ARAGONIT

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ARAGONITE JOURNAL ISSUED 25 YEARS

The Aragonite journal was established by the Slovak Caves Administration in 1996. Its first issue was presented on the specialized seminar on show caves, held in September 1996 at Medzev town on the occasion of the 150th anniversary of the Jasovská jaskyňa Cave opening to the public. The main initiators of its foundation were Jozef Hlaváč, former director of the Slovak Caves Administration, and Pavel Bella, head of the Cave Protection Department. Initially, the journal served mainly for a presentation of the results from the research, monitoring, management, development and protection of show caves in Slovakia, as well as the caves developmentally linked with them. The subject of the journal was extended in 2002 because by the decision of the Ministry of the Environment of the Slovak Republic the scope of the Slovak Caves Administration was expanded to the protection and management of all caves in Slovakia.

More than 170 research articles, of which almost two thirds peer-reviewed, have been published so far in the Aragonite journa). They are focused on cave and karst geomorphology (40 articles), cave geology (23 articles), karst hydrology and hydrochemistry (23 articles), cave biology – invertebrates (18 articles), cave history (9 articles), mineralogy and carbonate speleothems (8 articles), cave climatology (8 articles), chiropterology (7 articles), cave microbiology (6 articles), palaeontology (6 articles), natural radioactivity in caves (6 articles), cave glaciology (5 articles), speleoarcheology (4 articles), geophysics (3 articles), osteology (2 articles), geoecology and the environmental assessment of caves (2 articles), as well as applied didactics in regional geography of karst area (1 articles).

Numerous reports refer to gating, cleaning and other protection measures realized in caves and their surroundings (buffer zones), surveying and speleological documentation of caves, the development, management and attendance of show caves, environmental educational activities, conferences and other events related to karst, cave and caving. It also commemorates important anniversaries of caves and speleological organizations or personal jubilees. Reports from the visit of foreign show caves and karst areas, as well as reviews of selected new domestic and foreign speleological books and other publications, are also included in many issues of this journal.

From 2008, the abstracts of papers and posters from the scientific conferences 'Research, Use and Protection of Caves', organized by the Slovak Caves Administration every two years, are also published in this journal. The issue 22/1 was completely devoted to the 23rd International Cave Bear Symposium (ICBS 2017). This latest issue is intended especially for participants of the 9th International Workshop on Ice Caves (IWIC-IX).

By 2008, only one issue of the journal was prepared and printed annually. In the following years, seven times two issues per year were distributed. So far, a total of 32 issues have been published, including the latest.

Especially in the last 15 years, the Aragonite has gradually become a scientific and professional journal specialized dominantly to karst and caves in Slovakia and their protection. From the point of view of the scientific level, it considerably approached to the Slovenský kras journal (Slovak Karst, Acta Carsologica Slovaca), whose 57th volume was published in 2019. The main scientific journal in the Slovak karstological and speleological literature is still the long-term issued Slovenský kras. However, the Aragonite journal also gained a dignified position in the professional community dedicated to karst and caves. A number of registered citations of the articles published in the Aragonite journal can be found in the worldwide WOS and SCOPUS scientific databases.

Mostly regionally focused research articles and professional reports are published in the Aragonite journal. Several of those would be redundant for the Slovenský kras journal, and not suitable for the Bulletin of the Slovak Speleological Society which presents almost exclusively the results of speleological exploration realized by volunteer cavers. Most of the articles published in the Aragonite journal were prepared by employees of the Slovak Caves Administration and cooperating organizations in the research and protection of caves in Slovakia. In many of these articles, environmental applications for the protection of caves are inferred. Therefore, this journal is intended mainly for the presentation and chronicle-like record of various and numerous activities of the Slovak Caves Administration, which since 2008 is an organizational unit of the State Nature Conservancy of the Slovak Republic.

In view of the overall benefit of this journal, the offer to start and improve the publication activity for young scientists can not be forgotten. For more than one decade, the Slovak Caves Administration trying to involve several younger scientists in specialized research and monitoring of caves, that are necessary for the more precise environmental protection of these significant and vulnerable natural phenomena.

Thanks to many initiative and often contributing authors, editorial board, as well as to Bohuslav Kortman, linguistic editor, and Ján Kasák, design editor, for their precise work done in preparing and publishing of the Aragonite journal. It is to be hoped that the younger generation of our employees will continue to publish and improve this useful journal.

Pavel Bella

DOBŠINÁ ICE CAVE (SLOVAKIA, CENTRAL EUROPE) AND ITS UNIQUE UNDERGROUND GLACIER ORIGINATED IN THE MID-MOUNTAIN POSITION OF THE MODERATE CLIMATE ZONE

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Abstract: Ice caves belong to the significant, but very fragile and vulnerable natural phenomena. One of the best known and important ice caves in the world is the Dobšiná Ice Cave that occurs in the temperate climate zone, in the mid-mountain part of the Western Carpathians. The cave was formed by sinking allochthonous palaeo-river Hnilec in the Middle Triassic Steinalm and Wetterstein limestones of Stratená Nappe. Several faults markedly disrupt the limestone above the cave which thickness is 10–50 m. Its most spacious part is represented by a descending sack-like cavity that is permanently filled by ice with a volume of more than 110,000 m^3. The slowly moving underground glacier is an important natural archive with paleoclimatic record slightly over 2,600 years. The ice originated by freezing of meteoric waters seeping into the cave while ice at the lower edge of the glacier decreases mostly by sublimation due to air circulation (a gradual ice exchange in the cave). The glaciation of the cave probably started in the Middle Pleistocene. In the Dobšiná Ice Cave, three specific zones for animal occurrence (with a total of 65 invertebrate species) can be distinguished. The parts of the cave with a perennial glaciation are the poorest in terms of species diversity with only 4 species of springtails and mites. Non-glaciated parts are the habitat of most troglobiotic/stygobiotic and eutroglophilic animals and the peculiar inverse habitat at the entrance serves as an important locality for several endemic, cold-adapted species of the soil fauna. The cave represents a unique underground wintering site of cold-preferring forest bat species *Myotis mystacinus*, *Myotis brandtii* and *Eptesicus nilssonii* (in the territory of Central Europe) with significant representation of other species such as *Myotis myotis*, *Plecotus auritus*, *Myotis dasycneme* and *Myotis nattereri*. The Dobšiná Ice Cave was open to the public one year after its discovery in 1870. It belongs to the first electrically illuminated show caves in the world. But its development for tourism, as well as the discovery of non-glaciated parts, has caused negative human impacts, which resulted mainly in changes in the morphology and extent of ice surfaces in some parts of the cave. According to Act No. 543/2002 Coll. on Nature and Landscape Protection, the Dobšiná Ice Cave is protected as a national natural monument. In 2000, it was inscribed on the World Heritage List within the Slovak-Hungarian site named Caves of Aggtelek Karst and Slovak Karst.

Keywords: cave morphology, speleogenesis, speleoclimatology, cave ice, cave biota, human impact, Slovenský raj National Park, Western Carpathians, World Heritage

INTRODUCTION

The Dobšiná Ice Cave ('Dobšinská ľadová jaskyňa' in Slovak; Slovakia, central Europe) is a rare natural karst phenomenon of worldwide importance. It is a typical example of the glaciation of a descending sack-like cavity trapped cold air. It is unique by the unusually large volume of ice in the mid-mountain position of the temperate climate zone, below the alpine zone (Bella and Zelinka, 2018; and others). Based on the extension of the property No. 725 'Caves of Aggtelek Karst and Slovak Karst', the Dobšiná Ice Cave was declared as a part of the World Heritage at the UNESCO World Heritage Committee meeting in Cairns on December 2, 2000 (Fig. 1; the nomination project was elaborated by Tulis et al., 1999).

Based on interdisciplinary researches and their environmental applications, special approaches are needed in its use and protection as a very vulnerable cave, one of the most visited show caves in Slovakia. A review of basic knowledge and data on lithological and structural settings, morphology and genesis of the cave, its climate and glaciation, ice dimensions, ice age and movement, large- to small-scale ice surface forms, and cave biota, as well as on human impacts and cave protection is given in this article.

LOCATION

The well-known Dobšiná Ice Cave is located in the southern part of the Slovenský raj (Slovak Paradise) National Park, on the right side of the Hnilec River valley, north of the town of Dobšiná (Rožňava district). The Slovenský raj represents a karst area consisting of several plateaus (Glac, Geravy, Skala, Pelc, Duča) divided by ravines and gorges, occupies the north-eastern part of the Spiš-Gemer Karst in the northern part of the Slovenské rudohorie Mountains (Slovak Ore Mountains). The Slovenský raj is one of the most important karst areas in the Western Carpathians with numerous caves including one of the longest cave system in Slovakia.

The entrance of the Dobšiná Ice Cave, northwest-facing in a coniferous forest, lies on the northern slope of Mt. Duča (1141 m) at an elevation of 969 and 130 m above the bottom of the Hnilec River valley (Fig. 1). The narrow meandering gorge, incised by the Hnilec River, occurs near the cave, north-west of the Stratená Village.

GEOLOGICAL SETTINGS

The Dobšiná Ice Cave is formed in the Middle Triassic Steinalm and Wetterstein limestones of Stratená Nappe. Steinalm limestone prevails in the cave, Wetterstein limestone crops out only the Ruffínyho koridor (Ruffíny´s Corridor) and the eastern part of the Zrútený dóm (Collapsed Chamber) (Tulis and Novotný, 1989, 2007; Novotný and Tulis, 2000, 2002).

Several faults markedly disrupt the limestone above the cave. Morphologically, they are visible in a length of 5–70 m, max. 120 m. NW–SE-trending faults dip to the northeast, E–W-trending faults dip to the south, NNE–SSW-trending faults dip to the east-southeast, and N–S-trending faults dip to the east. They are reflected in the control of cave origin and development, in the predisposition

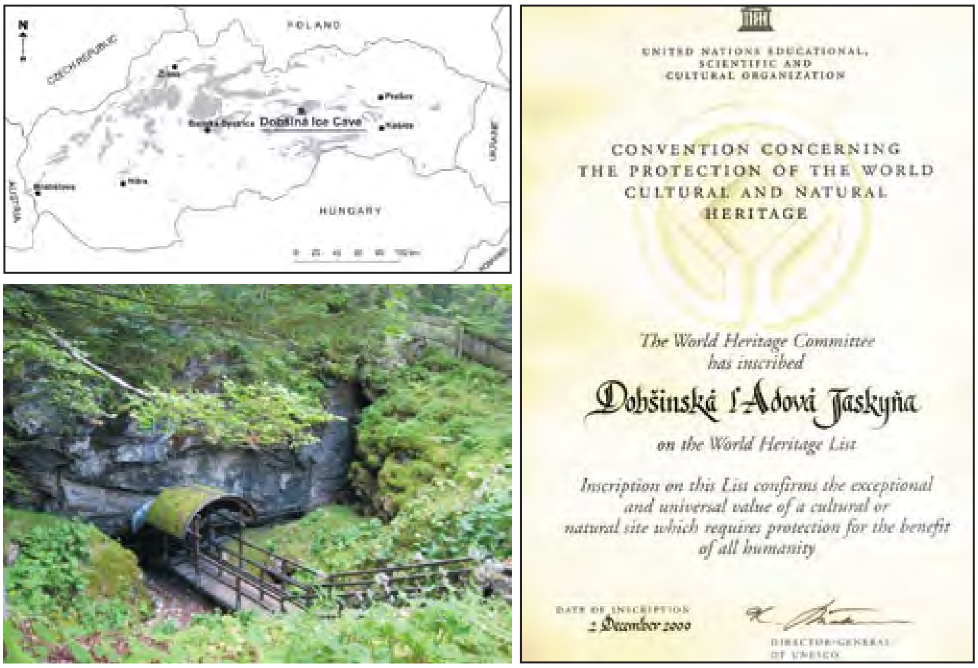

Fig. 1. Location of the Dobšiná Ice Cave (karst areas in Slovakia in gray color), its entrance in the collapsed doline, and the certificate of the Dobšiná Ice Cave inscription on the List of World Heritage. Photo: J. Zelinka

of drainage routes for water percolating from the surface into the cave, as well as in the fracturing and weathering of cave ceilings and walls. The most significant NNE–SSW-trending fault dips at 68°–77° to the east-southeast leads from the southern edge of the cave through the Malá opona (Small Curtain), Malá sieň (Small Hall), and along the north-western edge of the Veľká sieň (Great Hall). The course of the direction of faults is predominantly irregular wavy, their dip is also uneven. In short segments along some faults, there are tectonically disjointed rocks falling from the ceiling. Some faults are filled by the tectonic breccia (1–5 m long segments with the thickness of breccia fill of 0.1–1 m). In the chimney above the Veľký vodopád (Great Falls or Niagara), the breccia in the NNE-SSW-trending fault is disjointed due to concentrated water percolation and frost weathering. The smaller occurrence of tectonic breccias is in the NW-SE-trending faults (in the Zrútený dóm, at the eastern part of cave entrance).

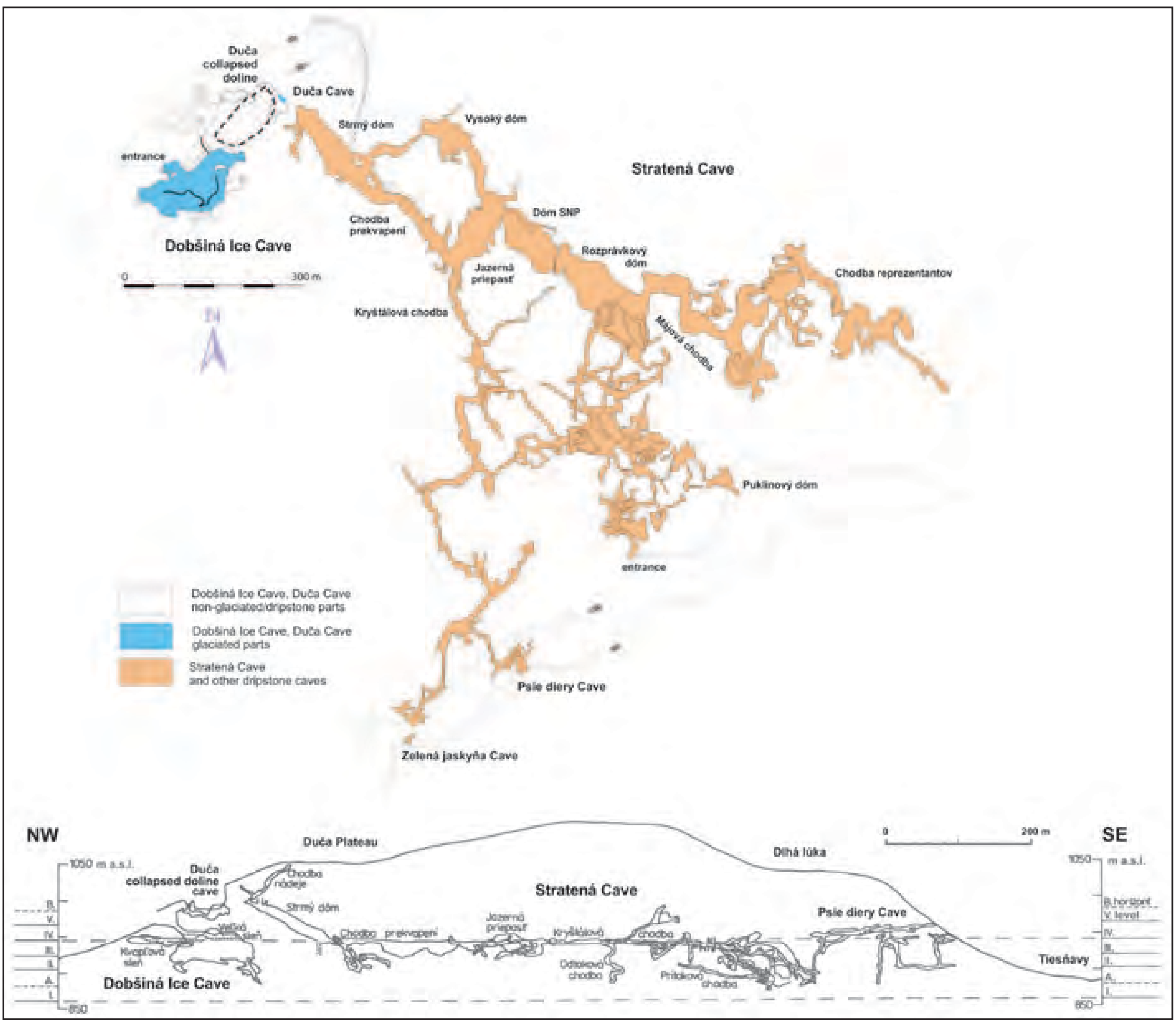

Fig. 2. Position of the Dobšiná Ice Cave within the Stratená Cave System (map from Tulis et al., 1999; side projection after Novotný and Tulis, 2005).

Fig. 3. Flat solution ceiling of the main evolution level of the Stratená Cave System – Kvapľová sieň in the non-glaciated part of the Dobšiná Ice Cave (A), the lower part of the Duča Cave (B). Photo: P. Staník (A), F. Miháľ (B)

Another short fault segments occur as narrow fissures (fault opened in millimeter dimensions) without a tectonic fill. Predominantly these faults allow water from rain and melting snow to percolate into the cave. Cracks are oriented in a direction and inclination parallel to the NW–SE- and NNE–SSW-trending faults. The ceiling of the biggest cavity named the Veľká sieň is controlled by an anticline, that is, by upwardly convex, folded structures of limestone. Their bedding-planes are dominantly dipped to the west-northwest and the east, in accordance with the orientation of the arms of the anticline. N–S-trending faults dip to the east probably follows bedding-planes in the eastern arm of the anticline (Novotný and Tulis, 2000, 2002; Tulis and Novotný, 2007).

MORPHOLOGY AND GENESIS

The cave developed by sinking allochthonous palaeo-river Hnilec, whose waters entered the fractured limestones on the right side of its valley. The Hnilec River springs on the eastern edge of the Nízke Tatry Mountains, at the foot of Mt. Kráľova hoľa (1946 m), and flows into the southern part of the Slovenský raj. In this area, the origin and development of underground karst phenomena are conditioned mostly by the allogenic position of limestone strata (contact karst).

The length of the Dobšiná Ice Cave is 1483 m with a vertical span of 75 m (Novotný and Tulis, 2005). From a genetic point of view, it is a former inflow part of the larger Stratená Cave System, which is more than 23.6 km long (Tulis and Novotný, 1989; Novotný and Tulis, 2005) and is the third-longest cave system in Slovakia. The upper horizontal and subhorizontal parts of the Dobšiná Ice Cave at about 945 m a.s.l. are featured by wide flat solution ceiling, ceiling channels, and preserved allochthonous fluvial sediments. Together with continued parts of the Duča Cave and Stratená Cave, they represent the large cave level formed in the Late Pliocene (Tulis and Novotný, 1989; Novotný, 1993; Bella et al., 2014; Figs. 2 and 3). In the Late Pliocene and the Early Pleistocene, underground passages of these caves were interconnected. Probably in the Middle Pleistocene, they were separated by breakdown linked with the origin of the Duča collapsed doline (Kucharič et al., 1980; Novotný and Tulis, 1996, 2005; Fig. 4).

The lower descending parts of the Dobšiná Ice Cave are featured by different morphology. According to older geomorphological studies, a descending sack-like voluminous cavity (later filled by permanent ice) originated because of the collapse of the cave ceiling (with the formation of an opening to the surface) and the bedrock floor between level passages (Droppa, 1957, 1960; Jakál, 1971). But an original solution morphology with ceiling pockets and inward-sloping smooth facets show that the Ruffínyho koridor is a fragment of primary descending phreatic loop or conduit, later enlarged or remodelled to the present morphology and dimensions (Bella, 2012). Facets or planes of repose (see Lange, 1963) originated by the solution of the limestone in slowly moving and standing water, possibly assisted by an accumulation of insoluble fine-grained rock particles during the final phreatic developmental phase. Therefore, the descending voluminous cavity consists not only of the cavity resulted from the collapse and breakdown of destabilized rocks in roof positions, but also preserved the fragments of older phreatic (or epiphreatic) cavities.

The main part of the cave is represented by a large cavity (with a volume of about 140,000 m^3) descending from the surface opening to a depth of 70 m. At present, it is mostly filled with ice that reaches the ceiling in some places and divides this cavity into several parts – Malá sieň, Veľká sieň, Ruffínyho koridor, and Prízemie (Ground Floor; Figs. 5, 6 and 7). The original solution rock forms have been mostly remodelled by frost weathering, while calcite speleothems completely destroyed. In the upper parts of the Dobšiná Ice Cave, all original solution morphologies, as well as calcite speleothems (dripstones, flowstone, moonmilk, and some others) are still present (Kvietok, 1949; Tulis and Novotný, 1989; Novotný and Tulis, 1996, 2002). Smaller non-glaciated parts are known also in the lower part of the cave – Suchý dóm (Dry Chamber) and Kvapľová pivnica (Dripstone Cellar). The Peklo (Hell) is gradually filled with ice.

CAVE CLIMATE, PERCOLATING WATER, AND ICE FORMATION

The surface area (in the vicinity of the cave) is in the moderately cool (mean annual air temperature 4,7 °C; mean air temperature in January -5,4 °C, in July 14,2 °C) and very humid subregion (mean annual precipitation total 900–1000 mm) (according to Lapin et al., 2002; Faško and Šťastný, 2002; Šťastný et al., 2002).

The cave ice originated as a result of cold air stagnation and freezing of meteoric waters seeping into the cavity, mainly in spring when the snow cover on the slope above the cave is melting and the cave interior is cold. The thickness of limestone above the cave reaches 10–50 m (see the cross-section of the cave and surface landforms in Droppa, 1957; Fig. 4). The most seepages of meteoric water on the cave ceilings are controlled by the NNE–SSW-trending fault (Malá sieň, the north-western edge of the Veľká sieň) and its N–S-trending branches. Water seepages along the transverse NW–SE-trending faults are less common (e.g. in the Veľká sieň above the ice column named Oltár (Altar) and in the Zrútený dóm (Novotný and Tulis, 2000). In addition to the previously mentioned sack-like voluminous cavity, the Zrútený dóm is also partially filled with ice (under the nearby Duča collapsed doline; Figs. 5 and 6). The ice-filled part of Dobšiná Ice Cave is located from 920 to 950 m a.s.l.

This cave is classified as a statodynamic cave with congelation ice (according

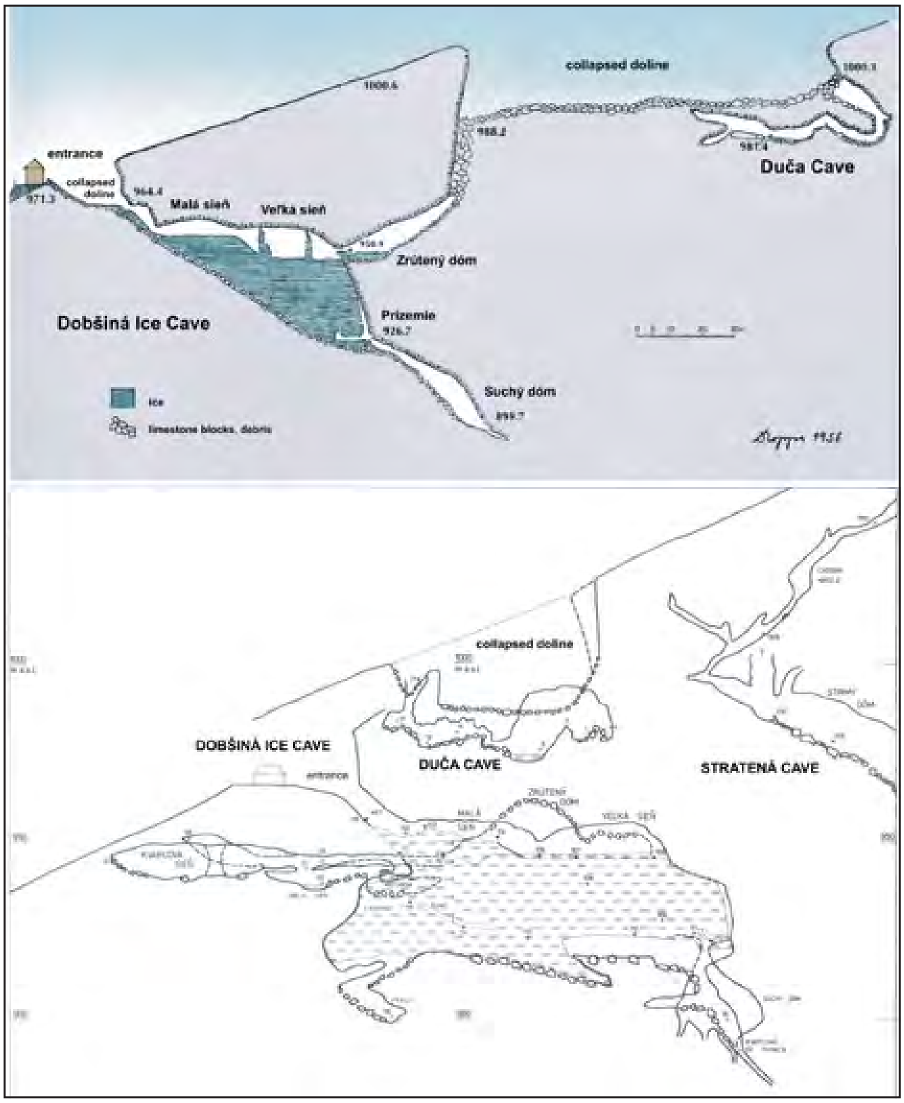

Fig. 4. Simplified longitudinal section of the glaciated part of the Dobšiná Ice Cave and Duča Cave, as well as surrounding landforms on the surface (compiled by Droppa in 1956; published in Droppa, 1957); below the side projection of the Dobšiná Ice Cave and the adjacent part of the Stratená Cave (from Tulis and Novotný, 1989).

Fig. 5. Map of the Dobšiná Ice Cave and Duča Cave (compiled by Droppa in 1950; Archive, SMOPaJ Liptovský Mikuláš).

to the classification of Leutscher and Jeannin, 2004). The average annual air temperature in the Veľká sieň is −0.4°C to −1.0°C (in February, −2.7°C to −3.9°C; in August around +0.2°C). The air temperature in lower parts of the cave is about 0°C or under the freezing point all year (Petrovič and Šoltís, 1971; Halaš, 1989; Piasecki et al., 2004, 2005, 2008a, 2008b; and others). In term of average annual air temperature, the colder parts are the Prízemie and Zrútený dóm. The Malá sieň and Ruffínyho koridor are warmer due to the spatial configuration of glaciated parts and the course of air exchange in the winter period. However, in addition to seasonal changes, also short-term changes were recorded in glaciated parts of the cave (Korzystka et al., 2011).

