original sandstone platform was broken and moved both horizontally and vertically along both fault systems.

Annual surface and near-surface temperature course of selected crevice-type caves in the Moravian-Silesian Beskids

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Due to cave air ventilation, relatively warmer air may rise during winter from the cave through ventaroles to the surface. Such ground microexhalations cause local melting of the snow cover, which is often used by researchers to discover new caves (Lešinský 1999). Same approach was successfully applied for crevice-type caves, remarkable features accompanying gravitational disintegration of rock massifs in landslide-prone regions (Baroň 2002, Baroň et al. 2014). Cave ventilation is one of the most important variables affecting cave microclimate and unlike karst caves, there has been little research into the longer-term ventilation of pseudokarst caves (Kašing, Lenart 2020). Latest research in Velká Ondrášova crevice-type cave showed that this issue is more complex than expected (Kašing, Lenart 2020). Crevice-type caves have a specific microclimate that changes throughout the year. Authors emphasise temperature seasonality of the near-surface parts of the cave, where the temperature difference during the year was up to 10 °C.

Each cave is unique in terms of morphology, size, depth and air ventilation. Here we present results of one-year surface and near-surface temperature monitoring on eight different ground microexhalation sites, which started in November 17, 2021 and was finished on November 11, 2022. All ground microexhalation sites are located in the Moravian-Silesian Beskids (Outer Western Carpathians, Czechia, Fig. 1a). These are two known and one just discovered locality on the southern slope of the Radhošť ridge: Salajka Cave, Záryje 1, Záryje 2 (~1060 m a.s.l., Fig. 1b, d). Fourth site is located near the Pustevny

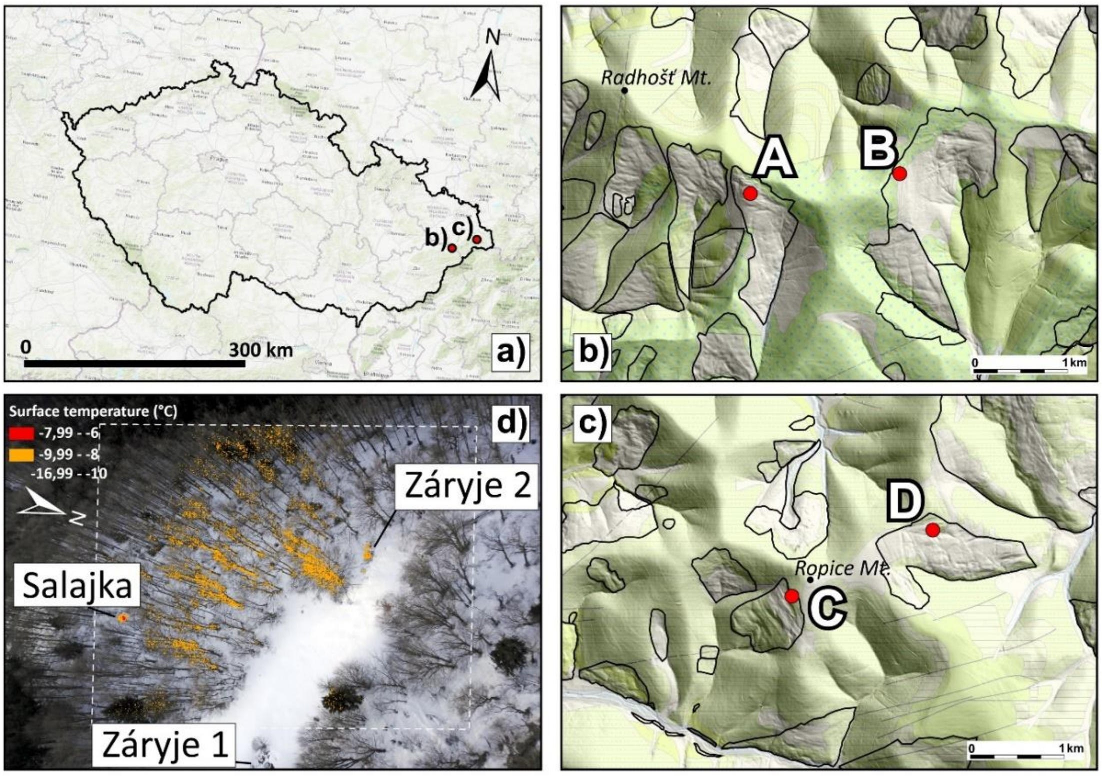

Fig. 1. Location of study sites. a) – position of study locations in Czechia; b) – Radhošť ridge site group (A – Záryje 1, Záryje 2, Salajka, B – Metodějka); c) – Ropice massif site group (C – Ropice 1, Ropice 2, D – Šindelná 1, Šindelná 2); d) oblique aerial RGB and thermal photo (dashed line) of location A captured on 11. 3. 2021. Background thematic data sources: a) World Topographic Map – ESRI; b), c) black outline – landslide database from Pánek et al. 2019, Geological map 1:50 000 – Czech Geological Survey, shaded relief derived from DMR 4G – ČÚZK.

mountain saddle close to the known Cyrilka cave entrance and is called Metodějka (1005 m a.s.l., Fig. 1b). The remaining four sites are located in the Ropice massif (Fig. 1c). Two sites are part of one landslide on the southwest slope below the Ropice peak: Ropice 1, Ropice 2 (~1030 m a.s.l.), and the last two are located next to each other on a landslide below the Šindelná saddle: Šindelná 1, Šindelná 2 (~910 m a.s.l.). Most of the sites were identified as places of air exhaustion, either from cave entrance (Salajka cave), or cavities (Záryje 1, Metodějka, Ropice 1 and 2, Šindelná 1 and 2). One site was discovered from infrared thermography difference (Záryje 2, Fig. 1d).

We visited each site once a month, just after the sunrise, and photographed the surface of the ground microexhalation and its surroundings using a dual RGB/thermal camera (on thermal image, surface temperature is captured in °C). We also used soil thermometers to measure soil temperature at a depth of 5 cm in various distances from ground microexhalations and we measured ambient air temperature using a handheld anemometer. We did not visit both site groups (Radhošť ridge and Ropice massif) on the same day, but we switched the group location every two weeks. On four sites (Záryje 1, Ropice 1 and 2, Šindelná 2), we installed sensors inside the ventaroles that continuously measured near-surface air temperature.

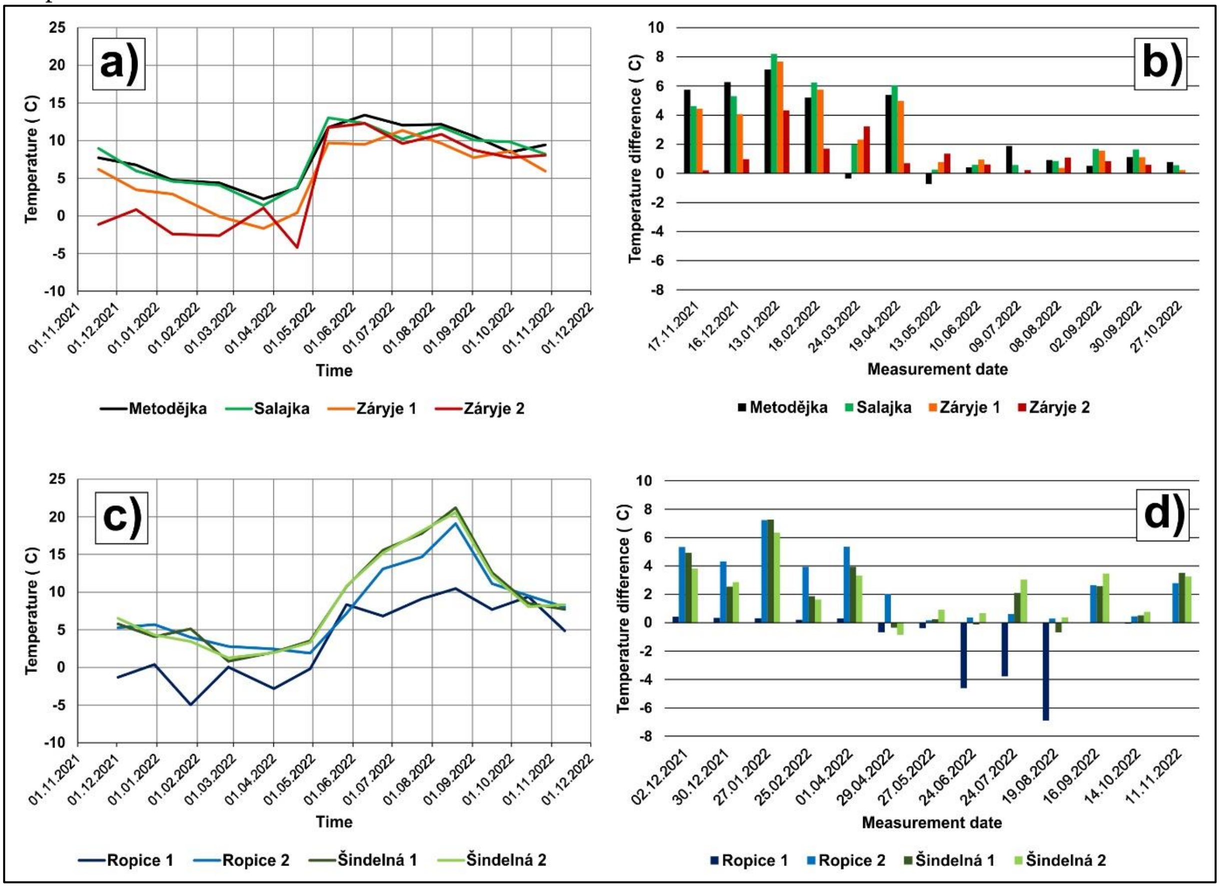

Fig. 2. Ground microexhalation surface temperature curve (a) and difference in surface temperature between ground microexhalation and surrounding surface (b) of Radhošť site group and (c, d) Ropice massif site group.

Surface temperature course of ground microexhalations in all sites (Fig. 2a, c) reveals distinct half-year seasonality with relatively low temperatures during cold months with transition to higher temperatures during May 2022. We can classify study sites according to the i) course of difference between surface temperature of ground microexhalation and its surroundings (Fig. 2b, d) and ii) ground microexhalation temperature drop below 0 °C during cold months (Fig. 2a, c). As a distinctly warm microexhalation we can classify sites, which reveal i) large difference in temperature from its surrounding surface during cold months and ii) never reach 0 °C. Examples are Salajka cave entrance and Metodějka ventarole from the Radhošť ridge group (Fig. 2a, b), and Šindelná 1, Šindelná 2 and Ropice 2 from the Ropice massif group (Fig. 2c, d). We suggest that prevailing mechanism of heat transfer between underground and distinctly warm microexhalations is by convection. We expect sufficient amount of relatively warm air in underground spaces (microexhalation temperature didn't drop below 0 °C). The site Záryje 1 reveals similar characteristics in i), but at the end of cold season its surface temperature dropped below 0 °C (Fig. 2a), probably as the supply of relatively warm air has run out.

The site Záryje 2 is an example of weak warm microexhalation. It reveals i) low difference in temperature from its surrounding surface during cold months and ii) temperature below 0 °C during almost whole cold season (Fig. 2a, b). Since in this site there are no visible signs of any open ventarole on the surface and the heat exchange between underground and surface is apparently weaker than on the other studied warm microexhalations, we suggest that prevailing mechanism of heat transfer here is conduction. Site Ropice 1 is an example of a cold microexhalation. It has an inverse microclimatic character (Fig. 2c, d). During cold season, it shows only negligible temperature difference from the surrounding surface. Cold ground microexhalation is active in summer, when relatively cold air is ejected to the surface. Prevailing heat transfer mechanism is convection. Ropice 1 (cold) and Ropice 2 (distinctly warm) could be microexhalations from the same dynamic cave or cavity system, as they are located on same landslide, relatively close to each other, and in corresponding altitudes (bottom cold, upper warm).

Difference in the temperature rise rate between two site groups (Radhošť ridge and Ropice massif, compare Fig. 2a and Fig. 2c) could be explained by their geographical distance (27 km) and different local conditions. Ropice 1 curve reveals similar course to the Radhošť ridge group, but this site has an inverse ventilation, making it incomparable in temperature to the other sites. Absolute difference in maximum surface temperatures of microexhalations measured at the two site groups (Fig. 2a, c) could be caused by a different day of measurement. There is also discrepancy between the absolute values and their variability of microexhalations and surroundings surface temperature differences (Fig. 2b, d). We suggest this reflects different size and character of underground cavity system conditioning disparate air and heat circulation.

Acknowledgements:

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Coldspots: low temperature of the ground in rock clefts (Stołowe Mountains, SW Poland)

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Like caves, scree slopes and local terrain depressions, deep rock clefts are characterised by exceptional thermal conditions (Kirchner et al. 2007, Zacharda et al. 2007, Raška et al. 2011). Their interior is often permanently shaded, and they favour the formation of cold air pools. In conditions of the Mid-mountains of Central Europe, rock clefts are one of the few sites where it is possible to survive the snow all year round, even despite progressing climate changes. Such places are called 'coldspots' by the authors.

Large rock fissures are common in rock labyrinths formed within Cretaceous sandstones and building the table mountains (mesas) elevated above the surroundings. Their examples are Mt. Szczeliniec Wielki (922 m a.s.l.) and Mt. Szczeliniec Mały (895 m a.s.l.) in the Stołowe Mountains, SW Poland. The most extensive fissures found here – Piekiełko and Diabelska Kuchnia (literally: Little Hell and Devil's Kitchen) have a depth of 20 m and narrow bottoms with a width of 2–6 m. They are accompanied by several minors, equally deep fissures (Migoń, Kasprzak 2015).

The unique topoclimatic conditions of the Piekiełko and Diabelska Kuchnia sites are well known, and in the past, an attempt was made to measure their specificity instrumentally (Otop, Miszuk 2011). These places remain relatively cold throughout the year, and the daily air temperature amplitudes are much lower here than in the neighbouring areas. In summer, even in anticyclonic weather conditions, they may not exceed 10 °C.

The authors focused on the hitherto unrecognised thermal properties of the ground. As part of monitoring the Piekiełko and Diabelska Kuchnia sites, a Geoprecision thermal string was installed, measuring the temperature of the sediment filling one of the side fissures to a depth of 1.5 m (from Sept. 14th, 2022). The application of the thermal imaging camera allowed the investigation of the rock walls' temperature. During the winter-spring transition period (March 7th, 2023), terrestrial laser scanning (TLS) and structure from motion photogrammetric imaging (SfM) were carried out to detect spatial variations in snow deposition (Fig. 1). A thicker layer of snow protects the ground and rock walls against severe freezing, at the same time cooling these places at air temperatures above 0 °C until ablation period.

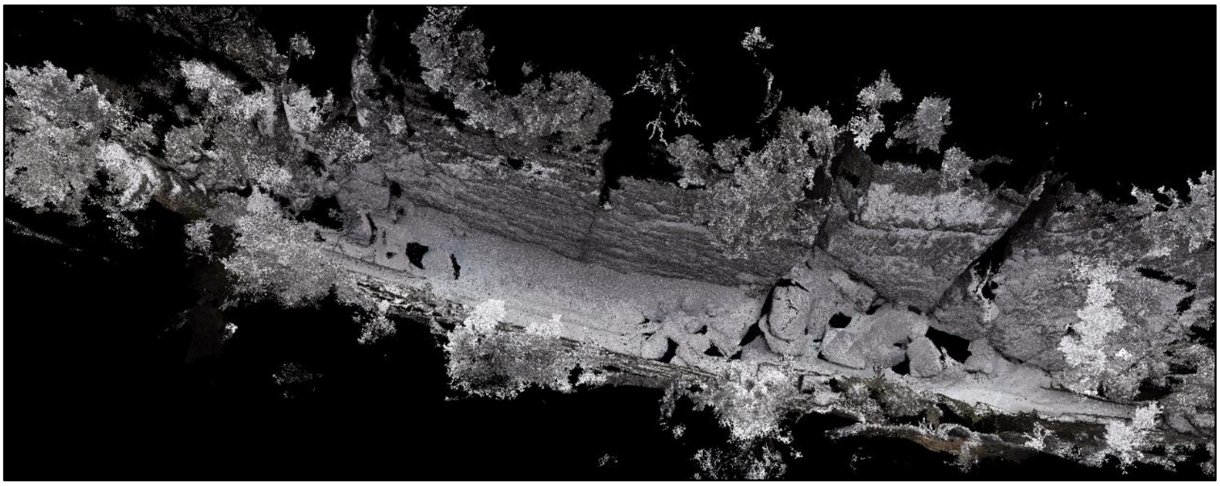

Fig. 1. TLS-based model of the Piekiełko cleft in Mt. Szczeliniec Wielki mesa.

The presented material comes from the project's initial phase and is intended to signal the research undertaken. The analysis of the digital terrain model indicates that a prospective place for conducting measurements over the centres of low ground temperatures is also an equally deep rock cleft in the central part of Mt. Szczeliniec Mały. The authors consider whether it is reasonable to assume that in the Stołowe Mountains there may be conditions for the persistence of 0 °C ground and rock temperature for at least 2 years in a row, i.e. whether permafrost occurs here. Specific topoclimatic conditions are also of interest in biological research.

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Ledové sluje Caves – new insights into the structure and age of crevice-type caves in crystalline rocks of the Bohemian Massif (Czechia)

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Introduction

The Ledové sluje Caves are a group of pseudokarst caves in the National Park Podyjí, located in the southeastern part of the Bohemian Massif, Czechia (48.8846N, 15.8439E). There is a total of 17 pseudokarst caves, mainly of the crevice- and talus-type. The longest one, the Brněnská Cave, is more than 400 m long, others are up to 40 m deep (Kopecký 1996). Although the caves have a complicated morphology, the main direction of their crevice-type corridors (NE–SW) is parallel to main rocky scarp of the host rockslide. Other shorter cave corridors follow NW–SE or NNW–SSE directions (Kopecký 1996). The caves resemble the typical morphology previously described by, e.g., Lenart (2015) or Margielewski and Urban (2017) from flysch rocks of the Outer Western Carpathians. The rock surfaces inside the caves are covered or impregnated by opal, silicate, phosphate or gypsum coatings (Cílek 1993). Some of the caves are iced during the cold season, hence the name of the whole site – "Ledové sluje" in Czech means "ice caves".

The Ledové sluje (LS) site is situated in the Znojmo Highlands, i.e., a slightly undulating landscape of the Bohemian Massif on the border between Czechia and Austria (Fig. 1). Although the average altitude of the Znojmo Highlands does not exceed 365 m, the southeastern marginal slope of the Bohemian Massif is deeply incised by the Thaya (Dyje in Czech) River. The resulting canyon, with frequent rocky steep slopes, reaches depths greater than 200 m. The site has been studied many times, as

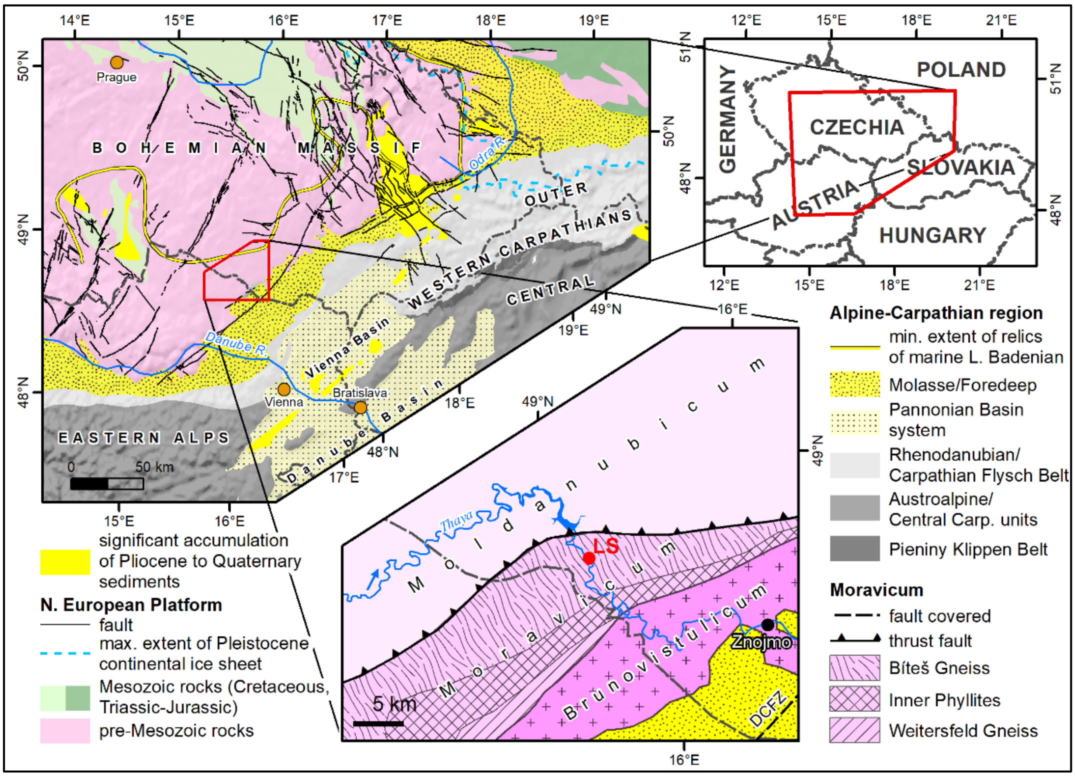

Fig. 1. Simplified geological map of Alpine-Carpathian-Bohemian Massif junction area (based on Špaček et al. 2015) with geological setting of the study area – the Dyje Dome. LS – Ledové sluje site; DCFZ – Diendorf-Čebín Fault Zone.

it represents one of the sporadic slope failures developed in crystalline rocks (Bíteš orthogneiss) of the Bohemian Massif (Fig. 1). However, despite a number of geomorphic, geophysical, and speleological investigations and different interpretations of the genesis and age of the caves and the host rockslide (e.g. Demek 1996; Košťák 2001), this pseudokarst phenomenon has not yet been fully explained.