Generally, the Dobšiná Ice Cave features a different winter and summer regime of air circulation. The colder air circulates from the surface into the cave during the winter season and reverses during the summer season (Droppa, 1957, 1960; and others). But the ventilation of the cave is largely adapted to the so-called 'chimney effect' through the Duča collapsed doline located at a higher position than the cave entrance (Piasecki et al., 2004, 2005, 2008b; Pflitsch et al., 2007; Korzystka et al., 2011). The connecting chimney-like cavity between the Zrútený dóm and the Duča is fully filled by limestone blocks and debris allowing air ventilation. In winter, cold air flows into the underground through the cave entrance. In the Malá sieň, the main airflow divides into two sub-flows. The upper sub-flow continues through the Veľká sieň into the Zrútený dóm and from there ascends to the Duča collapsed doline, while the lower sub-flow descends from the Malá sieň into the lower cave parts. The air from the lower parts circulates upwards through the Ruffínyho koridor, it continues below the ceiling of the Veľká sieň, Malá sieň and cave entrance, as well as through near-entrance fissures outside the cave. In summer, the air from the chimney-like cavity below the Duča collapsed doline descends to the Zrútený dóm and continues through the Veľká sieň, Malá sieň and the entrance outside the cave. In the lower cave parts, the air ascends from the lowest non-glaciated parts (Kvapľová pivnica, Suchý Dóm) and continues upward into the upper glaciated parts (Fig. 8).

The average annual air temperature in the upper non-glaciated parts ranges from about +3.0°C to +3.5°C (Droppa, 1957, 1960; Korzystka et al., 2011; and others). These parts are featured only seasonal, non-significant changes in air temperature (Korzystka et al., 2011). There are several smaller lakes of different size and depth (from a few centimeters to one meter) changed over the year. The lakes are supplied with seeping meteoric water from the surface (from rainfalls and snow-melting) percolating into the cave through faults. Most of the lakes are not perennial; many of them are completely empty during dry seasons, especially in winter. The largest occasional lake is in the Kvapľová sieň (Dripstone Hall) where seeping water accumulates in the shallow depression on the floor covered by impermeable sediments. The water temperature of the lakes in the nonglaciated parts is similar to the air temperature (2.7–3.7°C).

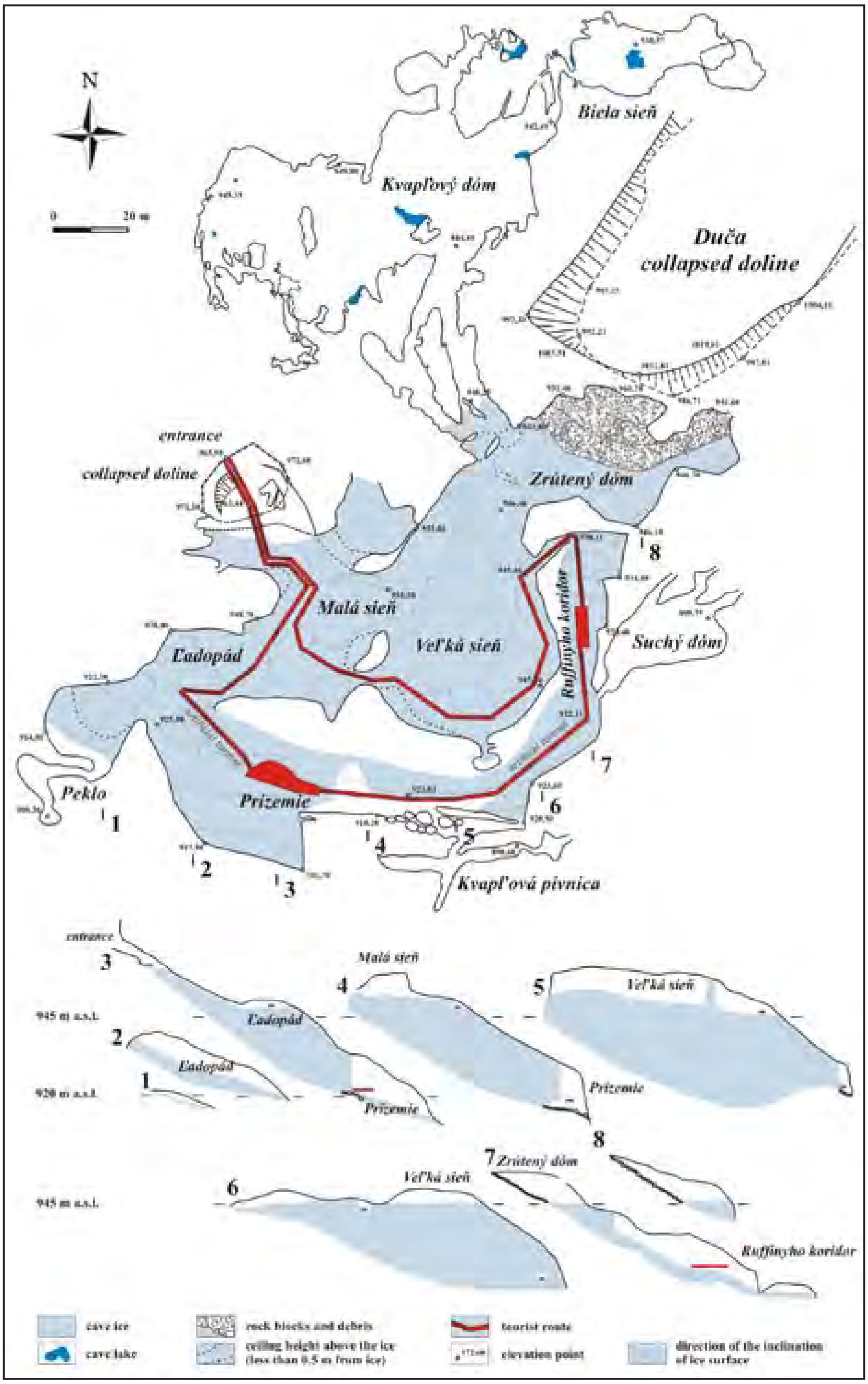

Fig. 6. Map of the Dobšiná Ice Cave and cross-sections through its ice fill (from Tulis et al., 1999).

The relative air humidity in the ice-filled parts is mostly 75–90 % (sometimes up to 95 %), while in the upper non-glaciated parts ranges from 85 % to 98 % (Droppa, 1957, 1960; Korzystka et al., 2011; and others). The course of the annual changes of relative air humidity in the cave is similar to the course of the annual changes in air temperature. During spring and summer, the relative air humidity inside the cave increases, while after the first autumn freeze decreases (Korzystka et al., 2011).

The ice fill in the Dobšiná Ice Cave occurs as floor ice, icefalls and tongues, ice curtains, stalagmites, stalactites, columns and pillars, as well as ice crystals. Floor ice stratification was formed in relation to the seepage of meteoric waters over the years (Fig. 7B and C). Freezing waters form new layers of floor ice on the top surfaces of the ice body, mainly in spring during the seepage of snow-melting waters from the surface. In the upper glaciated part, the ice decreases by melting and sublimation, while in the lower glaciated part mostly by sublimation on steep ice wall (Krenner, 1873, 1874; and others; Fig. 7B and C) as well as at the contact with a basement formed by collapsed limestone blocks and debris. Ice crystals are developed by desublimation[1] (Strug et al., 2004; Pflitsch et al., 2007). Seasonally, sublimation and desublimation processes are

[1] *deposition, i.e. transformation of gas into solid without an intermediate liquid phase*

intensive mostly during the winter phase of air circulation, while the ice melting due to heavy rains and the subsequent intensive seepage of warmer waters in summer.

Based on the first field observations, Krenner (1873, 1874) stated that the effect of heavy rains is reflected in the cave after 12 to 20 hours. In occasional shallow ablation depressions with stagnant water, pond ice forms from seeping and melting water. In some places during heavy rains, seeping water flows on the ice surface from the upper part of the ice body to its lower edge and continues to the lower-lying non-glaciated part. Much of the seeping water outflows from the surface of the ice body before they could freeze. In some places, they also occasionally participate in the ice decrease in the lover parts of the cave. From the lower edge of the ice body, these waters flow into the lower-lying non-glaciated parts (Šincl, 1931; and others). Solution grooves on the inclined bedrock floor of the Suchý dóm (Jakál, 1971) were probably deepened mostly by them.

ICE SURFACE AND VOLUME

In earlier literature, the ice volume was estimated at 125,000 m^3 and the ice surface was reported at 7171 m^2 (Pelech, 1878, 1879, 1884[2]; this data was furnished by E. Ruffíny who first measured the cave). The 1896 edition of the Baedeker guide reported that the area covered with ice was about 8000 m^2 and that the total mass of ice was estimated at 140,000 m^3 (Baedeker, 1896). According to Droppa (1960, 1964), the ice volume is at about 145,000 m^3 and the ice surface at about 11,200 m^2. Based on geophysical and geodetical measurements in 1995, the following results were specified: the ice volume was 110,132 m^3, the surface of ice fill was 9772 m^2, the maximal thickness of floor ice reached 26.5 m, and the average thickness of floor ice was 13 m (Géczy and Kucharič, 1995; Tulis and Novotný, 1995, 2007; Novotný and Tulis, 1996; Fig. 8). A comparison of more recent conditions with early pictures of the cave when it was discovered and maps of the time, the ice surface increased after the earlier measurements, mainly in the lower part of the cave. It was found that from the beginning of the 20th century through 1925, the debris bottom of the Prízemie was completely covered by ice, probably because of a water supply from both halls located in the upper part of the cave (Tulis and Novotný, 2003).

The available data (published measurements) have shown that the largest volume of cave ice in the world is found in the Dobšiná Ice Cave, despite the fact that it is at altitudes below 1000 m a.s.l. (only one big cavity is largely covered and filled with congelation ice). In the Scărişoara Cave, the ice volume was reported as about 100,000 m^3 (Holmlund et al., 2005; Perşoiu and Pazdur, 2011). The total ice volume in the Eisriesenwelt Cave was estimated at about 30,000 m^3 (Klappacher and Haseke-Knapczyk, 1985; Silvestru, 1999; Friedrich, 2009; Obleitner and Spötl, 2011). However, this volume was probably larger;

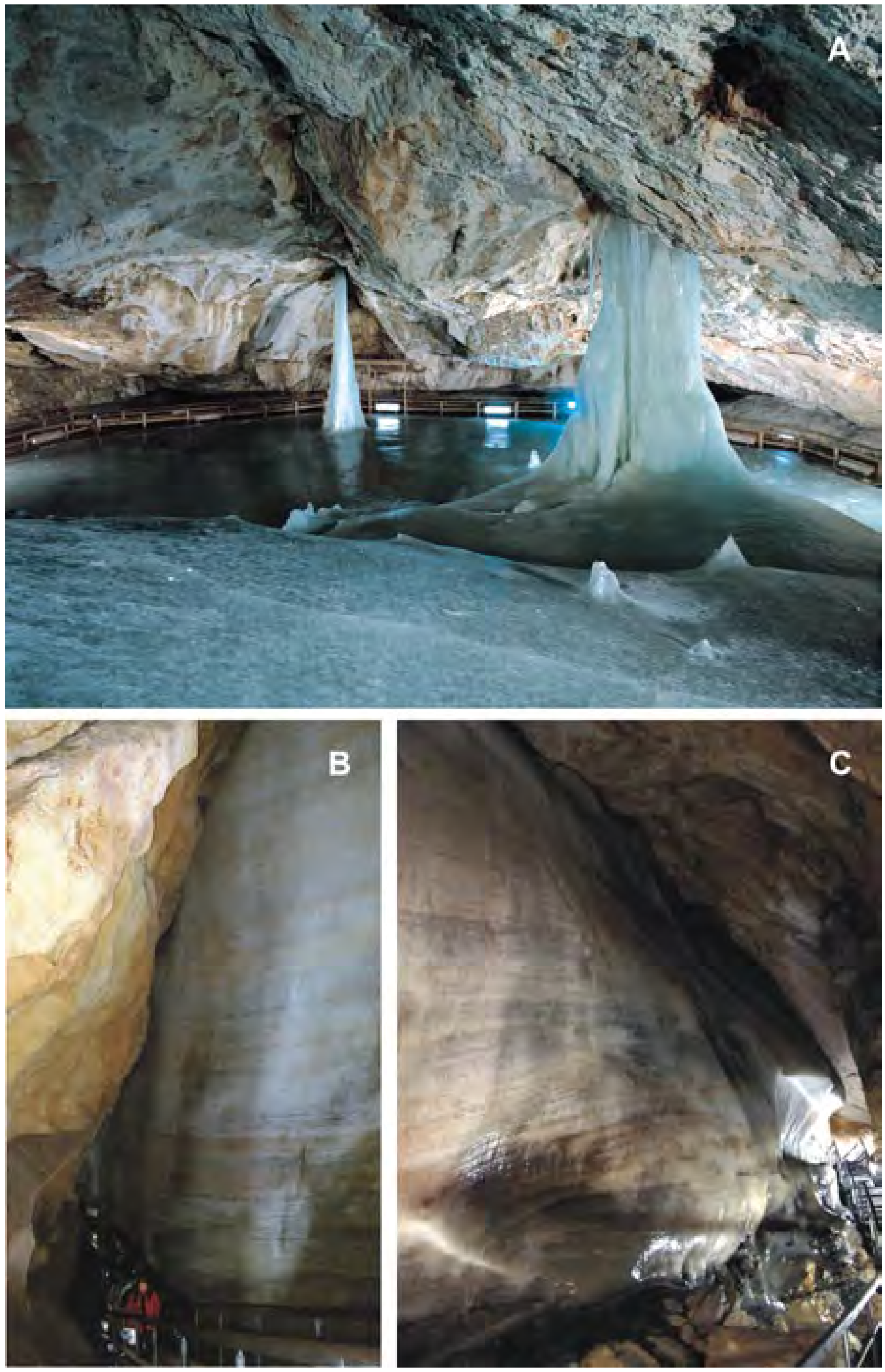

Fig. 7. Veľká sieň in the upper glaciated part of the Dobšiná Ice Cave (A), Ruffínyho koridor (B), Prízemie in the lower glaciated part (C). Photo: M. Eliáš (A), P. Bella (B, C)

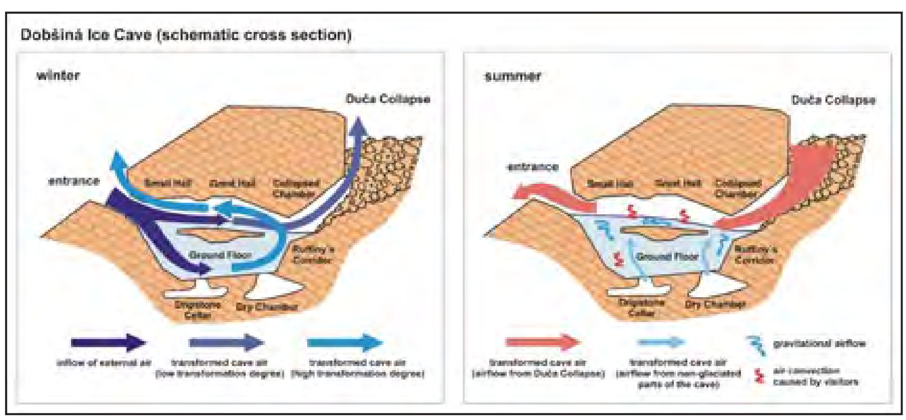

Fig. 8. Seasonal changes of air circulation in the Dobšiná Ice Cave (from Pflitsch et al., 2007 and Korzystka et al., 2011).

[2] *see also Lowe (1879a, b).*

therefore, based on laser scanning, the ice surface in the Eisriesenwelt Cave has been determined to be 27,890 m^2 (Petters et al., 2011; Milius and Petters, 2012).

Compared with the Dobšiná Ice Cave, glaciated parts of another well-known ice caves in the temperate climate zone are situated at higher altitudes, mostly in high-mountain positions – in the Austrian Alps at 1641–1775 m a.s.l. (Eisriesenwelt Cave) and at 1420–1450 m a.s.l. (Rieseneishöhle Cave), in the Southern Carpathians (Romanian Western Carpathians) at 1100–1120 m a.s.l. (Scărişoara Cave; the upper edge of its entrance abyss lies at 1165 m a.s.l.). The locations of all these caves are not very different according to their altitude (Scărişoara Cave – 46° 29' 23" N, Rieseneishöhle Cave – 47° 32' 5.4" N, Eisriesenwelt Cave – 47° 30' 11" N, Dobšinská Ice Cave – 48° 52' 19" N).

AGE OF ICE

Based on the direct counting of ice layers (with a thickness of 3–5 cm) the first assumed age of the oldest existing ice in the Dobšiná Ice Cave was about 5000–7500 years BP (Droppa, 1957). Later, it was refined to 4133 years BP based on the measurement of floor ice increments in the Malá sieň (Droppa, 1960, 1964).

Since the height of entrance opening to the artificial Kaplnka Cavity (Chapel) was lowered from 1.8 to 0.87 m over 100 years, Tulis and Novotný (2003) assume that the basal melting rate in the Dobšiná Ice Cave is about 1 cm/year (they noted that the Kaplnka is placed in the map from 1903?). However, compared to the edges of this opening, the ice layers gravitationally subsided above its upper edge. Therefore, the basal melting rate was slightly less than 1 cm/year. Taking into account the maximum floor ice thickness of 26.5 m, their estimated mass turnover time of the deepest ice layer is 2700–3000 years (Tulis and Novotný, 2003). Based on the last measurement in February 2020, the upper edge of entrance opening to the artificial Kaplnka Cavity was lowered about 25 cm over the last 17 years[3], i.e. about 1.45 cm/year.

Another indirect dating of ice was focused on the radiocarbon method (^{14}C) applied to the dating of organic matter fragments preserved in the ice. The skin of an undetermined bat, found 2.9 m above the ice base level in 2002, was dated at 1178–988 years BP. The average growth of ice during the last millennium was determined to 2.16 cm per year (Clausen et al., 2007). The remains of another frozen bat (*Myotis blythii*, *Myotis mystacinus*) were found in the lowermost part of the perennial ice block. The radiocarbon dating of the bat´s soft tissues yielded ages of 1266–1074 years BP and 1173–969 years BP. The dates testify that the ice crystallized at the turn of the Dark Ages Cold Period and the Medieval Warm Period. The calculated deposition rate of cave ice varies between 0.7 and 1.4 cm/year at that time and is similar to the present ice accumulation rate (Gradziński et al., 2016).

Fig. 9. Ice scoring due to the movement of underground glacier on limestone blocks, March 2019. Photo: P. Bella

The older period of the ice deposition was determined within the vertical profile on the high ice wall in the Prízemie based on the radiocarbon dating of 24 samples of the bat guano with the ages of 2595–610 years BP. The average ice deposition rate at 1130–800 years BP (Medieval Warm Period) reached 2.19 cm/year. It was significantly increased in comparison to the previous Dark Ages Cold Period (0.52 cm/year), as well as in the XII–XIV centuries (0.85 cm/year) (Milovský et al., 2019). Also, the latest radiocarbon dating of bat bones (Perşoiu et al., July 2019, unpublished data) determined the older age of the ice than Clausen et al. (2007) and Gradziński et al. (2016).

Based on the oldest dating age, it can be assumed that the exchange of ice fill takes at least about 2600 years (the similar period is estimated by Tulis and Novotný, 2003). In the context of a reconstruction of the development of cave levels and river terraces in the Hnilec River valley, Novotný and Tulis (1996) consider that the glaciation of Dobšiná Ice Cave started probably in the Middle Pleistocene. After its separation from the other part of the cave system by breakdown, the descending sack-like cavity originated in which cold air could be trapped (see also Tulis and Novotný, 2007). Cold air enters the cave through the opening to the surface created by the collapse of the cave ceiling.

GROSS MORPHOLOGY OF ICE BODY AND ICE MOVEMENT INDICATING AN UNDERGROUND GLACIER

From a large-scale morphology, the ice body in the Dobšiná Ice Cave represents a downward sloping glacier-like ice block with large terraces, small ice-hillocks and mounds deposited in the cave part descending from the opening to the surface (Krenner, 1873, 1874; Pelech, 1879; Balch, 1900; Měska, 1936; see also Bella, 2018; Fig. 4). Flat or slightly inclined ice surfaces (large terraces) develop in cave sections where intense seepage of meteoric waters, stagnation of melted and seeping waters in shallow lakes in ephemeral ablation depressions, and the subsequent freezing of lake water are seasonally or interannually repeated (Bella, 2018). In some places, the formation of the flat ice surface is also conditioned by the barrier contact of the growing ice surface with the inclined cave ceiling, in front of which the floor ice has accumulated as horizontal layers (Krenner, 1873, 1874; Pelech, 1879; Balch, 1900; Bella, 2005)[4].

The movement of underground ice-mass is evidenced mainly by the differently oriented ice stratification, the deformation and displacement of the tourist path, as well as by ice scoring observed in the subglacial cavity in the Prízemie (Fig. 9). The basement of the ice is formed by limestone blocks and debris collapsed and weathered from the ceilings. The glacier-like ice body is slowly moving from the cave entrance, Malá sieň, and Veľká sieň toward the Prízemie and Ruffínyho koridor. This direction corresponds with the direction of the inclination of the ice rock basement. Krenner (1873, 1874) was the first to presume a glacier-like movement in the cave[5]. Later, Měska (1936) wrote that 'Dobšiná ice' is an underground glacier. Nevertheless, measurements of ice movement were made much later. Based on geodetic measurements during 1981–1990, the rate of horizontal ice movement in the Malá sieň was 10.7–14.8 mm/year and in the Veľká sieň 5.4–18.1 mm/year, the average rate of vertical ice movement in the Ruffínyho koridor was 6.7 mm/year (Lalkovič, 1995). Another geodetic measurement of deformed and slightly displaced parts of the

[3] *The height of entrance opening was 0.5 m, but its flat floor was raised with new ice layers that reached about 10 cm above the lower edge of a nearby stainless steel pathway (the ice floor and the lower edge of this pathway were originally at the same height).*

[4] *Pelech (1879) wrote that the greater part of the ice floor of the Veľká sieň was a smooth glassy surface, having an area of 1726 m^2, with no elevation or depression (in the height of summer it has been the resort of skaters).*

[5] *He concluded that a tent-like positioned of ice plate, intersected by a large cleft (occurred in the Veľká sieň and called the Bedouin´s Tent), is a result of ice movement.*

tourist path along the lower part of the ice body (realized by Filip, 1996) determined the maximum rate of horizontal ice movement of 2–4 cm/year (Tulis, 1997). Therefore the slowly moving ice body in the Dobšiná Ice Cave presents a true (flowing) ice glacier (Ford and Williams, 2007). Its lower edge is formed by a steep to vertical wall on which the ice decreases mostly by sublimation due to air circulation (Fig. 4C).

A new point network for further geodetic measurement of ice movement was placed in November 2019, in cooperation with the Institute of geodesy, cartography and GIS in the Faculty of mining, ecology, process control and geotechnologies of the Technical University in Košice.

MORPHOLOGY OF ICE SURFACES AND ITS CHANGES

The surface of the ice body in the Dobšiná Ice Cave is featured by several medium- and small-scale morphologies (Bella, 2003, 2007, 2018). In many places, ice morphologies were modified or formed due to human impact in relation to the development of the cave for tourism or its speleological exploration. Long-lasting forms consist of supraglacial ice-deposited, ablation and compounded ice-deposited/ablation forms and more or less sporadic intraglacial and subglacial ablation forms. Ephemeral supraglacial ice-deposited and ablation forms are observed seasonally during and after an intense seepage of rainfalls or snow-melting waters into the cave through overlying fractured and karstified limestone with high permeability.

Supraglacial ice-deposited forms are generated by the freezing of tiny water film or sheet wash water flow (slightly inclined ice floors in some places with ice micro-terraces or lobes, inclined or cascaded ice slopes, ice curtains) or by the freezing of dripping water (ice stalactites, stalagmites, columns, and mounds). Supraglacial ablation forms are induced by air flow (sublimation large scallops and flutes, sublimation steep ice walls, ablation windows and smaller holes, ablation ice irregular protrusions, ablation oval mound-shaped elevations) or generated by stagnant ponded water (ablation bevels at the edge of flat ice floors). Anthropogenic supraglacial forms are represented by artificial trenches cut into the ice (Veľká sieň – Ruffínyho koridor, Malá sieň – Veľká sieň) and melting depressions near electric reflectors. Flat ice floors as supraglacial compounded ice-deposited/ablation forms are generated by the repeated ice melting and freezing of stagnant ponded water (Bella, 2005, 2007). They occur in the near-entrance part of downward sloping ice body (Malá Sieň) and in the lower position where the ice surface is barred by a cave rock roof (Zrútený dóm at the contact of glaciated and non-glaciated parts of the cave, also the former smooth horizontal ice floor in the Veľká sieň described by Fehér, 1872; Krenner, 1873, 1874; and Pelech, 1879; Fig. 10).

Two artificial tunnels excavated trough the ice body (Ľadopád / Icefall – Prízemie, Prízemie – Ruffínyho koridor), as well as the adjacent Kaplnka Cavity, belong to anthropo-

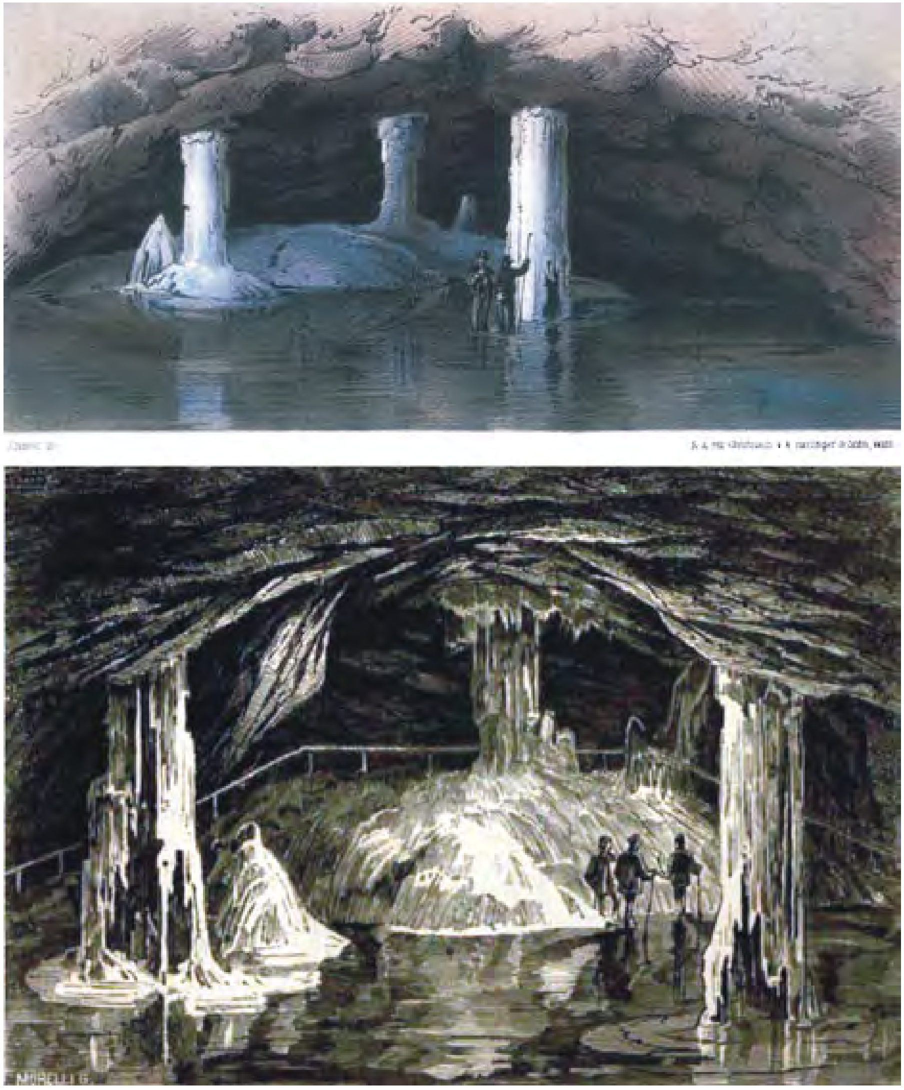

Fig. 10. Former flat ice floor in the Veľká sieň after the illustrations of Krenner from 1874 (up) and Morelli from 1878 (down; published in Pelech, 1878).

Fig. 11. Sublimation large scallops and flutes deepened into the walls and ceiling of artificial tunnel between the Prízemia and Ruffínyho koridor. Photo: P. Bella

Fig. 12. Ablation shaft-like depression and meandering runnel cut into the ice floor of the Veľká sieň, November 2019. Photo: P. Bella

genic intraglacial forms. As natural intraglacial ablation forms, large sublimation scallops and flutes induced by air flow were hollowed into the walls and ceilings of these artificial tunnels (Fig. 11). Sporadic subglacial ablation cavities at the contact of ice body with bedrock or debris were generated by ice sublimation due to air flow, e.g. in the central part of the Prízemie.

Based on changed border lines of the ice occurrence in older cave maps, it can be considered that limestone boulders and debris deposited on the floor of the Prízemie and the adjacent lower part of the cave leading to its southern edge were continuously covered by ice from the beginning of the 20th century to 1925. This extension of ice cover resulted from an increased water supply through artificial drainage channels cut into the ice from the upper-lying glaciated part of the cave, mostly from the Malá sieň and the entrance part (Tulis and Novotný, 2003). Water from the Veľká sieň is artificially drained to the Zrútený dóm (especially after the relocation of the tourist trail through the artificial trench between the Veľká sieň and Malá sieň, excavated probably in 1950[6]) and the adjacent part of the Ruffínyho koridor. During the last decades, increased water supply in the Zrútený dóm caused a decrease in the floor ice. The former higher level of the ice floor is indicated by ablation inward-sloping smooth facets on the ice remains elevated along the southern limestone walls of the Zrútený dóm (Bella, 2005, 2007). Here, the slightly larger surface of ice is also drawn in the older cave maps.

The former large flat ice floor in the Veľká sieň, having an area of 1,726 m^2, was used by skaters (Pelech, 1879; Fig. 10). The first summer skating ceremony took place in July 1893, the last figure skating training were during 1947 – 1952 (Székely and Horváth, 2009).

[6] *In connection with the investigation of the causes of ice decrease from 1947 and the proposition of stabilization measures, A. Droppa elaborated two maps of the cave in 1950 – one showing the artificial trench between the Veľká sieň and Malá sieň, the other not (Archive SMOPaJ, Liptovský Mikuláš).*

At present, this flat ice surface is changed to a slightly inclined ice floor (with ice microterraces) by continuous ice increments. The flat floor ice began to change after digging a channel along the edge of this hall in order not to flood the tourist paths and cover it with ice. Since the water could not reach the rock wall as a barrier, the flat ice surface could not be persisted by repeated freezing and thawing of the floor ice as pond ice. The surface of rising floor ice became more inclined when freezing the water flushed to the adjacent side of the artificial channel. During some periods, an artificial channel draining water from the foot of the elevated ice part of the Veľká sieň could contribute to the persistence of the flat ice floor. The significant changes in the floor ice surface in the Veľká sieň occurred after the last skating. The greatest increase in the slope of the ice surface has been observed since the late 1980s when they stopped digging the drainage channels at the foot of the large ice mound-like elevation.

Ephemeral supraglacial ice-deposited and ablation forms are observed seasonally during and after an intense seepage of rainfalls or snow-melting waters into the cave through overlying fractured and karstified limestone with high permeability. These morphologies originate mostly in the upper ice-covered parts of the cave with seasonal temperature variations. Ice-deposited forms are usually formed at the end of winter and persist during spring and sometimes, partially, until the beginning of summer. Physical ablation forms are formed mostly during summer and persist until the end of winter, after which they are usually filled and covered by new ice. Anomalies of ice stratigraphy (depressions filled by newer ice) are related to former ablation forms.

Ephemeral supraglacial ice-deposited forms formed by the freezing of thin water film, sheet wash water flow, or dripping water (seasonal ice curtains, stalagmites, stalactites, or columns). Ephemeral supraglacial ablation forms are generated by dripping water (dripping pits, dripping multipit depressions, ice spires), by dripping and stagnant water (shallow pans, dripping kettle-shaped holes), by falling/running or intensively dripping water (vertical half-tube grooves on ice columns, shaft-like depressions), by sheet wash water flow (parallel rills), by channeled water flow (shallow meandering runnels on slightly inclined ice floor, outflow straight or meandering channels leading from shaft-like depressions or larger kettle-shaped dripping holes) or by the upward expansion of freezing stagnant ponded water (small ice bulges with radial and concentric cracks) (Bella, 2003, 2007; Fig. 12). Some of these ablation forms were observed and described already after the discovery of the cave[7].

Small lakes in ephemeral ablation depressions form on the ice surface in places of the intensive seepage of meteoric water, mostly due to heavy rain (in the Malá sieň and in the upper part of the Veľká sieň). A shallower and larger lake seasonally occurs on the flat ice floor of Zrútený dóm where water comes from the adjacent sloping part of the Veľká sieň and percolates through the fractured ceiling in the southwestern part of this chamber. Grand ice pillars in the Veľká sieň and Malá sieň are 8–11 m in height, 2–3 m in diameter (Pelech, 1879; Balch, 1897, 1900), but they are significantly reduced or eventually collapsed due to heavy rains.

INVERTEBRATES

In the whole Stratená Cave System 176 invertebrate taxa were identified, while 65 species are known in the Dobšiná Ice Cave (Kováč et al., 2006; Papáč et al., 2020). The collapsed doline at the entrance of Dobšiná Ice Cave is the peculiar inverse habitat, which serves as an important locality of several cold-preferring species of soil fauna such as beetle *Choleva nivalis* (Kraatz, 1856) and springtail *Appendis-*

[7] *Pelech (1879) mentions a kettle-shaped basin 5 m in diameter, hollowed out by the water that drops from the roof, and furnished with an outlet. Balch (1900) described a small stream dribbled continuously from the roof and cut a channel across the ice floor, noticed during a cave visit in July 1895.*

Fig. 13. Troglobiotic springtail *Protaphorura janosik* – characteristic species of Dobšiná Ice Cave with occurrence also on the ice surface, body size 4 mm. Photo: Ľ. Kováč and A. Parimuchová

Fig. 16. The northern bat (*Eptesicus nilssonii*). Photo: Z. Višňovská

Fig. 14. Crustacean *Bathynella natans* – stygobiotic species found in pools in non-glaciated parts of the cave, body size 1 mm. Photo: Z. Višňovská

Fig. 15. Winter cluster of the species *Myotis mystacinus* and *Myotis brandtii*. Photo: Z. Višňovská

toma absoloni Rusek, 1966. The shallow soil profile at the entrance inhabits a new cold-adapted species of springtail *Megalothorax dobsinensis* Papáč, Raschmanová et Kováč, 2019. Its occurrence is limited exclusively to the cold and wet parts of the entrance microclimatic gradient and is considered as glacial relict (Papáč et al., 2019).

The parts of the cave with perennial glaciation are the poorest in terms of species diversity. It is the consequence of the oligotrophic conditions and low air temperature that limits the decomposition of organic matter and the development of microbial colonies, which are direct food sources for microbivorous arthropods (Kováč, 2018). Only 4 species were recorded in glaciated parts, two of them are obligate cave springtails *Deuteraphorura kratochvili* (Nosek, 1963) and *Protaphorura janosik* Weiner, 1990. *P. janosik* is a characteristic species of the whole cave system with a higher population density also on on the ice surface (Fig. 13). The qualitative and quantitative microfungal occurrence in air and guano of glaciated and non-glaciated parts was recorded by Nováková (2006). The number of spores in the air was mostly influenced by climatic conditions (rain), with the highest values in the non-glaciated Biela sieň (White Hall).

The largest part of Stratená Cave System (including non-glaciated parts of the Dobšiná Ice Cave and Duča Cave) represents an underground environment with a microclimatically more balanced regime and air temperature between 3–6°C. These parts are the habitat of most troglobiotic and eutroglophilic animals such as mite *Pantelozetes cavaticus* (Kunst, 1962), *Cyrtolaelaps mucronatus* (G. et R. Canestrini, 1881), springtails *Pygmarrhopalites aggtelekiensis* (Stach, 1929), *Megalothorax carpaticus* Papáč et Kováč, 2013, isopod *Mesoniscus graniger* Frivaldszky, 1865, or millipede *Allorhiscosoma sphinx* (Verhoeff, 1907).

In the Dobšiná Ice Cave, water microhabitats are limited to parts without perennial ice. Stygobiotic aquatic fauna is represented by even smaller crustaceans *Elaphoidella* sp. and *Bathynella natans* Vejdovský, 1882, recorded only in pools in non-glaciated parts (Fig. 14). The presence of true cave animals and glacial relicts in the terrestrial and aquatic fauna communities indicates the stable environmental conditions of Dobšiná Ice Cave despite its long-term open to the public.

CHIROPTEROFAUNA

The Dobšiná Ice Cave is an important underground site for bats in Europe. So far, 14 species of bats have been identified in the cave. These are mostly cold-preferring forest bat species. A hibernation period is relatively long here, it usually lasts from October until May.

The whiskered bat (*Myotis mystacinus*) and Brandt´s bat (*Myotis brandtii*) are eudominant bat species in the cave. For hibernation, they use mostly non-glaciated parts of the cave, especially the Kvapľová sieň with an average temperature of about 3.5°C. A clustering into different sized aggregations is typical for them here (Fig. 15). The highest abundance of *M. mystacinus* and *M. brandtii* (643 individuals) was found in the Dobšiná Ice Cave during the winter season of 2016/2017 (Višňovská et al., 2017). Recent available data have shown that the Dobšiná Ice Cave, along with the neighboring Duča

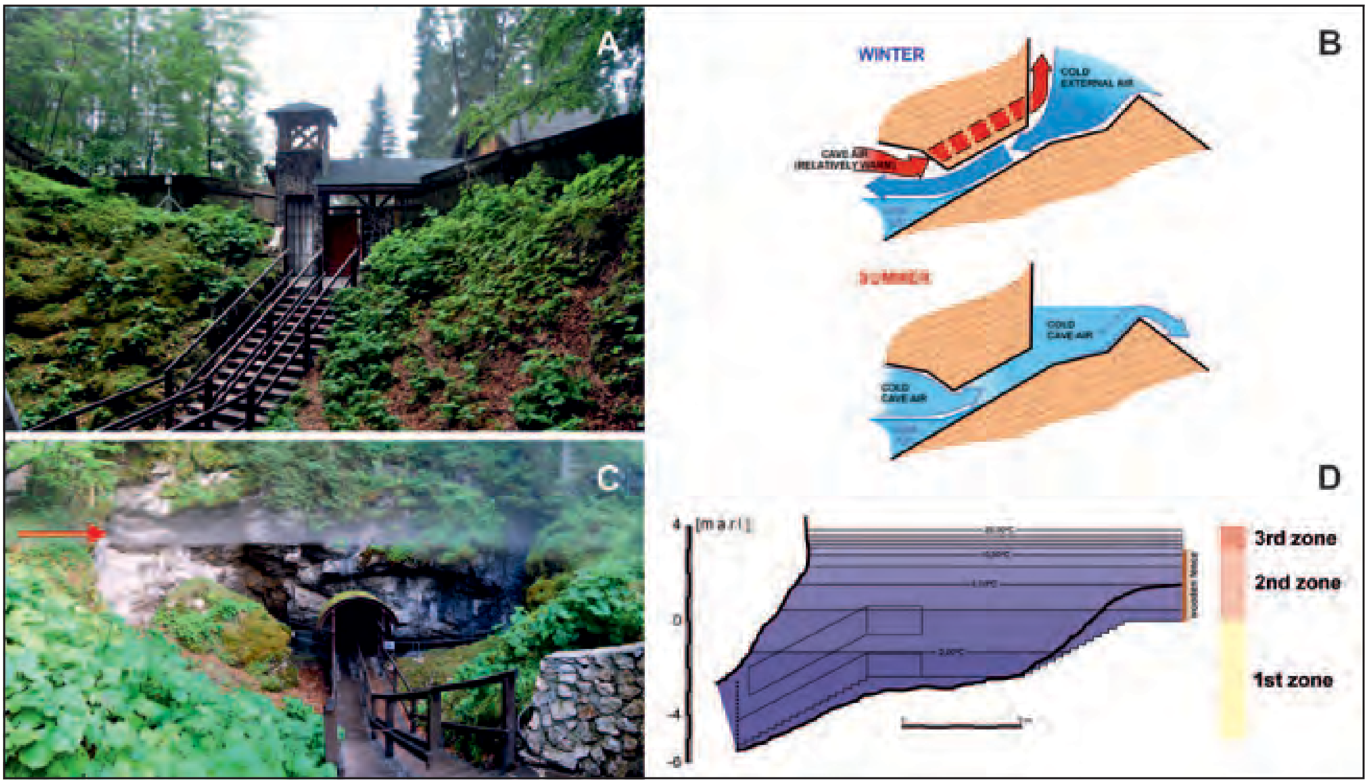

Fig. 17. Climatic conditions in the entrance collapsed doline: A – wooden fence around the western and northern parts of the collapsed doline with a cave entrance; B – scheme of air exchange between the entrance collapse and the cave interior in summer and winter seasons (from Piasecki et al., 2005); C – condensation of water vapour in the contact zone between cold cave air and warm external air in summer 2003; D – vertical thermal structure of the atmosphere in the entrance collapse in summer season: 1st zone with a insignificant vertical temperature gradient – air temperature closes to the temperature inside the cave, 2nd zone with a higher vertical temperature gradient – faster growth of air temperature with the height, 3rd zone with a very high vertical temperature gradient – at the contact between the cool air in the collapsed doline and the outside warmer air (from Piasecki et al., 2005). Photo: T. Sawiński (A, C)

Cave, with which it is genetically related, is the most important wintering site of the whiskered bat and Brandt´s bat in Central Europe (Uhrin, 1998; Bobáková, 2002; Višňovská et al., 2017).

Large *Myotis* species such as greater mouse-eared bat (*Myotis myotis*) together with the more thermophilous lesser mouse-eared bat (*Myotis blythii*) are present exclusively in warmer non-glaciated spaces of the cave, with a total number not exceeding 25 individuals in recent times. Also, the brown long-eared bat (*Plecotus auritus*) and Natterer´s bat (*Myotis nattereri*) regularly hibernate here in low numbers. It was just in this cave that in 1964, the pond bat (*Myotis dasycneme*) was discovered for the first time in Slovakia (Uhrin, 1998).

In glaciated cave spaces, the northern bat (*Eptesicus nilssonii*) occurs almost exclusively (Fig. 16). It is a rare species preferring hibernation in colder mountain caves of northern and central Slovakia (Kováč et al., 2014). Its total abundance in the Dobšiná Ice Cave reaches about 60 individuals, which is comparable to the winter population in the Demänová Ice Cave in the Nízke Tatry Mts. (Bella et al., 2014). Both localities represent the most important well-known hibernacula of the northern bat in Slovakia.

The presence of other species (*Barbastella barbastellus, Myotis bechsteinii, Myotis daubentonii*) in the cave is sporadic. Findings of *Eptesicus serotinus, Rhinolophus hipposideros* and *Nyctalus noctula* were documented only by the analyses of osteological material from Holocene (Horáček, 1976; Obuch, 2012).

HUMAN INFLUENCES ON THE CAVE ENVIRONMENT AND ITS PROTECTION MEASURES

Ice caves belong to the most fragile and vulnerable natural phenomena. The Dobšiná Ice Cave has been disturbed by human impacts related to its tourist development or speleological exploration. At present, after several reconstructions and innovations of the technical infrastructure of the cave, the tourist trail is 475 m long with a vertical span of 43 m (Droppa, 1960). By 1970 the attendance at the cave ranged from 52,297 to 128,233 visitors per year. At present, the cave is open from May 15 to September 30. In some past periods, it was open for longer time during the year, e.g. in the 1870´ from the beginning of May till the end of November (Pelech, 1879).

The air circulation in the cave was partially changed as a result of the discovery of its non-glaciated parts in 1947. About 25,000 m^3 of ice melted within 4 years. The critical places where the air circulation changed were determined based on smoke tests. Seven dry stone walls, directing warmer air to the cave opening from the surface, were installed to repair human-influenced and changed microclimatic conditions (Ondroušek, 1952). However, climatic conditions were not stabilized until after treatment of the cave entrance in 1954 (Droppa, 1960).

A last artificial tunnel and a trench for a tourist path cut in the ice in the 1970s, which partially disturbed air circulation in the entrance of the cave (with a decrease of ice stalactites and the ice wall in the Malá sieň), had to be filled with snow and ice to restore the area to its original state (Bobro et al., 1995a,b; Zelinka, 1996).

The spatial changes if ice morphologies, as well as the ice extent in the lower part of the cave, have largely resulted from human impacts. Artificial drainage channels cut into the floor ice in the Malá sieň and Veľká sieň concentrate and accelerate the flow of water into some lower-lying part of the cave, mostly into the southern part of the Prízemie, as well as into the Zrútený dóm and Ruffínyho koridor. A channel, by which the water was flowing down into the lowest part of the cave, has been dug along boarded footway in the Veľká sieň already in the second half of the 1870s (Pelech, 1879). By this means the formation of ice in the Veľká sieň was limited to a considerable extent. The mentioned extension of ice cover on the floor of the Prízemie and near the Peklo (Hell) directly follows artificial drainage channels descending from the upper-lying Malá sieň and the entrance part (Tulis and Novotný, 2003). Vertical ice formation, resembling an icefall, is formed on the steep ice wall of the Ruffínyho koridor due to artificial water drainage from the Veľká sieň. Moreover, the changing level of floor ice in the Zrútený dóm is influenced by water artificially drained from the upper part of the Veľká sieň. Also, the former large flat ice floor in the Veľká sieň, suitable for skating, was changed due to digging an artificial channel draining water into the lower-lying part of the cave.

The reconstruction of a fence around the western and northern parts of the collapsed doline with a cave entrance and the cutout of several trees that had shaded the entrance area in 2010 caused climatic changes in the near-entrance area of the cave, including melting of permafrost and formation of new openings into the cave. The thermal stratification and the spatial distribution of the air temperature inside the collapsed doline was precisely determined in 2012 (Korzystka-Muskała et al., 2014) and compared with microclimatic conditions before the previously mentioned anthropogenic changes, based on data obtained during analogous research from 2003 to 2004 (Piasecki et al., 2004, 2005; Fig. 17). The project, which was aimed at stabilizing the microclimate conditions in the entrance area of the cave, was realized in 2015.

The Dobšiná Ice Cave cannot be interconnected with the Duča Cave and the Stratená Cave by speleological exploration, because the existing underground air circulation would most likely change. In order to protect the cave, it is also important to respect the conservation measures for the Stratená Nature Reserve, in which the cave is located. In 2016, the area above the cave was legislatively re-established to the strictest protected zone A of the Slovenský raj National Park. The forest cover above the cave must be preserved, as the seepage of water from rainfalls and melting snow into the cave could be disrupted. The forest also affects the heating of the sloping surface and rocks above the cave and prevents soil erosion (Šincl, 1931; and others).

Basic measures for the protection of the Dobšiná Ice Cave, recommended by the participants of the international scientific conference held in 1970 on the occasion of the 100th anniversary of its discovery, are still adequate and important for the protection and management of this rare cave open to the public (see Slovenský kras, vol. 9 published in 1971). They must be specified on the basis of new observations and researches.

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THE HISTORY OVERVIEW OF THE DOBŠINÁ ICE CAVE

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Abstract: Dobšiná Ice Cave ranks among the ice caves of the world importance. This fact is also proven by its inclusion to the UNESCO World Natural Heritage List. This unique cave was discovered 150 years ago, in 1870. It was opened to the public the following year. Thanks to its natural values, it almost immediately caught the attention of the scientific circles of the Habsburg Monarchy and eventually people from abroad, as well as tourists and general public. In addition to being the object of scientific interest, the cave has also become an important factor in the development of caving, tourism and the region itself, which is closely linked to its one and half century long history.

Key words: cave history, cave discovery, show cave, protection, cave research, tourism, attendance

INTRODUCTION

The Dobšiná Ice Cave was discovered through the well-known Ice Hole in the Duča Hill on June 15, 1870. It was officially opened the following year. The underground glacier became the subject of scientific interest and the first climatic measurements and observations were carried out in the cave. Gradually, scientific opinions on the causes of its glaciation appeared. The question of the origin of the cave itself has also been presented. Gradual changes and the ice fill decrease caused the need to protect the cave. The climate of the cave with regard to its glaciation, the underground glacier itself, the origin of the cave, or its fauna are still the main areas of the research. From its opening to the present day, the cave has been a great attraction for tourists and has key importance for the development of tourism in the region, which was reflected in the exhibition of tourist facilities in its immediate vicinity, or even the establishment of bus connections and construction of a railway station. The possibility of summer skating on the ice surface in the Great Hall has been a special attraction for tourists for several decades. The aim of this article is a brief presentation of the history of the Dobšiná Ice Cave with regard to its scientific research, opening, and operation, its role in the development of tourism, as well as an overview of visitors throughout its history. The article is divided into five parts. Selected information is arranged chronologically to provide the reader with a clear cross-section of the cave's history.

DISCOVERY OF THE DOBŠINÁ ICE CAVE

The underground hole located in the Duča peak has always been known by the local people, who called it the Ice hole (Fig. 1). This deep hole was partially filled with ice. The ice used to be mined from its margins. At its bottom, many rocks, branches, and tree trunks were thrown. A similarly, the ice was mined from the Demänová Ice Cave, which was used by the inhabitants of the Svätý Mikuláš (Liptovský Mikuláš) for food cooling, and from the Silica Ice Cave, where a brewery briefly operated during the middle of the 19th century (Prikryl, 1985).

1870, June 15: A young mining engineer Eugen Ruffiny (Fig. 2), lieutenant Gustáv Lang, and municipal officer Ondrej Mega entered the cave through an ice hole. Its depth was estimated by counting the duration of the echo after a shotgun shot. The necessary equipment (such as ropes, ladders, staples, and anchors) was brought by the coachman to theundeground entrance. Ruffiny, tied up to a supporting rope made of a wooden crankshaft, equipped with a torch and a signal rope with a bell, slowly descended into the underground. Through a partially plugged hole at the bottom of the vertical space, he reached the Small Hall of the Dobšiná Ice Cave. He accidentally slipped and happened to rip the signal line. His coworkers thought it was a signal for them to pull him out, and he ended up stuck between two rocks, only narrowly avoiding a disaster. Eventually, Land and Mega followed Ruffiny into the underground. The lead figure of the discovery expedition was doctor Nándor Féher and it was financially supported by the mining director Márton Szontág (Pelech, 1878; Prikryl, 1985; Lalkovič, 2009; Horváth, 2007).

Fig. 1. The Dobšiná Ice Cave was discovered through this vertical Ice Hole in Duča on June 15, 1870. Source: Collection of the Slovak Museum of Nature Protection and Speleology

Fig. 2. Discoverers of the Dobšiná Ice Cave Eugen Ruffiny, Gustav Lang, and Ondrej Mega. Source: Collection of the Slovak Museum of Nature Protection and Speleology

CAVE DEVELOPMENT FOR TOURISM AND ITS PROTECTION

1870, June 22: The municipality of Dobšiná accepted a report on the discovery of the cave, written by the participant of the discovery expedition, Nándor Fehér. Dobšiná has committed to take care of the cave as an extraordinary natural monument and to preserve it in its original condition, as well as to make the cave accessible for the public (Prikryl, 1985; Lalkovič, 2001).

1870, August 15: Two months after the discovery, the cave was already provisionally opened. It is said, that the cave opening was associated with a celebration in honour of the discoverers. The temporary tour route was covered with anti-slip sawdust and the stairs were cut directly into the ice. Interestingly, only the later press says that the celebration was associated with ice-skating, probably with the aim of promoting the cave (Prikryl, 1985).

1871: The town of Dobšiná opened the cave for the public. The entrance was modified, wooden sidewalks and stairs were built (Fig. 3). They were sprinkled with a wooden sawdustagainst slipping, and the town also provided a guide. The cave was lit by an open flame. In order to meet the wishes of the visitors, the spaces of the Small and Large Halls were also lit by 20 to 120 kerosene lamps and candles. Some parts were illuminated with magnesium light. Torches and other light sources that could soot ice in the cave were forbidden. Cave visitors used to put their signatures into the guest book. The cave had been opened from 1st May to the end of November. That year, the cave had only 292 visitors (Pelech, 1878; Prikryl, 1985; Lalkovič, 2009).

1881: The first experiments with electric lighting of the cave began. It was at the time of the first experiments with electric lighting in caves in general, and therefore we can rightfully consider them to be pioneering. Electric lamps illuminated the Small and Large Halls for three days, which attracted many people (Hazslinsky, 1999; Lalkovič, 2009).

1887: As one of the first caves in Europe, the Dobšiná Ice Cave was constantly lit by electric light. An arc light was used as the light source, as evidenced by a large number of embers found in the cave (Fig. 4) (Hazslinsky, 1999; Lalkovič, 2009).