This paper presents preliminary results of the structural analysis of the rock massif, revealing the structural control of the caves at the LS site and types of slope movements that formed the caves. Complemented by the terrestrial cosmogenic nuclide (TCN) dating of main scarp of the rockslide, it deciphers possible age of one of the most important pseudokarst phenomena in Central Europe.

Methods

A combination of geomorphic mapping, rock mass structural analysis, and TCN dating was used to determine the structural control and age of the investigated crevice caves (CTCs) and their host rockslide.

Geomorphic mapping was focused on features related to slope failures, and was conducted by surface GNSS mapping and speleological survey inside the CTCs. The rock massif exposed within the caves (Fig. 2, right) was investigated by structural analysis. The methodology by Margielewski and Urban (2003) was used to determine the mass movement types responsible for the genesis of individual CTCs. Structural data of faults, fractures and foliation planes, measured in dip direction/dip angle format for planes and trend/plunge format for lines, were plotted as contours in the lower hemisphere of Lambert equal area projection. To approximate the cave age, the landslide main scarp was dated using terrestrial cosmogenic nuclides (TCN) dating. A total of four rock samples were collected for ^{10}Be dating along a selected transect (profile with minimal evidence of secondary rockfall, subsequent weathering and post-landslide erosion) on the subvertical scarp surface (Fig. 2, left).

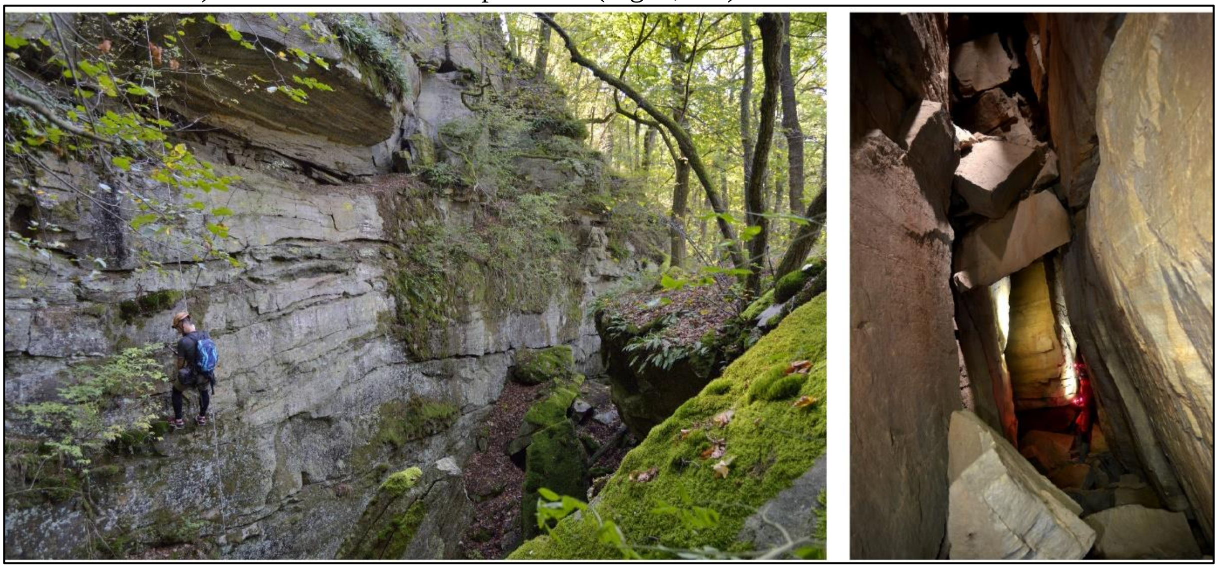

Fig. 2. Main scarp of the LS rockslide (left, photo by M. Kašing) and interior of the Brněnská Cave (right, photo by J. Lenart).

Results and discussion

The eight CTCs (Ananas, Grotte 1, Grotte 2, Netopýří, Sintrová, Pod schodištěm, Nová and Brněnská Caves) and the Main Trench were analysed based on changes in the anisotropy of upslope and downslope rock blocks (Fig. 3). The main structural control of the rock massif corresponds mainly to NE- to ENE-striking steep fractures and faults, predominantly facing the SE (contour max. density 145/83). The metamorphic foliation dips gently towards the NW (max. 300/5). Identified mainly on the basis of striation surfaces and tectonic mirrors, faults are characterized primarily by ENE-striking (max. 334/83) and secondarily also WNW-striking (197/86) structures with SW-oriented striations with dip range 30–80° (max. 240/63).

The structural analysis also revealed a clear pattern of identically oriented slided rock blocks repeating over the rockslide. These blocks with NW-oriented gently inclined foliation (300/5) indicate that deformation has occurred along the planar sliding surface.

The overall pattern of NE- to ENE-directed structures, controlling most of the cave passages at the site, represents longitudinal structures with respect to the foliation planes. This structural setting of the rock massif together with the geomorphic position of the site on a NW-facing slope, defines conditions prone to rock sliding, representing the main predisposing factor for the origin and evolution of the crevice-type caves at the LS site.

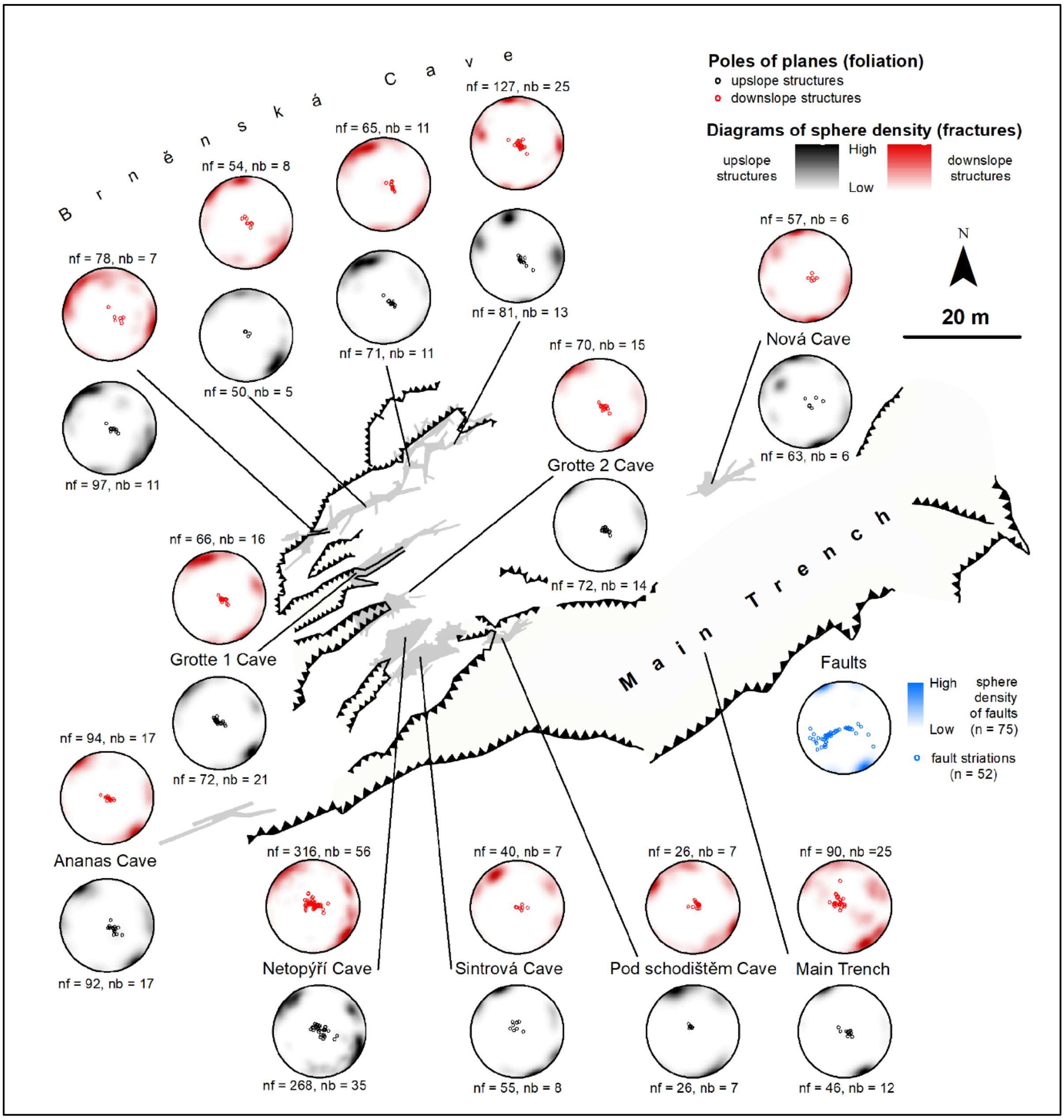

Fig. 3. The results of structural analysis revealing structural control of caves and types of slope movement developed within the Ledové sluje rockslide; number of measured faults and striations (n), fractures (nf), foliation planes (nb).

The rock samples *LS0*, *LS1*, *LS2* and *LS3* were collected from the 15 m high vertical scarp of the main trench, gradually from the top to the bottom. The analysed ^{10}Be ages showed a gradual age decrease along the profile. The uppermost sample was taken as reference one. The sample *LS1* taken 5 m below, gave an age of 42.6 ± 4.4 ka. The third sample *LS2*, taken 9.5 m below the first. gave an age of 26.6 ± 3 ka, and the lowermost sample from the foot of the rock wall gave the youngest age of 23.4 ± 2.7 ka. It follows that the vertical rock wall of the main scarp had been gradually exposed, together with the slow or sudden sliding of the rock mass, where all the crevice-type caves were formed.

As obtained ages have to be considered as minimum ages of the respective main scarp exposure, they can be considered as minimum ages of the whole rockslide. As all the crevice-type caves are situated below the main scarp within the gravitationally disrupted rock mass and are of intermediate and subsequent type according to the classification by Urban and Margielewski (2013), we suggest that their age corresponds to the obtained age of the rockslide. However, we cannot rule out the possibility that some of the subsequent caves may have opened before the main gravitational event and others after.

Conclusions

The genesis of the Ledové sluje Caves is closely related to the evolution of the host rockslide. The main structural control of the caves is directed mainly by NE- to ENE-striking steep fractures and faults, predominantly facing to SE (max. 145/83). The foliation planes dip slightly towards the NW (max. 300/5). Minimum ages of the rockslide were obtained from the main rock scarp. The revealed ages 42.6 ± 4.4 ka, 26.6 ± 3 ka and 23.4 ± 2.7 ka place the main gravitational event, and thus the opening of the crevice-type caves, in the Late Pleistocene. As all the caves within the LS site are of intermediate and subsequent type, they are most likely of similar age as the whole rockslide.

Acknowledgments

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Pseudokarst studies in the Broumov area – situation in 2020

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The Broumovská vrchovina Highland geologically represents the Czech part of the Intrasudetic Basin. The basin fill comprises sedimentary and volcanic rocks of the Carboniferous, Permian, Triassic and Cretaceous age, shaped into the form of a complex mid-altitude relief by geomorphic processes. About one-third of its area is covered by the Polická vrchovina Highland, composed of Upper Cretaceous sedimentary rocks, especially spiculitic marlstones and quartzose sandstones.

Quartzose sandstones, exhumed by erosion, gave rise to development of extensive sandstone rock cities with rugged and varied pseudokarst relief on the surface and in the subsurface, including caves and chasms. Speleological research was started here in 1980, after the establishment of the local caving club of the Czech Speleological Society, 5-03 Broumov.

As of 2020, basic speleological research in this area, as yet unfinished, registers almost 200 pseudokarst caves and chasms of all types reported from sandstone pseudokarst areas. Small caves are the most numerous, although many caves exceed 100 m in length. The longest Teplická Cave attains the length of almost 2 km. These long caves are located in thick block talus accumulations on the bottoms of gorges, and often host subterranean streams.

Registration and documentation of speleological objects are accompanied by geo- and biomonitoring of underground spaces and observations of their meso- and microclimate. Sandstone terrain in this area still provides great potential for new major discoveries and scientific studies.

Although this contribution is formally submitted by only a single author, the research as well as the formulation of its results have been contributed by all members of Caving Club 5-03 Broumov of the Czech Speleological Society.

Study and documentation of cave root forms in the Broumov area

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Speleological research of pseudokarst terrains in the Broumov area reflects, from its very beginning, the issue of cave root forms. The first finds of root forms come from the Kořenka Cave in the Teplické skály Cliffs. The progress in basic research in all pseudokarst districts in the Broumov area resulted in the identification of many tens of root form individuals in a number of other caves or rock shelters.

Due to the collaboration with experts in biology, the theme of root forms was recognized as an interesting and prominent biospeleological problem. These features continue to be registered, documented and studied as independent cave sub-ecosystems. Although root forms mostly concentrate in areas of sandstone pseudokarst, they have been noted also at other sites of pseudokarst or classical karst. The Broumov area displays tens of sites containing a wide range of root-form morphologies. It is also this very area where, after decades of registration and study, a proposal for a unified system of the registration, monitoring and documentation of this phenomenon originated (Jenik 1998, Kopecký 1998).

Although this contribution is formally submitted by only a single author, the research as well as the formulation of its results have been contributed by all members of Caving Club 5-03 Broumov of the Czech Speleological Society.

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Caves in sandstone near the village of Bozhenitsa, NW Bulgaria

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Introduction

Pseudokarst caves in sandstone in Bulgaria have been episodically discussed in the literature (Kostov et al. 2018). This article aims to examine the morphology of caves in Cretaceous sandstone in Northwestern Bulgaria. The sandstone near the village of Bozhenitsa forms a series of rock cites with significant geological, geomorphological, historical and cultural value.

The village of Bozhenitsa is located at the southern foot of the Gola Glava mountain ridge in the Fore-Balkan region of the western Stara Planina (Balkan) zone. The village is situated 82 km NE from the capital Sofia and 20 km from the municipal center Botevgrad. The village is situated at the height of 285 m a.s.l. The lower course of the Bebresh River passes through the village and forms a canyon – a popular climbing spot in Bulgaria.

Preconditions for cave formation

The caves near Bozhenitsa are developed in Cretaceous sandstone of the Roman Formation (Fig. 1). It was first introduced as Formation de Roman by Ivanov and Nikolov (1983). It is represented by sandstones, marls, siltstones, clays with thin limestone interlayers. The thickness of the formation is about 2000 m, while its chronostratigraphic range is the Upper Barremian-Aptian. The high density of fracturing of the sandstone is a precondition for the formation of a significant number of small caves and niches. Small rock towers are also developed in some places in the area.

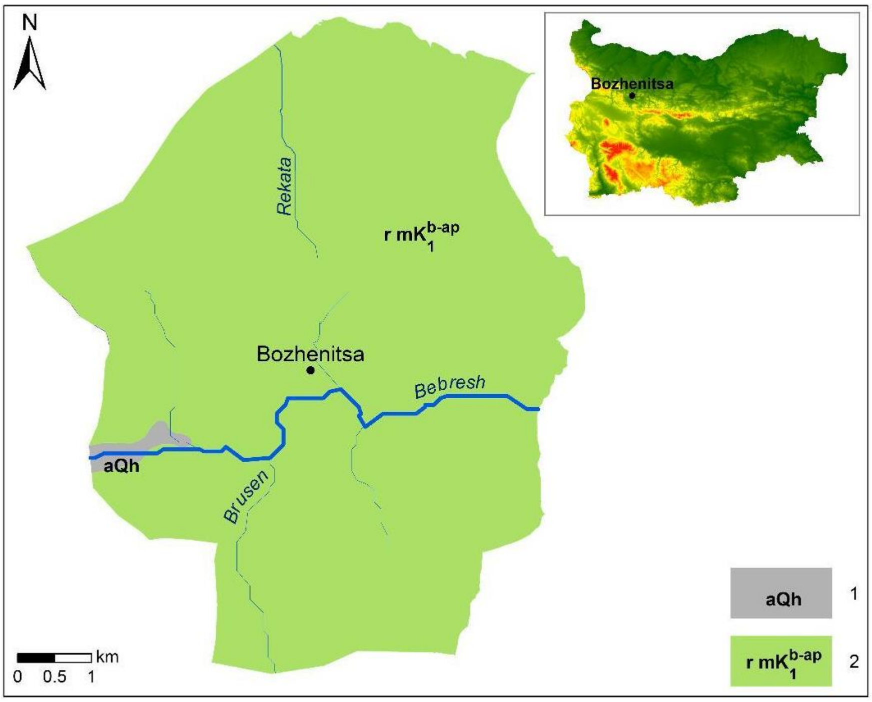

Fig. 1. Geological map of the Bozhenitsa Village area (after Angelov et al., 1995 and Tzankow et al., 1995). Explanation of symbols: 1 – Quaternary: alluvial deposits, flood terraces, sands, gravels, clays; 2 – Lower Cretaceous: Roman Formation – sandstones, siltstones, clays, marls and sandy limestones

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Caves near the village of Bozhenitsa

So far, 26 caves have been explored within the area of Bozhenitsa village. The caves are mainly located in two areas: to the south of the village in the area of the medieval Urvich fortress and 1.5 km northeast of the village in the vicinity of the Murta hamlet.

Most of the caves were mapped in the 1970s by members of the Biser caving club in Botevgrad. Most caves are small, with only five exceeding 20 m (Table 1). The longest cave in the area is Shtarban Dupka Cave with a length of up to 151 m, located south of the village. The caves are dry with deposits such as clay and weathering rock detritus. Some caves were modified by anthropogenic impact – an

example is the rock monastery in the medieval fortress of Urvich situated south of the village of Bozhenitsa (Fig. 2). This complex consists of two small rock churches, connected by a 10 m stair (Koev 2011).

Fig. 2. Rock church in the medieval fortress Urvich, village of Bozhenitsa (photo V. Angelkov)

Table 1. The longest caves near the village of Bozhenitsa.

Name	Length (m)	Vertical size (m)
Shtarban Dupka	151	0
Urdina Dupka	70	4
Mandrata	40	0
Urvich 3	23	1
Svinarnika	20	0

Conclusion

People have used the sandstone caves near the village of Bozhenitsa since the prehistoric time. Some of these uses are of considerable cultural significance – for example the rock church in the Urvich fortress, which is one of the interesting mountain fortresses in Bulgaria. They need detailed study and promotion as geosite of high scientific and aesthetic value.

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Sea Caves on the Kaliakra Cape, North Bulgarian Black Sea coast

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Introduction

The Bulgarian Black Sea coast is 378 km long. The first published information about sea caves dates back to the end of the 19th century (Mumdzhiev 1893). The coast is characterized by complex geology. Neogene limestones are exposed in the northern part of the Bulgarian Black Sea coast, with rocks rising up to 70 m above the sea at the Kaliakra Cape. The longest sea cave in the area is the Tyulenova Cave near the village of Tyulenovo north of the Kaliakra Cape with a length of 107 m.