1914: The cave was connected to Dobšiná's municipal power plant network. Electric lights were outdated and also partook in the ice melting. After 1918, the conditions of the ice fill in the cave worsened. Regular changes of the cave's administrator lead to the bad technical condition of the cave and also caused insufficient protection of the cave ice (Prikryl, 1985; Lalkovič, 2009).

the 1920s: the town of Dobšiná leased the cave to Ondrej Fejér. During this period, climate research and measurements in the cave declined (Benický, 1970).

1941: In the autumn of that year, the storm caused the destruction of forest vegetation. A lot of water got into the cave as a result, which had a negative effect on the state of the cave's ice fill (Zelinka, 2012).

1944–1945: As a result of the war events associated with the outbreak of the Slovak National Uprising in August 1944, the crossing of the front line and military operations in 1945, the cave was closed during this period.

1953: The national enterprise Turista took over the cave. An overhaul of the cave's technical equipment happened, including the replacement of electrical wiring and lighting with cold discharge lamps and modifications to the tour route (Benický, 1970).

1954, May: After the general reconstruction of the equipment and the tour route – the cave was re-opened for the public.

1965: The Slovak National Council entrusted the administration and operation of the cave with the East Slovak Museum in Košice (Benický, 1970).

1970: The cave service is provided by the newly created Slovak Caves Administration. The Slovak caves are centralized.

1973: In order to create a suitable sightseeing route and simplify the cave service, a corridor in the ice body between the entrance of the cave and the end of the Small Hall was artificially built. This change significantly affected the thermodynamic regime of the cave, which over time manifested itself in the glaciation of the originally unglazed areas of the Hell part, where floor ice with a thickness of 2 to 4 m was gradually formed. During the winter of 1996, the corridor was closed again, but the ice filling of the Hell section will not decrease. On the walls of the Small and Great Halls, hoarfrost forms again (Zelinka, 1996).

1979: The cave was declared to be a protected natural creation (Zelinka, 2012).

1995–1997: Gradually, the reconstruction of a part of the wooden sidewalk of the cave tour route was being carried out (Labaška, 2004).

1996: In accordance with legislative changes, the cave was declared a national natural monument (Bella, 2006).

1997–1998: The current building of the entrance area of the cave was built (Janíček, 1998; Hlaváč, 1999).

1999: Reconstruction and modernization of the electric lighting of the cave were carried out (Filo, 2000).

2000: Dobšiná Ice Cave is included in the UNESCO World Natural Heritage List (Hlaváč, 2001).

2003–2008: The high attendance of visitors and the aggressive environment caused the early deterioration of the wooden sidewalks in the cave (Fig. 5). In response to this situation, the Slovak Caves Administration proceeded to completely replace the wooden sidewalks with stainless steel ones. The exchange took place in three stages (Labaška, 2004, 2008).

2006–2007: Cleaning of the lower parts of the cave, especially the Dry Dome, was carried out. With the help of cable cars, wooden waste from the construction of the original tour route and later reconstruction was removed (Staník, 2007).

2010: Completion of extensive reconstruction of the entrance area of the cave (Peška, 2010).

Fig. 3. Remains of a wooden pathway of the original tour route. Photo: M. Kudla

Fig. 4. After the beginning of the use of electric lighting in 1887, the cave was lit by arched lamps. There are still a lot of embers in the cave due to a lamp usage. Photo: P. Herich

Fig. 5. Sightseeing route equipped with wooden walkways and stairs, which were gradually replaced by stainless steel structures in the years 2003 to 2008. Photo: M. Rengevič

2015: In order to stabilize the microclimatic conditions, the slope in the entrance part of the cave was stabilized, a new grid was installed and the original wooden entrance fence was replaced with a plastic one. The original plants were planted around the entrance of the cave.

CAVE RESEARCH AND EXPLORATION

1870–1871: The first research in the cave was carried out by Nándor Fehér together with the discoverers. He focused mainly on climatic measurements and explaining the presence of ice in the cave. The results were published in his work in 1872. It is noteworthy that he describes the hollow columns and the ablation of the ice formation 'Well', which was pierced by the seepage water from the ceiling in three places. It then accumulated in the 'lake' below him and flowed through a narrow deep trough. He also describes the stratification of the underground glacier or the innovation in the part called Chapel. It is important to mention that the lower parts of the cave were not covered by floor ice at that time. He noted that the ice filling of the cave was caused by the freezing of seepage water. As a task for other researchers, he set the question of dating the beginning of the ice fill (Fehér, 1872).

1873, April 11: The cave of the National Museum in Budapest, József Sándor Krenner, visited the cave on behalf of the Hungarian Royal Science Society. He explored the cave with the participation of Joseph Sturezenbaum, Nándor Fehér, and discoverer Eugen Ruffiny. He reported on his results at a meeting of the Science Society and later published it (Krenner, 1873).

1874: Krenner published a more detailed independent work on the Dobšiná Ice Cave. It deals in detail with its genesis and glaciation. He notes that in the cave glacier there are regularly alternating layers of white and greenish ice with tiny air bubbles, locally interlayered by the limestone dust. The work also contained a modified map of the cave by Eugen Ruffiny with marked wooden paths of the tour route. It was illustrated is a series of colorful lithographs. Krenner assumes that the cave was created by the creek that flowed through it and the bottom of the cave later collapsed, becoming a cavity with a static, draft-free climate and the ice began to form. He also described the summer and winter air circulation. He distinguished the mass of an underground glacier, which he compared to layered rock, from the other ice formations. He noticed the increments and declines of the underground glacier (Krenner, 1874).

1878: Doctor János Pelech published an extensive study about the cave. He started to perform regular temperature measurements, which have not been performed before. He measured temperatures every month during 1881 at four different locations. He measured in front of the cave portal, in its entrance, in the Great Hall, and in the lowest part. He published the results in his work Stratenské údolí and Dobšiná Ice Cave, which is the first tourist guide dedicated to this area. He describes the stratification of the ice supposedly formed by ice sheets as smooth as glass. He calculated the ice area of the cave by the current mining technique to be 7171 m^2 and the volume of the ice in the cave to be 125,000 m^3. The work contains a detailed description of the cave, the morphology of floor ice, and a description of forms of ice filling, especially ice columns. It emphasizes their modeling by water and describes the Well. By measuring temperatures in the cave, he found that the highest temperature was at the entrance, the lowest at the bottom, where the ice hardly ever heated (Pelech, 1878).

1879: English geologist from Cambridge Walter Bezant Lowe published an English translation of Pelech's work in London. In the same year, he also published a brief article in the journal Nature. Thanks to that, he promoted the cave in Anglophone professional circles (Prikryl, 1985).

1881: Josef Wunsch visits the cave. In his contribution to the cave, he assumes that it was created by water and collapse, considers a static climate and abundant seepage water leachate to be the cause of glaciation. He states that more than 10,000 visitors have visited the cave in 10 years (Wunsch, 1881).

1881, July: The cave is visited by German natural scientist Bruno Schwalbe, who deals with the issues of ice formation in caves. He also visited the Demänovská Ice Cave and Silická Cave. Presentations from the journey were presented by the Physical Society in Berlin; the lecture was also published in the press. He states that the ice is only formed at the bottom and edges of the cave space. Where the ice is forming, the draft is absent, the air temperature is slightly below zero, and the air is saturated with water vapor. When describing the Dobšiná Ice Cave, he relied on Krenner's work. He noticed the different structures of the ice (Prikryl, 1985).

1882, July – 1888, March: Temperature measurements and climatic research of the cave were carried out by the director of the burgher school in Dobšina Ede Hanvai. During this period, he realised 1952 measurements and published their results multiple times (Prikryl, 1985).

1884: William Ambróz reports on a visit to the cave in Obzor. He describes the ice columns in the cave, which were 8 to 11 m high and 2 to 3 m wide. Like Fehér and Krenner, he points out that in one of them – the Well, water flows on the inner walls and collects in the 'boilers' below it. He also remarks on the stratification of the ice (Ambrož, 1884).

1888: An extensive study on the glaciation of the cave was published by Moklós Fischer, a high school professor from Spišská Nová Ves. He explains the glaciation with the help of physical phenomena and strictly rejects the theory that the ice filling of the cave is a remnant of the Ice Age. According to the airflow regime, he divided ice caves into static and dynamic. He claims that it is not sufficient to measure only the temperature of the air in the cave, but it is also necessary to measure the temperature of the rock area (Prikryl, 1985).

1888–1893: The works of the internationally renowned geologist and ice cave expert Eberhard Fugger are published. He described every well-known ice cave. Under the number of 87, he lists the Dobšiná Ice Cave. He refuses the opinion that ice is formed in the caves in summer and disappears in winter (Prikryl, 1985).

1891: Professor Emil János Tarlenday responded to Fischer's study. He criticized the theories expressed so far about the causes of cave glaciation. He considered temperature-dependent evaporation-related processes to be a key factor in ice formation (Prikryl, 1985).

1911: The climatic conditions of the cave were investigated by Lajos Steiner of the Hungarian Meteorological Institute. He regularly measured the temperature in the cave – including the temperature of the cave walls, but also in the outdoor environment. He found that in the summer, the air temperature in the cave rises above 0 °C, but the wall temperature remains below freezing. His work was stopped in 1918 by the collapse of Hungary. He published his results in 1922 (Prikryl, 1985).

1925: The Austrian Cave Research Group produces a high-quality, detailed, and so far the best floor plan of the cave (Collection of the Slovak Museum of Nature Protection and Speleology; Vacková, 2001).

1947, August: In the northwestern part of the Collapsed Dome, the gap between the ice and the rock wall lead to the unexploerd spaces. After their widening, unglaciated dripstone parts of the cave were discovered. The associated change in the microclimate of the cave caused the loss of the ice floor, which was not stopped in 1950 by sealing draft holes into the dripstone sections (Kvietok 1948, 1949; Droppa, 1960).

Fig. 6. Microclimatic measuring station in a cave from the sixties. Source: Collection of the Slovak Museum of Nature Protection and Speleology

1957–1960: Anton Droppa was in charge of detailed geological and geomorphological research of the cave. He also created a map, which contained unglaciated parts of the cave discovered in 1947 (Droppa, 1960).

1950–1965: In order to protect and preserve the natural values of the cave, especially the ice fill, the Slovak Academy of Sciences and Slovak Hydrometeorological Institute took over the supervision of the cave and did climatic observations there (Fig. 6) (Prikryl, 1985).

1980–1989: Based on the previous knowledge of the research, microclimatic measurements of the cave were performed by Jaroslav Halaš in this period. He focused on elements influencing the physical properties of the cave's air, methods of heat transfer based on physical processes, measuring the temperature of the rock mantle, and the overall thermal balance of the cave. Based on the results of the research and his own point of view, he's gained new knowledge about the changes in temperature and stated that cave has good conditions for the maintenance and formation of the ice. He used automated measurement recording for the first time (Halaš, 1989).

1986–1996: Ján Tulis and Ladislav Novotný carried out geological and geomorphological research of the cave, including research of spatial changes of the ice fill by geodetic and photogrammetric methods (Novotný and Tulis, 1996, 2001).

1997–2001: The Slovak Caves Administration has started to implement systematic microclimatic monitoring in order to learn more about long-term changes in the cave climate and the development of the cave's speleo-climatic regime, depending on its attendance. This was the time of the first stage of microclimatic monitoring using six automatic stations called BABUC. Five were placed inside the cave, one on the surface (Zelinka, 2009).

2001: As a part of the international program, research and monitoring of the cave began in cooperation with experts – specialists in cave climate from the Institute of Geography of the University of Ruhr in Bochun, Germany, but mostly with specialists from the Institute of Geography and Regional Development of the University in Wroclaw in Poland. For the more detailed study of the microclimate and glaciological research of the cave, a cooperation agreement was concluded with the University of Wroclaw in 2002–2005, 2005–2008, 2009–2013. So far, the research has mainly focused on temperature changes of air and ice at different depths due to external and thermodynamic changes of air and ice morphology, based on a detailed study of very slow airflow in individual parts of the cave. Furthermore. monitoring of seasonal increases and decreases in the ice floor and vertical ice formations, as well as seasonal surface occurrences of condensing ice forms, were carried out. One of the outputs of this cooperation is a number of published research reports or results from speleo-climatic monitoring (Zelinka, 2009).

2001: The biggest international professional event in glaciological research was the construction of a borehole in a part of the Dobšiná Ice Cave called the Great Hall under the Well formation, where the georadar identified the greatest ice thickness (Fig. 7). The aim was a geochemical and isotopic study, as well as the dating ice from a drilled core. The initiator of the project and the international guarantor in relation to financing from EU funds was the Dutch company SelorEEIG. In Slovakia, the activities are connected with the project of a coordinated representative of Hydeko-KV from Bratislava. The technical side of the project, such as core drilling, transport, and processing, elaboration of isotopic and chemical results was led by the experts of the Niels Bohr Institute of the University of Copenhagen in Denmark. Special 'tailor-made' drilling rig was designed by the experts from the University of Bern, Switzerland. The dating of the bat's remains was done at the University of Kiel in Germany (Zelinka, 2009).

Fig. 7. Deep drilling into the ice of the Great Hall using a special drilling set made by experts from the University of Bern for the isotope study, geochemical study, and dating of ice. Photo: J. Zelinka

2001–2009: Frequent failure and unsuitability of existing monitoring devices required their replacement with a newer system, the so-called Black boxes. The measurements were extended to monitor the temperature changes of the air within the vertical profile, the surface temperature of the rock and ice, as well as the air temperature in parts without the ice (Zelinka, 2012).

2007: A new integrated monitoring system from the Slovak manufacturer MicroStep – MIS, Bratislava, was installed in the cave. It is a complex modern system that was able to do its own measurements, remote monitoring, and transmission of recorded data. It enabled data control, processing, and archiving within a central database. It consisted of 11 dataloggers and 57 sensors of monitored quantities, which enabled detailed microclimatic 'mapping' of the cave. In addition to the new habitats, the measurements in the cave are extended by spatial and area measurements of the speed and direction of airflow in stable places, the surface temperature of the rock mantle, and its temperature at different depths. The outdoor meteorological station is supplemented by precipitation measurements (Zelinka, 2009).

TOURISM AND SPECIAL EVENTS

1872–1873: The town of Dobšiná built the first pub in the Hnilec valley and shortly after, the smaller hotel where a guide also lived. One of his tasks was to supply visitors with candles (Benický, 1970; Prikryl, 1985).

1874, June: Finishing off the railway line on the route Rožňava – Dobšiná (Konček, 1989).

1887: The town of Dobšiná built a spa and a skating rink near the cave. The cave became an important object of tourism (Prikryl, 1985; Konček, 1989).

Fig. 8. Hotel under the cave in the valley of the river Hnilec built in 1888 on a postcard from 1922. Source: Collection of the Slovak Museum of Nature Protection and Speleology

1888: A new more spacious hotel was built by the city of Hnilec valley after the old one burnt out (Fig. 8) (Prikryl, 1985; Konček, 1989).
1890: Baedeker's tourist guide of Austria-Hungary is published with a section dedicated to the Dobšiná Ice Cave. There is also a mention of the ice cave and its electric lighting (Prikryl, 1985).
1890: In honour of Archduke Charles Louis of Habsburg (grandfather of the last emperor of the Habsburg Monarchy, Charles) on the occasion of his visit to Gemer and his interest in the Dobšiná Ice Cave, a concert was held in the Great Hall. This was the first concert in an ice cave in the world (Prikryl, 1985).
1893, July 16: Thanks to Mikuláš Markó and Gedeon Rohonczy, the first Ice Festival connected with ice skating took place in the cave In addition to the entrance fee, visitors could pay extra for ice skating. During the first years after opening the cave, the ice in the Great Hall was used by local youth for skating. Since this year, skating has been organised in the cave (Fig. 9) (Holzman, 1999; Székely and Horváth, 2009).
1897: The tourism development and its organization required an establishment of building a post office and a telegraph station under the cave.
1909, July 25: The last Ice Festival was held in the cave. It was connected with the celebration of the fortieth anniversary of the discovery of the cave. The organizers encountered many complications. The world-famous opera singer and figure skaters, who were supposed to perform in the cave, did not show up in the end. Also, there were not enough cars in Dobšiná to transport visitors to the cave (Holzman, 1999; Székely and Horváth, 2009).
1911: An open tourist shelter was built at the entrance of the cave, where visitors could hide in case of bad weather (Benický, 1970).
1925: The Carpathian Association – a tourist organization mostly of Carpathian Germans, provided bus connection for cave visitors.
1926: The magazine named Gemer – Malohont refers to the activities of the Club of Czechoslovak tourists, which published the tourist guide 'Dobšiná Ice Cave'. It was supposed to be in the circulation of 2000 pieces, translated into Esperanto, and sent out to all the countries of the world. The club also decided to build overnight accommodation for students visiting the cave.
1927: The Czechoslovak Tourist Club established an accommodation under the cave for pupils and students.
1931: A regular bus connection from Poprad to Dobšiná was established. This possibility of transportation increased the number of cave visitors.
1934: The opening of the railway line and station Červená skala – Ľadová jaskyňa (the Ice cave), significantly simplified the transport of the cave visitors.
1945: The hotel under the cave burnt down.
1949: The new hotel was built under the cave.
1949–1952: In this period, the cave served as a training place for the elite Czechoslovak ice-hockey players and ice skaters. Including the junior champion of Czechoslovakia in ice skating – Karol Divín (Fig. 10). Ice skating in the cave was harshly criticised, as it caused the damage of the ice fill and therefore it was prohibited.

Fig. 9. Scene of the Ice Festival associated with ice skating in the Great Hall of the Dobšiná Ice Cave from 1894 in a painting by Ladislav Bellony. The Man with the Trumpet is one of the organizers, Mikuláš Markó. Source: Collection of the Slovak Museum of Nature Protection and Speleology

CAVE ATTENDANCE

In one and a half centuries, the number of visitors to the cave has changed significantly. During the first years after the discovery and opening of the cave, it was visited by only a few hundred visitors a year. At the end of the first decade of its operation, the number of visitors almost doubled compared to 1971, reaching 2425 in 1881. Gradual construction of transport infrastructure, accommodation, tourism development, and last but not least the technical equipment of the cave and its electrification, caused an increase in the decade of the 19th century, which oscillated about 3000 visitors a year and gradually increased until the First World War when it fell to a minimum. Summer skating, which has been practiced in the cave since 1893, resulted in a significant increase in attendance. Public interest in the cave was revived again after the war, and attendance gradually increased until the second half of the 1930s, when it normally exceeded 20,000 visitors. The Second World War brought a significant drop in attendance. After its completion, the interest in the cave comes to life again. The improvement in the economic situation of the population in the 1950s brought about a multiplier increase in traffic, which exceeded 90,000 at the end of the decade. As a result of socio-political changes, the decline in attendance occurs in the 1990s. Currently, the average annual attendance is around 80,000 visitors (Fig. 11).

CONCLUSION

The Dobšiná Ice Cave was discovered on June 15, 1870, by three discoverers Eugen Ruffiny, Ondrej Mega, and Gustav Lang during a discovery expedition led by Nandor Feher. The cave was provisionally opened two months after its discovery. It was officially opened in 1871 after the construction of a tour route equipped with wooden walkways and stairs. The first experiments with electric lighting were carried out in 1881, and since 1887, the cave has been stably electrically lit, which ranks it among the first electrified caves in the world. After 1918, the condition of the ice fill deteriorated. In the period after the Second World War, a series of measures were implemented to prevent the ice fill from further damage. Anthropogenic influences, such as the construction of artificial corridors or drainage gutters, caused glaciation of the lower parts of the cave and changes in air circulation.

Right after the discovery of the cave, scientific interest focused on discovering the

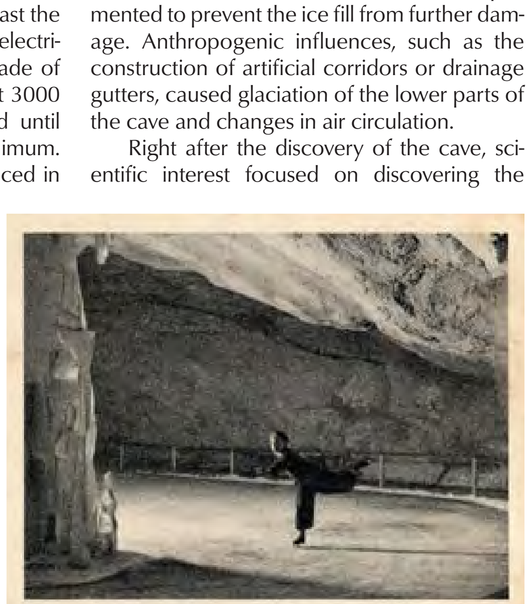

Fig. 10. Czechoslovak figure skating champion Karol Divín during training in the Great Hall. Source: Collection of the Slovak Museum of Nature Protection and Speleology

causes of its glaciation and understanding its climate, and later expanded to protect the ice fill. The first climatic measurements in the cave were performed by Nandor Feher. Jozef Sandor Krenner was one of the most prominent researchers exploring the cave in the 19th century. In 1873, he began to study the issue of glaciation and genesis of the cave. In professional circles, the awareness of the cave was increased by the work of János Pelech, who introduced regular temperature measurements in the cave. An English translation of his work was published in London by Walter Bezant Lowe. In 1947, unglaciated horizontal parts of the cave were discovered through the gap between the ice and the wall of the Ruined Dome.

Detailed geological and geomorphological research of the cave was carried out by Anton Droppa in the late fifties, and by Ján Tulis and Ján Novotný four decades later. The climatic situation in the 1950s was monitored by the Slovak Academy of Sciences and the Slovak Hydrometeorological Institute. In the eighties, Jaroslav Halaš researched the climate of the cave. By observing the physical properties of cave air and methods of heat transfer on the principle of physical processes, he obtained information about changes in the temperature of the rock mantle. Since 1997, the climate situation has been systematically monitored by the Slovak Caves Administration and since 2001 in cooperation with foreign researchers.

The discovery of the cave caused a boom in tourism in the region. Right after the discovery, accommodation capacities and the necessary infrastructure were built. In order to increase the attractiveness of the cave, the Ice Skating Festival has been organized irregularly since 1893. Since the interwar period, the ice surface in the cave has served as a training place for Czechoslovak skaters and hockey players. During the fifties, skating in the cave was completely banned, as the ice fill was damaged.

The number of visitors to the cave has gradually increased since it was opened. In 1871 it was visited by 292 tourists, currently, the traffic oscillates around 80,000 per year. The number of visitors was conditioned by several factors, such as the tourist infrastructure, which developed especially in the first decades until the cave was opened. Transport accessibility is important, which was significantly improved by the construction of a railway line and the opening of a stop under the cave in 1934. The socio-economic situation of the population is crucial. Attendance fell sharply during the two world wars. It was greatest in the 1970s and 1980s.

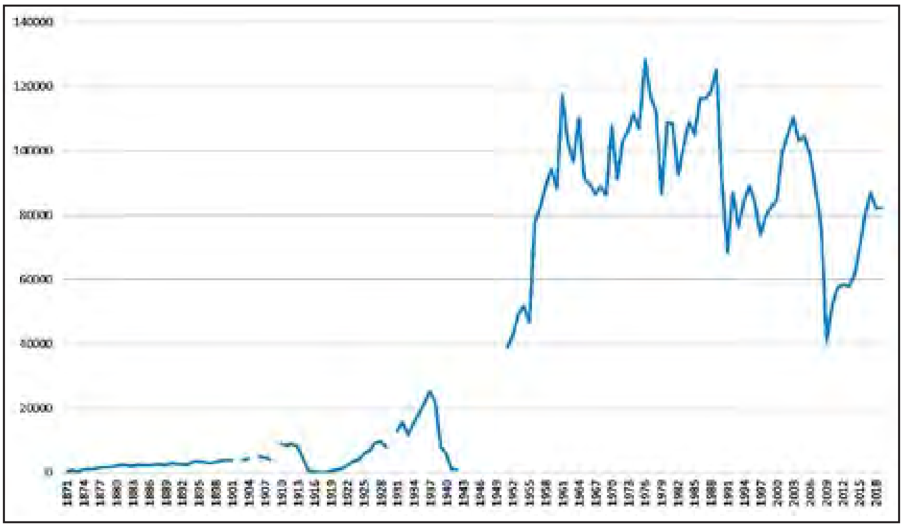

Fig. 11. History of the annual number of visitors of the Dobšiná Ice Cave from its opening in 1971 to 2019. Source: Holzman, 1999; Lalkovič, 1996, 1997; Gall, Nudziková, 2006; Nudziková, 2014

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TWENTY-FIFTH WORLD HERITAGE ANNIVERSARY OF THE CAVES OF AGGTELEK AND SLOVAK KARSTS

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It´s been 25 years since the 'Caves of Slovak Karst and Aggtelek Karst' joined the World Heritage list. During this time, we have gained many experiences about the management and protection of these exceptional caves. The soundness of our striving is also testified by two successful periodic reports on the state of conservation of the World Heritage site.

The Caves of Aggtelek Karst and Slovak Karst, based on a joint submission from Slovakia and Hungary, were declared part of the World Heritage as a sustainable example of geological and geomorphological processes at the UNESCO World Heritage Committee meeting in Berlin on December 6, 1995. In Cairns, Australia, in 2000 the addition of the Dobšiná Ice Cave to the area was approved. The caves and geological formations of the Aggtelek and Slovak karsts have outstanding importance for their extraordinary richness of forms, their complexity, and for being relatively untouched and concentrated in a small area. Today the area has more than 1,400 known caves. The karst phenomena were formed in a variety of shapes and habitats, which are significant from a biological, geological and archaeological point of view. In the temperate zone, caves do not occur in such complexity anywhere else in the world.

The World Heritage property Caves of Aggtelek Karst and Slovak Karst is located in the southern part of the Western Carpathians. The 55,256-hectare core zone of this trans-boundary Hungarian-Slovakian area is surrounded by the 51,237-hectare buffer zone. The Hungarian part includes the Aggtelek Karst (16,525 ha) within the mountainous Aggtelek-Rudabánya area of the North-Hungarian Range, and the Szendrő-Rudabánya area (3,658 ha). The Slovakian part includes the Slovak Karst (34,365 ha), the adjacent Ochtinská Aragonite Cave in the Revúcka vrchovina Highland, and the Dobšiná Ice Cave with other parts of Stratenská jaskyňa Cave system in the Slovenský raj (Slovak Paradise, 708 ha) located within the Slovenské rudohorie Mountains (Slovak Ore Mountains). These areas lie in the humid temperate climate zone, in the transition between oceanic and continental climate.

The Aggtelek and Slovak karsts represent a typical example of well-developed plateau karst in the humid temperate climate zone (Fig. 1). Numerous surface and subsurface landforms resulted from the high karstification of Triassic limestones (Fig. 2). The complicated multi-phase evolution of karst from the Late Cretaceous to the present is recorded in the morphology and sedimentary fills of caves. Mostly the variability of cave morphology and origin, carbonate and ice fill, as well as rare

Fig. 1. Canyon of Štítnik River in Slovak Karst. Photo: Ľ. Gaál

Fig. 2. Planation surface of Silica Plateau in Slovak Karst. Photo: Ľ. Gaál

cave fauna and archaeological findings are extremely rich in this trans-boundary Hungarian-Slovakian karst area. A high density of abysses developed on the top of karst plateaus (up to 20 abysses in the area of 0.5 km^2).

The Domica–Baradla cave system (more than 29 km) is an excellent example of a fluvially modeled 'ideal water-table cave' (Fig. 3). Several multi-level caves formed by allogenic sinking streams on the edge of karst plateau or through valleys. The Domica Cave belongs to the most significant caves in the world with the occurrence of shields. The Ochtiná Aragonite Cave is exceptional for very rich and varied aragonite forms of several generations (Fig. 4), as well as remarkable solution morphology (mostly flat ceilings and inward-sloping facets). The Dobšiná Ice Cave in the Slovenský raj, is known for the largest volume of cave ice in the world (more than 110,000 m^3), although it occurs in the mid-mountain position (its entrance lies at 969 m a.s.l.). The Silická ľadnica Cave (Silica Ice Cave) is the lowest-lying perennial ice cave up to the latitude of 50° north, in the temperate climatic zone.

An unusually high number of caves, together with the underground´s prevailing climatic conditions and the suitable geographical position of the Aggtelek and Slovak karsts, have created a variety of wildlife with many endemic species. These include *Plusiocampa spelaea* troglomorphic dipluran, the aquatic earthworm *Helodrilus mozsaryorum*, found only in Short Lower Cave of Baradla, *Neobisium (Blothrus) slovacum,* northernmost troglomorphic pseudoscorpion in the Europe, the *Pseudosinella aggtelekiensis*, *Pygmarrhopalites slovacicus*, *P. intermedius*, *Deuteraphorura schoenviszkyi*

Fig. 3. The main river passage in Baradla. Photo: Cs. Egri

Fig. 4. Aragonite in Ochtiná Aragonite Cave. Photo: Ľ. Gaál

springtails and *Duvalius hungaricus* and *D. bokori* beetles. Another species endemic to the region is the diplopod *Typhloiulus* sp., the largest terrestrial cave-dwelling invertebrate in this area, with a body length of 2.6 centimetres and 147 pairs of feet. The most significant cave from a cave biology perspective is the Domica-Baradla cave system, where more than 500 invertebrate species have been recorded. Of the 28 European bat species, 21 are present in this region. In the Domica-Baradla cave system, wintering colonies (approx. 5,000 specimens per year) of the pond bat (*Myotis dasycneme*) and the greater mouse-eared bat (*Myotis myotis*), as well as the Mediterranean horseshoe bat (*Rhinolophus euryale*), were recorded on the 1994 IUCN red list as vulnerable species. Important bat wintering places include the Jasovská jaskyňa Cave and the Drieňovská jaskyňa Cave (*Miniopterus schreibersii*), the Čertová diera Abyss in the Horný vrch Plateau and the Erňa Cave (*Pipistrellus pipistrellus*), as well as the Dobšinská Ice Cave (mainly *Myotis mystacinus/brandti* species). Other caves, for example, the Béke Cave, or the Drieňovská jaskyňa Cave, serve as breeding areas for the summer groups which reside here year-round.

Many archaeological artifacts were preserved from the settlement of caves by humans in the Palaeolithic, Mesolithic but mainly the Neolithic period. In more than 30 caves of the Slovak and Aggtelek karsts, the presence of prehistoric humans has been detected. These findings point to at least 35,000 years of prehistoric culture. The region´s cave discovery sites have revealed charcoal remnants from the end of the Middle Paleolithic period (Jasovská jaskyňa Cave), the Late Paleolithic period (36-28,000 years ago) tools of the 'Szélétien culture' (Domica Cave), of the Aurignacian culture (Jasovská jaskyňa Cave) and of the Gravettian cultures (Slaninová jaskyňa Cave); as well as Neolithic period (5–3,000 years ago) ceramics from the Gemer (Ardovská jaskyňa Cave) and Bükk (Baradla-Domica cave system) cultures. Remains also appeared from the Copper Aged Baden (Maštalná jaskyňa Cave), the Bronze Aged Pilin and Kyjatice cultures (Silická Ice Cave, Hosszútető Cave), as well as relics from the Iron Aged Hallstatt (Fajka jaskyňa Cave) and Celtic cultures (Čertova diera Cave). The most significant archaeological site is the Baradla-Domica cave system. Here, Bükk-Aged charcoal drawings inside the cave and its foreground are unique in Central Europe. The Babská Hole and the Majda-Hrašková Cave, used as burial sites by the Kyjatice culture, are where unique ritual masks made from human skulls were found. This series of prehistoric artifacts are complemented by cave inscriptions from the 13th century onwards. The Hussite inscription in the Jasovská jaskyňa Cave and the Turkish knife found here, originate from the Middle Ages. Around the Zádielska dolina Valley, several caves are said to be attached to the legend of the escape of King Bela IV. from the Tatars.

PROTECTION AND MANAGEMENT OF CAVES

Cave protection is generally much more complex than protecting the usual monument or other surface facilities. Impacts on the subterranean passages are not immediately apparent to the eye or tangible over the short-term; for example the influence of climate change or changes in the chemical composition of water. The longest karst caves were formed by the dual actions of flowing water abrasion and the carbon dioxide-rich water dissolving the carbonate bedrock. Besides this, the stability of the system is largely dependent on water infiltration and concentrated inflow through ponors. Thus, water plays a key role in the creation of caverns and an important mediating factor influencing both surface and subsurface processes (Fig. 5). In general, it can be said that in the caves everything is inter-dependent: the flora and fauna depend on the host rock of the cave, soil composition, water quality, airflow, and temperature. However, the same factors manipulate the emergence, development, and survival of karst formations as well. Therefore, it can be said that there is a very close link between natural components (elements) in the cave world.

In the Aggtelek and Slovak karsts, allogenic streams inflow into karst aquifers at the contact of non-carbonate and carbonate rocks through ponors at the end of blind valleys, as well as sinking in the riverbed at the bottom of through valleys. Therefore catchment areas of allogenic streams used by agriculture or other not suitable human activities are potential sources for karst water pollution. Due to the high degree of karstification, polluted water quickly sinks from the surface to the underground channels without or only with slight filtration. Monitoring of chemical composition of water in the Aggtelek

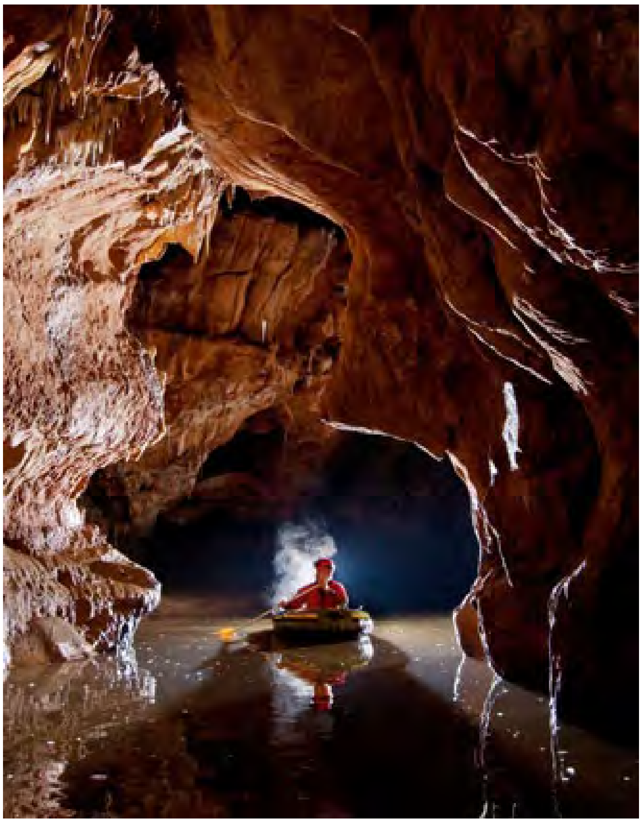


Fig. 5. Underground river Styx in Domica Cave. Photo: P. Staník

Fig. 6. Closing of the eastern entrance of Domica Cave. Photo: Ľ. Gaál

and Slovak karsts detected that the quality of cave water is sometimes affected by local pollution and microbial contamination. Also, soil erosion in the catchment area of the Domica Cave was accelerated by its inappropriate agriculture use (vast monoculture fields of corn). Soil sediments, together with parts of agriculture crops have been flushed into the cave during intensive storms and heavy rains, mostly during the 1950s and 1960s. Therefore it was necessary to change this agriculture practice by the preference crops with dense roots and grassing of steeper slopes. The forest above the caves is declared protected to prevent soil erosion on the karst surface (ten-years forest management plans give great attention to nature protection).

In the past, some abysses and dolines, as inputs into karst aquifers, have been polluted by waste (including toxic pesticides) and dead livestock. Also, limestone quarrying damaged some parts of the Aggtelek and Slovak karsts, mostly the right slope of Slaná Canyon by the large quarry of Gombasek opened in 1906 (some parts of nearby caves were destroyed). Currently, the spread of quarries is inhibited by the strict measures of nature protection. The cement factory in the vicinity of the Včeláre quarry produces dust polluting the Dolný vrch Plateau.

From a view of nature protection, the Aggtelek and Slovak karsts, as well as the associated part of the Slovenský raj above the Dobšiná Ice Cave and Stratenská jaskyňa Cave (genetically one cave system), occur in the territory of national parks or nature reserves. The Aggtelek Nature Reserve was established in 1978, and as a national park in 1985. The Slovak Karst was declared as a nature reserve in 1973, as a national park in 2002. Since 1977, both areas are members of the Man and Biosphere (MAB) Programme, an international biosphere network. In 2001, the Baradla and Domica caves were inscribed to the list of Ramsar sites as wetlands of international importance. In 2016, the area above the Dobšiná Ice Cave and Stratenská jaskyňa Cave was included into the strictest protected zone A of the Slovenský raj National Park.

The legislative protection of all caves in Hungary is declared by the Nature Protection Act from 1961. In Slovakia, all caves are protected as natural monuments according to Nature and Landscape Protection Act from 1995. In both countries, the caves are state-owned. Slovakia´s new Nature Conservation Act came into force in 1995, according to which, every cave earned protection as a natural monument. The most famous ones were declared national natural monuments by the Ministry of Environment. The following caves are located within World Heritage Site territory: Ardovská jaskyňa Cave, Brázda Shaft, Diviačia priepasť Shaft, Dobšiná Ice Cave, Stratenská jaskyňa Cave, Domica Cave, Drienovská jaskyňa Cave, Gombasecká jaskyňa Cave, Hrušovská jaskyňa Cave, Jasovská jaskyňa Cave, Krásnohorská jaskyňa Cave, Kunia priepasť Shaft, Milada Cave, Obrovská priepasť Shaft, Ochtiná Aragonite Cave, Silická ľadnica Cave, Skalistý potok Cave, Snežná diera (Ice Hole), and the Zvonivá jama Shaft. In Aggtelek Karst requiring enhanced protection include 25 caves (e.g. Almási shaft, Baradla Cave, Béke Cave, Danca Cave, Földvári Aladár Cave, Kossuth Cave, Meteor Cave, Rákóczi Caves 1, 2 and 3, Rejtek Shaft, Szabadság Cave, Szabó-pallag Shaft, Széki Shaft, Imre Vass Cave, Vecsembükk Shaft; and others).

To enhance the protection of caves, buffer zones have been delineated in the catchment areas of caves that are threatened by allogenic sinking streams polluted due to agriculture, limestone quarrying, or other negative human impacts. Buffer zones have been approved around the strictly protected caves and caves threatened by human activities. However, on the Hungarian side, buffer zones are implemented around all caves. Environmental authorities in Slovakia have constructed buffer zones around the following caves: Domica (616.6892 ha), Gombasecká jaskyňa Cave (642.4831 ha, include also Silická ľadnica Cave), Krásnohorská jaskyňa Cave (195.6266 ha), and the Ochtiná Aragonite Cave (65.4455 ha). Other significant caves such as the Jasovská jaskyňa Cave and Dobšiná-Stratená Cave System lie within protected areas.

Cave entrances and sinkholes have either been closed or fenced (Fig. 6). On the Hungarian side, 35 cave entrances have either been closed or fenced in, and 40 entrances were secured on the Slovakian side. Older doors are being renovated and new, more bat-friendly ones, constructed.

In order to eliminate trampling damage, the ladders and rope handrails have been installed. Moreover, the preservation of the shaft walls and calcite decoration of several caves in the Alsó-hegy / Dolný vrch Plateau has been assisted by the attachment of rock anchors to the walls.

Development of the caves for tourism was kept in mind the need for rigorous protection while simultaneously maximizing the opportunities for visitors. To this end, walkways, stairs, and bridges have been constructed where necessary. Structural metal and guardrails have been made from stainless steel. Industrial cameras have been installed in the particularly vulnerable Ochtiná Aragonite Cave to monitor visitor activity. The cave is illuminated with modern energy-saving LED lamps to inhibit the growth of underground flora aroused by excess light and heat.

The Baradla Cave has been known and visited from prehistoric times. Burning torches with smoke was prohibited in 1881. Traces of their use, as well as broken dripstones, can still be seen in the Baradla and other caves.

Twelve caves of this World Heritage site are opened to the public. During the last decade, on average, these show caves were visited by more than 255 thousand visitors per year (6 Slovakian caves – Dobšiná Ice Cave, Ochtiná Aragonite Cave, Krásnohorská jaskyňa Cave, Gombasecká jaskyňa Cave, Domica Cave and Jasovská jaskyňa Cave with 144,600 visitors per year; 6 Hungarian caves – Baradla Cave, Béke Cave, Kossuth Cave, Meteor Cave, Rákóczi Cave and Vass Imre Cave with 110,600 visitors per year). During the last development of caves for tourism, their technical infrastructure was upgraded. Handrails have been made from stainless steel, the cave underground is illuminated with modern energy-saving LED lamps to inhibit the growth of lamp flora.

Individual emphasis is devoted to the aragonite fill in Ochtiná Aragonite Cave. The condensation of water vapor and its reaction with CO_2 produced by visitors is considered as a risk factor for aragonite corrosion. Based on detail microclimatic monitoring the number of visitors is strictly limited. Up to now, no corrosion destruction on the surfaces of aragonite crystals (from acicular and spiral forms) was microscopically observed. Moreover, the presence of recent, still growing aragonite was detected, i.e. the regeneration of aragonite is still continuously in this cave.

The biggest problem is the ice decrease in the Silická ľadnica Cave. One of the reasons is the global rise of temperature, however, there is also a human contribution to ice decrease. After the discovery of the Archaeological Chamber in the lower part of the Silická ľadnica Cave in 1931, temperature conditions were disrupted by an upward circulation of warmer air to the upper ice-filled part. This negative human impact was eliminated by the closure of the excavated connection hole in 1998.

Several sinkholes and abysses were contaminated in times of communism. Until now, contaminants have been successfully removed from 19 abysses in the Slovak Karst. The most prominent action was implemented in 2005 and 2006 supported by the European Union project when the toxic debris was extracted from the abysses Fonotšág (15 m^3), Silická zvonivá priepasť (16 m^3), Dvojitá priepasť (53 m^3), and Snežná diera (98 m^3).

Very important is the inspection of a cave by rangers. Slovakia established its cave ranger service in 2002 from among volunteer cavers. Members not only perform regular checks of the caves but also maintain the locking mechanisms and perform environmental education activities. Unfortunately, the State Nature Conservancy of the Slovak Republic ceased monetary support for the service in 2010. In Hungary, these duties are regularly carried out by Aggtelek National Park´s rangers. If necessary, rangers also inspect the underground.

RESEARCH IN THE WORLD HERITAGE CAVES

Since being added to the World Heritage List, detailed geological and geomorphological research has been conducted in the Domica-Baradla cave system, Béke Cave, Dobšiná Ice Cave, Gombasecká jaskyňa Cave, Ochtiná Aragonite Cave, Milada Cave, and Jasovská jaskyňa Cave. Radioisotope dating analysis of sediments and paleomagnetic dating was realized in Domica Cave and Stratenská jaskyňa Cave. Geophysical methods were utilized to detect the unknown thickness of cave fluvial sediments in the Domica-Baradla cave system. The first comprehensive geochemical study of the Dobšiná Ice Cave defined ice sheet movement. Apart from the abovementioned caves, detailed research of cave fauna also took place in the Ardovská jaskyňa Cave, Silická ľadnica Cave, Diviačia priepasť Shaft, Kossuth Cave, Béke Cave, Rövid-Alsó Cave, Rákóczi Cave, and Imre Vass Cave. Moreover, the populations of wintering bats are regularly monitored. Microbiological analysis of Domica-Baradla cave system was made within the context of planning speleotherapy (Fig. 7).

Fig. 7. Microbiological research in Domica-Baradla cave system. Photo: Ľ. Gaál

Both the Aggtelek National Park Directorate and the Slovakian Caves Administration continuously monitor the especially important or endangered cave environments. The air quality of the Domica Cave, Baradla Cave, Ochtiná Aragonite Cave, and Dobšiná Ice Cave is constantly measured, as is the water quality of the Baradla-Domica cave system, Gombasecká jaskyňa Cave, and Jasovská jaskyňa Cave. In addition, radon levels in the Ochtiná Aragonite Cave must be periodically monitored. The water quality of the major karst springs is continuously observed, such as the Jósva, Hosszú-Alsó, Rövid-Alsó, and the Nagy and Kis-Tohonya.

TRAINING AND EDUCATION

Beside karst and cave protection, an important cultural heritage is passed on from generation to generation. Therefore, it is particularly important that the site management provides education and training opportunities to raise environmental awareness and communicate these messages to visitors, local residents, and nearby farmers; but most of all to the school children. In this regard, the Aggtelek National Park Manor House Environmental Education Centre and the Salamander Hostel Environmental Education School´s activities have presented the values and management of karst. These two centers organize exhibitions, lectures and prepare education materials together and separately. The Hubert Kessler Memorial House located by the Jósvafő entrance to the Baradla Cave hosts permanent exhibitions on the renowned cave researchers and the World Heritage caves. Permanent exhibits are also located in the entrance buildings to the Domica Cave, Ochtiná Aragonite Cave, Jasovská jaskyňa Cave, and Dobšiná Ice Cave. Information boards have been placed at the entrances to the other caves. Metal signs bearing the World Heritage logos have been installed by the entrances to the most important and strictly protected caves. In 2011, the Aggtelek National Park Directorate, Mining Museum in Rožňava, Slovak Caves Administration, and tenant of Krásnohorská jaskyňa Cave (J. Stankovič) created a joint traveling exhibition on the World Heritage caves which has visited several countries since then. The Slovak Caves Administration issued a World Heritage Caves in Slovakia publication in 2005 in Slovak, and in English in 2008. Aggtelek National Park published a monograph on the Baradla-Domica cave system in 2014.

Levels of sustainable tourism need to be determined with the involvement of local communities and monitoring systems need to be completed and implemented. Further research and exploration are needed with regard to the interconnection of the karst cave system. Longer-term tasks include the need to mitigate impacts caused by climate change, such as extreme changes in water levels. The current Management Plan requires review and a coordinated and harmonized management for this transnational property needs to be put into place.

FURTHER AIMS

In an effort to utilize the World Heritage caves for human health benefit, Aggtelek National Park and Slovak Cave Administration have realized a project of speleotherapy supported by the European Union in the years 2017–2020. The goal of this project is to prepare a suitable place for therapy in the caves Baradla and Béke (in Hungary) and Domica (in Slovakia). We are planning to build a new reception center for the Gombasecká jaskyňa Cave, and creating a speleopark for educational purposes. In the near future, we would like to put more emphasis on cave restoration to their original natural state, e.g cut-through tuff dam restoration, cleaning of cave wall surfaces contaminated with mud and soot, etc. Another important task is a renewal of cave ranger service in the Slovak part of World Heritage territory. In the development is also a plan for a geopark establishment, which could support the regulated tourist traffic.

FIFTY YEARS SINCE THE SLOVAK CAVES ADMINISTRATION WAS ESTABLISHED

Pavel Bella

At present, more than 7400 caves are known in Slovakia. They represent specific natural phenomena, and present significant geodiversity of natural values in Slovakia. Under the Constitutional Act No. 460/1992 Coll. amending the Constitution of the Slovak Republic no. 460/1992 Coll., all caves in Slovakia are the state property. According to Act No. 543/2002 Coll. on *Nature and Landscape Protection,* all caves are protected as natural monuments to which special measures of their protection are applied. The most important caves are declared national natural monuments (44 caves and abysses). On the basis of a bilateral Slovak-Hungarian project, the caves of the Slovak and Aggtelek karsts were inscribed on the World Heritage List in 1995, including the nearby Ochtinská aragonitová jaskyňa Cave (Ochtiná Aragonite Cave) in the Revúcka vrchovina Mountains. The Dobšinská ľadová jaskyňa Cave (Dobšiná Ice Cave) in the Slovenský raj (Slovak Paradise) together with all genetic system of the Stratenská jaskyňa Cave became a part of the World Heritage in 2000 due to the extension of the original site. The internationally significant wetlands of the Ramsar Convention include the Domica Cave since 2001 and the caves in the Demänovská dolina Valley since 2006. Because caves belong to the most vulnerable natural phenomena and their regenerative ability is very low and in some cases almost impossible, they require special approaches and measures for their protection and utilization.

The protection and practical care of all caves in Slovakia, the operation of the 13 show caves, as well as the management of caves as state property are provided by the Slovak Caves Administration (‘Správa slovenských jaskýň’ in Slovak) in Liptovský Mikuláš. Since 2008 it is an organizational unit of the State Nature Conservancy of the Slovak Republic.

The Slovak Caves Administration was established by the Ministry of Culture of the Slovak Socialist Republic 1970 on the basis of a decision of the Government of the Slovak Socialist Republic from May 1969. After the previous period of fragmented and uncoordinated development of caves in Slovakia, activities focused on research, exploration and protection of caves, as well as on the development and management of show caves as educational localities were concentrated in one organization with the nationwide operation. The concept of the development of the Slovak caving for the years 1971–1985 was elaborated and approved by the Ministry of Culture of the Slovak Socialist Republic after the discussion in the Speleological Advisory Board. The organizational unit of the newly established Slovak Caves Administration was the Slovak Karst Museum under the responsibility of which the Slovak Speleological Society could better develop its activities. The Slovak Caves Administration managed 12 show caves (Belianska jaskyňa Cave, Bystrianska jaskyňa Cave, Demänovská jaskyňa slobody Cave, Demänovská ľadová jaskyňa Cave, Dobšinská ľadová jaskyňa Cave, Domica Cave, Driny Cave, Gombasecká jaskyňa Cave, Harmanecká jaskyňa Cave, Jasovská jaskyňa Cave, Ochtinská aragonitová jaskyňa Cave, Važecká jaskyňa Cave) that belong to the main destinations of tourism in Slovakia. Among the first activities of the Slovak Caves Administration, the Ochtinská aragonitová jaskyňa Cave was opened to the public in 1972. The construction of its new entrance object was finished in 1976. The Slovak Karst Museum was mainly responsible for research, documentation and protection of caves while the Slovak Speleological Society provided cave exploration.

Entrance object of the Domica Cave built in 1984. Photo: P. Bella

In 1981–1989, these activities were performed by the State Nature Conservancy Center in Liptovský Mikuláš, which was established by joining of the Slovak Caves Administration and the Nature Protection Department of the Slovak Institute for the Monument Preservation and Nature Protection. This new national organization with greater scope gave more attention to protected areas. Nevertheless, the modern entrance object of the Domica Cave was built between 1981 and 1984 because the former object was insufficient for the development of tourism and was also threatened by occasional floods.

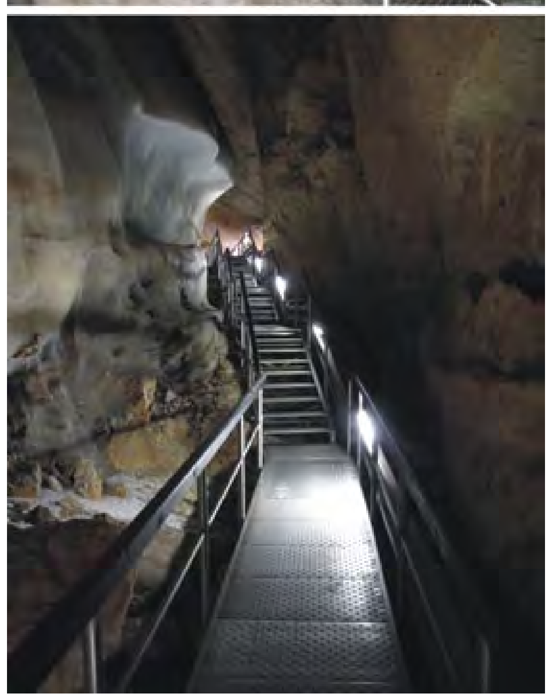
The Slovak Caves Administration was re-established in 1990 as one of the organizations under the Ministry of Culture of the Slovak Republic. After the establishment of the Ministry of Environment of the Slovak Republic in 1993, it came under its competence. In the first half of the 1990s, the scope of the Slovak Caves Administration covered only the management and protection of show caves as educational sites of national importance (cave guided tour, building and maintenance of technical objects and infrastructure in caves and their entrance areas, services for visitors and other similarly focused tasks). The Slovak Caves Administration has been initiative in the preparation of the bilateral Slovakian-Hungarian nomination project for the inscription of the caves of Slovak and Aggtelek karsts on the World Heritage List, as well as in the process of their assessment and approval. In 1996, the scope of the Slovak Caves Administration was extended to caves developmentally linked with show caves (the need to completely protect entire cave systems).