The aim of this article is to examine the abrasion sea caves of the Kaliakra Cape, mapped during field work by the Geological Institute at the Bulgarian Academy of Sciences in 2018.

Kaliakra Cape – location and history of caves research

The natural and archaeological reserve of the Kaliakra Cape is located 60 km NE of Varna. It is a narrow 2 km long rocky peninsula with a meridional direction and rising 70 m above the sea with steep to vertical slopes (Fig. 1). The Kaliakra Cape area is formed by limestone of the Miocene Odar Formation and Karvuna Formation. On the cape are the remains of the fortress and city of the Bulgarian despot Dobrotitsa – the ruler of the Dobrogea region at the end of the 14th century during the resistance against the Ottoman invasion.

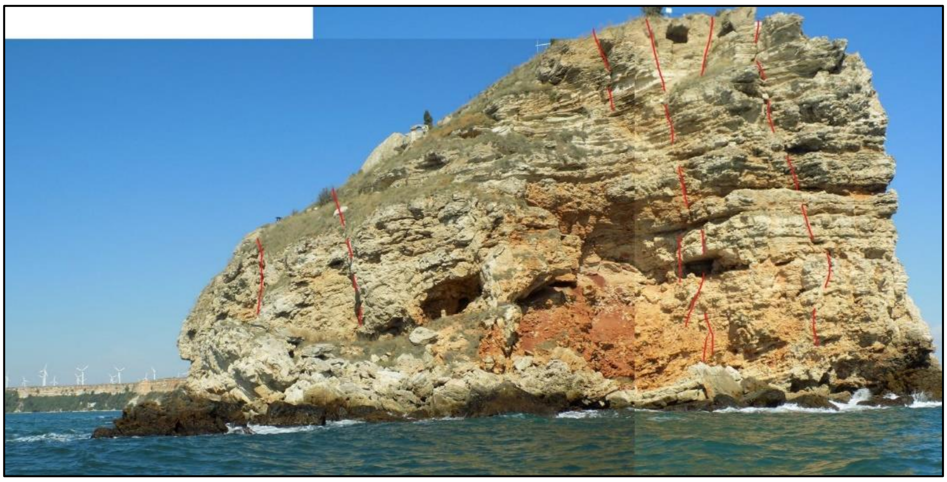

Fig. 1. Kaliakra Cape from the sea with mapped faults (photo K. Kostov).

The sea caves of the Kaliakra Cape have been studied by a number of authors since the end of the 19th century. The first known description of some caves on the Northern Bulgarian Black Sea coast is in the travelogue of Mumdzhiev (1898), who explored the coast from the town of Balchik to the village of Tyulenovo. The surface karst landforms in the area of the Kaliakra National Park were studied by Popov (1953), Popov and Mishev (1974). Pronin et al. (2013), Kostov and Nikolov (2013), as well as Kostov (2014) as well as contributed to the study of the caves in the area.

Sea caves on the Kaliakra Cape

The surface karst is characterized by the spread of extensive karren fields, known in the local toponymy as "kayrjak". North of the Kaliakra Cape is the most extensive karren field on the Bulgarian Black Sea coast up to 5 km wide, reaching the village of Bulgarevo (Popov, Mishev 1974). During the field work of the Geological Institute of the Bulgarian Academy of Sciences in 2018, the number of caves on the Kaliakra Cape was determined to be at thirteen, of which ten are dry caves and three are sea caves.

The northernmost sea cave is located 1.2 km north of the Kaliakra Cape, on the western slope of it. It was mapped by Ukrainian speleologists in 2013 (Pronin et al. 2013). The working name of the cave is PB-105/497. It is a complex of abrasion niche at 1.5 m above sea level and two anthropogenic niche-chambers, with the entrance facing west. The maximum length is 8 m. To the south of the cave and at the same hypsometric level, the entrances to two other small surf niches modified by anthropogenic activity can be observed, the precise documentation of which needs to be done in the future.

The largest mapped abrasion cave is located 330 m north of the Kaliakra Cape, on the western escarpment, just below the entrance to the military unit. The imposing entrance measures 31×11 m and can be accessed only by boat (Figs. 2 and 3). The maximum length of the niche is in the southern part and reaches 14 m. Beneath the arch, significant individual rock boulders up to 3 m high are characteristic. There are also smaller boulders with a high degree of erosion as a result of wave erosion. The deposits inside the cave are sandy-clay and terra rossa.

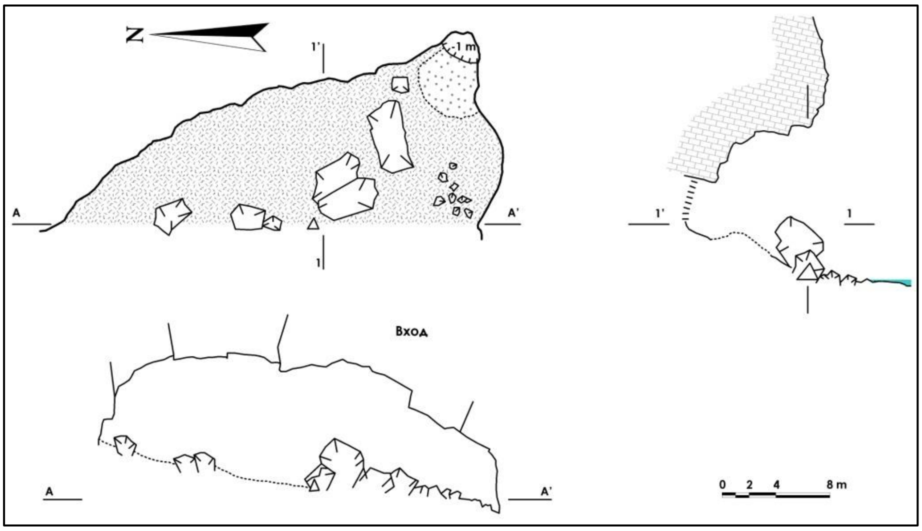

Fig. 2. Map and cross-sections of the largest abrasion cave on the Kaliakra Cape (authors material).

Directly below the restaurant and the museum at the Kaliakra Cape is the cave with the highest ceiling within the boundaries of the cape (Fig. 4). Unfortunately, access by boat was not possible during our field work due to the depths in front of the cave. A remote azimuthal sketch of the site was carried out. The length of the entrance is 26 m, and its height is 16 m.

Fig. 3. Survey of the largest sea cave in 2018 (photo K. Kostov).

Conclusions

The sea caves at the Kaliakra Cape were formed by mechanical abrasion along faults. The origin of some caves at a higher hypsometric level is related to karst processes. An interesting geomorphologic phenomenon is the presence of the largest abrasion caves on the leeward western side of the Kaliakra Cape, which can be explained by a characteristic circulation of seawater in the Kavarna Bay. No sea caves have been identified on the eastern side of the cape. In the region of the Kaliakra Cape, the abrasion rate is 0.05 m/year, and the monitoring has been conducted since 1983 (Peychev et al. 2005). This suggests that the large caves on the western side of te Kaliakra Cape are of the Holocene age.

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Fig. 4. The sea cave with the highest ceiling at the Kaliakra Cape (photo K. Kostov)

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From ‘pseudokarst’ features to better understanding of the evolution of tabular hills – the case of Labyrinth (Elbsandsteingebirge, Germany)

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The sandstone relief of the Elbsandsteingebirge in Saxony (East Germany) abounds in geomorphic features commonly referred to as ‘pseudokarst’. They include caves of assumed non-karstic origin, joint-aligned clefts, slots and corridors resembling clint-and-grike topography, tracts of ruiniform relief, closed depressions, and minor surface features such as karren and weathering pits (Rast 1959). These landforms occur in various geomorphic settings, including tabular hills and remnants of structural plateaus, and have been highlighted as important components of regional geodiversity, as well as local tourist attractions (e.g. Schneider 2004; Gerth 2012). However, they were seldom considered as carriers of significant information about geomorphological evolution of rock-cut landscapes and hence, their potential in this respect remains poorly explored. Among many residual elevations in the Elbsandsteingebirge, which still have the sandstone caprock, is the low hill of Labyrinth – the focus of this presentation.

The Labyrinth (397 m a.s.l.) is located in the western part of the Elbsandsteingebirge and forms an elevation between two larger plateau remnants: Bernhardstein in the south and Nikolsdorfer Wände in the north. Its relative height is c. 30 m, and the sandstone caprock, belonging to the K_{Sr1+2} unit of the Middle Turonian to Lower Coniacian age (Lobst 1993) and overlying the fine-grained members of the sedimentary succession, is less than 15 m thick. Thus, the caprock is much thinner than at the majority of mesas in the Elbsandsteingebirge, where thicknesses up to 50–60 m have been recorded (Migoń et al. 2018). The sandstone cap is ca. 200 m long and 100 m wide, and is cross-cut by two major subvertical joint sets striking N25E and E110S.

The name of the hill derives from the appearance of the caprock, which is broken along major fractures and heavily disintegrated all across the elevation, unlike in most other mesas, where the caprock is only dissected close to their perimeters. However, even the disintegration pattern itself is complex and at least a few variants of caprock morphology can be recognized (Migoń et al. 2020) (Fig. 1). In the southern and central parts of the hill the caprock relief shows like a large-scale clint-and-grike topography, with deep passages developed along orthogonal joints, which cut the entire thickness of the caprock (Fig. 1, area A). Some are 1–2 m wide unroofed avenues, but others are narrow slots with cross-sections resembling an inverted heart, additionally dissected in the bottom part (Fig. 2a, b). Thus, they can be easily walked through at the level close to the bottom of the caprock, but openings to the sky are absent (Fig 2c, d). Within this part narrow horizontal slots up to 0.5 m high have developed along bedding planes (Fig. 2e). Two northern tips of the caprock part, disconnected from each other, are minor rock mazes, with narrow passages exploiting jointed zones, but without subterranean corridors (Fig. 1, areas B1, B2). The south-western part of the Labyrinth represents a blocky chaos, with large sandstone compartments (some more than 10 m long) no longer resting in their original position, but suffering from tilting and differential subsidence (Fig. 1, area C). Interestingly, a part of this chaos forms a large closed depression in the middle of the hill. Similar topographies occur also elsewhere around the perimeter of the hill. Finally, there are many individual sandstone blocks within the outer slopes, separated from the caprock and displaced downslope over various distances.

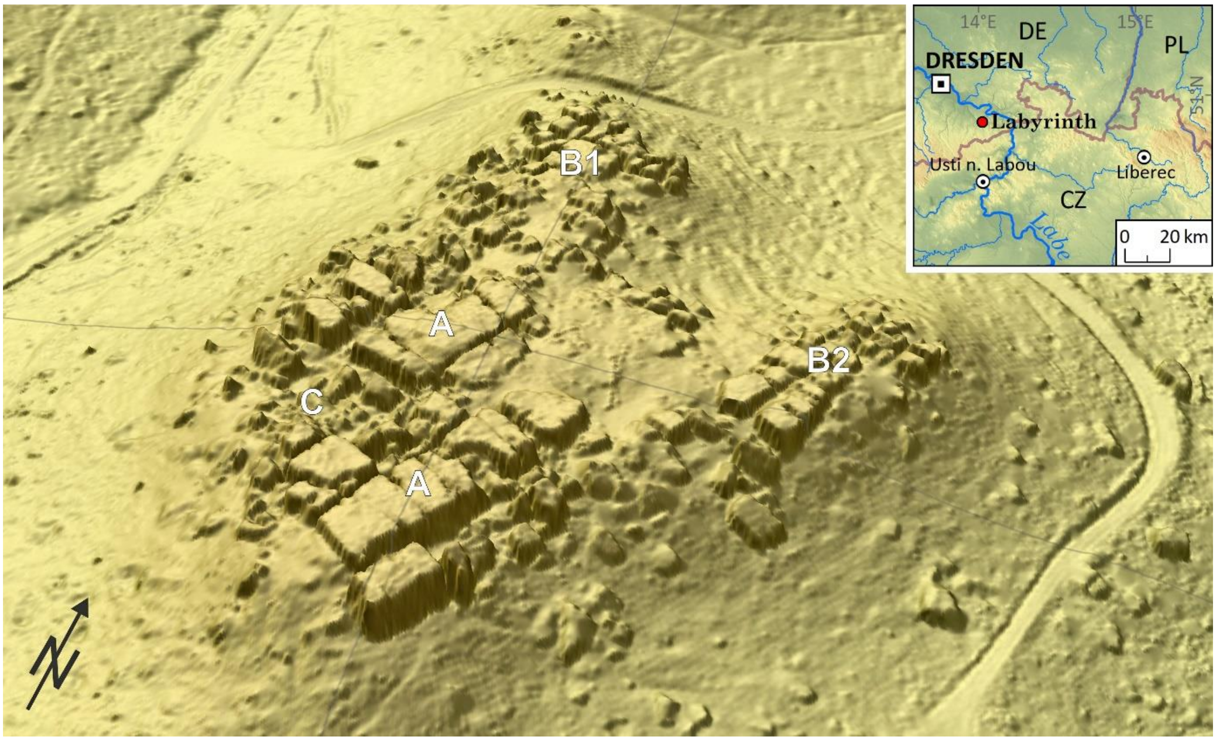

Fig. 1. Digital terrain model of the Labyrinth, with specific types of caprock morphology denoted by A–C letters (A – clint-and-grike topography with subterranean passages, B1, B2 – rock cities without covered passages, C – blocky chaos).

The analysis of landform inventory at the Labyrinth, including the spatial pattern of caprock dissection and disintegration, suggests an important role of geomorphic processes working in the subsurface in the evolution of the hill. The occurrence of roofed corridors and horizontal slots forming a system of subterranean passages indicates a considerable efficacy of processes of sand removal at depth. The nature of these processes can only be hypothesized, but removal by underground water flows is an obvious candidate. However, the system of passages looks truncated along the caprock cliffs. Consequently, one can assume that only a fragment of this system has survived and can be explored today, whereas other passages were likely destroyed along with ongoing caprock disintegration. Although there are no firm clues to state when these subterranean systems were fully functional, it is probable that this occurred before the mesa of Labyrinth became separated from its two larger neighbours. Breakdown of sandstone into sand and the removal of the latter at depth, which apparently continues today, resulted in the weakening of vertical support of upper caprock compartments, which began to settle (subside) into enlarging voids, producing the blocky chaos.

Thus, the ‘pseudokarst’ landforms at the Labyrinth are not only a local geomorphological curiosity (even though they may be considered as such by casual visitors), but they are part of a bigger story of how tabular hills with thin caprock in sedimentary tablelands may evolve. The development of drainage at shallow depth (less than 10 m) produced non-karstic caves and significantly contributed to the undermining and weakening of the caprock, which began to disintegrate over larger areas. The case of the Labyrinth shows that the geomorphic evolution of tabular hills does not involve cliff retreat only, whereas the inner parts do not change. To the contrary, the entire caprock part of the hill may suffer from joint-guided breakdown, gradually turning into blocky chaos, with irregular piles of sandstone blocks and closed depressions. In a later stage, no *in situ* remnants of caprock blocks are present and the only vestige of a once affected plateau remnant are dispersed boulders. Both the Elbsandsteingebirge, as well as other parts of the Bohemian Cretaceous Basin, including the Stołowe Mts. in SW Poland, offer examples of such residual boulder groups within a nearly flat terrain.

Fig. 2. Subterranean landforms in the residual hill of Labyrinth: (a) roofed passage with the floor incised; (b) vertical passage with the shape of an inverted heart; (c, d) tunnels within the rock city; (e) horizontal slots penetrating into the rock mass (height of the slot is c. 30 cm).

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The distribution of non-karst caves in Lower Austria with particular emphasis on frost weathering caves

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Lower Austria is located in the north-east of Austria. The diverse landscape varies from hilly areas in the Bohemian Massif in the north-west and extended lowlands in the north-east and east, to a pre-alpine hilly landscape and alpine karst plateaus in the south-west. By March 2023 a total of 5339 natural caves, longer than 5 m have been documented in Lower Austria. Most of them are located in the Northern Calcareous Alps which are dominated by Triassic limestone and dolomites (Fig. 1).

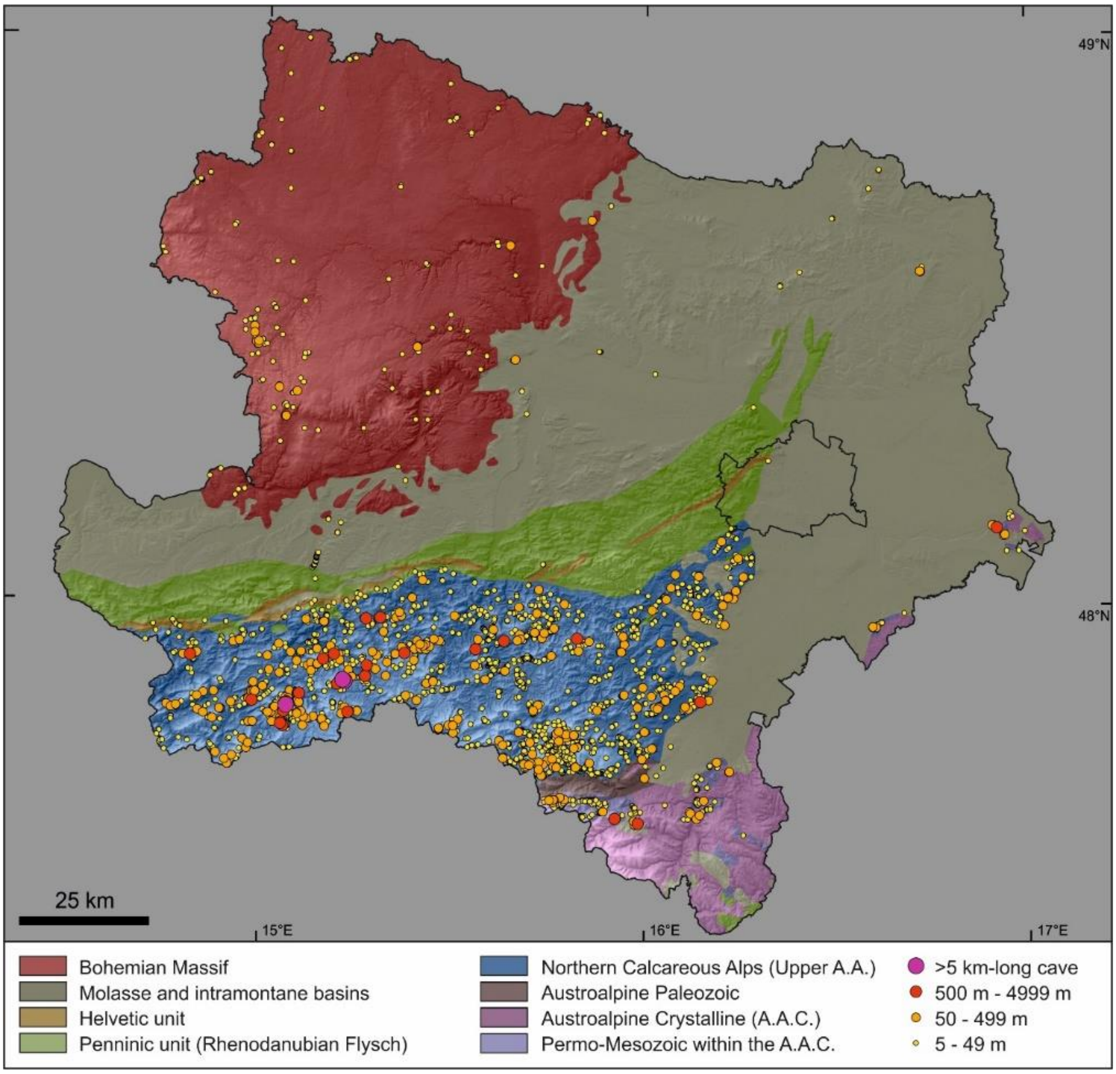

Fig. 1. Cave distribution in Lower Austria and Vienna. Background: simplified geological map with a shaded digital terrain model.

However, if we look at the distribution of cave types based on the classification of Oberender and Plan (2018), we find that karst caves are not the predominant cave type in Lower Austria. In fact, 47% of the caves are to be addressed as non-karst caves, another 5% are also indicated with some uncertainty as mechanical weathering and erosion caves. 37% of the caves are clearly karst caves, while 4% involves some uncertainty and 7% are not classifiable. Another special feature are two caves that were formed by calcareous tufa deposits and are referred to as deposition caves (Fig. 2).