For the development of activities concentrating to nature protection, the cave protection section was established in 1995. Its main tasks resulted mainly from the ‘Strategic aims of the development of the management and protection of show caves in the Slovak Republic’ approved by the Ministry of Environment of the Slovak Republic in March 1996. Following the ‘Program of supports and concepts for the development of sites, which are included in the World Heritage List' (Resolution of the Government of the Slovak Republic No. 509/1996), the Slovak Caves Administration started to implement and provide a set of measures to protect the Slovak part of the World Heritage site 'Caves of the Slovak Karst and Aggtelek Karst'. Since 2000, such activities were also applied to the Dobšinska ľadová jaskyňa Cave and the related parts of the Stratenská jaskyňa Cave System. The Slovak Caves Administration also participates in the development and operation of speleotherapy and speleoclimatic recondition stays in caves based on the agreement between the Ministry of the Environment of the Slovak Republic and the Ministry of Health of the Slovak Republic from 1998. In the second half of the 1990s, the building of the new entrance object of the Jasovská jaskyňa Cave, the extension of the entrance objects of the Bystrianska jaskyňa and Važecká jaskyňa caves, as well as a new electrical installation in the Ochtinská aragonitová jaskyňa Cave were realized.

The Slovak Caves Administration, together with the Ministry of Environment of the Slovak Republic achieved that in 2001, all caves became the property of the state on the basis of an amendment to the Constitution of the Slovak Republic. By the decision of the Ministry of Environment of the Slovak Republic from 2002, the scope of the Slovak Caves Administration has been extended to all caves in Slovakia. This increased the demands on its activities. The cave protection section was enlarged and divided into two departments aimed at research, monitoring, and documentation of caves, and at practical care of caves. In Rimavská Sobota town, another detached workplace of the organization was created, which performs and provides practical care for caves in the southern and eastern Slovakia. At that time, the Slovak Caves Administration consisted of these organizational units: director's secretary, cave protection section, cave operations and marketing section (including 12 show caves), technical section, and economic section. The organization employed 80–85 permanent employees, reasing during the tourist season up to 110 employees.

In this successful period, buffer zones of treatment caves began to be designed, which the previous law abolished. The entrances of many caves were closed by iron gates or grilles, damaged closures were reconstructed or replaced (together in 147 caves), several caves were cleaned from waste. Cave protection and practical care are realized in cooperation with the Slovak Speleological Society. The proposal and practical implementation of many conservation measures require actual and wider scientific knowledge and data on the cave environment. Therefore, applied research and monitoring of caves significantly improved including the development of cooperation with domestic and foreign research institutes and universities. In terms of the greatest complexity knowledge about the caves as natural complexes, multidisciplinary (geological, geomorphological, hydrogeological, spleoclimatological and biospeleological, as well as geoecological) researches, and narrower targeted monitoring of cave environment (hydrological, speleoclimatological and biospeleological) are carried out by the Slovak Caves Administration. Several caves, mainly of international and national importance, were integrated into the environmental monitoring system. Based on the nomination projects, elaborated by the Slovak Caves Administration, the Domica Cave and the caves in the Demänovská dolina Valley were included in the list of internationally important wetlands of the Ramsar Convention. Finance obtained from show caves were used primarily to maintain and complete their technical infrastructure and to improve the quality of services for visitors (the new entrance objects of the Dobšinská ľadová jaskyňa, Harmanecká jaskyňa and Belianska jaskyňa caves, the extension of entrance objects of the Demänovská ľadová jaskyňa and Važecká jaskyňa caves, stainless steel handrail in the Demänovská jaskyňa slobody Cave). With significant financial support from the European Union funds, the facilities of several show caves (stainless steel path in the Dobšinská ľadová jaskyňa Cave), including the needs of environmental education (educational center in the Domica Cave), gradually improved. These funds were used also to the removal of toxic substances from several abysses in the Slovak and Važec karsts in

Entrance object of the Jasovská jaskyňa Cave built in 1996. Photo: M. Eliáš



Stainless steel path in the Dobšinská ľadová jaskyňa Cave renovated in 2003–2008. Photo: P. Bella

2005–2006. Educational exhibitions were installed in the entrance objects of some show caves, educational trails were built on the foot access routes.

By later decision of the Ministry of Environment of the Slovak Republic resulting from the amended Act on budgetary rules of public administration, the Slovak Caves Administration was incorporated in 2008 into the State Nature Conservancy of the Slovak Republic. The performance of several tasks in this large organization has become complicated. Nevertheless, some projects supported by the European Union funds were realized (the extension of entrance object of the Dobšinská ľadová jaskyňa Cave, stainless steel handrails in the Demänovská ľadová jaskyňa and Belianska jaskyňa caves, Domica Cave, Ochtinská aragonitová jaskyňa Cave, Gombasecká jaskyňa Cave, and Harmanecká jaskyňa Cave, the electric lighting based on the LED technology installed in the Belianska jaskyňa Cave). In 2016, the Brestovská jaskyňa Cave was opened to the public as the 13th show cave managed by the Slovak Caves Administration. During the last decade, the annual attendance of show caves operated by the Slovak Caves Administration was 473–633 thousand visitors (the annual attendance over 600 thousand visitors is since 2015). In terms of the current organizational structure, the Slovak Caves Administration consists of the cave protection section (composed of the cave reasearch and monitoring department, and the cave care department), the show caves section (composed of the cave management department including 13 show caves, the business department, and the technical department), and the section of information support for caves.

Since 1997, the scientific conferences 'Research, Utilization and Protection of Caves' have been organized by the Slovak Caves Administration every two years. Since 1996, the Aragonite journal began to be published. Since 2002 it is co-publisher of the Slovenský kras journal. The Slovak Caves Administration has published also several important monographs as parts of the Speleologia Slovaca series (Geodynamics and development of caves in the Slovak Karst, Geoecological research and environmental protection of caves, Genetic types of caves, The caves in the Demänovská dolina Valley, The cave biota of Slovakia, Caves in Slovakia – genetic types and morphology) and other books (Karstological and speleological terminology, Caves of the World Heritage in Slovakia, Domica-Baradla cave system). Multidisciplinary researches, which has been developing by the Slovak Cave Administration for more than two decades, forms the dominant part of scientific activities in the framework of the whole State Nature Conservancy of the Slovak Republic.

The Slovak Caves Administration is the founding member of the International Show Caves Association (ISCA). Together with the Slovak Speleological Society, it represents Slovakia also in the International Union of Speleology (UIS) and the European Speleological Federation (FSE). Some employees of the Slovak Caves Administration hold or held positions in the management and specialized commissions of the ISCA (Board of Directors, Scientific and Technical Committee, Media Committee, New Technologies and Communications Study Group) and UIS (Pseudokarst Commision).

The Slovak Caves Administration has been and still is involved in organizing international events under the auspices of ISCA and UIS. The 6th Congress of the International Show Caves Association in 2010 was held in Slovakia. In cooperation with the relevant UIS commissions, the Slovak Caves Administration organized the 8th International Symposium on Pseudokarst in 2004 (Teplý Vrch) and the 2nd International Workshop on Ice Caves in 2006 (Demänovská Dolina). In 2020, it organizes the 9th International Workshop on Ice Caves (Liptovský Mikuláš). In 1973, it participated in the organization of the 6th International Speleological Congress in former Czechoslovakia. In 2013, within the 16th International Speleological Congress held in the Czech Republic, the Slovak Caves Administration realized the post-congress excursion to selected show caves in Slovakia. From the older period, it is necessary to recall the international conference organized in 1970 on the occasion of the 100th anniversary of the Dobšinská ľadová jaskyňa Cave discovery.

The past 50 years have clearly demonstrated that the Slovak Caves Administration has an important place and role in the Slovak speleology as well as within the state nature protection in Slovakia.

8th International Symposium on Pseudokarst, Teplý Vrch, Slovakia, 2004. Photo: P. Bella

6th Congress of the International Show Caves Association, Demänovská Dolina, Slovakia, 2010. Photo: P. Bella

90 YEARS OF THE SLOVAK MUSEUM OF NATURE PROTECTION AND SPELEOLOGY

Eva Greschová – Iveta Chomová

The year 2020 will commemorate 90 years of the founding of the cultural institution whose specialisation has secured its uniqueness among all the Slovak museums. The Slovak Museum of Nature Protection and Speleology in Liptovský Mikuláš nowadays differs from other natural history museums, especially in its research and documentation of caves, as well as various aspects of documenting the history and current protection of nature.

LIPTOV COLLECTION

Its origin dates to the 2nd of June 1930, when the Local Assembly founded the Museum of Slovak Karst. However, the history of the collection of various information dates back to 1904. At that time, close to the Burgher casino, the local patriots founded the so-called 'Mikuláš collection' of memorabilia – old documents, minerals, plants, antiques, coins, books, etc. Václav Vraný was chosen as its trustee because he had experience in museum work in Spiš region, where he helped to organise a collection for the Hungarian Carpathian guild. To the newly formed museum in Liptovský Mikuláš, he gifted a collection of plants from the Tatra region. Ján Volko-Starohorský was one of the active members at that time.

Václav Vraný, a teacher, botanist, museologist, and the Co-founder of the Liptov Collection in 1904. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

The museum committee printed a *'Plea to the inhabitants of Liptov'* not to forget the small humble Liptov collection that was created under the protection of the Burger casino. At the time everything that had to do with Liptov was collected. In 1909, Václav Varný was forced to leave Liptovský Mikuláš, he became the custodian of the museum in Martin, and the Liptov collection fell apart. There are no written documents about its gradual demise. It is only from the contemporary literature and newspapers we know that a part of the collection was put away in the house of the father of JánVolko-Starohorský.

Ján Volko-Starohorský accepted the post of a professor in Gymnasium of Michal Miloslav Hodža. He had tried to revive the Liptov collection and repeatedly appealed for the collection of historic artefacts of Liptov. His collection was exhibited in the cabinet of nature of the gymnasium which was called The Under the Kriváň' museum and was open to the public. This transitional period led to the opening of the museum that would continue in the tradition of Liptov collection. After a while, the school inspectors became dissatisfied with it and forced Volko to remove the collection from the school premises.

MUSEUM OF SLOVAK KARST

Volko's efforts edged closer to reality in 1928 due to the changes in the municipal institution but mainly because of an effort to keep the town of Liptovský Mikuláš relevant. And so, on the 24th May 1928, doctor Ivan Stodola, leading commissioner Oldřich Lúžný, and the functionary of Demänová caves Alojz Lutonský discussed the possibility of re-opening of the museum in Liptovský Mikuláš in the local Tranovský inn. Givendiscovery of the nearby Demänová Cave of Liberty in 1921, the museum was to be orientated towards the caves and the karst.

In the following four pre-meetings and four actual meetings, they invited other people, including the town's officials, to discuss the question relating to the opening of the museum. In the last meeting on the 18th January 1930, they had decided that the owner of the museum would be on the board of trustees and named the members of the first board of trustees who were to place the museum in the Town hall in the square of Liptovský Mikuláš. Oldřich Šťastný was to draft the charter of the museum. On the 2nd June 1930, a meeting was held establishing the assembly of the Museum of the Slovak Karst. Ján Volko–Starohorský was named a trustee of the collections and the statute of the museum was approved. According to the charter from the 18th July 1932, the museum had to keep the collection in a good condition, expand it and keep it open to the public. Its activity was to be aimed at caves and karst areas of Slovakia.

From the beginning, there was an effort to build a specialised Slovak institution that was supported not only by the Demänová Cave Association but also other caves. They promised to supply karst exhibits, photographs, and maps. After two years, all three rooms of the museum were filled with exhibits. The other function of the museum was to be the museum of history and the town. Apart from expanding the collection, Ján Volko-Starohorský saw another potential for the museum. As a secondary school professor, he understood the importance of science and education. Upon his suggestion, in August 1932, the Natural Science Department was created. The best results were shown by the geological and geographical department by means of published articles, creating green zones in the city and its surrounds.

The members of the first board of curators of the Museum of Slovak Karst. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

Ján Volko-Starohorský, the museum custodian – museum exposition in the former County House on the Liberators' Square in Liptovský Mikuláš. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

In 1936, the Museum of Slovak Karst joined the Association of Czechoslovak museums. The museum kept its word in being a cultural institution but at the same time, it felt the need for expansion. However, because it was functioning only thanks to subventions and membership fees, they could not afford to buy the Pálka house. Things took a different turn in 1938 after social and political changes. From the Domica Cave, which belonged to Hungary, they brought to Liptovský Mikuláš a collection of archaeological artefacts from the Neolithic period. They also brought a part of the estate of Emil Alexy the so-called Alexy´s collection, in the main consisting of historical and ethnographic memorabilia. They were given extra rooms in the town hall for safekeeping of the artefacts. No damage was done to them during the war.

The fate of the museum was to be discussed after the war. At the municipal assembly meeting in 1946, the board of curators discussed the possibility of building a new museum close to the Demänová Cave of Liberty. The project was not realised but the building plans of that period shows a majestic building that was intended to have combined with the research centre. A request to create a museum was also given by Cave Department the Club of Slovak Tourists and Skiers created in 1944 in Martin.

In the special meeting called for by the Association of Slovak museums in October 1947, a suggestion for two new museums appeared. One, a district museum aimed at the history and culture of the region and the other, aimed at speleology. However, at that time the Club of Slovak Tourists and Skiers, as the new owner of the Domica Cave, asked for the return of the artefacts. The conflict had escalated into a criminal complaint against the custodian because he had refused to return the collection. In the event, Ján Volko-Starohorský resigned and all the artefacts were returned to the Domica.

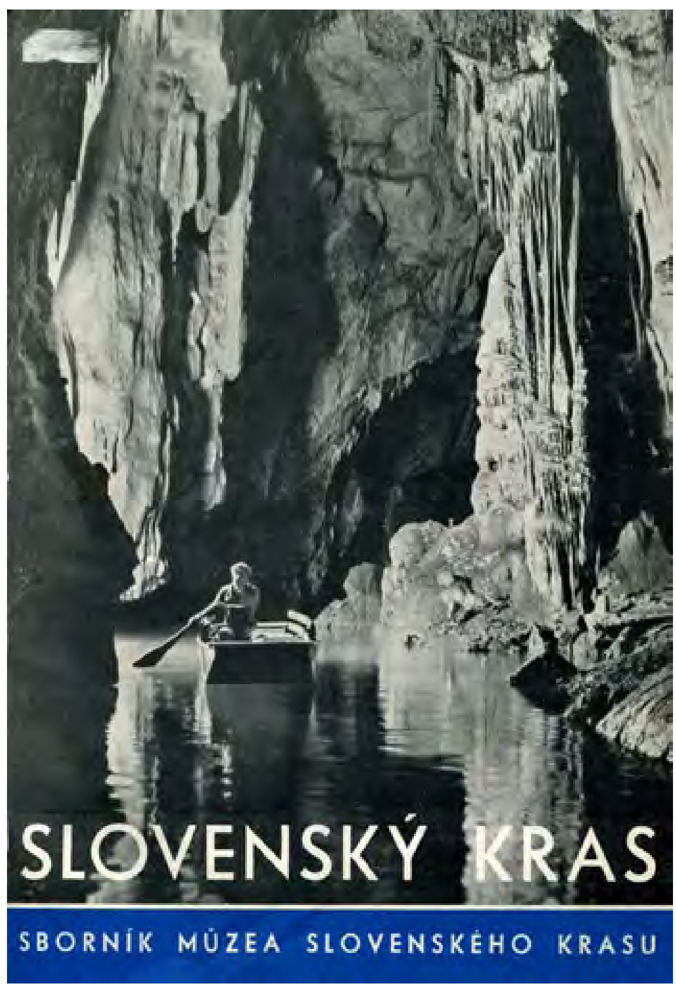
This situation had simply served to complicate the whole process of gaining larger premises. In 1948, an intervention of Dr. Vladimír Wagner from the Commission of Education, Sciences and Art in Bratislava was called for in order to stop the removal of museum artefacts.

Vojtech Benický, the administrator and the first director of the Museum of the Slovak Karst. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

At the same time, it was recommended to sort out the artefacts into the historical, cultural, and the karst part.

In the town hall building were three rooms with the exposition. The first two were dedicated to karst museum and in the third one was Alexy´s collection. Everything else was packed and stored in the Mikovský house. In July 1961, by the ruling of Educational and Cultural Commission of the District board in Liptovský Mikuláš, the above-mentioned artefacts had been allocated to various institutions (Liptov Museum in Ružomberok, Gallery of Peter Michal Bohúň in Liptovský Mikuláš, Literary and Historical Museum of Janko Kráľ in Liptovský Mikuláš, Ethnographical Museum in Liptovský Hrádok and Matica Slovenská in Martin).

To advance the effort of the museum to become a specialised karst museum came in 1949 when Vojtech Benický became the new curator. It was supported by Club of Slovak Tourists and Skiers, which was on the 10th September renamed to Slovak Speleological Society (abbreviated to SSS). Its creation resulted in the end of the curatorship. Vojtech Benický became the trustee of the museum. The society rented the historical building of the former Jesuit monastery and gradually,



The Slovak Karst Almanac, which has been published by the museum since 1958. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

Museum of Slovak Karst. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

the whole collection was moved there. In July 1951, the first exposition of speleology was opened to the public with the area of 653 m². It was based on the exhibition of Club of Slovak Tourist and Skiers, first exhibited in Slovak national museum in Martin in 1946. The artefacts were installed according to various karst areas and were supplemented by a relief map of Slovakia that had marked important karst areas. Individual parts of the exposition were dedicated to Liptov Karst, Domica and Belianska Cave, history of speleological discoveries, and research and protection of the caves. On the 1st January 1952, the museum administration was handed to the Regional National Committee in Žilina and Vojtech Benický became its director. A year later a new system of recording was established, but it was in 1976 that a single uniformed recording of exhibits was implemented. From the 1st of April 1954, the museum was integrated into central Slovak administration and the new branch of Geographical Department of Slovak Academy of Science was established. Its purpose was to continue to do research into Slovak Karst. It was in here where former custodian Anton Droppa was employed. The building of the former district court became the property of the state on the 1st September 1954 and on the 4th January 1955, the Museum of Slovak Karst became the owner of the whole building and its surroundings.

At that time the museum paid much attention to voluntary cavers, especially their involvement with the museum. The museum, from the research point of view, was orientated towards the caves nearby, mainly Demänová Cave and the local karst. After a period of stagnation of voluntary cavers, from the second half of the 1950s onwards, Slovak speleologists and cavers attended scientific research events that were organised by Vojtech Benický. In 1955 and 1956, in collaboration with other research institutes, they prepared complex speleological research of the Ice abyss in Onhište, Jánska Valley. Research into Zvoniva Abyss on Plešivská Plateau was realised, as were explorations of Demänová cave of Peace and the karst phenomenon in Vernár. From the 1st January 1956, the museum became a part of Slovak Museum in Bratislava as its scientific branch. The Scientific Council was established which guided the scientific research of the institution. as a result, re-instalment of the exposition had begun and a diorama of the caves Domica and Čertova pec was added. To expand the collection, its paramount aim was to obtain maps, photographs, and documentation from all Slovak caves and karst areas. Thus, into the karst part of the museum, archaeological artefacts, photographs, maps, fragments of sinter etc. found in Domica were added. It was further expanded by a collection of artefacts associated with geology, speleology, and similar fields e.g. documentation of maps, photographs, the flora of karst areas, karst sinter, archaeological artefacts, and minerals. In 1957 the documentation committee headed by Benický established a cave registration list. As a result of this, the museum could build a cadastre of karst phenomena, each file included registry letter and all other relevant documentation.

With all the changes happening with the museum in the 1950s, systematic expansion of the library continued. The library was focused on speleological literature. They included work of Ján Volko-Starohorský but also new material obtained by exchange of the domestic and foreign literature. From 1958 the museum published the scientific speleological periodical Slovak Karst.

In the 1960s exploratory activities were done in Strážovské vrchy, Malá Fatra, Pieniny, Prosiecka Valley, Čierna Valley under Krakova hoľa, Western Tatras, the surface situation of Stanišovská Cave was established, as were climatic conditions in Demänová Ice Cave, etc.

In June 1965, the Management, protection and operation of the caves were moved from the Ministry of Internal trade to the Commission of the Slovak National Council for Education and Culture. The caves in the central Slovakia region (Harmanecká Cave, Važecká Cave, Demänová Ice Cave, Demänová Cave of Liberty) based on the ruling of central Slovakia regional committee became the part of the Museum of Slovak Karst from the 1st January 1966. At the same time, the museum moved from under the District national committee in Liptovský Mikuláš to the Regional National Committee for central Slovakia. A new organisational charter was approved in which the museum is characterised as specialised, and whose aim is to collect exhibits and central documentation about karst areas in Slovakia, the collected materials are scientifically processed and publically exhibited. In connection with preparations for the International Speleological Congress in 1968, a new exposition in regards to early problems of karst creation, history of karst research, and first written documents about caves were reinstalled, and from May 1969 opened to the public. The permanent exposition was supplemented by temporary exhibitions which in that period preferred mainly speleology but through the occasional and shared exhibitions, there was a space for other topics such as the history of the town and the surroundings.

In connection to the abolition of the regional national committees, the government took action by which the complex care for caves would be assigned to one organisation ruled by the Ministry of Culture of Slovak Socialistic Republic. On the 1st January 1970 in Liptovský Mikuláš, Slovak Caves Administration was founded, into which they incorporated 12 publicly accessible caves and the Museum of the Slovak Karst. This act revived the Slovak Speleological Society. Jozef Jakál became its first director. Its activity became the concept of evolution of caving in Slovakia between 1971–1985. The museum became its organic part as the centre for the documentation connected to caves and karst. It continued to fulfil its original museum mission. At the same time, the renewed Slovak speleological association had operated on the museum soil which featured the connection of the specialised, scientific, and human resources aimed at research, discovery, and promotion of the Slovak caves. Because of the friendly relationship with the foreign speleologists that were formed in the past, the museum became a host of many foreign study trips and expeditions. In 1973 Vladimír Nemec left and Alfonz Chovan became the new director of the museum, who had been a leader of the Slovak Speleological Society since 1976. A research speleolaboratory in the Gombasecká Cave was assigned to the museum in the same year. Their job was to monitor climatic and microclimatic levels of the ice caves, questions of bio speleology, speleoarchaeology, and the protection of the karst. At the same time, they were conducting geomorphological, geological, and hydrological research.

With the merging of Slovak Caves Administration and the Department of Nature Protection of the Monument Board of the Slovak Republic with its seat in Bratislava, on the 1st July 1981 in Liptovský Mikuláš, Central Office of State Nature Conservancy was formed. Its director was Anton Lucinkiewicz, a former director of Slovak Caves Administration. They became a part of the Ministry of Culture of Slovak Socialistic Republic. This move, a three-year effort of Jozef Klinda, helped with the Organisation of the State Protection of Nature Protection in Slovakia. The Museum of Slovak Karst was incorporated into this organisation. This act was mirrored in its new name The Museum of Slovak Karst and Nature protection. The major landmark of the activity and the organisation of the museum was the approval of the first Concept of Development of the Museum of Slovak Karst and Nature protection till 1990 by the Minister of Culture of SSR. The coordinators were the director of the museum Alfonz Chovan and the worker of the ministry of culture, Jozef Klinda. In 1987, upon the proposal of Ladislav Dolan, a worker of Central Administration of Museums and Galleries in Bratislava, the museum was renamed again to The Museum of Evolution of Nature Protection. From 1988 till 2001 the director of the museum was Marcel Lalkovič. This way the museum slowly changed its course and was becoming educational, as well as a museum and the centre of documentation. A big plus of that period is, that after they moved from the building of Central State Protection of Nature on the street of Street 1.maja, into the new building, the room-space of the museum greatly improved.

View of a part of the new exposition in the reconstructed building of the Slovak Museum of Nature Protection and Speleology – Protected Nature of Slovakia, Mountain Biotope. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

SLOVAK MUSEUM OF NATURE PROTECTION AND SPELEOLOGY

Among the changes that the 'Velvet Revolution' brought, were the changes in the organisation of the Central Office of State Nature Conservancy, and it resulted in the creation of the independent museum, which from the 1st July 1990 was renamed to *The Slovak Museum of Nature Protection and Speleology*. The name was created by Jozef Klinda, Jaroslav Halaš, and Marcel Lalkovič, who in 1990 helped it to become a part of the Ministry of Culture of the Slovak Republic. Even now the museum presents itself as a specialised centre of complete documentation of development and the current state of the nature protection and caving in Slovakia.

From the second half of 1996 till the end of 1998, the museum along with other cultural institutions of Liptovký Mikuláš became a part of Upper Liptov cultural centre with its headquarters in Žilina. After this short period, the museum was threatened with losing its nationwide influence; however they managed to become a part of the Ministry of Environment of the Slovak Republic. To be part of that Ministry, in 1999 under the coordination from Jozef Klinda, who directly helped with the organisation, Vlastimila Herdová, with human resources, Marta Hermanová, with the accountancy, Viola Procházková, and the director of that time.

View of the current renovated museum building. Source: Archive of Nature Protection and Speleology, Liptovský Mikuláš

From 1999, The Slovak Museum of Nature Protection and Speleology has been a specialised workplace in the field of nature protection. In 2005 in the museum created a specialised public Archive of the Slovak Museum of Nature Protection and Speleology. (From the 1st September 2019 it was renamed to The Archive of Nature Protection and Speleology.) The main mission of the archive is to add to, gain, elaborate, protect, and make available archive funds and collections that are associated with nature protection and speleology in the Slovak Republic.

Thanks to the financial funds of the European Union, the museum has improved material, technical and various special equipment; and nowadays it increases environmental subconsciousness of the wider public by methods of education, acquisition, lectures, print, and expositions. Up until now, the largest reconstruction of the historical building of the museum and its surrounds had been realised between 2011–2014. Along with the building projects, was running a preparation for the expositions that lasted from September 2014 till November 2015. Revitalised exposition is combined with multimedia, computer technology, lighting effects, and sound. The separate expositions are distributed on four floors of the building. The credit for these changes is mainly attributed to the current director of the museum Danka Šubová and her team.

Today, the Slovak Museum of Nature Protection and Speleology is a major specialised centre in relation to complete documentation about the development and current state of the protection of nature and caving.

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SLOVAK SPELEOLOGICAL SOCIETY AND ITS ROLE IN SLOVAK CAVING

Peter Holúbek – Bohuslav Kortman

Slovak Speleological Society (shortly SSS) is a voluntary organization registered by the Ministry of Interior of the Slovak Republic based in a town Liptovský Mikuláš. The society unites amateurs interested in research, exploration, and protection of caves and karst in general. Along with professional organizations the Slovak Caves Administration and the Slovak Museum of Nature Protection and Speleology, both also based in Liptovský Mikuláš, the SSS forms a backbone of today's Slovak speleology.

Karst in the Western Carpathians belongs to remarkable landscape elements of Slovakia. It spreads on an area of roughly 2700 sq. km. In the National Database of Caves of the Slovak Republic, administered by the Slovak Museum of Nature Protection and Speleology, 7495 caves with a total length of 499km of known corridors are registered. The substantial part of them was discovered and documented by members of the SSS.

Caves on the territory of today's Slovakia have been attracting humans since time immemorial. The earliest archaeological findings date back to Palaeolithic. The first written record mentioning cave is a medieval script from 1266. The script mentions how a cave's entrance bounds a piece of land. Another manuscript from the late 15th century describes cave ice. The first detailed description of cave filling in Slovakia dates to 1672 and the first cave maps appeared in the 18th century. In the 19th century, the cave research became more widespread and several authors are known from this period, all of them publishing mainly in Hungarian or German language. Interest in cave exploration increased even more after the discovery of The Dobšiná Ice Cave in 1870 and its subsequent opening for the public. Shortly after, the first brave descent into 100m deep abyss Zvonica in the Slovak Karst was accomplished. In addition to that, a discovery of the Belianska Cave in 1881 and its opening for the public influenced the perception of the caves in the region.

Practical speleology in Slovakia started only after the collapse of the Austro-Hungarian empire and the formation of Czechoslovakia in 1918. Discoveries of sizeable Demänová Cave of Liberty in the Low Tatras in 1921 and of Domica Cave in the Slovak Karst in 1926 were widely medialized and in a short time opened for the public which led to an unprecedented increase of interest in cave tourism. A journal Krásy Slovenska also played an important role in this process and started to publish articles about Slovak caves. Since the journal's 11th volume published in 1932, it has carried a subtitle *Journal dedicated to tourism and caves*. During this golden era of Slovak caving, the Važecká Cave, Bystrianska Cave, Jasovská Cave, and Driny Cave were discovered and opened for the public and they remain operational to these days.

Speleology in Slovakia has a long tradition, the first countrywide organization was established in 1944 called *Jaskyniarsky zbor* as a part of *Klub slovenských turistov a lyžiarov*. An idea of an entirely independent organization was fulfilled at the 3rd Assembly of *Jaskyniarsky zbor* on the 10th of September 1949 in Demänová Valley, when the organization was renamed as Slovak Speleological Society (shortly SSS). A professor of archaeology Vojtech Budinský-Krička became the first chairman of the society and Vojtech Benický, an active caver and photographer, was elected to be a secretary. After the first year, geologist Michal Maheľ took over the position of the chairman. At that time, the Museum of Slovak Karst in Liptovský Mikuláš was also part of the SSS and works on opening Vyvieranie Cave in Demänová Valley for the public were in progress. In 1951, the extensive Gombasecká Cave in Slovak Karst was discovered. In the year that followed, another cave was discovered - the Demänová Cave of Peace with its vast corridors located in Demänová Valley. The journal *Krásy Slovenska* published several articles about exploratory activities. Morevoer, multiple monothematic journal issues exclusively about caving were issued in 1950 and 1951. During complicated times in 1952, the SSS handed its assets, documents, and cash to the Museum of Slovak Karst. The society was not officially dissolved but it stopped its activities as a countrywide organization.

However, practical speleology in Slovakia did not cease. In the meantime, the speleological activities were performed by professional cavers employed by the Management of Tourism. In 1952 two groups were created, one in Demänová Valley and the other in Slovak Karst. The Museum of Slovak Karst also performed organized speleology, mainly in northern and central Slovakia. On the other hand, Karol Silnický operated from 1962 without any institutional support and performed exploratory activities with students in caves of Borinský Karst in the Little Carpathians. From 1960, the Speleological department of the Slovak Geographical Society covered cave exploration activities. Between the years 1960 and 1982, research was performed mainly under the guidance of a professional speleologist Anton Droppa employed by the Geography Department of the Slovak Academy of Science. In 1967, the Museum of Slovak Karst in Liptovský Mikuláš employed Alfonz Chovan and gave him a task to unite speleologists in Slovakia. In October of the same year, A. Chovan organized a meeting in Prosiecka Valley of all active cavers in Slovakia, this meeting is considered to be 9th Slovak-wide meeting of cavers, also known as Speleology week. However, in 1968, disagreements between the cavers and the management of the museum led to an idea of an independent Slovak-wide speleological organization. Based on an impulse from cavers, the Advice body for the Speleology of the Ministry of Culture of the Slovak Socialist Republic started to conceive such an organization. Based on the recommendations made by the Advice body, in 1969 a meeting of representatives of active local caving groups in Slovakia was held in Liptovský Mikuláš. The representatives presented a proposal of a new organizational format of the Slovak speleology and the participants chose a historical name for the organization – Slovak Speleological Society. To secure the organization›s goals a preparatory committee was elected from active cavers from the whole Slovakia, who discussed a draft of a constitution of the organization. In accordance with the constitution, the SSS was, organization-wise, integrated into the Museum of Slovak Karst in Liptovský Mikuláš. At the end of 1969, the Ministry of Interior approved the Constitution of the SSS and on the 10th of April 1970, the preparatory committee established 20 lo-

Five chairmen of the Slovak Speleological Society at the event to mark 60-th anniversary of its founding held in November 2009 at the Slovak Museum of Nature Protection and Speleology; from the left D. Kubína, A. Chovan, Z. Hochmuth, J. Tulis, and B. Kortman.

cal caving groups throughout the country. The following day, a general assembly was held, at which 13 board members of the SSS were elected. Dušan Kubíny was elected a chairman and so replaced Jozef Jakál responsible for the preparatory process of formation of the SSS. Also, Jozef Jakál was at around the same time appointed as a director of the Slovak Caves Administration.

Restored SSS has continued traditions of discovering, research, documentation, and protection of karst and caves. Each of the local groups had an assigned warrantor-specialist who advised the group on exploratory activities. In 1970, the publishing of an informative journal named Bulletin of the Slovak Speleological Society has commenced. As of 2020, the bulletin has 51 published volumes. At the end of 2004, an internet website www.sss.sk was registered, which informs about the latest news in the SSS. The political transformations affecting societal life in Slovakia at the turn of the 1990s lead also to changes within the SSS. At 11th general assembly of the SSS, a new constitution of the organization was adopted, a new board was elected and Ján Tulis became the chairman of the SSS. In 1992, the government stopped subsidising the SSS through the Slovak Museum of Nature Protection and Speleology. In addition to that, the SSS lost paid positions of Secretary and Office assistant. The situation was resolved in 1993 when the Society received an annual donation of 300,000 SKK from the newly formed Ministry of Environment and hired a part-time office assistant. On the 1st of January 1995, the Act No. *287/1994* Coll. on *Nature and Landscape Protection* came into force. According to the new law, any speleological research was possible only with a permit issued by the corresponding Local Environmental Office. The chairman of the SSS Ján Tulis then secured the permits for the local groups needed for the research. In 1999, the annual donation was cut and later entirely abolished. Nowadays, the SSS has finances only from membership fees, projects, 2 % of taxes to NGOs (specific for the Slovak tax legislation), occasional donations from the Slovak Caves Administration, and a sale of archive materials to the Slovak Museum of Nature Protection and Speleology.

Bulletin of the Slovak Speleological Society


The opening of the 27th *Speleomíting* of the SSS, Liptovský Ján 2018. Photo: I. Šulek


The opening of the 60th *Jaskyniarsky týždeň* of the SSS. Belianske Tatras 2019. Photo: V. Ruček

In September 2002 came into force the Act No. 543/2002 Coll. on *Nature and Landscape Protection*. The board of the SSS tried to negotiate a permit for all local groups of the SSS with the Ministry of Environment. However, the attempts were unsuccessful, and the local groups were left with no option but to request permits from the authorities individually. The change has finally come in 2017 when the Ministry of Environment issued a permit for cave research for the whole SSS which expires in 2020.

Nowadays, the Slovak Speleological Society unites almost 1000 cavers organized in 52 local groups operating across Slovakia. Annually, a meeting of Slovak cavers *Speleomíting SSS* is organized, where members present results of their activities. Also, typically every summer a week-long meeting *Jaskyniarsky týždeň* is held in a selected karst region, often with participants from abroad. The SSS, in collaboration with the Mountain Rescue Service, organizes an annual training of SRT for new members. On top of that, selected active cavers collaborate with the Mountain Rescue Service and regularly practice transport of an injured patient from complicated caves.

Every year, members of the Slovak Speleological Society discover, explore, and document several kilometres of cave corridors. Over the last 70 years of our activities, the length of discovered and documented corridors in Slovakia and abroad has accumulated to a considerable figure of over 300 km. It is well documented that just over the last 15 years, we discovered 120 km of cave corridors. Among us are specialists in archaeology, zoology, palaeontology, cartography, and other science disciplines so needed for practical speleology. For the interested people from the public, experienced cavers organize courses of speleology. Furthermore, we collaborate with the speleology organizations from the neighbouring countries, mostly with those from the Czech Republic, Poland, and Hungary. Slovak Cavers successfully operate also in caves worldwide. Perhaps the most common destinations are the Balkan Peninsula and the underwater caves of Mexico. Our members also developed internationally utilized Therion software used for cave measurement data processing. The SSS is one of the founding members of the International Union of Speleology and it is also a member of the European Speleological Federation. In 2018, the SSS operated with a budget of 13,500 €. The funds were used to cover the running costs of the secretariat and the webpage, organization of the central events, and publishing of the journal with over a thousand copies printed.

ONE HUNDRED YEARS SINCE THE BIRTH OF ANTON DROPPA, EMINENT RESEARCHER OF SLOVAK CAVES

Dr. Anton Droppa is one of the founders of modern Slovak scientific speleology. He is well known for its rich publishing activities focused mainly on regional karst geomorphology and speleology of Slovakia. His most important domestic work is the research monograph on the Demänová Caves from 1957 that represents the longest cave system in Slovakia and a typical example of a multi-level cave system in the mid-mountain position. Within the long-term speleological research, A. Droppa surveyed and documented 412 caves with total length of 54,958 m. He worked on maps of the caves in the Demänovská dolina Valley, Dobšinská ľadová jaskyňa Cave, Domica Cave, Jasovská jaskyňa Cave, Bystrianska jaskyňa Cave, Belianska jaskyňa Cave, and many other caves. These maps are integral parts of his book publications and research articles. He gradually explored almost all karst areas in Slovakia, including show caves and many other important caves. In his wide-ranging speleological activities, he directed and actively participated also in the exploration and discovery of caves. In 1973, he published an overview of examined caves in Slovakia and classified them by genesis. Numerous regional geomorphological studies and reports, which he published mainly in the Geographical Journal, Czechoslovak Karst, and Slovak Karst journals, contributed significantly to the knowledge of karst and caves in Slovakia and stimulated their further research and exploration.

He also dealt with the alpine karst in the Carpathians, the typification of karst areas in Slovakia, the formation of canyon-like valleys in the Western Carpathians, as well as with the chemical denudation of allogenic karst in the Demänovská and Jánska dolina valleys on the northern side of the Nízke Tatry Mountains. In order to apply the results of speleological research into practice, he has developed many proposals and assessments concerning the utilization and protection of caves. Several of his maps have been used in planning the development of show caves and in ensuring their protection.

A. Droppa is known abroad mainly for his studies on the correlation of the development of cave levels and river terraces. He developed this important problematics on the example of the caves in the Demänovská dolina Valley and the Váh River terraces, as well as its tributaries in the Liptovská kotlina Basin. His case study about the correlation of horizontal caves with river terraces in this part of Slovakia, published in the ‘Studies in Speleology’ in 1966, has been referenced in many research articles and books. Moreover, the longitudinal section of the Demänová Caves with their evolution levels, compiled by A. Droppa, was included in several foreign widely known karstological and speleological books, especially published in the 1970s and 1980s (e.g. Sweeting, 1972; Bögli, 1978; Jennings, 1987). Consequently, he correlated the development of upper-lying inactive river horizontal caves

Anton Droppa (1920–2013)

in the Slovenský raj (Slovak Paradise) with the formation of a large planation surface represented by the karst plateaus there. In the 1970s and early 1980s, he realized several case studies on the chemical denudation of karst. Results obtained from his corrosion measurement experiments in the Demänová Karst were published in the ‘Annales de la Société Géologique de Belgique’ in 1983.

He attended international speleological congresses held in Ljubljana, former Yugoslavia (1965), Stuttgart, Germany (1969), Olomouc, former Czechoslovakia (1973), and Bowling Green, Kentucky, USA (1981). In the framework of the International Union of Speleology, he has been a member of the karst denudation commission and the commission on the longest and deepest cave in the world.

For the wider public, A. Droppa prepared a series of popular-educational book publications on several show caves – Belianska jaskyňa Cave, Demänová caves, Dobšinská ľadová jaskyňa Cave (Dobšiná Ice Cave), Domica Cave, Gombasecká jaskyňa Cave, and Važecká jaskyňa Cave, which were published between 1959 and 1962. Also, he presented the most important caves in Slovakia, including show caves, in a pictorial book publication from 1967; its supplementary edition was published in 1973. For the Encyclopedia of Slovakia, which was been published from 1977 to 1982, he wrote most texts about karst phenomena and caves.

Anton Droppa was born on 30 June 1920 in the Lazisko village at the northern foot of the Nízke Tatry Mountains. Since his life´s desire was to become an airman, in 1941 he enrolled in a two-year military academy in Bratislava. Shortly after the outbreak of the Slovak National Uprising, he flew on 31st August 1944 with a group of airmen to the Soviet Union. He became a fighter pilot 1st Czechoslovak Fighter Aviation Regiment. He participated in the fighting in the Ostrava operation in Opava, Moravian Ostrava, and Cieszyn. After the Second World War, A. Droppa was a member of the 1st Czechoslovak Fighter Regiment. In 1947, he was transferred to an aviation pilot school in Olomouc to participate in the education and training of new pilots. In order to increase his qualification as a pedagogue, he enrolled in a daily study of history and geography at the Faculty of Philosophy of Palacký University in Olomouc. He became interested in karst and cave on the initiative of univ. prof. dr. František Vitásek. In 1949, A. Droppa was one of the founding members of the Slovak Speleological Society. He graduated from the Faculty of Science of Masaryk University in Brno in 1951. In the same year, he became a member of the Slovak Geographic Society. From 1952 A. Droppa worked as a custodian at the Slovak Karst Museum in Liptovský Mikuláš town. In 1955, A. Droppa became a researcher at the Institute of Geography of the Slovak Academy of Sciences in Bratislava, at its detached workplace in Liptovský Mikuláš. In 1960, he reached a scientific degree as a candidate for geographical sciences (CSc., equivalent to the current Ph.D.). From 1961 to 1982, he was the chairman of the speleological branch of the Slovak Geographical Society. He worked at the Institute of Geography of the Slovak Academy of Sciences until 1985. After 1985, he worked for several years as a scientific consultant at this institute. He continued to maintain contacts with the Slovak Museum of Nature Protection and Speleology and the Slovak Caves Administration in Liptovský Mikuláš, as well as with local cavers. He passed away on July 13, 2013 in Liptovský Mikuláš.

For his contribution to natural sciences, the Slovak Academy of Sciences awarded him the Silver Plaque in 1980, and the Dionýz Štúr Gold Plaque in 1985. He was included in the list of prominent personalities of the Slovak Academy of Sciences. In 2008, the President of the Slovak Republic lent him Pribin´s Cross II. class for significant contributions to the development of the Slovak Republic in the field of speleology and geography. For his lifelong creative work and extraordinary results achieved in geomorphological research of karst and caves in Slovakia, he became an honorary member of the Association of Slovak Geomorphologists at the Slovak Academy of Sciences. The results of his long-term research activity will continue to be a source of scientific knowledge of Slovak karst areas and caves.

A. Droppa›s speech at the 5th Scientific Conference ‘Research, Utilization and Protection of Caves’ held in 2005 on the occasion of his 85th birthday (on left, Jozef Hlaváč, the former director of the Slovak Caves Administration). Photo: P. Bella

Pavel Bella, Peter Holúbek

ABSTRACTS

9th INTERNATIONAL WORKSHOP ON ICE CAVES (IWIC-IX) & 12th SCIENTIFIC CONFERENCE 'RESEARCH, USE AND PROTECTION OF CAVES' Liptovský Mikuláš, Slovakia, May 12–15, 2020

postponed due to the COVID–19 pandemic

UIS CALL TO ACTION: INTERNATIONAL YEAR OF CAVES AND KARST

George Veni

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International Years are a series of events held around the world by international teams to increase the public and government's appreciation for the year's topic. This often results in increases in funding, better regulations, protection of peoples and important areas, and new business opportunities.

The International Union of Speleology (UIS) is organizing the world's first International Year of Caves and Karst (IYCK) for 2021. Why? Despite all of our combined accomplishments, caves continue to be destroyed. Trash is still dumped underground. Karst aquifers are polluted. Many rare cave ecosystems are now endangered. Precious archaeological and paleontological materials in caves are still commonly lost and looted. And sadly, many government officials, educators, and even scientists and environmental managers do not understand caves and karst enough to prevent these tragedies, or even recognize that they are tragedies.

An IYCK is a next step to raise the level of understanding and respect for caves and karst as globally important physical, ecological, and cultural systems. A successful IYCK will lead to new caves opened for exploration, and more funds and other support for that exploration, as well as for research, management, and protection, at levels we've never seen before.

The UIS asks you as organizations and individuals to join the dozens of organizations around the world who are supporting the IYCK. What can you do?

1. Get involved! This is a once-in-a-lifetime chance to greatly improve the understanding and appreciation of caves worldwide.
2. Begin reaching out to potential partners for assistance. They do not need to be from the caving community!
3. Begin planning activities you can do in your community, region, and country to support the IYCK. Begin planning now! It will be 2021 faster than you think.
4. Visit the IYCK website (www.iyck2021.org) for information and post your events there.
5. Please contact me (gveni@nckri.org) or other members of the UIS Bureau at any time if you need assistance or have questions.
6. With your help, together we will educate the world through the International Year and International Day about our precious caves and karst areas. Together, we can save the world's caves and karst for the future.

9th INTERNATIONAL WORKSHOP ON ICE CAVES (IWIC-IX)

SEASONAL ICE BULGED ELEVATIONS IN THE DOBŠINÁ ICE CAVE GENERATED BY UPWARD EXPANSION OF FREEZING PONDED WATER

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The surface of perennial ice body in the Dobšiná Ice Cave (Slovenský raj, Spiš-Gemer Karst, Slovakia) is featured by several large- and small--scale morphologies (Bella, 2007, 2018). One of the less frequent forms are ephemeral small circular ice bulged elevations upward-expanding from the pond ice in the central part of supraglacial ablation depressions. Lower and wider ice bulges, up to about 1–2 m in diameter and up to several centimeters in height, are occasionally observed on the floor ice in the Malá sieň (Small Hall) near the entrance zone, where large seasonal temperature changes occur. Higher and narrower ice bulges, up to about 0.8–0.9 m in diameter and up to 10 cm in height, are known from kettle-shaped dripping holes deepened into the upper sloping part of the ice body in the Veľká sieň (Great Hall; Fig. 1). Ice dome-shaped bulges, not hollow and not filled with water, are fractured by mostly radial and concentric cracks or fissures. The most significant fractures are formed on the upward-expanding surface of higher and narrower ice bulges (fissures up to 1 cm wide and about 2 cm deep).

Fig. 1. Upward-expanding ice elevations in dripping kettle-shaped holes, Veľká sieň, Dobšiná Ice Cave. Photo: P. Bella

These small ice elevations generated by upward expansion of freezing stagnant ponded water mainly in spring when water from the melting snow is seeping into the cold cave interior. Lower and wider ice elevations originated in shallow and larger pools (in ephemeral shallow pond basins), while higher and narrower ice elevations in deeper and smaller *pools (mostly in interannual* kettle-shaped dripping holes). The edges of lower and wider ice elevation in the Malá sieň are at the same height as the surrounding floor ice. The pond ice in the kettle-shaped holes, about 1 m in diameter, is almost completely upward-expanded into the ice bulge. The oscillated water table of occasional pool in the kettle-shaped holes is indicated by 5 cm wide and 30 cm high lateral notch deepened into vertical ice walls. The height differences between the pond ice and the upper edges of kettle-shaped holes are 0.9 m or more.

Similarly shaped ice elevations, but larger in size, have been studied on the surface of several glaciers. The origin of ice mounds in the 'ice lake' could be explained by the refreezing of an accumulated pocket of meltwater within the ice (Van Autenboer, 1962). Also, the frosted type of ice blister described by Echelmeyer et al. (1991) appears to be formed by buckling from below caused by freezing expansion of trapped meltwater. The shallower surface waters in the 'ice lake' froze to the surrounding glacial ice after the runoff season, while water in the deeper pools is fully confined by ice. During continued freezing of the confined water, the expansive forces either gradually, intermittently, or suddenly forced the ice cover. The ice blisters cracked at their apexes, and secondary cracks formed until all the water in the blisters had frozen and expansive uplift stopped (Sumgin, 1941; Lewis, 1962; Kovacs, 1992 and others).

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ICE AGE FAUNA FROM DEMÄNOVSKÁ ĽADOVÁ JASKYŇA CAVE (NORTHERN SLOVAKIA)

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Demänovská ľadová jaskyňa Cave is located in the Demänovská dolina Valley (Nízke Tatry Mts.) in northern Slovakia south of Liptovský Mikuláš town. The cave entrance is situated at an altitude of 840 m, approximately 90 m above the valley bottom of the Demänovka River. This open (650 m) inactive fluviokarst cave (Bella et al., 2018) is among the first Slovak caves described in the literature. The mention of the cave, previously known also as Čierna jaskyňa Cave or Dračia jaskyňa Cave, can be already found in the works of P. J. Hain (1672) or F. Brückmann (1739). In addition to its ice decorations and historical inscriptions, the cave is also known for its palaeontological record from the Pleistocene period. The cave bear skeleton, discovered in the cave by J. Buchholtz Jr. during his exploration of the site from 1714 to 1724, was exhibited in the first half of the 18th Century at the Dresden Technical Museum as the skeleton of a 'dragon' (Kučera et al., 1981; Lalkovič and Komorová, 1991).

In 1953, F. Skřivánek (1954) carried out saving research in the cave. He described the Pleistocene fauna finds from three sites. Most of the finds were cave bears (*Ursus* ex gr. *spelaeus*, probably *U. ingressus*). To a lesser extent, cervid remains (originally determined as *Cervus* sp.) have also been discovered together with a bovine molar (formerly determined as *Bos* sp.), a felid skull fragment (formerly determined as *Felis* sp.) and a mammoth tusk fragment (formerly determined as *Elephas* sp.).

A part of the cave bears' finds from former collections (one skull and three juvenile skull fragments) and deposited in the museums in Ružomberok and Žilina were later studied by M. Sabol (2000, 2002).

At present, the osteological finds from the cave were also found in the collections of the Slovak Museum of Nature Protection and Speleology in Liptovský Mikuláš during the revisory research. These remains belong to the taxa as follows: (1) *Cervus elaphus* – fossil finds of at least 2 individuals (cervical vertebrae, scapula, humerus, metacarpal bone, sacral bone, pelvis, femur, tibia), found in the cave before 1969; (2) *Vulpes* cf. *vulpes* – Holocene find of a skull with the mandible, obtained in 1970; (3) *Barbastella barbastella* and *Pipistrellus pipistrellus* – Holocene skulls, found in 2016; and (4) *Ursus* ex gr. *spelaeus* – probably finds already described by F. Skřivánek in 1954.

Based on published and found data, the faunal finds from Demänovská ľadová jaskyňa Cave can be divided into two groups: (A) finds belonging to individuals from the Pleistocene (*Ursus* ex gr. *spelaeus*, *Cervus elaphus*, *Bos – Bison* sp., and *Mammuthus* cf. *primigenius*) and (B) finds belonging to individuals from the Holocene (*Felis* sp., *Vulpes* cf. *vulpes*, *Barbastella barbastella* and *Pipistrellus pipistrellus*).

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MICROCLIMATE AND ICE DEPOSITS RESEARCH IN CRNA LEDENICA ICE CAVE (BIOKOVO NATURE PARK, CROATIA) 2016–2019

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Crna ledenica Ice cave is located at the northern slope of the highest Biokovo Mt. ridge. This area is in the central part of the Biokovo Nature Park in the Dalmatia region (southern Croatia). Biokovo Mt. (1762 m a.s.l.) is known for numerous karst phenomena, especially large and deep dolines and shafts. Apart from being a relief barrier between the Adriatic coast and continental inland of Dalmatia, Biokovo Mt. is a strict climate boundary that is also important for local cave climate and hydrological properties. Some of the shafts in this high mountain area contain perennial ice and snow deposits. In the past, the ice was extracted and transported to the coast and hinterland for conserving food and other purposes.

Crna ledenica (Black ice cave) has four entrances at elevations 1479–1503 m a.s.l. connected with one vertical passage and a large hall. The hall dimensions are 58 x 28 m with a maximum height of 33 m. The cave was developed in tectonically highly disturbed and well karstified Cretaceous limestone beds. After initial karst corrosion, important processes in cave formation were collapsing and enlargement driven by cryofraction.

Although it was known to the local population for a long time and explored by cavers for many years, the cave was surveyed for the first time by the cavers of the Croatian Biospeleological Society in 2004. In 2016 it became a microclimate observation point in the frame of caver›s research project supported by the Department of Geography (UniZG), Speleological section HPD Imber (Omiš) and Caving Club Samobor. The microclimate is monitored by data loggers in the cave and at the surface. The data is collected in a one-hour interval. Recently, in 2019, a one-year project was started with the support of Biokovo Nature Park. The new partner is Emil Racoviță Institute of Speleology (Romanian Academy, Romania). Besides the monitoring of microclimate, the aims of the project are geomorphological research, sampling, and monitoring of ice and snow dynamics. In two field trips, four samples of organic matter from several layers of ice were collected and sent to the laboratory for radiocarbon analyses. Additionally, for stable isotope analyses, 42 samples of ice were collected. The aim was to measure $\delta^{18}O$ and δ^2H in ice layers at different depths and identify the mechanism behind ice genesis (freezing of water vs. snow metamorphosis) and the possible climatic information embedded in the stable isotope composition of water.

SHALLOW ICE CORE PROFILES FROM SNEŽNA CAVE, SLOVENIA

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The potential use of cave ice as a climatic recorder in central Europe has been discussed in the literature (e.g., Kern and Perşiou, 2013; Kern et al., 2011; Mihevc, 2018). Recently, our group of Slovenian and American scientists has sought to determine whether permanent ice in caves in Slovenia contains climatic records (Carey et al., 2019, 2020). Herein we extend knowledge of geochemistry of Slovene cave ice by reporting on results of our second investigation of Snežna Cave, north-central Slovenia.

In June 2019 we drilled 2 shallow ice cores into the horizontal face of ice in Snežna Cave (*Snežna jama na planini Arto*), Southern Calcareous Alps, using a modified Sipre auger. Cores were kept frozen until divided into 2 cm sections. Six samples from various ice surface locations were also collected. Samples were melted and analyzed for $\delta^{18}O$ and δD, nutrients, and major cations and anions. Nutrient and major element samples were filtered through 0.4 µm filters prior to analysis. Analytical and processing blanks were also filtered and analyzed as samples to evaluate possible sample contamination.