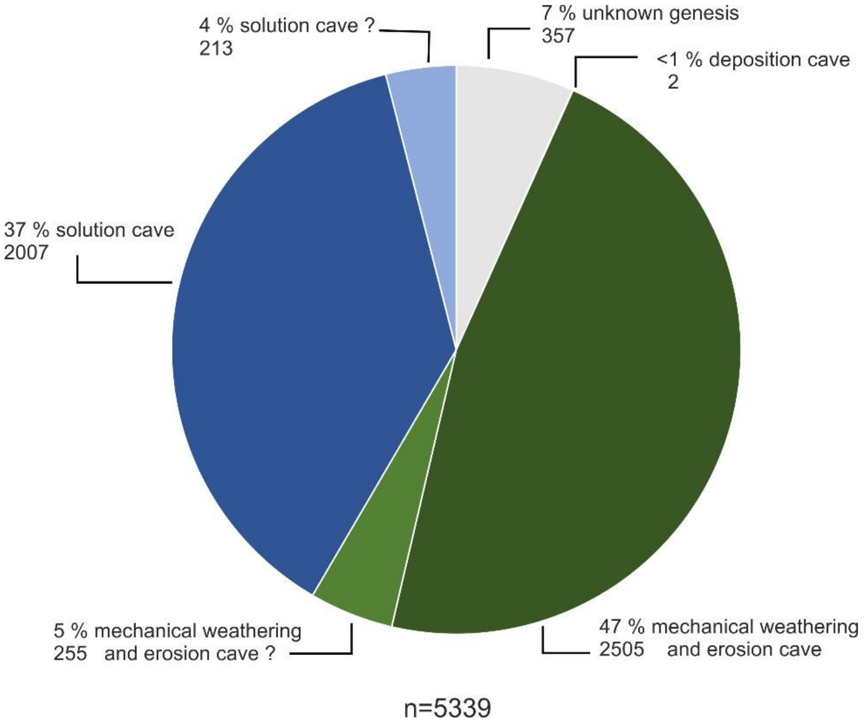

Fig. 2. Distribution of cave types in Lower Austria.

Looking at the subtypes of the 2759 mechanical weathering and erosion caves in Lower Austria (Fig. 3), the clear dominance of frost weathering caves is remarkable: 50% can be clearly assigned to this subtype, a further 17% with some uncertainty. For details about the classification criteria please notice Oberender and Plan (2018).

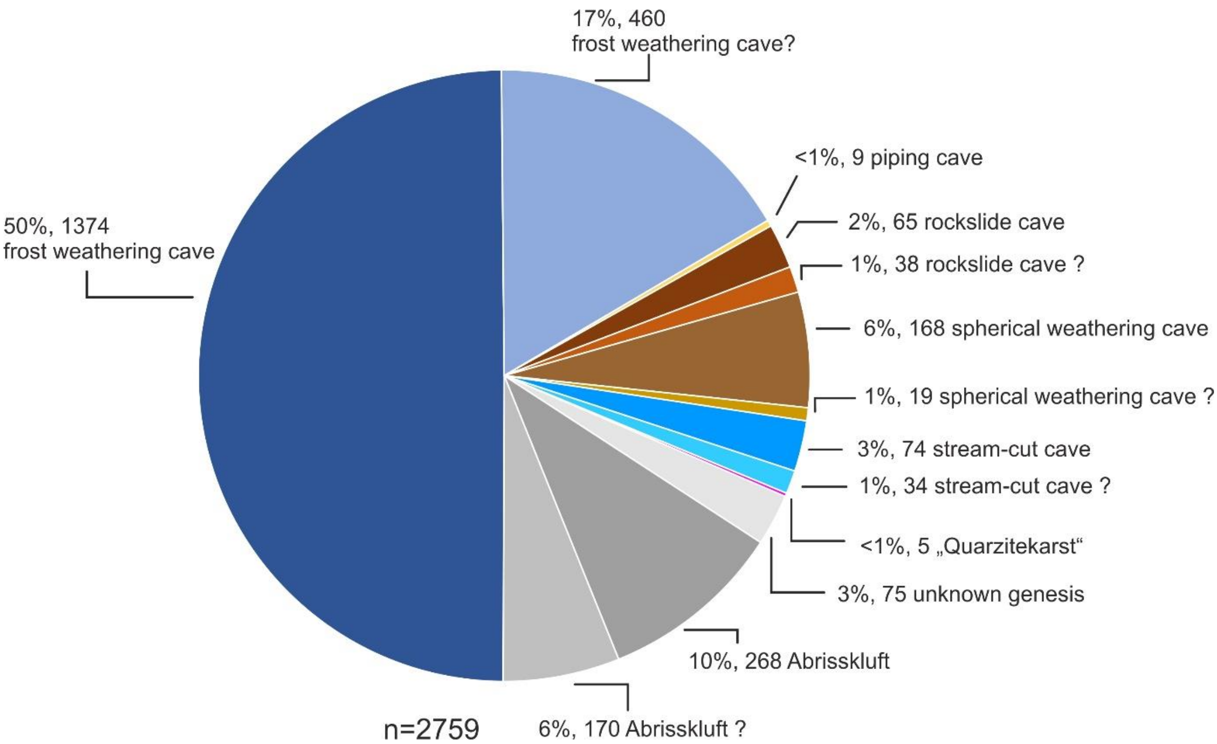

Fig. 3. Distribution of subtypes of the mechanical weathering and erosion caves in Lower Austria.

While piping caves are clearly tied to loess occurrences and spherical weathering caves occur exclusively in the granites of the Bohemian Massif, the occurrence of frost weathering caves, “Abrissklüfte”, rockslide caves and stream-cut caves is apparently not linked to a specific geology. Nevertheless, most frost weathering caves occur in carbonate rocks.

Many individual processes are involved in frost weathering. Not only the increase in volume during the freezing process from water to ice causes an increase in pressure in the rock structure, but also the unfrozen water that is compressed in the pore space. Water migrates in the direction of the already existing ice and thus increases local stresses. The stress fields change during the thawing processes and can even trigger renewed freezing. Deprez et al. (2020) have written an important review on this complex interaction. The efficacy of these processes is strongly related to the local porosity and permeability. This in turn depends on the type of rock, but also significantly on the tectonic stress and the associated fracture network. The dissolution processes in carbonate rocks obviously also lead to an increase in water pathways in the rock. In addition to porosity and permeability, temperatures below 0° C and sufficient rock moisture play an important role in effective frost weathering. It is therefore not surprising that most of the frost weathering caves in Lower Austria occur in the Northern Calcareous Alps.

After initial field observations in 2012 (Oberender, Plan 2015), we developed a conceptual model on frost weathering cave genesis. In order to evaluate the model and to develop a better understanding of the effectiveness of frost weathering as a cave-forming process, as well as to make a first effort to quantify the processes involved, a second more comprehensive field study was conducted in three caves in Lower Austria from May 2018 to May 2022. The three caves are located on a north-south transect, from the Bohemian Massif where the Amphibolithöhle (ABH) is formed in paragneiss and amphibolite at 507 m a.s.l, to the Northern Calcareous Alps, where Untere Traisenbacherhöhle (UTH) is located at 595 m a.s.l and Eisenhuthöhle (EHH) developed in the Rax mountains in 1500 m a.s.l., both caves formed in Middle Triassic limestone. In each cave five temperature-loggers were installed: two measure the air temperature, one near the entrance and one at the back wall. Three measure the rock temperature in 3, 10 and 40 cm depth. To observe rock moisture variations two profiles with different electrode spacing for geoelectrical measurements were installed. To collect the sediment formed by frost weathering, a 4 x 4 mm net was hung in each cave and rock debris was collected monthly. In order to be able to characterise the host rock, rocks were collected in the caves and its porosity and permeability were determined in the laboratory and thin sections were made.

The temperature measurements have shown that in the ABH between 2018 and 2021, the air temperature only fell below 0°C for 1.5 hours, while the rock temperature never dropped below freezing. Therefore, no frost weathering could have taken place here and is therefore irrelevant for cave formation under present conditions. The picture is different at UTH and EHH. At the pre-alpine UTH, the years 2019 and 2021 were particularly significant. Here, 280 and 111 frost hours were recorded at a depth of 3 cm, respectively. In the high-alpine EHH, between 1150 and 1844 frost hours were documented annually between 2018 and 2021. The number and size of rock fragments are also significantly higher in the EHH than in the UTH. However, most of the rock fragments did not break out during the winter months, but breakdowns were recorded during the periods with high frequency of dew.

Based on the geoelectric measurements, it was possible to identify fissures that are water accumulating. Also, drier and wetter phases can be clearly distinguished due to repeated measurements.

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Genesis of the Jaskinia Pod Świecami (Poland) – studies based on interdisciplinary geomorphological, geophysical and geodetic data

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The caves formation is a result of the interaction of natural processes such as karstification, erosion, weathering, suffusion, gravity induced processes and sedimentation, as well as anthropogenic processes. The development of a cave is also influenced by rock properties (mineral composition, structure and texture, porosity) and state of its secondary alteration (infiltration, relaxation). These factors have been changing in time and space with varying intensity and have had a predominant or insignificant influence on the cave development. Owing to these processes, the interior of the cave has been modified. These changes include the cave environment, flowstone cover, cave sediments, as well as forms of cave relief, in particular the shape of the ceiling and floor, and rock structure in its surroundings. Their correct reading and interpretation with the help of specialized research make it possible to understand the speleogenesis.

The paper presents the results of interdisciplinary research conducted in the area of the Jaskinia pod Świecami (Cave Under the Candles) formed in the Neogene (Miocene) calcarenites (Gubała, Kasza 1998). The study site is located in central Poland, in the Kielce Upland (342.3) within the Szydłów Foothills (342.37) (Solon et al. 2018). The aim of the research was to determine the cave's genesis based on geomorphological, geophysical (electrical resistivity tomography ERT and georadar GPR) and laser scanning (TLS) surveys, conducted on the surface and inside it. Observations of the cave's interior confirmed its complex genesis.

The present-day cave entrance is situated in the lowermost part of the abandoned quarry wall. It is narrow, partially covered by weathering material dropped from the top of the quarry wall. Behind the entrance is a relatively large chamber up to 8 m wide, sloping to the east. It is 50 m long and passes into the essentially horizontal passage. Both chamber and passage run along an uneven fissure (Fig. 1B) of the W-E direction. The other cavities of the cave are: a low passage, about 20 m long, running toward the north (perpendicular to the main passage), and a narrow passage, 8 m long, running westwards from the entrance chamber. Both of these passages were formed along cracks that are currently uneven and more or less weathered. Vertical tubular voids (called candles) as well as undulating weathering-erosion strips visible on the cave walls (Fig. 1A) evidence a rainwater infiltration and dissolution of calcarenites by underground waters.

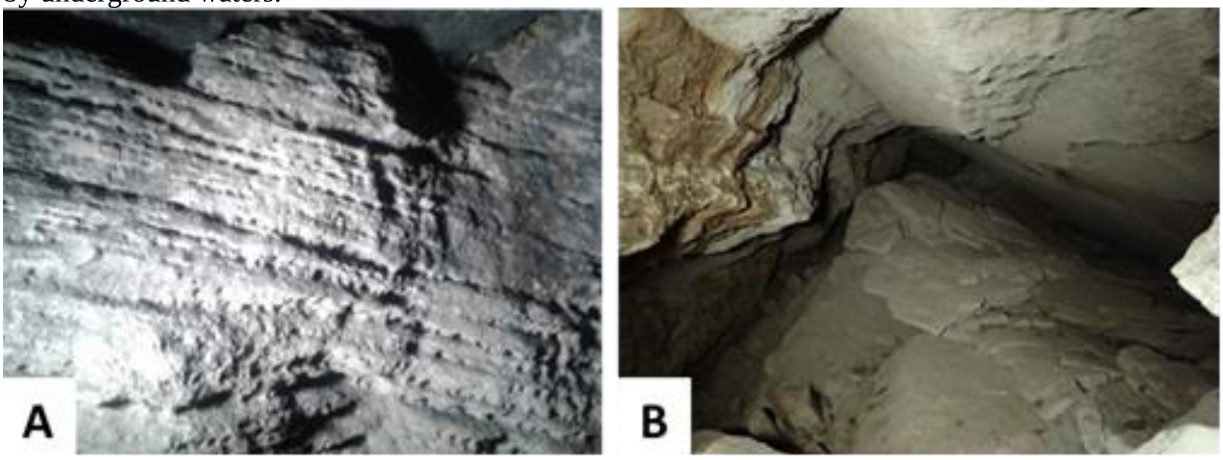

Fig. 1. The interior of the cave: A – Weathering-erosion strips, B – Gravity induced movements related to the fissure along the cave main chamber and passage responsible for their development (photo B. Pasierb)

As a result of the TLS survey, good-quality 3D measurements of the cave geometry were obtained. According to the TLS studies, the length of the main passage, running W-E, is 46.5 m. This dimension is smaller than that resulting from geomorphological and speleological recognition (Gubała, Kasza 1998) by 11.5 m. The resulting difference in the dimensions of the cave may be due to the inability to carry out measurements in appropriate places. Due to the size of the device and the requirement to position each station, it was very difficult or impossible to acquire the point cloud from extreme locations in the corridors. The maximum height of the Jaskinia Pod Świecami based on the TLS measurements was recorded in the confluence zone of the corridors and is 3.6 m.

ERT cross-sections visualized the shape of the cave under an almost 4 m thick overburden of clastic rocks (formed mainly of Pleistocene glacial till of the South-Polish glacial complex, with a small contribution of fluvioglacial and aeolian sands), and determined the locations and extent of heterogeneities present in the bedrock. Particularly a lot of heterogeneities – zones of inner rock cracking and loosening – were located in the near-surface layer to a depth of 1 m below the ground surface. As indicate ERT surveys, the recorded vertical voids (candles) are not associated with any rock structures, such as fissures, bedding (planes), etc., which confirms the statement of Morawiecka and Walsh (1997) and Walsh and Morawiecka-Zacharz (2001), that the candles developed owing to the circulation of aggressive, glacial water associated with local degradation of permafrost. Studies by Dobrowolski et al. (2007) prove that their development occurred during the anaglacial phase of this glaciation.

Below the overburden, in limestone complex, a high resistivity anomalous zone was registered on ERT cross-sections, which imaged the cave along with the zone of cracks and fissures that developed around it. The fading crack zone was outlined quite deeply – up to the 18 m below the ground surface.

The echograms obtained from the GPR survey also recorded near-surface zones of cracking and loosening, as well as zones of fissures formed around the cave. In particular, fissure zone is located near the abandoned quarry, near the cave entrance, and in the vicinity of the northern corridor. It indicates important role of karst-weathering processes in the cave development. On the echograms such zones are also present in the cave surroundings and in the distant part of the main cave passage, and its extension.

The development of the cave took place as a result of the epigenetic (tectonic, deep weathering) loosening of the rock massif followed by karstification and anthropogenic activities characteristic of areas of intensive exploitation of rock resources. These two latter processes brought about collapses of detached rock fragments from the cave ceiling (Fig. 1B). It can be postulated that the most important initial process was a dissolution of the rocks below the present-day cave, while the subsequent gravitational collapses formed the present-day cavities.

The use of integrated geophysical methods not only confirms their effectiveness in mapping of caves, but also enabled a thorough and precise assessment of the processes occurring there, the degree of karstification and associated danger caused by the shallow near-surface occurrence of crack and void zones. In addition, under conditions of increased anthropo-pressure, there is a reasonable assumption that the development of the cave will determine the deformation of zone surrounding a cave, which will consequently lead to its further degradation contributing to the formation of superficial depressions.

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“Pseudokarst” – a classical term redefined in the context of the development of karst and cave research

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“Pseudokarst” as a descriptive term – introduced in 1906 – became especially popular in the second half of the twentieth century. The term was used in different ways in different countries. This is explained by the geological diversity of the phenomena, which have nothing or very little in common with the phenomenon of karst and yet visually resemble karstic features. The UIS-Pseudokarst Commission, founded in 1997 tried to bundle the activities, increasingly aware that the term is invariably descriptive and does not give any information about the physical and chemical processes involved. In the presentation we will give a comprehensive description of the history of the term and a cross-section of the diversity of opinions on the topic (Halliday 2004; Doerr, Wray 2007; Eberhard, Sharples 2012; Holler 2019, Bella et al. 2022; and others).

Many authors tried to apply it to landforms and caves not related to karst processes all over the world and presented it in various papers – as in the “Nachrichtenbrief /Newsletter” of the UIS Pseudokarst Commission since 1998 or during virtually all of the thirteen pseudokarst-symposia since 1982. In the course of time, however, the acceptance of the term "pseudokarst" became problematic because the boundaries between "karst" and "non-karst" turned out to be not exactly defined. Karst itself is highly heterogenous with several processes involved and even more so is “Pseudokarst”. Nevertheless, the "pseudokarst" has such a wide lithological and process-genetic variability that the term cannot be defined in a simple way. We find caves and – somewhere – karst-like surface features in granites, gneiss, schists, sandstones, poorly consolidated Pleistocene sediments, volcanic rocks and other rocks, as well as in glaciers – among others – like abrasion, (frost) weathering, mass movements and neotectonics. In some cases – like caves in siliciclastic rocks – some authors postulate karst in the classical sense as a speleogenetic factor (e.g. Fabri et al. 2021), since a dissolution may be the determining process of their origin and development. But probably not all “pseudokarst” researchers are that convinced, however. When it comes to the combination of (chemical) dissolution and disintegration – for instance in sandstones with calcitic matrix – the boundary between “karst” and “pseudokarst” appears very indistinct and the assignment to one or the other terms becomes difficult.

Bearing in mind, that the term “pseudokarst” originated in the visual similarity of phenomena, one often finds caves with special features in non-karst areas which have no counterparts in karst areas at all. Therefore, it is no wonder that some authors reject the term “pseudokarst” altogether.

The discussion becomes even more delicate when we consider the many cases where "pseudokarst caves" occur in karst areas. In a comprehensive study of the approximately 4000 caves in Lower Austria (Oberender, Plan 2018), it was concluded that erosion and weathering processes have played a significant role in the development of caves in the alpine karst areas (Fig. 1), being the dominant factor in up to 50% of the caves in several sections. Also numerous crevice caves are known in the mountains built by carbonate rocks. Some solution caves in dissected high-relief karst areas are fractured and subsequently truncated due to gravitational slope movements.

The UIS Pseudokarst Commission, however, considers the term mainly as a large bracket that bundles the heterogeneous speleogenetic aspects that have little to do with "karst" emphasizing explicitly the importance of the speleogenetic processes behind it. In this sense the comprehensive term “pseudokarst sensu lato” should gather - in the Commission and during meetings - speleologists (cavers and scientists) exploring or researching non-karst or polygenetic caves and other non-karst formations sometimes somewhat similar to karst. The current and future main goal therefore is to identify, define and investigate the physical and chemical fundamentals involved in relation to various geological, geomorphological and climatic environments worldwide which does not fit into the context of “karst”.

Fig. 1. Untere Traisenbacherhöhle (1866/37) in the pre-alpine karst of Lower Austria. Presenting a more or less classical karstic-appearance, the cave ends abruptly a few meters behind the figure (photo courtesy of L. Plan, Vienna). The formation of this cave – situated in highly karstifiable Middle Triassic Limestone – is thus probably entirely due to frost weathering which was measured during several years, enhanced by chemical dissolution along near-surface cracks.

The original term – "faked" karst phenomena outside the karst areas – could be redefined as (still solely descriptive) "pseudokarst sensu stricto". This term should be limited to those phenomena that actually look deceptively similar in morphology to karst phenomena but their initial and main genetic processes were/are not associated with the chemical dissolution of the (karst) bedrock, e.g. crevice and weathering caves in insoluble rocks, karren-like landforms in insoluble or poorly soluble rocks, suffusion/piping caves in volcanoclastic rocks and loess, corrasion and deflation caves in arid areas, and other similar natural features.

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Extensive non-karst speleothems in gneiss (Rudolfstollen, Austria)

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The Rudolfstollen, an artificial tunnel from the 2. World War was excavated in gneiss of the southern Bohemian Massif to an overall length of about 1300 m. It stretches roughly in W-E direction for some 400 m with some parallel corridors in the southeastern continuation of the adjacent Pöstlingberg (523 m a.s.l.) at an altitude of 270 m.

It came to the attention to cavers as early as 1969 that here – barely 25 years after the excavation – there exists a variety of dripstones and flowstones despite the fact that there is no limestone overlying the tunnel. These dripstones are clearly different from those well known features from areas where concrete and cement are present. Since 2007, these speleothems have been intensively studied and alternative hypotheses for their genesis were finally formulated.

The first two models – the origin of the calcium from Neogene sediments or loess – were excluded due to a lack of both in the areas above the tunnel as well as in the wider catchment areas. The extensive use of fertilizer or anti-moss chemicals which might be responsible for a certain content of calcium in the soil cover above the tunnel could not be verified, too.

The actual hydrogeological model, based on surface and subsurface observations yielded a subsurface runoff from the mountain NW of the tunnel in the uppermost and loosened parts of the gneiss, which is entirely covered by soil, seeping into deeper parts of the gneiss in areas of more intensive faulting.

It could be observed that in the western part of the tunnel only dark brown to black straw soda stalagmites occur, with drip-water of pH < 3 and high contents of Ca, SO_4, but also Fe and Al. On several parts of the wall elemental sulfur was detected. This points towards the weathering of pyrite and the subsequent formation of sulfuric acid which occurs obviously in some parts of the gneiss but could not be detected macroscopically yet in the tunnel (Fig. 1).

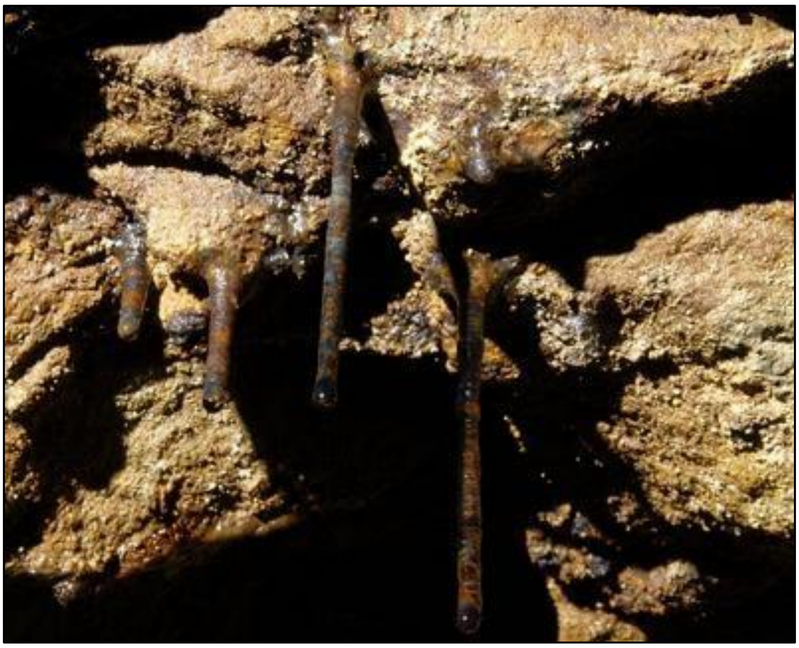

Fig. 1. Ferruginous stalactites and dripwater with pH 2.6 in the western section of the Rudolf-stollen (photo H. Thaler).

Further to the east of the tunnel the dark brown speleothems are more and more replaced by bright white stalagmites and flowstones of remarkable extent over a distance of some 160 m (Fig. 2). Here the pH is >7 and the dripwater resembles a karst water with an elevated content of Ca and HCO_3.

Dissolution experiments with the gneiss proved this peculiar hydrochemical behaviour even without the presence of macroscopic pyrite: after 3 years of soaking in two types of distilled water (pH 7.5 resp. 4.4 lowered by CO_2) the electric conductivity was 20 to 30 times higher compared to granites from the same area.

To explain the source of Ca and C and the catchment area determinations of ^{14}C of the white speleothems as well as ^{18}O of the dripping water were made. ^{14}C yielded values of 97 and 99 pmC, respectively, which definitely excludes the participation of Neogene and Pleistocene sediments, pointing to biogenic and atmospheric CO_2 as the only source of carbon. On the other hand the ^{18}O variations enabled to estimate the average transit time of the water, yielding 6 years. The independence of drip water temperatures in the tunnel from external variations can be taken as a proof for this long transit time, too.

Fig. 2. Speleothems in the eastern part of the Rudolfstollen (photo H. Thaler)

As a source for Ca the hydrolysis of Ca-feldspar turned out to be the most probable option, taking place in groundwater upstream of the western part of the tunnel

$$Ca[Al_2Si_2O_8] + CO_2 + 4\ H_2O \rightarrow Ca(HCO_3)_2 + 2\ SiO_2 + 2\ Al(OH)_3$$

This basic equation may be modified taking the weathering of the pyrite in some parts of the gneiss into account where the emerging sulfuric acid also reduces the stability of the feldspar significantly.

As SiO_2 is less soluble at low pH and $Al(OH)_3$ has its lowest solubility around pH 7 it is obvious that in the eastern part where the pH increases steadily towards the east the contents of SiO_2 and Al in the dripwater are already low, whereas in the western parts, where only black ferruginous stalactites occur, both are abundant. However, it remains unclear yet, whether there is a hydrochemical transition zone between these two hydrogeochemical environments respectively how much they interfere. This will be the focus of future investigations.

The resulting speleothems have nothing in common with their karst counterparts except their appearance: it is impossible to distinguish them visually from normal dripstones and flowstones. On the other hand, the rate of formation is many times higher than in alpine karst caves, as long-term measurements showed.

We may therefore call speleothems like these *pseudokarst sensu stricto.* Likewise the non-carbonaceous speleothems of granite caves, consisting of pigotite or opal-A which often resemble phenomena in karst areas could be assigned to this descriptor.

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Iron springs in the Blue Mountains, New South Wales, Australia

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Introduction

A sequence of extreme weather events from drought (2017-2019), bushfires (2019-2020), and floods (2020-2023) has allowed us to see iron minerals being deposited by temporary springs along a highway running through the Blue Mountains National Park, New South Wales, Australia. Usually these seeps are clear, and covered by vegetation, but recent weather extremes have made it easier to see a process of accelerated iron mineral deposition. It also allowed us to view some of the smaller sandstone caves which were usually hidden by vegetation.

This paper discusses some of the processes which may be operating within the quartz sandstone, leading to the attractive and unusual shapes, and how extreme weather led to the mobilisation and re-deposition of iron minerals.

Location and setting

Mount Banks is a raised area of a plateau located in the Blue Mountains National Park, 115 km west of Sydney, Australia. The area is famed for its rugged scenery set in Triassic quartz sandstone, deeply dissected by creeks and sheer cliffs. The sculptural quality of ironstone bands in quartz sandstone has made them a tourist attraction.

Distinctive ironstone weathering patterns can be seen in exposed areas of the plateau which is mainly Banks Wall Sandstone in this area (Fig. 1). The most likely source of iron for the ironstone is the erosion of Neogene (Miocene) basalt cap on Mt Banks (Pickett et al. 1997). The process of erosion allows iron oxyhydroxides to be re-worked by soil chemistry and biology, dissolving or precipitating iron oxyhydroxides downstream from the original source.

Fig. 1. Small sandstone caves under ironstone-capped bluff near Mt Banks (photo J. Rowling).

Springs

The Blue Mountains National Park has abundant sclerophyll vegetation dominated by eucalypts, and this generally keeps the water table low due to transpiration, especially during the long drought of 2017-2019. It is this act of transpiration which releases eucalyptus oil into the air, making the Blue Mountains appear blue.

During a major bushfire of 2019-2020, a large area was burned, including much of the vegetation in the study area of Mt Banks to Clarence a little further west along the Bells Line of Road. After the fires, there were flooding rains. A “La Niña” wet weather event lasting from 2020-2023 brought significant rain and floods to the region. Without vegetation to draw down the water table, springs were seen in the area, coloured red-orange from apparent iron oxide precipitation. Gradually, vegetation returned

naturally from a combination of epicormic buds and seed and the springs are now less obvious. When active, springs could be seen on rounded rock faces below perched swamps and on road cuttings (Fig. 2).

Fig. 2. Road cutting in quartz sandstone with iron spring at bottom, leached middle area and top reddish regolith near Clarence (photo J. Rowling).

<u>Perched swamps</u>

Perched swamps in the national park are naturally acidic from organic acids. During the bushfires, parts of some swamps burned completely through the peat subsoil right down to the sandstone but others stayed wet. After flooding rain, water levels in the swamps rose.

<u>Exposed sandstone plateau</u>

The plateau has very thin soils, mainly composed of sand, quartz sandstone and ironstone clasts and a mat of interlocked roots of several plant species. The bushfires burned some of these mats, which subjected the soils to high temperatures close to the surface. Near Mount Banks picnic area, it was possible to see some of the effects. After the fires and the first rains, the ash bed became a thick, foul-smelling black paste. This may have prevented some of the soil from being simply washed away, and was still present three years later.

<u>Heat on iron deposits</u>

The delicate iron oxyhydroxide patterns in the sandstone are mainly goethite with some hematite on older surfaces. When subject to high temperatures, surface goethite can dehydrate to ferric oxide (rust). The temperatures required to do this are at least 500 C° (Beuria et al. 2017) which can easily be achieved in bushfires. Possible there was also some small-scale iron reduction in low-oxygen situations.

<u>Acid and microbes on wet iron oxide powder</u>

Rain will wet the iron oxides, allowing them to be washed away from their original position and settle into cracks or get washed into swamps. As the soil in the Blue Mountains is generally acidic, it can dissolve iron oxide particles. The process for converting ferric oxide to goethite is usually very slow, but there are a number of microorganisms which work in wet anoxic environments such as found in swamps, and these can convert the material from iron oxide to iron oxyhydroxide. Humic and fulvic acids also dissolve iron oxides. Other organisms operating in wet, oxygen-rich, near surface environments can further alter the iron products back to goethite. This can be seen sometimes as an irridescent floating deposit on the water known as flocs (floculants). The material can also be lodged in rock joints forming dyke-like deposits.

<u>Groundwater mixing</u>

The quartz sandstone is generally porous, except where iron banding occurs. Rain falling on the plateau can be absorbed into the sandstone. This tends to be relatively neutral pH. On the other hand, water in the perched swamps tends to be very acidic, often with low oxygen and can dissolve iron oxides. Where the two waters meet, there can be some mixing corrosion and iron deposition at the mixing front which could be in the solid sandstone. The patterns formed by these mixing fronts can appear roughly circular, tubular, and repetitive as the groundwater levels change. In general, the patterns are formed valley-side as this is the general direction of groundwater flow.

Near the springs were small features similar to flowstone, comprised of sand grains and organic material as well as bacterial iron flocs at the air/water interface making irridescent patterns. These bright colours usually occur close to the surface where there is plenty of oxygen. Deeper in the rock, the patterns are less distinct, most likely because a different bacterial species works in lower oxygen levels. The process can be seen in road cuttings where newly exposed rock has less colour than older exposed rock.

Formation of caves and flat ironstone layers

Within the sandstone, either impervious ironstone shapes or occasionally impervious shale layers redirect groundwater as springs. Generally the rock massif just above the impervious layer is a softer sandstone where the grains are poorly cemented and frequently burrowed by insects. The quartz in the softer sandstone is only held together by a small amount of silica (probably common opal). This layer is more cavernous and sometimes appears whiter than the rest of the sandstone.

Above the soft layer, one may see a layer of ironstone, caused by a mixing of acidic and neutral waters. The sequence can repeat in some areas, depending on groundwater sources. The iron-rich layer sometimes forms the ceiling of small sandstone caves (Figs. 3 and 4).

Fig. 3. A swamp edge forms the roof of a small cave near Mt Banks (photo J. Rowling).

Fig. 4. Cavernous sandstone near Mt Banks (photo J. Rowling).

Relationship between iron springs and small caves in sandstone

The following is a suggested on-going sequence of weather and groundwater events leading to formation of iron springs and their relationship to small caves in quartz sandstone:

1. The existing surface has ironstone patterns in the quartz sandstone, derived from eroded basalt.
2. Severe bushfire removes vegetation and dehydrates some ironstone surfaces.
3. Rain washes iron oxides into joints and swamps.
4. A long period of unusually wet weather, coupled with lack of vegetation allows the water table to rise considerably.
5. Acidic and biochemical reactions dissolve iron compounds in the groundwater and re-deposit iron oxyhydroxides as flocs.
6. Mixing of fresh (rain) and acidic (swamp) waters within the sandstone deposits iron oxyhydroxides at the mixing boundary, typically a curved layer.
7. Removal of quartz grain cement by mixing groundwater results in a softer, more easily eroded sandstone as well as depositing small flowstone-like patterns.
8. Over time, iron oxyhydroxide flocs block the pores in the sandstone, forming impermeable layers of ironstone.

Conclusions

In conclusion, the formation of these beautiful patterns is on-going as erosion exposes the iron banding. The sandstone caves are caused by leaching of quartz cement, initially by groundwater mixing to weaken the rock and later assisted by insect burrowing.

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Broumovsko Geopark – the land of sandstone

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The Broumovsko National Geopark (Národní geopark Broumovsko) was founded in 2011. In 2013, it presented its first geotourism products to visitors – an educational trail through 40 important geological sites and their descriptive web presentation. Significant development of the geopark took place in the years 2017-2020 as part of the joint Czech-Polish interregional project, focused on the development of tourism and geotourism in the Central Sudetes region. At the same time, the final territory of the geopark was marked out and the number of interpretive geosites was increased to 80. In 2018, based on the expert evaluation of detailed nomination documentation and terrain attractions, it received the National Geopark certificate, issued by the Ministry of the Environment of the Czech Republic. Geopark development activities are currently focused on thematic geoscience field excursions with an expert geoguide, environmentally oriented educational programs for schools, cooperation with local municipalities in maintaining geosites and building geotourism infrastructure. Cooperation with other geoparks and important national and foreign geoscientific institutions is also being successfully developed.

The Broumovsko National Geopark is located in northeastern Bohemia over the entire territory of the so-called Broumovský výběžek and the territory of the Žacléř region. Its territory is delineated according to the administrative division within the boundaries of the Broumovská vrchovina geomorphological unit, which, in fact, corresponds to the Czech part of the Intra-Sudetic Basin geological structure. The total area of the Geopark Broumovsko is 570 km^2.

The geological richness and geological history of the Broumovsko Geopark is interpreted in an engaging and comprehensible for the general public form, both on the website and on field trips and lectures. Emphasis is placed on understanding important natural and geological patterns in relation to contemporary everyday life. Geotouristic attractions are linked to three genetically distinct geological areas and structures.

The southwestern part of the Broumovsko Geopark presents the oldest, Carboniferous sandstones and conglomerates (up to 315 Ma old) with a number of coal-bearing geological strata assemblages of various thicknesses that are accessible in the numerous rocky outcrops (Fig. 1) of the tectonic ridge of the Jestřebí hory mountains. The more than 400-year-long history of black coal mining in the region of northeastern Bohemia is also linked to these series.

Fig. 1. Carboniferous arcosic sandstones on the Jestřebí hory ridge (photo S. Stařík).

The northeastern part is presented by the distinctive volcanic ridge of the Javoří hory mountains, built by volcanic and volcaniclastic rocks of basalt-andesite to rhyolite composition in combination with miscellaneous aluvial and lacustrine sediments of the Broumov basin (Fig. 2). Both are of the Permian age (approximately 295-275 Ma).

Fig. 2. Permian sandstone wall in Hynčice, Broumov basin (photo S. Stařík)

The central part of the Geopark Broumovsko is represented by the geomorphologically distinct brachysynclinal structure of the Police Cretaceous Basin (Polická křídová pánev). The marginal cuestas, formed by blocky arkosic and glauconitic sandstones, are overlain in its central area by sandy marlstones and relicts of the youngest quartz sandstones in the form of rock cities. All the mentioned marine sediments are of the Upper Cretaceous age (95-89 Ma). The morphology of the sandstone rock cities is characterised by the extensive occurrence of pseudokarst phenomena, especially scree and fissure caves.

Fig. 3. Cretaceous quartz sandstones towers and arcs in Adršpach rock city (photo S. Stařík)).

In addition to the geomorphological and pseudokarst phenomena of sandstone rock cities, objects of professional interest in the Broumovsko Geopark are also fossils of Upper Cretaceous marine fauna, specific Permian volcanic rocks and structures, fossils of Permian fauna and flora, and an exceptionally rich occurrence of Carboniferous plant fossils.

Lonely-standing rock towers: how stable are they?

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Solitary rock towers are specific landforms that often form a dominant element in the landscape. These iconic rock forms are characterised by their elongated, mostly cylindrical shape, but there are also some of them that are even overhanging on all sides. Inevitably, this raises the question: how stable are these towers? Since they are erosional remnants of an ancient, mainly sandstone rock, the answer is that they are actually the most stable elements of the original landscape. But are they really?!

In recent times, we have known several cases of collapses of these tall rock towers in the area of he Bohemian Cretaceous Basin, often with a surprising finding – the total destruction of the sandstone mass that originally formed the tower. It's remarkable that the tower was ever to hold together. Most of these collapsed towers were located in heavily visited tourist areas, often directly on one of the main tourist trails or were even used as rock climbing terrains. Such towers can be considered as extremely endangering. How many such potentially unstable towers can actually exist, typically in sandstone landscapes? This is a difficult question to answer. However, our project intends to contribute to the understanding the stability of rock towers.

The aim of our project is to use multidisciplinary geophysical research combined with an advanced UAV imaging to obtain a comprehensive external and internal image of the rock towers. By using a complex, non-invasive approach, we will be able to better understand the basic mechanical and structural properties of the studied rock forms.

The base of the rock towers has been investigated by a combined 2D geophysical survey comprising electrical resistivity tomography (ERT), ground penetrating radar (GPR), electromagnetic measurements (EMI), and shallow seismic survey (SSR). 3D geophysical imaging was performed where possible (particularly in view of the spatial conditions). The main focus of the subsurface geophysical imaging is to detect a bedrock base and roots of the studied rock tower, i.e. how the tower is embedded in the underlying bedrock. The detailed geometry of the above-ground parts of the towers was acquired by UAV-based photogrammetry and a detailed 3D model could have been created.

Newly, a seismic response of the rock will also be studied using ambient vibration survey to identify prominent structures within the rock mass. In addition, other physical properties of the sandstone rock will be investigated using the EMI and GPR methods directly on the tower, which can provide information on weathering, water saturation or major crevices and fractured zones based on changes in measured conductivity/resistivity, characteristic EM wave reflections or attenuation of the EM signal.

The interpreted physical characteristics, obtained from geophysical measurements are then used as an input into a stability assessment of the rock towers under study. Such an approach can extend knowledge beyond standard geological research. This stability evaluation can then be used as an input to a hazard assessment of potentially unstable rock forms. Nevertheless, this has to be preceded by basic research on the key parameters of the rock mass.

The UIS Pseudokarst Commission – a quarter of a century of its activity

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In the second half of the 20th century, the exploration and study of non-karst caves became very popular and widespread. In a consequence adequate tools (i.e. methodology, terminology) for the description of such caves and their characteristics, as well as for the determination of the general field of such activity became necessary and thus were developed (Bella et al. 2022). This also created a need for cooperation between researchers studying such caves, therefore several international meetings were organised, mainly in Central Europe, such as in 1982 (Symposium o Pseudokrasu, Janovičky, Czechoslovakia – with the participation of representatives from 3 countries), 1985 (2th Symposium o Pseudokrasu, Janovičky, Czechoslovakia – 5 countries), 1988 (3rd Pseudokarst Symposium, Königstein, East Germany – 6 countries), 1990 (4th Pseudokarst Symposium, Podolanky, Czechoslovakia – 10 countries), 1994 (5th Pseudokarst Symposium, Szczyrk, Poland – 5 countries), 1996 (6th Pseudokarst Symposium, Galyatetö, Hungary – 8 countries). The important results of these symposia were published in the proceedings of these meetings. In the International Union of Speleology (UIS), and especially during the international meetings organised by this Union, the creation of an adequate UIS commission was postulated. The formal request for the establishing of a pseudokarst commission was passed during the 6th Pseudokarst Symposium in 1996 and addressed to the 12th International Speleological Congress (La Chaux de Fonds, Switzerland, 1997). Consequently, during this Congress the Pseudokarst Commission was established. The main creators of this Commission were István Eszterhás (Hungary) and Jiří Kopecký (Czechoslovakia) (Fig. 1).

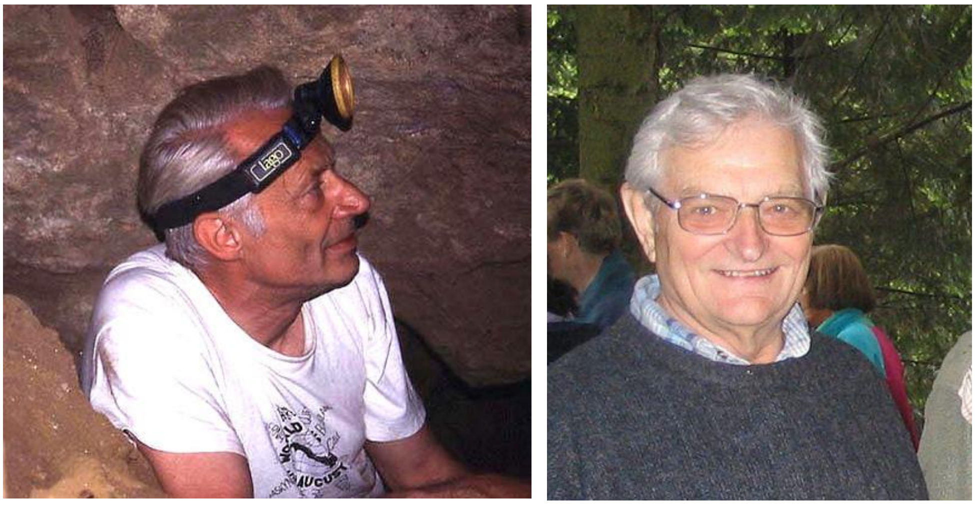

Fig. 1. Portraits of István Eszterhás (left) and Jiří Kopecký (right).

István Eszterhás was the first president of the Commission (up to 2008), while Jiří Kopecký has been its honorary president. The number of its members at the beginning of the 21st century oscillated around 20. The main aim of the Commission activity has been the inspiration and organisation of the international meetings, therefore between 1998 and 2014 seven international meetings were held, as follows: 7th International Symposium for Pseudokarst (1998, Moneasa, Romania – 6 countries, 10 participants), 8th International Symposium on Pseudokarst (2004, Teplý Vrch, Slovakia – 10 countries, 51 participants), 9th International Symposium on Pseudokarst (2006, Bartkowa, Poland – 12 countries, 44 participants), 10th International Symposium on Pseudokarst (2008, Gorizia, Italy – 11 countries, 61 participants), 11th International Symposium on Pseudokarst (2010, Saupsdorf, Germany – 10 countries, 55 participants), 12th International Symposium on Pseudokarst (2012, Tui, Spain – 8 countries, 27 participants) and 13th International Symposium on Pseudokarst (2014, Kunčice pod Ondřejníkem, Czechia – 9 countries, 52 participants). Materials of these symposia were published as proceedings or at least abstract books. General assemblies of the Commission members were held during each symposia, but some members had their meetings also during the international speleological congresses.

The second important activity of the Pseudokarst Commission was the publication of the Pseudokarst Commission Newsletter. Since 1998 up to 2022 thirty issues of this Newsletter were published. The first issues – also called "Nachrichtenbrief" by the editor, Istvan Eszerhas – consisted of a few pages printed in black and white, while from no. 19 they consisted of 12-51 pages printed in colours and containing scientific articles, meeting reports and announcements, obituaries etc. in two languages, English and German. The Newsletter no. 30 was published on the occasion of the International Year of Caves and Karst (IYCK) in 2022 and contained 11 scientific-popular articles promoting various types of pseudokarst caves in four continents, as well as a preface commenting on the problem of the pseudokarst caves promotion during the IYCK (82 pages in English only).

The third area of the Commission activity is the Commission website (address: http://www.pseudokarst.com/). It presents documents produced by the Commission assembly and executive group, issues of the Pseudokarst Commission Newsletter, reports and announcements of meetings and other events, past symposia proceedings, as well as cave photographs.

The Pseudokarst Commission currently has 34 members, representing 17 countries from all inhabited continents. The following four members have passed away in the last years: Ahmad Afrasiabian (17.07.2017), John Dunkley (1.02.2018), Istvan Eszterhás (2.08.2020), and Erich Knust (6.07.2021). However, 8 new and – the most important – young people have been adopted to the Commission as its members.

The rejuvenation of the Commission composition is a very positive trend, because the activity of the Commission should adapt to modern media, communication and cooperation possibilities. For example, as recent observations have shown, the traditional meetings attract relatively few participants, because there are other ways of working together or cooperation, e.g. online meetings or other internet contacts coordinated with ad hoc organized fieldworks/explorations, which are possible owing to easy and not very expensive travelling. Such new ways of working should be used by the Commission members. Therefore, in line with the Commission composition, the Commission executive body should be renewed to include people who are used to the new possibilities and trends.

Perhaps the development of new fields of exploration and research, as well as modern methods of cooperation will provide an opportunity to solve the term "pseudokarst" definition and interpretation, which were discussed and highlighted by some researchers in the first decades of the 21st century (Panoš 2001; Bella 2011; Eberhard, Sharples 2012; Urban 2014; Wray, Sauro 2017; Holler 2018; Bella et al. 2022). As it has been recently suggested (Bella et al. 2022), this term – although not strictly scientific – can gather speleologists (cavers and scientists) exploring and studying specific or polygenetic caves, and the Pseudokarst Commission can be very adequate forum enabling discussion and ideas exchange during various forms of meetings.

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Peştera de la Cascada Bohodei (Cave at the Bohodei Waterfall) in the Bihor Mountains, Romania - a natural quartzite cave or a very old mine?

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Peştera de la Cascada Bohodei (Cave at the Bohodei Waterfall) is an extremely interesting cavity, developed in quartzitic sandstone in the Bihor Mountains in the northwestern part of Romania (Fig. 1), a presumably unkarstifiable rock under the current and recent climatic conditions. However, it is not clear whether the Peştera de la Cascada Bohodei is a natural cavity or a very old mining operation. The cave was spotted by Liviu Vălenaş in 1965 and explored very briefly for 10 m. It was only in 2021 that Liviu Vălenaş and Maliwan Vălenaş fully researched and mapped it.

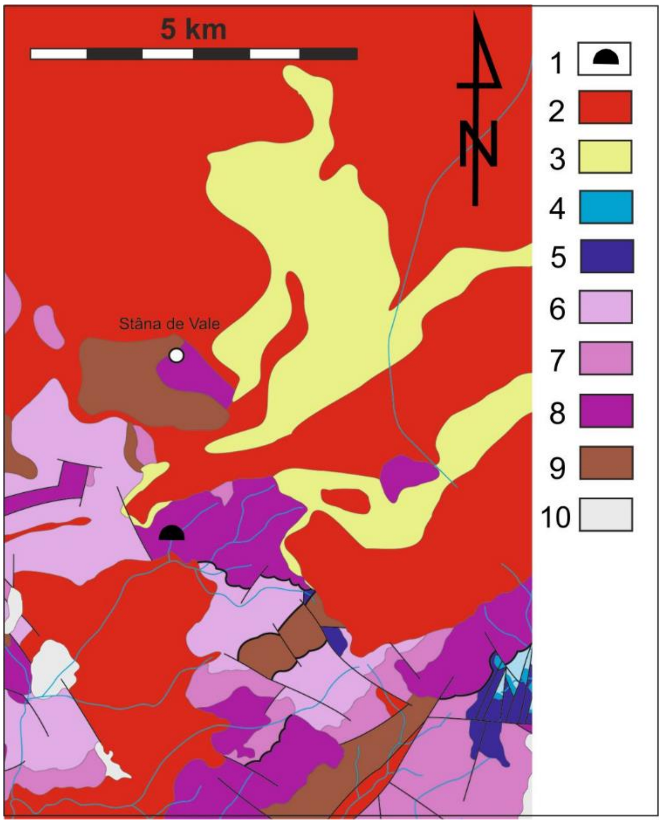

Fig. 1. Location of the Peştera de la Cascada Bohodei against the geological map. Explanation of symbols: 1 – cave, 2 – Upper Cretaceous-Palaeogene igneous rocks, 3 – Upper Cretaceous sedimentary rocks: limestones, sandstones, marls and volcanoclastics, 4 – Middle Jurassic carbonate rocks, 5 – Lower Jurassic sandstones and clays, 6 – Upper Triassic dolomites and limestones, 7 – Middle-Upper Triassic limestones and dolomites, 8 – Lower Triassic sandstones and clays, 9 – Permian sandstones and conglomerates, 10 – metamorphic rocks (author's material).

The cave is 24 m long (aerial length: 21.0 m) and its vertical extend ranging +3.0 m (Vălenaş 2022). It is located on a rocky promontory, in front of the Bohodei Waterfall, on the geographical right slope. An entrance (1.4 m/1.6 m in sizes) gives access to a rectilinear gallery, 21 m long (Figs. 2, 3, 4). In the final section, the gallery becomes ascending and it ends suddenly, without any continuation. In this section there are also two very small pools of water, as basins in the rock. A 1 m "diverticule" completes the topography. Finally, in the middle section a pillar divides the cave into two narrow and low portions (Fig. 2).

In terms of geology, geomorphology and genesis the cavity is developed in quartzitic sandstones of the Lower Triassic, immediately near the contact with the eruptive Vlădeasa Massif (Bleahu et al. 1980, 1981) formed on a N-S oriented fault line. The most pressing issue is to determine whether the cave is a natural cavity or a very old mining work. There are pros and cons to both hypotheses. Thus, the fact that it is absolutely rectilinear may be an argument for a prospecting mine. But a counterargument could also be formulated: the cavity developed naturally on a rectilinear fault line which is not uncommon for natural caves. The pillar in the middle section can also be interpreted as an old support pillar. Until it is thoroughly researched by mining specialists, we rather believe that the Peştera de la Cascada Bohodei is a very old mining work (Vălenaş 2022).

Sulfide minerals are visible on the walls of the main gallery (Fig. 4). Most likely, however, other minerals also occur. I have no record of a survey being conducted by a mineralogist so far.

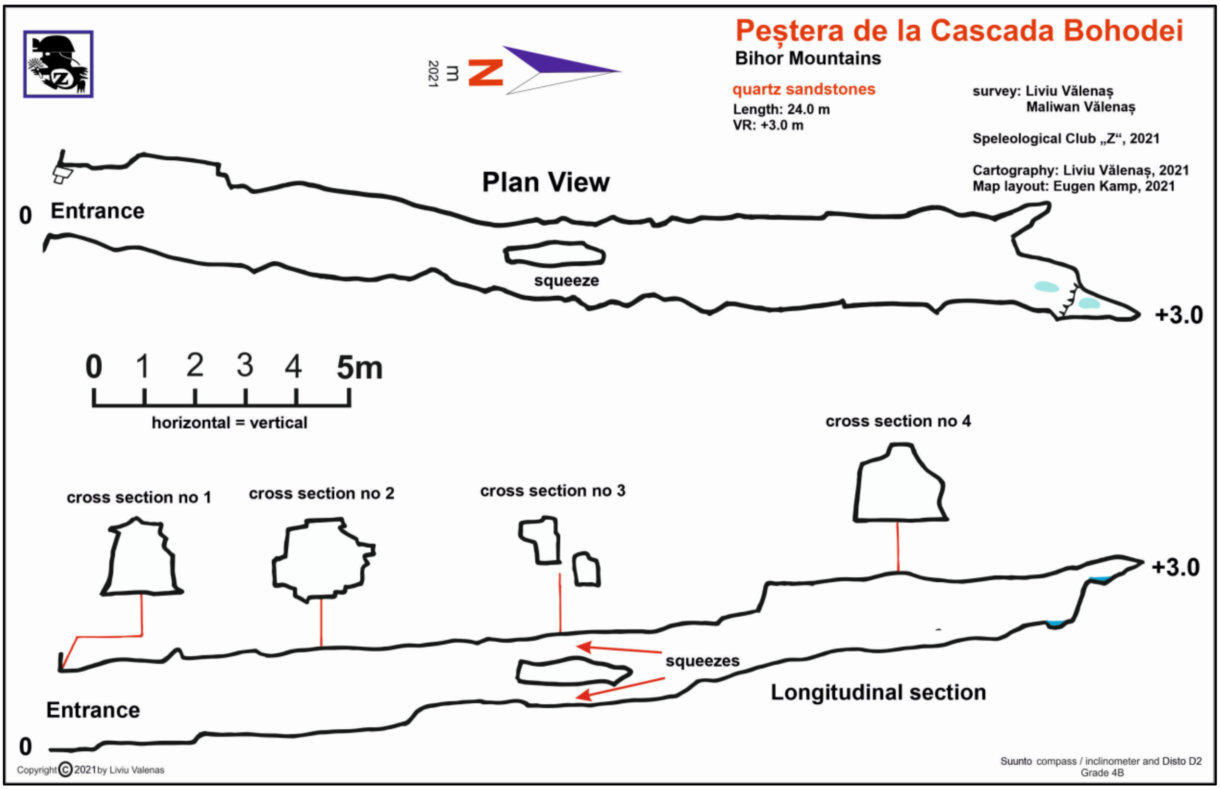

Fig. 2. Map of the Peştera de la Cascada Bohodei (author's material).

Fig. 3. Entrance of the Peştera de la Cascada Bohodei (photo L. Vălenas).

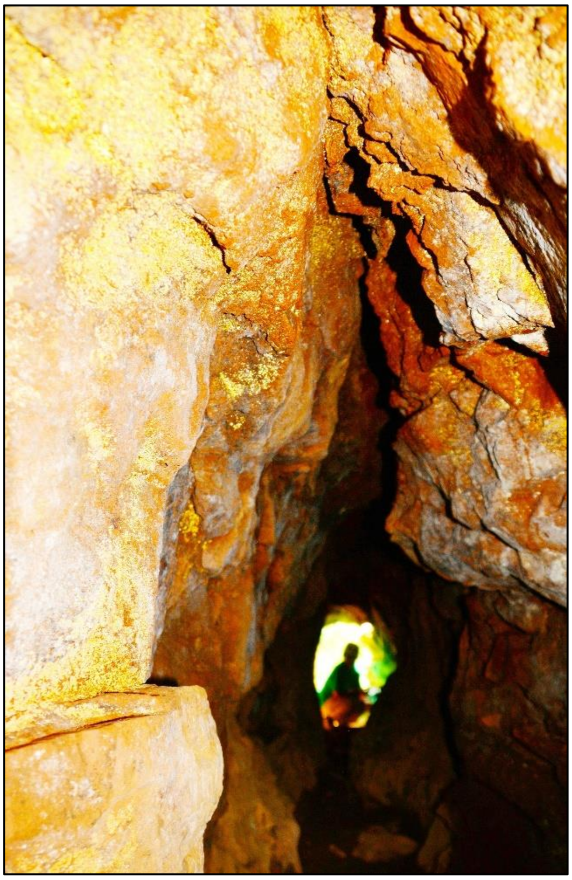

Fig. 4. Gallery of the Peştera de la Cascada Bohodei with sufide minerals on the walls (photo L. Vălenas).

In conclusion, it should be stated that it is not clear that the cave at the Bohodei Waterfall is just a very old mining work (a prospecting tunnel) dating back several centuries. It is certain that it does not appear in the old mining registers. But if the mine is 400-500 years old, this fact would be explainable (Vălenaș 2022). I did not find visible traces of human excavations, but it is up to the mining specialists to prepare a more thorough investigation.

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Geomorphology and hydrogeology of genuine karst in the quartzitic sandstones of northeast Thailand

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Introduction

The northeast of Thailand, so-called Isaan, largely belongs to the Khorat plateau, composed mainly of sedimentary rocks, mostly quartzitic sandstones, but also sandstones with calcareous cement. Magmatic rocks also appear in some places. The age of these geological deposits is Mesozoic: Triassic, Jurassic, Cretaceous (Veeravinantanakul et al. 2018). The caves and pits studied by us until 2020 are in the Phu Kradung Formation of the Jurassic age (Veeravinantanakul et al. 2018, Nakchaiya 2020) in quartzitic sandstones. The entire Khorat plateau is strongly tectonised (Doerr 2000a, b). From a geomorphological point of view, the plateau, which slopes very gently towards the Mekong River, is situated between altitudes of 180 m and 300 m. Evidences of erosion regularly appear, either in the form of completely isolated mountains, or in the form of mountainous massifs, with heights of up to 500-600 m.

Karst geomorphology

Only in recent years a more coherent image of the karst in northeast Thailand has emerged. Apart from the poljes (which have not yet been identified, but they probably exist too) the northeast of Thailand includes all possible forms: water losses (ponors), karst springs (some with high to very high flow), karren, karren fields, caves, pits (Vălenas 2016a, b, 2020d). Sinkholes, on the other hand, at least at the current stage of research, are not characteristic (Mouret C., Mouret L. 1994). There are also canyons, which are very similar to those in limestone in other areas. Caves are of two types, or a combination of these types. The smaller caves have a tectonic foundation, being developed along faults and diaclases. But even here the role of corrosion is obvious as a determining factor in the widening of these faults and diaclases. It should be taken into account that the entire area is subjected to a monsoon climate, with extremely high rainfall in the May-October period. This is the determining factor in the formation of caves in northeast Thailand. Recently, research has highlighted another important factor: the bio-corrosion created by the abundant, tropical and subtropical vegetation and especially by the bio-corrosion created by the extremely aggressive organic acids released by the roots of trees and plants, which perforate the cave ceilings (Mouret C. 2017). The bio-corrosion created by bats is also discussed, especially through guano deposits, but this does not appear to us to be a determining factor. Finally, the large caves are almost all rectilinear, developed on layer surfaces. Almost all the caves are relatively horizontal with the biggest vertical range (VR) at Tham M eut (Fig. 1), reaching -30.3 m (Vălenas 2020e). There are also typical pits, almost all related to faults and diaclases. Tham Din Pieng cave (Dunkley 2011) has a particular morphology, which is a continuous maze (but focused on two water courses), with many pillars – a morphology similar to sandstone caves in Venezuela (Ellis 2017, Dunkley, Bolger 2017). This fact is exclusively due to the fact that Tham Din Pieng develops in sandstones with calcareous cement. The specific (and maybe unique?) karst features of the quartzitic sandstones of northeast Thailand are also the so-called "mini-cenotes", perfectly vertical pits up to 6 m deep, occupied at their base by stagnant lakes (in the dry season), in the monsoon season however completely flooded (Fig. 2). They were formed by continuous corrosion due to the water accumulated in them, but also by bio-corrosion. Their age seems relatively recent (Vălenas 2020i).

Regarding the length of the sandstone caves in northeast Thailand, the only large precisely surveyed caves (by the author of this article) are: Seri Thai System, 856.7 m long, Tham Meut, which is a practically rectilinear cave 481.5 m long (Vălenas 2020e), Tham Phu Pom No 1, 283 m long and Tham Nam Lot, 181 m long. But there is also Tham Patihan (Mouret C., Mouret L. 1994), which may be almost 1 km long and especially Tham Din Pieng, which probably has a development of up to 1.5 km, being a typical maze (Dunkley et al. 2017). These two caves will be accurately surveyed in the next year, 2024. Finally, most caves are devoid of concretions or stalagmite formations, except for those developed in sandstone with calcareous cement.

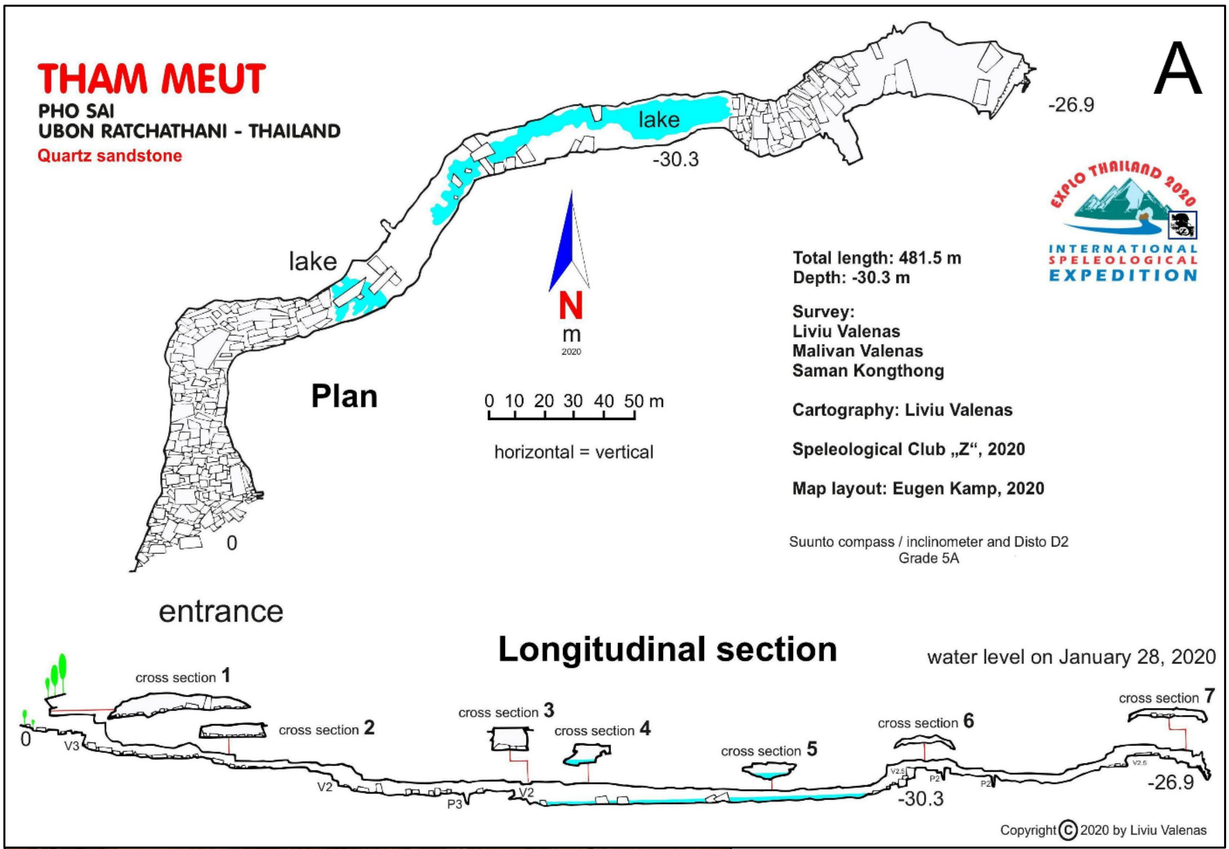

Fig. 1. Tham Meut Cave: A – map, B – lake in the passage (map and photo L. Vălenas).

Fig. 2. Mini-cenotes in the Phu Pom mountain, Amnat Charoen (photo V. Pustai).

Karst hydrogeology

Unfortunately, there is still a partial and deficient picture of the karst hydrogeology in northeast Thailand. The reason is that almost all speleological researchers were engaged in research and exploration exclusively in the dry season, December to May. However, certain conclusions can be drawn. Virtually all large caves are active in the monsoon season, but some are also active in the dry season. Tham Meut (Vălenas 2020e), which is a ponor-cave, has extremely long lakes without flow in the dry season, whereas in the monsoon season it is completely flooded. The discharge of water must take place directly into the Mekong River in an underwater resurgence. The same is the case at Tham Patihan, with the difference that the entrance area of the cave consists of two levels, the lower level, 120 m long, being completely flooded in the monsoon season (Mouret C., Mouret L. 1994). At Tham Din Pieng, the resurgence is approximately 500 m apart from the terminal sump, in the unknown section there is also a tributary coming from a side sink (Ellis 2017). A rather spectacular case is at Tham Nam Lot (Vălenas 2016a, b, 2020g). The ponor is located only 50 m from the upstream terminal sump of the cave, and the downstream karst spring at 45 m aerial distance. The underground course in the cave is 120 m long. Another interesting active cave is Tham Ghia (Fig. 3), developed almost linearly, 133 m long (Vălenas 2020h). It is a natural tunnel: in the dry season it is full of lakes without flow, in the monsoon season it is completely flooded. The downstream entrance gives rise to a large resurgence from which a water course emerges, which after 1 km flows directly into the Mekong. We can also note Phu Noy Mountain in Ban Kham Mae Mui village (Vălenas 2017), with 13 small caves (up to 39.7 m long). But these small cavities, in the monsoon season, represent the main catchment area of an important karst spring (located 1 km away), which feeds the water that runs through the village (Vălenas 2017 and 2020g). Our research, starting in February 2023, will elucidate several hydrogeological aspects. Analysis of karst waters, fluorescein markings, etc. will be carried out in order to enlighten the intensity of silica dissolution as well as the hydrogeological framework.

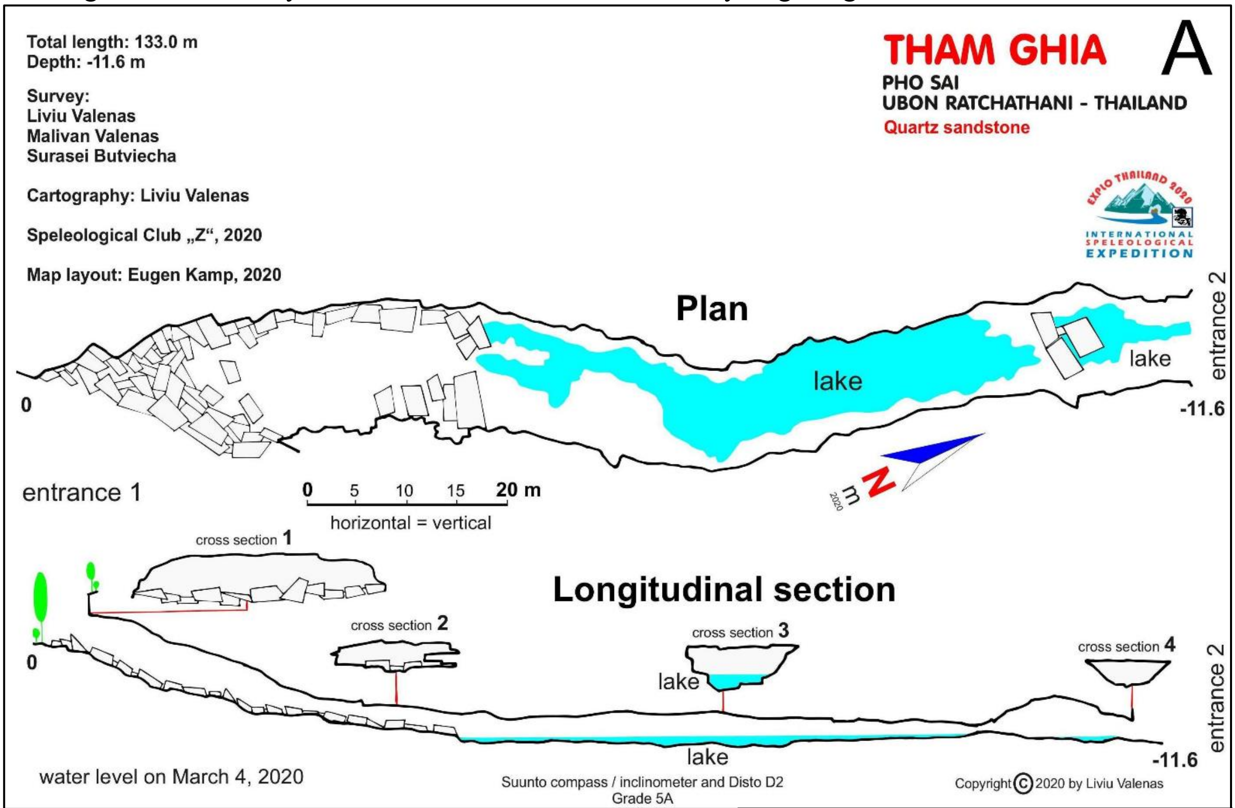

Fig. 3. Tham Gia Cave: A – Map; B – Passage; C – Entrance no. 1 (photo by L. Vălenas).

Conclusions

The area covered by the sandstones in Isaan (northeast Thailand) is huge, over 150,000 km². After 1990 various speleologists from Europe, Australia, and others, spotted some larger caves in these sandstones, surveying them rather briefly (or not at all), and since 2000 they abandoned the research, considering, by mistake, this "pseudo-karst" as uninteresting. Subsequently – since 2006 – the author, supported by the "Z" Speleology Club, has explored and surveyed 87 caves and pits in detail, in sum almost 3 km of galleries (Vălenas 2020a, b, c, f). Research has clearly shown that it is not a matter of any "pseudokarst", but of a genuine karst, with all possible forms including sinkholes, resurgences, karren, and underground networks up to 2 km development. The primary "engine" of this karst is the dissolution of silica, the matrix of the quartzitic sandstones exclusively under the conditions of the monsoon climate.

Top Thailand sandstone caves, length (m) / VR (m)

1. Seri Thai System, Sakon Nakhon, 856.7 m /-22 m (Valenas /Speleological Club "Z", 2023)
2. Tham Patihan, Ubon Ratchathani, 776 m /-27 m (unpublished data: Mouret & Leclerc, 1994)
3. Tham Din Phieng, Nong Khai, 550 m /? (Dunkley, Ellis & Bolger, 2018)
4. Tham Meut, Ubon Ratchathani, 481.5 m /-30.3 m (Valenas /Speleological Club "Z", 2020)
5. Tham Phu Pom No 1, Amnat Charoen, 284 m /-8,6 m (Valenas /Speleological Club "Z", 2019-2020)
6. Tham Nam Lot, Ubon Ratchathani, 181 m /-11.5 m (Valenas /Speleological Club "Z", 2016)
7. Air Raid Shelter Cave, Phitsanulok, 150 m /-? (Dunkley, Ellis & Bolger, 2018)
8. Tham Ghia, Ubon Ratchathani, 133 m /-11.6 m (Valenas /Speleological Club "Z", 2020)
9. Tham Phu Pha Dam, Udon Thani, 125 m /7 m (Bolger, Dummer, Ellis, 2019)
10. Tham Cham Pha Tong, Sakon Nakhon, 120 m /? (unpublished data: Mouret & Leclerc, 1994)
11. Tham Phu Phanom Di No 8, Ubon Ratchathani, 110 m /-8.7 m (Valenas /Speleological Club "Z", 2018).

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Developing the Speleopark of A Mariña Shire, Lugo province, Galicia, Spain - caves and convergent forms among limestones, quarzites and granites in the north of Lugo

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Introduction

Geodiversity refers to the number and variety of geological elements present in a region: Rocks and sediments of the substrate; geometry and structure; composition; minerals; relief forms and the processes that give rise to each of them; aquifers and water resources. And among this diversity we include the caves. For many people the concept of a “cave” is related exclusively to karst. But they ignore that this term characterizes a landform without establishing restrictions by the composition of the substrate where it is located, nor by the genetic process that gives rise to the cavity (Stone 1953; Charles, Courbon 1997).

In 2020, the eve of the *International Year of Caves and Karst* promoted by UIS, the Galician Federation of Speleology initiated a project aimed at the dissemination and promotion of caves and karst as a global phenomenon, taking advantage of the natural and speleological heritage located in the shire of A Mariña Central (municipalities of Burela, Alfoz, Foz and Mondoñedo, where within a distance of just 30 km one can visit cavities developed in limestone, quartzites, granites and various schists. This grouping of resources allows us to carry out activities aimed at showing different types of landscapes, plurality of geodynamic processes involved and a great variety of surface and underground meso- and microforms. Our idea is to take advantage of all these elements, because together they give rise to a rich and varied cave heritage, a sample of our geodiversity (geomorphodiversity) as an irreplaceable part of our geological heritage.

One concept: “convergent forms”

Certain forms produced both on the surface and in the subsurface are similar in their geometry and immediately recognizable despite developing in rocks of a very varied lithology (Eraso, Pulina 1994). Also it should be noted that a similar visible form does not necessarily mean that the formation process was the same. This is what we call “convergent forms” (Fig. 1). We use this concept to build the script and the routes of the speleopark.

Fig. 1. Convergent forms: pigotite pool speleothem (a) and calcite pool speleothem (b) are convergent forms – the same environment (pool waters), but different substances and different processses. The first is a biospeleothem that grow by dentrites related to filament algae, while the second one grow from crystal formation. The other two photographs are natural arches developed in granites (c), and in quartzites (d). They are also convergent forms: different lithologies but the same processes (erosion and gravitational movements (photos M. Vaqueiro).

One idea: speleopark

Speleopark: What is it for us?

A territory with well-defined limits, which includes a number of representative sites related to caves and karst systems, not only related to geological and paleontological heritage, but also those of archaeological, ecological, historical and cultural interest, and that together allow to discover the fact that there are caves in many types of rocks, visualizing the different phenomena related to caves and discovering and appreciating the value of the nderground Natural Heritage.

For whom and for what?

We consider different types of visitor profile:

- Educational visit: students and school-oriented activities for the promotion, discovery and knowledge of the subterranean natural environment.
- Speleological scientific tourism: The aim is for participants to recognize the geodiversity, biodiversity and cultural heritage related to these spaces.
- Research visit: planned activities (projects) whose objective is to increase the knowledge and understanding of the caves located within the speleopark. It also includes basic or preliminary cave science activities like topography of a cave, the geolocation and inventory of underground natural resources.
- Free recreational visits: activities related to caving as a federated sport.

One place: shire of a Mariňa Central (North Lugo)

The speleopark area

The Speleopark of A Mariña Shire (Fig. 2) covers a relatively small area (335 km²), located in the northern part of the Lugo province, which encloses caves and geomorphosites (Tab. 1) in the municipalities of Burela, Alfoz, Foz and Mondoñedo. The resources of the speleopark (Fig. 3) are located relatively close to each other. Moving between extreme sites takes less than 1 hour by car.

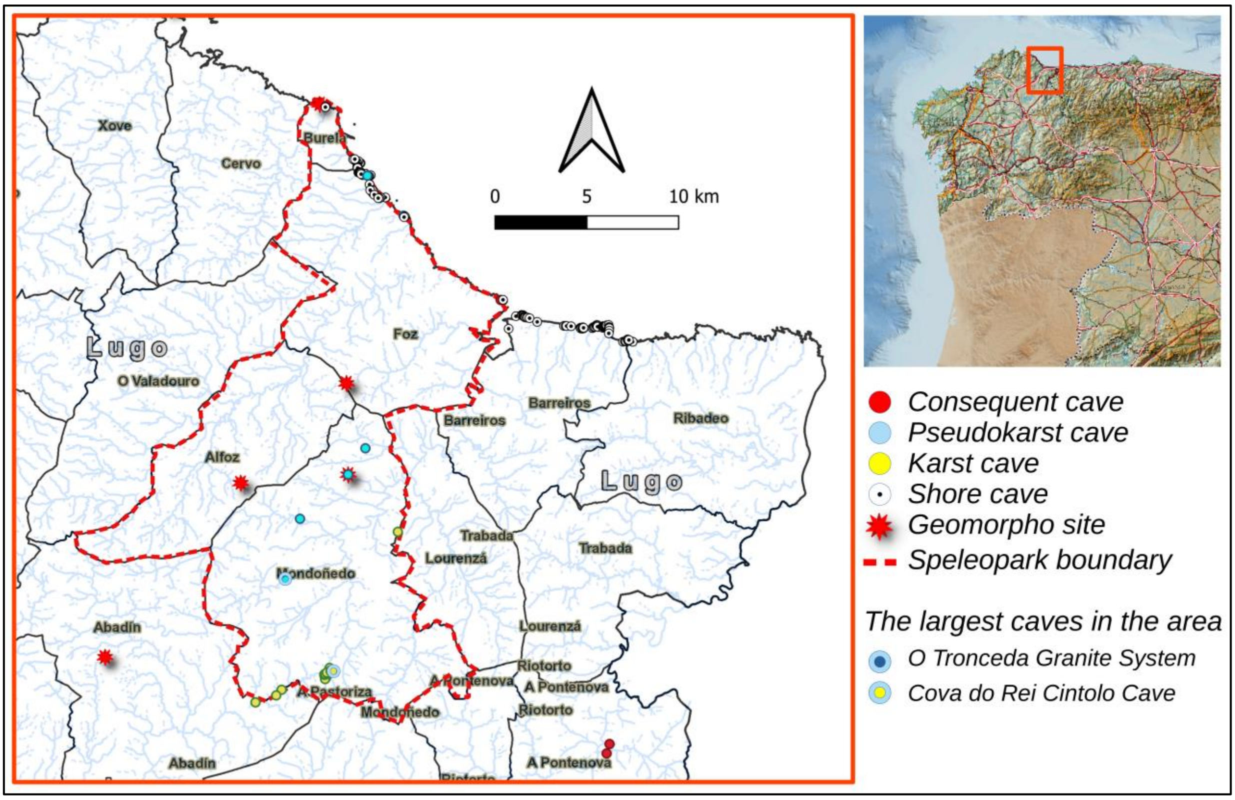

Fig. 2. General map of the geoheritage inventoried in the speleopark and its surroundings.

Tab. 1. Number of sites per municipality included in the last update (December 2022) of the resources inventory of the Speleopark of A Mariña Shire.

Municipality	Caves	Other geo(morpho)sites
Burela	23	1
Foz	43	3
Alfoz	2	2
Mondoñedo	24	0

Geological settings

The northern zone of the Speleopark of A Mariña Shire is characterized by the quartzites of the Lower Cambrian, embedded between Hercynian two-mica granites on the west side, and granodiorites on the east side (Martínez-Alvarez et al. 1975). The central zone is characterized by Hercynian granites and granodiorites, as well as by outcrops of quartzites, limestones and other calcareous rock of the Lower Cambrian age (Arce-Duarte et al. 1976). The east zone is characterized by the quartzites and slates of the Lower Ordovician and uppermost Cambrian series of the other two zones.

Most shore caves are located in quartzites, although there are also some in granites and schists. Some preserve speleothems and tubifications at levels elevated above sea level. Among the karst cavities, Rei Cintolo Cave stands out, which is the largest cave in Galicia. Among the cavities in granites highlights the roofed canyon of O Tronceda and the shelters with tafoni and biospeleothems were explored by the German geologist Guillermo Sultz in the 19^{th} century. So far no significant parakarst cavity has been identified. Most cavities in quartzites are related to pseudokarst processes.

And how we will do it?

The protection of our caves and underground heritage is fundamental. And that is why it seemed prudent to develop the process in the three phases proposed by Cigna and Forti (2013):

- PHASE I – Resource inventory and assessment: it includes geosites, geomorphosites and caves (geoposition, topography, and values inventory), and also resource assessment attending to their accessibility, fragility, representativeness, scenic value, critical factors and existing damage.
- PHASE II – Organization of geosites and their resources: preliminary plan for each one of the resources and preliminary plan for itineraries that integrate different sites.; finally, detailed plan of routes along the territory including visits to cavities
- PHASE III – Implementation, that must include: monitoring and impact monitoring; promoting cave research in the area; and the update of resources inventories and guides.

Where we are?

We still have a long way to go, but in 2021 we present the first inventory of resources and the main route of the speleopark. Recently an inventory update was presented, including the results of 3 camps focused on the exploration and topography of new caves in granites and quartzites in the area.

And at the same time from 2020 we have organized and carried out promotional/educative activities in the area, some aimed at university students (using granite and limestone caves as classrooms), others in the form of summer camp aimed at teenagers living in the area. And also courses focused on training speleologists for the campaigns of digital modelling of our caves.

For 2023, new classes with university students are already scheduled, as well as educational and discovery visits of the speleopark with schoolchildren. One of the main events this year will be the celebration of “Geolodia 2023” from the province of Lugo in the Speleopark of A Mariña Shire. The "Geolodia" (Geology-Day) is an initiative promoted by the Geological Society of Spain in which on the same day, one geological field trip in each Spanish province, guided by geologists are held, free and open to all audiences.

Fig. 3. Visual synthesis of speleopark geoheritage: a) Shore caves in quartzites (Punta da Arca, Burela); b) Shore caves in quartzites (Praia Palomas, Burela); c) Speleothems at a fossil level in a quartzite shore cave (Praia dos Alemáns, Foz); d) Outcropping of carbonate rocks on granites (Calera de Ribera, Alfoz); e) Rills on granites (A Frouseira, Foz); f) Tafone forms in granites (A Frouseira, Foz); g) Pigotite speleothems from the roofed canyon of O Tronceda granite cave system (Tronceda, Mondoňedo); h) Opal-A speleothems from the Ameixoada granite block caves (A Campá, Mondoňedo); i) Tafoni from the Ameixoada granite block caves (A Campá, Mondoňedo); j) Bear (Ursus sp.) scratches from the limestone Arcos cave (Orxal Mt., Mondoňedo); k) Calcite-malachite speleothems from the limestone Rei Cintolo cave (Supena, Mondoňedo); l) Anthodites from the limestone Rei Cintolo cave (Supena, Mondoňedo) (all photos M. Vaqueiro, 2016-2023).

Who promotes the Speleopark?

The project is an initiative of the Rural Development Group of A Mariña Shire (G.D.R. Terras de Miranda) and the Galician Federation of Speleology. Also the municipalities of Burela, Foz, Alfoz and Mondoñedo participate and collaborate.

Discussion

Our project aims to value and protect the caves heritage with a global vision, because it is a fact that caves exist in all types of rock, and also that underground landscapes are the reflection of a wide variety of processes that have taken place over time, leaving their traces in the cavity.

We are fortunate that in the shire of A Mariña there are examples of many types of caves in a relatively small area. And this allows us to disseminate caving in all its facets, in addition to promoting the protection of all these spaces. We cannot forget that promotion and protection go hand in hand: "*The more we know, the more we can preserve and protect*". And one way to educate is by bringing the caves to all kinds of audiences.

But the viability in time of the project will be conditioned to the involvement of the managers of the municipalities. Both for its necessary support to the project, and for the need to move forward in a responsible and sustainable way.

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Changes in the relief of sandstone cliffs due to historical stone quarrying

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The Elbe Sandstones is mainly built of quartzose sandstones with isolated occurrences of Tertiary volcanics. The area represents the northwestern part of the Bohemian Cretaceous Basin (outcrops of rocks of the Lower to Middle Turonian age, corresponding to the Bílá hora and Jizera Formations). This territory was under long-lasting influence of human activities but their impact has been already mostly obscured by natural physical processes (reshape of former quarries by rock falls, gradual erosion and weathering) and vegetation growth. During the project focused on mapping and documentation of old quarries and mining localities, an intensive anthropogenic impact was identified. More than 2 350 abandoned quarries for sandstone building stone are currently registered in the area of the Bohemian Switzerland National Park and the Elbe Sandstones Protected Area (of the total area ranging 323 km^2), of which over 1 380 are shelf quarries. Old exploitation sites can be found in the landscape as minor pits, inconspicuous small exposures or blocks (large sandstone boulders were quarried and bear evidence of exploitation). At other sites, however, large quarries were in operation and these show a significant impact on the natural relief of sandstone massifs (Figs. 1, 2 and 3).

Fig. 1. An example of a small shelf quarry (natural relief versus excavated middle part of the rock massif (Malé Tiské Stěny Cliffs, no dating) (photo Z. Vařilová).

Fig. 2. Left: A deep incision with vertical walls, formed by sandstone wedging and detachment to produce building stone. The faces bear traces of chiselling (Pekelský důl Valley, carving with the year 1809) (photo Z. Vařilová). Right: a 3D model of the Dachslöcher Quarry, where strata-parallel, bench-by-bench extraction was conducted for the production of 185 pieces of masonry stones and 78 pieces of tiles (one-off mining in 1852 - State Archive in Litoměřice) (model by. J Horák).

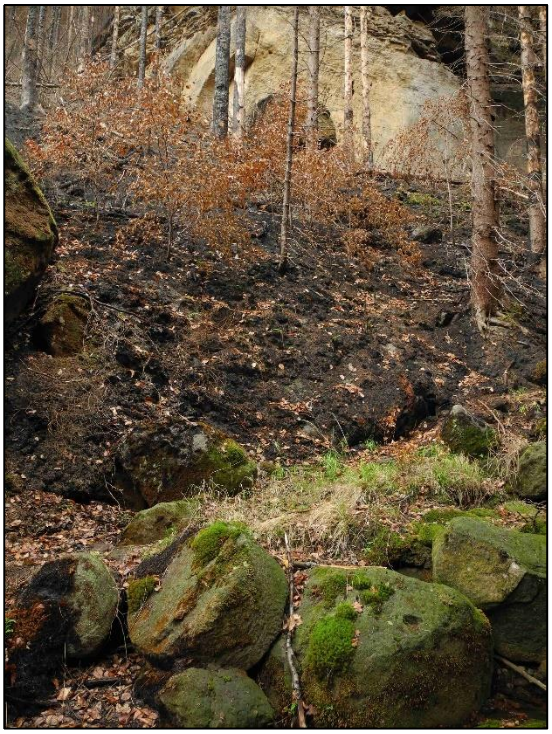

Fig. 3. Left: A gorge bearing the abolished name "Mühlsteinschlichte" (1788 – State Archive in Litoměřice) was probably the site of sandstone quarrying for the production of millstones (preserved half-product of a millstone 80 cm in diameter). Right: a neighbouring shelf quarry with subsequent minor exploitation of sand (elliptical detachment with traces of chiselling 70 x 86 cm in size). (photos N. Belisová).

At places most affected by stone extraction, the cliffs are formed by sub-horizontally stratified fine- to coarse-grained quartzose sandstones with only low amounts of kaolinite matrix. A typical "block" disintegration proceeds along a system of orthogonal joints. Quarrying of building stone made use of these natural structures of sandstone massifs and resulted in the creation of artificially articulated cliff faces, removal of parts of the rock massif from tens up to thousands of cubic meters in volume, creation of new niches and slits, cliff levels or artificial overhangs (Fig. 3). It also resulted in changes in the gradient and height of the rocky slopes and in the formation of new discontinuities (especially in the Elbe River Canyon). Here, the quarry faces often reach several tens of metres in height and can extend across several natural cliff levels. Therefore, abandoned quarries generate a risk of rockfall, the preparatory stage of which has been shortened considerably relative to that of natural dynamics of rocky-slope evolution (Fig. 4) (Zvelebil 1990, Vařilová et al. 2022). There are also several underground sand pits which exploited low-strength quartzose sandstone in the study area (the most extensive is the Sandloch site at Ludvíkovice village with the overall length reaches 132 m, maximum height of 6.5 m).

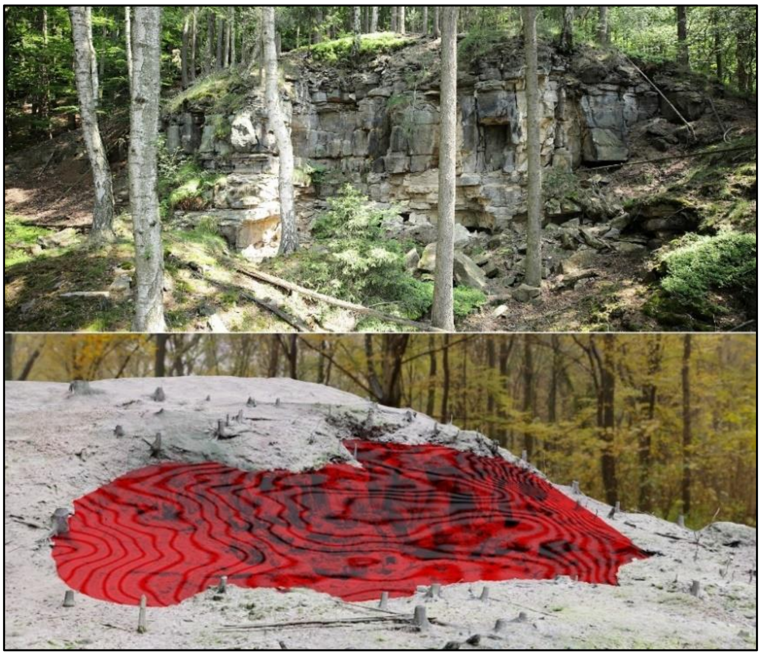

Fig. 4. A whetstone quarry near Podskalí in the Elbe River Canyon with unstable rock wall; the extracted mass of sandstones with a volume about 1200 m^3 is marked on the 3D model by red color (photo and model J. Horák).

Historical quarrying/mining activities produced a range of typical features in the landscape and in rock massifs, which help to recognize human traces and distinguish them from natural processes (a shelf quarry, unfinished mining zones, bags after the insertion of splitters, surface tool marks, borings for loading explosive cartridges etc. – Fig. 5). In some cases during mapping and documentation of old quarries, it is difficult to decide whether it is targeted stone extraction, old remediation or the result of natural processes of rock disintegration (e.g. scar surface after a rockfall). Even if the shapes of some locations resemble a quarry, there is a lack of other demonstrable evidence: traces of quarrying/mining methods, waste from the quarry or landscaping (working platforms, access roads, etc.). Despite these problems, identification of questionable sites as old quarrying sites is sometimes possible with the aid of archival sources or a comprehensive field research of the surroundings, e.g., on the basis of continuity with other, already proven quarrying/mining sites nearby and their forms. On some cliff faces, the traces of tools have been completely erased by the "action of time" – not only the complete coverage of the surface with organic coating (moss and algae) but especially weathering processes affecting former quarry faces, and even natural relief has been restored with secondary surface crusts, including honeycomb formation.

Fig. 5. Several typical examples of traces after sandstone quarrying preserved on cliff faces in the Elbe River Canyon and the village of Janská (bags after the insertion of splitters and surface tool marks) (photo Z. Vařilová and J. Preclik).

Acknowledgements:

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The consequence cave of Sandloch
– a result of the collapse of historical underground sand pits

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The site of Sandloch (or Losdorfer Labyrinth) at Ludvíkovice village represents a historical underground sand pit exploiting Cretaceous friable sandstone of the Middle to Upper Turonian age (Jizera Formation) used as sand probably already from the 16th century according to oral tradition. It is one of the largest unsecured excavated objects, which has been repeatedly affected by rock beakdowns. This makes it unique within the Elbe Sandstones area. Spacious excavated spaces were originally promoted as a tourist destination in the latter half of the 19th century. After a fatal injury by fallen rock mass during sand extraction in 1914, mining operations were stopped and the entrance to the adit was ultimately closed (John 1980; Hantschel 1907).

The entrance to the Sandloch is currently poorly accessible although it lies at the foot of a hill in an immediate proximity of the developed area of Ludvíkovice village. The first attempt to survey and document the underground spaces was made by cavers in 1983. The space is divided into several segments: large entrance hall (Grosse Halle), narrow adit with a staircase, connecting passage, little hall (Kleine Halle) (Veselý 2010, according to the historical plan published by Patzig 2003). After a new documentation and geodetic survey, a detailed plan and a 3D model were created. The overall length was determined to be 132 m (Figs. 1, 2 and 3). This can be compared to the older mapping, which indicated the length of 110 m from the entrance to the face of the main adit in a little hall (Veselý 2010). The maximum height is actually 6.5 m, the height of artificially excavated corridor is max. 5.5 m.

The shape of the "cave" is controlled by geological and tectonic setting. Even in the past, the underground spaces probably had an originally natural character (an overhang or a shallow natural cave located at fault intersection, gradually deepened by people). The original excavated space was then markedly affected by repeated collapses of the ceiling and partly also by falls of the walls. The entrance

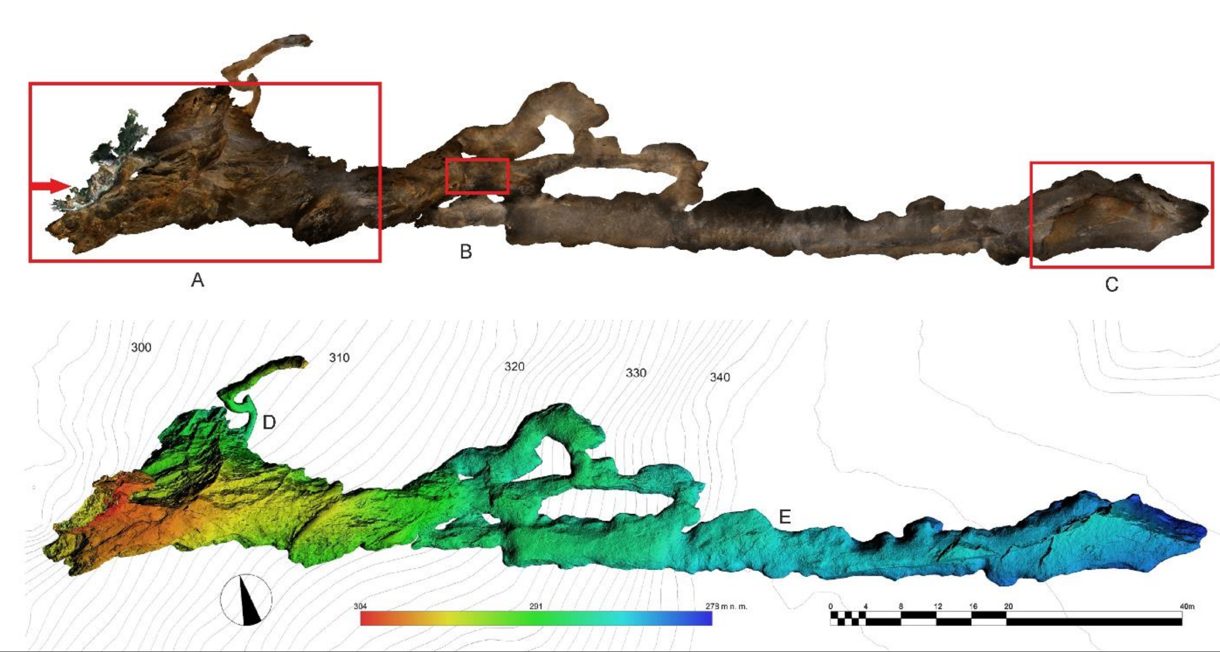

Fig. 1. Orthographic top view of a textured model (upper) and hypsometric analysis (lower) of surfaces of excavated underground spaces at the Ludvíkovice locality. Unstable areas with ceiling collapses (A, B, C) and parts of the corridor with preserved traces of mining (D, E) are marked. Red arrow points the entrance. Situation as of 2022.

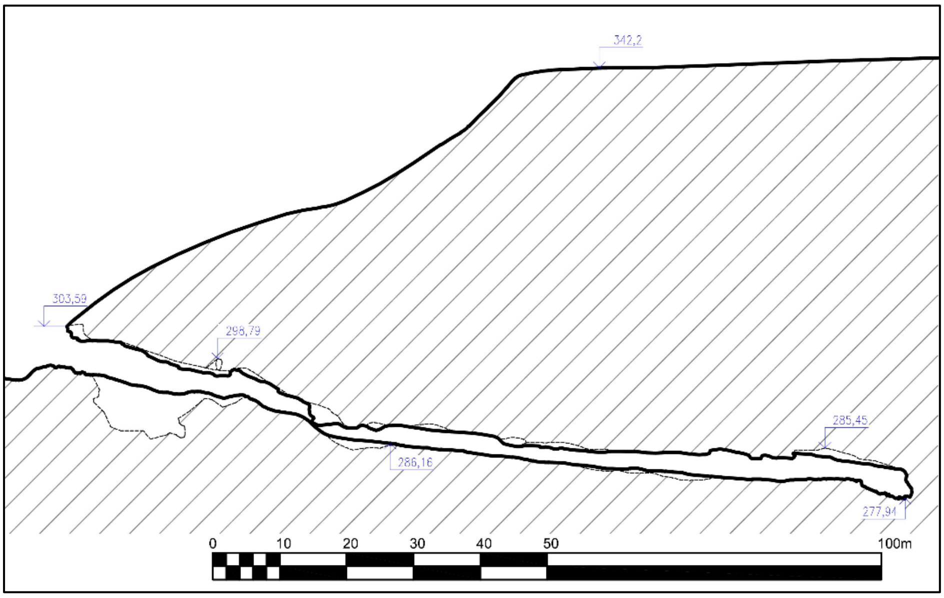

Fig. 2. A profile of the underground space of the Sandloch locality. Situation as of 2022.

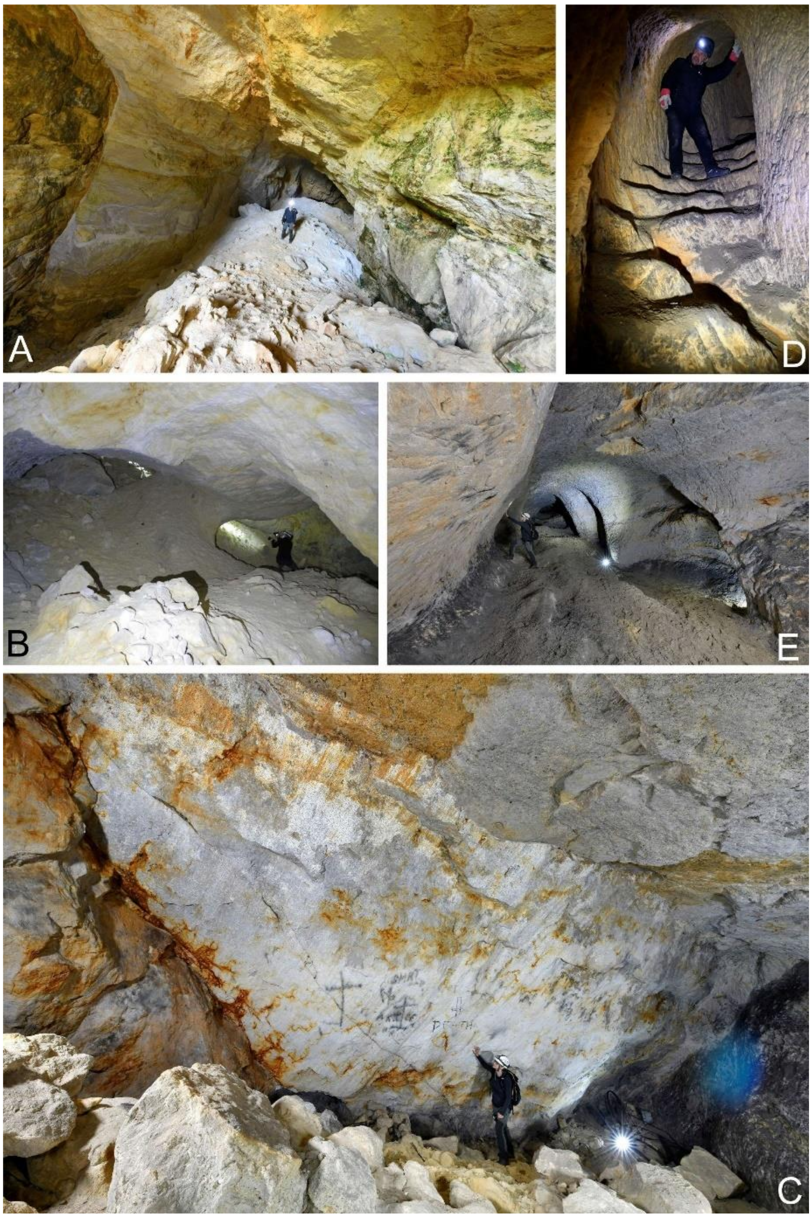

Fig. 3. Shape of the Sandloch. A – Large entrance hall with huge accumulation of rock break-down material (Grosse Halle); B – Middle unstable part with a smaller rockfall; C – Exposed striated shear plane now forming the wall of the little hall (Kleine Halle) at the end of the underground sand pit modified by catastrophic break-down events; D – Dead-end narrow adit with a staircase; E – Relatively stable main adit with relicts of mining: artificial niches and traces after tools usage (photos by J. Preclík, Z. Vařilová and N. Belisová)

hall, the middle part and the little hall at the adit face have again acquired a more natural character due to the fall of the ceiling vault. The beds of quartzose sandstones dip to the S/SE at an angle of 15–20°. Incoherent soft sandstone with extremely low strength prevails, whitish to yellowish to orange in colour (due to iron oxides admixture). The sandstone is medium-grained, with conglomerate beds. Conglomerate beds represent lithological boundaries forming detachment surfaces of rock breakdowns. The breakdowns were also facilitated by intensive tectonic deformation, especially by intensive fracturing and several shear faults.

This locality is a prime example of a consequence cave (i.e. developed as result of the collapse of the abandoned mine – e.g. Eszterhas, Szentes 2010) in sandstones, which is still very unstable. Fresh-looking detachment surfaces in the entrance dome and the terminal dome confirm the presence of imminent risk, which is evidenced by traces of fresh fallout together with several modern inscriptions signifying death.

A similar adit, now not accessible (completely buried in the latter half of the 19th century) is the Sandhöhlen near the village of Stará Oleška. Artificial underground spaces due to extraction of soft clayey sandstone are also found in the German part of the Elbe Sandstones. Unlike the Sandloch locality, they are still accessible for tourists now (e.g., Lichterhöhle or Hampelhöhle in the area of the Kleinhennersdorfer Stein hill).

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