$\delta^{18}O$ and δD data all fall close to the regional meteoric water line. The 6 surface samples are more enriched than all but one of the ice cave samples, suggesting they represent recent summer precipitation or evaporation or sublimation loss of ^{16}O and ^1H from these samples as they sit at the ice surface. Ice core profiles show a saw-toothed pattern with variations of as much as 4.1 ‰ in $\delta^{18}O$ and 25 ‰ in δD. Variations in isotopic values are not spatially repeatable with depth in the two cores, perhaps suggesting that the ice surface does not remain horizontal throughout the year or that there is preferential melting and mixing of waters at some depths in certain locations of the ice floor. Differences in surface profiles (i.e., the top 14 cm), given their relatively close spacing (<10 m apart), suggest a complicated history of deposition and metamorphism of the ice profile. However, in both cores at depths of 14–24 cm, $\delta^{18}O$ values are comparable (between -11.0 ‰ and -11.4 ‰), supporting the idea that at least at some depths processes of either similar source input or thaw/freeze, or both have existed over the entire ice surface.

Nitrate concentrations in the 2 cores ranged 1.1–5.5 µM with little pattern in the variation. Core A has a higher mean value of 3.2 µM, compared to 2.2 µM for core B. These values are similar to those measured (3.0 µM) in our previous sampling of Snežna Cave ice at 1.0 m depth (Carey et al., 2019). Chloride values ranged from 6.8–20.3 µM, with means of 11.3 µM for core A and 9.6 µM for core B. These are higher than our previously measured value of 2 µM at 1 m in Snežna ice, but similar to values at 3 m depth in a vertical ice profile above the floor of the cave. These measurements were made 23 months apart and may reflect real temporal differences in incoming precipitation. All but 2 of 29 ice core samples had reactive silicate concentrations of >1 µM, mean of 0.51 µM. This indicates that there has been little to no dissolution of aluminosilicate minerals contributing to the glaciochemistry of the ice, similar to our previous work on Snežna Cave and other ice caves in Slovenia (Carey et al., 2019, 2020).

These data add to our increasing knowledge of ice cave geochemistry in Slovenia. Although it is still unclear if reliable paleoclimatic information is recorded as a primary signal in the cave ice and what processes, such as thaw-freeze, seasonal input, or variations in hydrology control the glaciochemical signature.

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SAND WEDGES AND POLYGONS IN CAVE SEDIMENTS – EVIDENCE OF PERMAFROST?

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Sand-filled wedges and polygonal structures were found in stream-transported sediments of Victoria cave (Southern Ural, Russia; 53 °N). The cave is hosted in Devonian limestone and can be accessed via a shaft, joining at a depth ca. 80 m the horizontal Stream Passage (width 3–6 m, height 3–10 m). A stream flows for a distance of ca. 650 m before disappearing in a terminal sump. The discharge is only a few L/s during the dry season but reaches hundreds to a few thousands of L/s during snowmelt. A dry karst valley, punctuated by a series of sinkholes and ponors, extends to the NNW of the cave entrance. This valley, as well as the slope of a small ridge composed of Middle Devonian limestone, schists, and quartz sandstone, comprise the catchment for the cave.

Massive, up to 3–4 m-thick mud banks, truncated by the stream, occur along the Stream Passage. In the upstream part of the passage, they host multiple <1 cm to 12–15 cm-thick sand layers and lenses. In the downstream part of the passage, the banks consist of uniform silt.

In an exposure, we identified 9 sand layers in a 3 m-thick silt sequence. At least three of these largely horizontal layers are associated with sand-filled wedges extending into the underlying silt (Fig. 1). The tips of the wedges are commonly indistinct as the sand infill grades into silt (Fig. 1A). The height of the wedges does not exceed 20 cm, and the cracks extend laterally for 50 to 70 cm. In plan view, they show slightly curved outlines and a polygonal arrangement (Fig. 1C).

The bulk fine-grained part of the sequence consists of poorly sorted silt, ranging in grain size from 1 to 100 m. Sandy layers are composed of coarse (modal value ca. 1 mm), moderately to poorly sorted sand. The mineralogical composition of the silt is uniform across the sequence (quartz, albite, orthoclase, chlorite, muscovite, and traces of smectite), whereas the sand only consists of quartz and traces of feldspar and illite. The studied sediments are thus allochthonous, likely sourced from Middle Devonian schists (silt) and quartz sandstone (sand) from the catchment area. Single-grain Optically Stimulated Luminescence (OSL) dating yielded an age of the sand deposits of 24.5–24.9 ka (±2.3–2.6 ka; three dates).

Accumulation of massive silt (slackwater facies) and minor sand (channel facies) requires hydrological conditions very different from today. Taking the Hjulström-Sundborg diagram as a guide the settling velocities for silt in Victoria cave are 0.1–1.0 cm/s, whereas those for sand are 3–10 cm/s. Transformation of the Stream Passage into a large body of very slow flowing and partly stagnant water requires lowering the transmissivity of conduits somewhere beyond the terminal sump of the cave.

The rock massif hosting the cave experienced permafrost condition between 57 and 33 ka (Dublyansky et al., 2018). It stands to reason that permafrost was even more extensive during the Last Glacial Maximum when sand was deposited in the cave (24.5–24.9 ka). The presence of large and probably episodic quantities of water (required to transport sediments into and deposit them in the cave) and sub-zero temperatures of the rock at a depth of at least ca. 90 m below the surface can be reconciled by dynamic thawing of permafrost by focused conduit flow. The wedge-shaped sand-filled cracks in silty sediments of Victoria cave are therefore interpreted as periglacial features formed in a deep cave setting, where subzero temperatures were related to permafrost rather than local air circulation. Specific mechanisms of the wedge- and polygon formation (desiccation, frost shattering, ice wedging) remain to be elucidated.

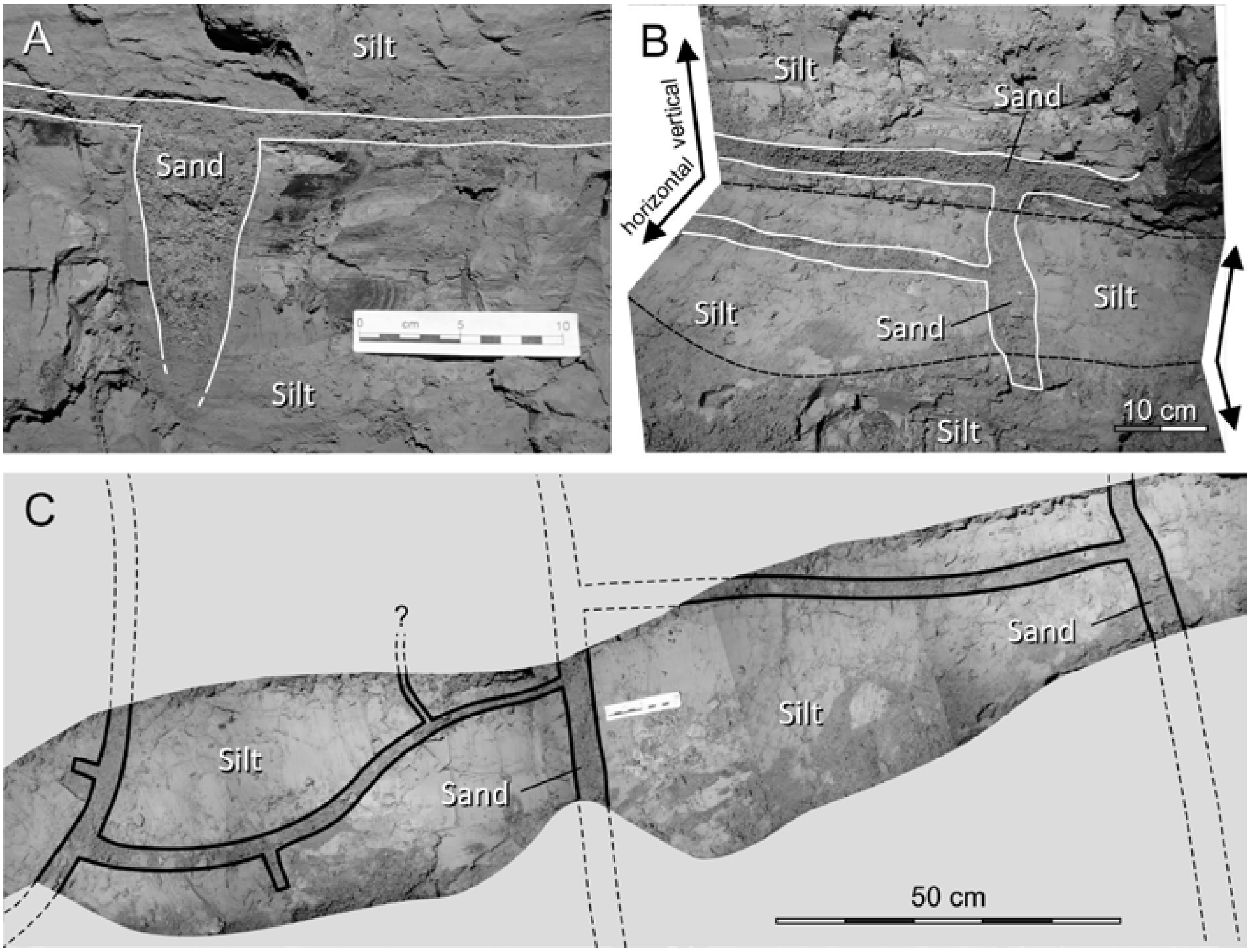

Fig. 1. Sand wedges and polygonal structures in alluvial sediments in Victoria cave (Southern Ural, Russia). A – Sand layer and associated sand-filled wedge in underlying silt; sand grades into silt in the lower part of the wedge. B – Three-dimensional structure of a sand layer and a vertical sand-filled wedge-shaped cracks cut by a step-like exposure. C – Plan view of sand filled wedge-shaped cracks, with polygonal arrangement. Outlines of cracks are emphasized; dashed where extrapolated.

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GEODETIC MEASUREMENTS OF ICE SURFACE CHANGES IN THE DOBŠINÁ ICE CAVE

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Dobšiná Ice Cave has been the subject of scientific research since its discovery. First planimetric survey was done by Eugene Ruffíny in 1871. Since then, several mapping of the cave spaces were realized, according to available maps. The first geodetic survey by the Department of Mine Surveying and Geodesy was carried out in the 1980s. The Institute of geodesy, cartography, and GIS (TU Košice) began a systematic cooperation with the Slovak Cave Administration in 2010 within the project of the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic (VEGA) 'Research of the dynamics of ice filling of cave spaces by non-contact methods in terms of their safe and sustainable use as a part of the natural heritage of the Slovak Republic', continuing with the cooperation until now. The main goal of the continuing surveys is not only the detailed spatial survey of the cave, but also the point monumentation of the geodetic point field in the cave ceiling, and the stage measurements of the ice filling dynamics – floor ice, ice walls in the Ruffíny's corridor, and ice tunnel. Measurements were realized by tacheometry by total stations, but also by non-contact surveying technologies – terrestrial laser scanning and digital

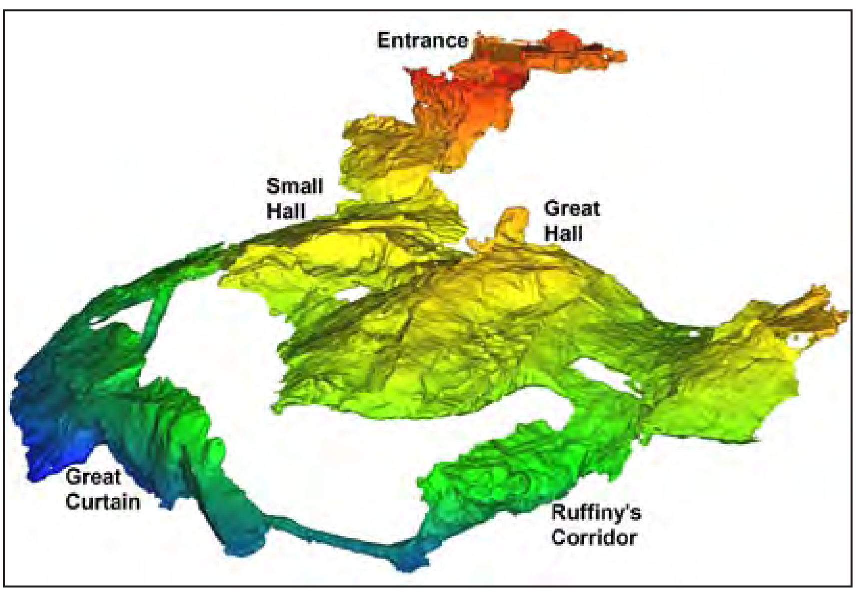

Fig. 1. 3D model of the cave generated from laser scanning data.

close-range photogrammetry. All surveys were geodetically connected to the national coordinate system S-JTSK and vertical datum Bpv by global navigation satellite systems.

Stage measurements are mutually evaluated, compared, and processed into spatial difference maps and 3D model of the cave. Partial results of the survey were published in several scientific journals at home and abroad.

In 2018, terrestrial laser scanning was done along the guided tour and capturing especially the spatial course of the ice filling, which resulted in the digital spatial model (Fig. 1). The obtained results show that the ice filling of the Dobšiná Ice Cave is not static but, on the contrary, flexibly dynamically reacting to slight climatic and hydrological changes. As resulting from Fig. 2, during the nine months between March and December, there was a decrease in the floor ice volume of 127 m^3 and an increase of 84 m^3 in the interpolation area of the floor ice of 1607 m^2, representing 41 % of the total area of the Small Hall and the Great Hall. In an effort to protect and preserve this worldwide unique natural formation for generations to come, in the context of changing climatic conditions, all scientific knowledge towards the knowledge of fragile microclimate patterns is welcomed, where the detailed spatial model in relation to the cave climate monitoring system plays a key role.

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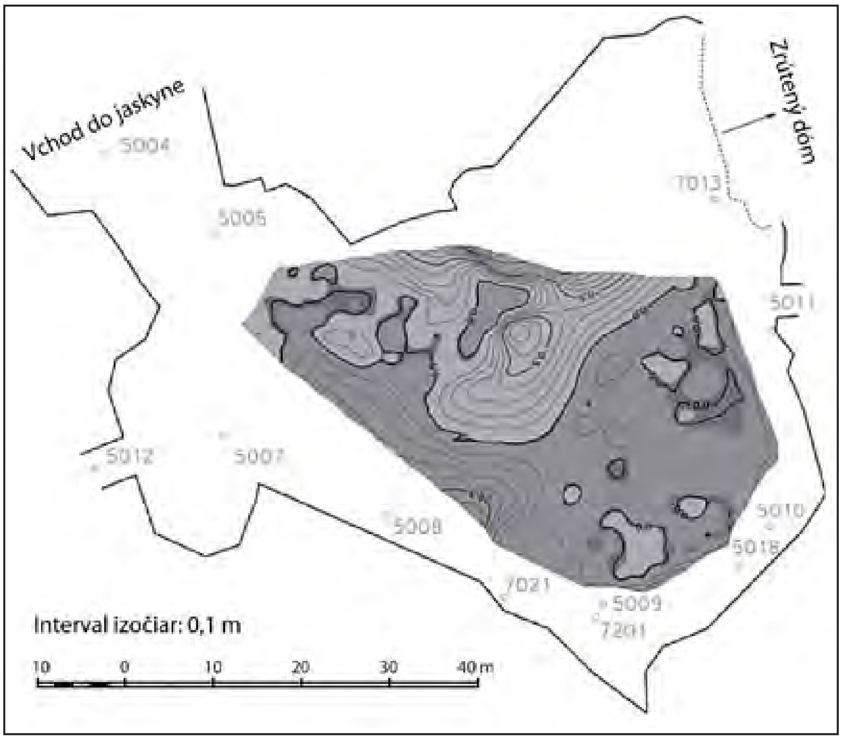

Fig. 2. Changes in the volume of floor ice between March and December 2018.

DOBŠINÁ AND DEMÄNOVÁ ICE CAVES: WHAT DO THEIR ICE BLOCKS REVEAL?

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This paper is part of a broader study on ice show caves, aiming to assess to what extent visitors impact on the biodiversity of the subterranean glacial ecosystems. Dobšiná and Demänová caves are two Slovak ice caves located at about 80 km from each other. Demänová Ice Cave is a northern part of the Demänová caves system, located in the Demänovská Valley in the Low Tatras National Park, while Dobšiná Ice Cave (969 m a.s.l.), a part of the Stratená Cave System, is located on the south-western edge of the Slovak Paradise National Park in the Spiš-Gemer Karst.

Known for a very long time, both caves have been opened for the public around the same period, meaning the half of the 19th century. Dobšiná Ice Cave, opened in 1871, became in 1887 the first electrically illuminated cave of the world. Due to the increase of communication, means of locomotion, and general interest of people in visiting sites, the number of the visitors of those caves is ever-growing (Demänová Ice Cave was visited by 3,133,416 tourists from 1970 to 2014, 70,769 tourists being reported in 2014 alone; Nudziková, 2014) putting stress on the underground environment, that hasn't been yet quantified in any way.

To our knowledge, there are few reports on the microbial diversity of these two caves, the data available mainly referring to the invertebrate fauna. The first study on microorganisms from Dobšiná Ice Cave (Nováková, 2006) compares the abundance of microscopic fungi from outside and inside this cave, and reports on the presence of some species such as *Botrytis cinerea* and *Aspergillus fumigatus* isolated from bat guano. On Demänová Ice Cave microbiome, Ogórek et al. (2018) report based on ITS sequences alone, on the phenotypic and genotypic diversity of airborne fungal spores. No information about the microbiome entrapped in the underground ice blocks of the two caves is available, even if this would bring valuable insights not only about the evolution of the microbial communities in relation to the climate changes occurred in past times but also on how intense visiting affects the structures of the microorganisms communities.

Here we report some of our preliminary data on the microbial biodiversity of the two underground ice blocks. Focussed mainly on the viable bacterial communities entrapped in the ice, our work complements that of Ogórek et al. (2018) in what concerns Demänová Ice Cave microbiota and starts the systematic study of Dobšiná Ice Cave microbiome.

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INVESTIGATION OF ICE-ENTRAPPED MICROBIOME OF DOBŠINÁ AND DEMÄNOVÁ ICE CAVES

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Dobšiná Ice Cave is located in the Slovak Paradise National Park in the Spiš-Gemer Karst, at an elevation of 969 m. This ice cave was formed around 400,000 years ago. The ice volume is around 110,100 m^3 and its thickness is around 26 m. Air temperature is between -3.8 to +0.5 °C and relative air humidity 85–98 %. The cave reaches a length of 1388 m, of which 495 m are accessible to tourists (Bella and Zelinka, 2017).

Demänová Ice Cave is part of the Demänová Caves system and it is located on the north slope of Low Tatra Mountains, at an elevation of 840 m. The corridors are 1975 m long, from which 650 m are accessible to tourists.

The passages descend from the entrance to the depth of 40 to 50 m. The ice volume in Kmet's chamber is 1042 m^3 and its maximum thickness at 3 m (Strug et al., 2006). Air temperature in the glaciated parts is around 0 °C, while in the non-glaciated parts it can rise to 5.7 °C. Relative air humidity is between 92 and 98 % (Bella and Zelinka, 2017).

Collected samples consisted of ice from both caves, Dobšinská Ice Cave – Collapsed Dome and Demänová Ice Cave – Kmet›s Dome. The ice was first cultivated on different media, for both fungi (DRBC [Dichloran Rose bengal Agar], SGA [Sabouraud glucose agar], BWA [beer-wort agar]) and bacteria (YES-yeast extract agar). Isolates were transferred to other plates and cultivated separately. For the molecular analysis, DNA was extracted from bacteria isolates, continued with amplification and sequencing. At this preliminary stage, a total of 17 species of bacteria were identified and will be presented in the poster.

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CHEMICAL AND MICROBIOLOGICAL COMPOSITION OF WATERS IN THE DOBŠINÁ ICE CAVE, PRELIMINARY RESULTS OF 2019 RESEARCH

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The Dobšiná Ice Cave belongs to the most important ice-filled cave in Slovakia and the world. The cave is located in the southern part of the Slovenský raj National Park, north of the Dobšiná town. The entrance of the cave lies on the northern slope of Mt. Duča at an elevation of 969 m, 130 m above the bottom of Hnilec River Valley. The cave is formed in the Middle Triassic Steinalm and Wetterstein limestone of Stratená Nappe (Novotný a Tulis, 2000, 2002). Several faults disturb the limestone above the cave with a thickness of 10–50 m. The faults allow water from rain and snow to percolate from the surface into the cave. The main part of the cave is represented by a large cavity filled with ice with a volume of about 110,000 m^3 (Novotný and Tulis, 2002). The cave has non-glaciated parts too, with calcite speleothems.

In the past, little attention was given to the chemical and microbiological composition of the seepage water in the Dobšiná Ice Cave. The quality of precipitation waters percolating into the cave was studied by Tereková (1990). Only older incomplete analyzes of dripping water in Malá sieň are known (Peško, 2000).

The paper presents the preliminary results of 2019 research in the cave. The aim of the study was to determine the chemical and microbiological composition of cave waters, their quality, and temporal and spatial variability. Dripping water and water from the small lake was sampled from the several places in the cave – Malá sieň (Small Hall), Veľká sieň (Great Hall), Zrútený dóm (Collapsed Chamber), Kvapľová sieň (Dripstone Hall). A total of 24 water samples and 2 ice samples was taken during the year.

The main process of forming the chemical composition of waters is the dissolution of carbonates. The TDS values of monitored waters ranged from 218 mg·L^{-1} to 357 mg·L^{-1}. Water is characterized by the basic distinct Ca-HCO$_3$ type with the highest proportion of A$_2$ components in the range of 80 % to 95 %. HCO_3^- is the main anion with concentrations in the range of 123 mg·L^{-1} to 210 mg·L^{-1}. The contents of Ca^{2+} as the main cation were in the range of 27 mg·L^{-1} to 111 mg·L^{-1}. The contents of Mg^{2+} were lower (only to 6 mg·L^{-1}). The cave waters have increased ammonium ions and COD. Saturation indices of waters calculated for calcite were different in varied parts of the cave a showed temporal variations. Generally, cave water is supersaturated and in equilibrium with respect to calcite, undersaturated with respect to dolomite. Water from melting ice, unlike dripping water, has very low mineralization (less than 42 mg·L^{-1}) and higher pH (higher as 8,8).

At selected localities, we determined the microbial profile of the samples by identifying cultivable chemotrophic microbiota on the basis of legally determined main microbiological indicators of water quality. The abundance of cultivable psychrophilic microorganisms ranged in the order of values above 10^2 CFU/ml, cultivable psychrotolerant mesophiles above 10^1 CFU/ml, and total coliform bacteria counts in the range of 0–37 CFU/ml. No faecal contamination (*Escherichia coli* and enterococci) was noted.

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DYNAMICS OF TEMPERATURE CHANGES IN THE SILICKÁ ĽADNICA CAVE (SLOVAK KARST) AND ITS INFLUENCE ON THE ICE ACCUMULATIONS

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The Silická ľadnica Cave is known as the lowest-lying ice cave (503 m) at a given latitude. The reduction of the volume of ice cave accumulations is alarming, and this has prompted the monitoring and research of climate and ice accumulations by researchers and students of the Institute of Geography of UPJŠ in Košice since 2011. These activities are covered by Speleoclub UPJŠ. With the gradually improving methodology of ice cave monitoring, we are able to identify the factors affecting the degradation of the ice cave accumulations more rigorously. Synchronously, we are moving towards a proposal of actions to prevent the degradation of the ice accumulations in the cave. The methodology for monitoring the changes of ice cave accumulations is based on terrestrial laser scanning technology, which was published in Šupinský et al. (2019). By creating a time-series database in ultra-high spatial resolution, it is possible to accurately quantify and analyze the volume change of cave accumulations over time.

In cooperation with the Minotaurus speleoclub, a monitoring system consisting of data loggers with temperature sensors was built. The monitoring system consists of 30 units located in the cave and its immediate surroundings in order to detect temperature differences in horizontal and vertical dimensions. This system and the first results of monitoring were presented in Hochmuth et al. (2017). Later, the monitoring system was supplemented with an anemometer, which records the airflow in the cave. Based on long-term observations, it is clear that the low temperature of the iced part in the Silická ľadnica Cave is mainly due to (i) the microclimatic conditions of the surrounding area (precipitation, evaporation, temperature), (ii) the land cover, (iii) the amount of ice accumulations, (iv) the temperature and amount of water of the Čierny potok Brook flowing through the non-iced parts of the cave, and (vi) exchange of the air mass from the exterior and interior of the cave.

The main scope of the microclimate research of the cave is to understand and explain the mechanism of air mass exchange and the factors causing the occurrence of cold air. The paper presents the results of the temperature monitoring in the Silická ľadnica Cave and presents selected situations in which there is a dynamic change of the temperature distribution in a short period. One of the described situations is the cold airflow in winter. The temperature of the cave drops lower compared to the air temperature recorded on the weather stations located 2 m above ground because the ground air layer in the cave exterior is considerably colder due to radiation and it flows into the cave. With each of these 'events' (5 to 10 times per winter season), the entire volume of air in the iced parts of the cave is cooled. Cold air gradually penetrates through the debris and into the non-iced parts of the cave, where it gradually heats up. A correlation between the temperatures in the iced and the non-iced part of the cave (below the hatch and rocks) is recorded. At the end of the air inlet, however, we observe the opposite phenomenon, where relatively rapid warming from below, while the air temperature in the cave drops from the original values before the cold air inlet. The cold air flowing into the non-glacial parts displaces the warmer air but flows along the ceiling. What is important here is the effect of a crack on the eastern side of the cave, which apparently communicates with unknown, non-iced parts, where it shows minimal hypothermia, and warm air blows and warms the eastern part of the cave.

The discussion may be stimulated by not yet fully understood facts. It is the effect of floods of the creek flowing in the lower non-iced parts, which brings or takes thermal energy from the cave. It is also necessary to address the issue of assessing the optimal flow between the ice-free and non-ice-free parts and its possible regulation, to investigate the anthropogenic effects of speleological research and flow-affecting interventions in the more distant parts of the cave system, the change of the land cover in the exteriors respectively.

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AGE AND POLLEN ANALYSIS OF CAVE ICE, DOBŠINÁ ICE CAVE, SLOVAKIA

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Dobšiná Ice Cave (in Slovak: Dobšinská ľadová jaskyňa) is one of the most magnificent ice caves in the world. It was formed in the Middle Triassic limestone as a result of the underground flow of the Hnilec stream. The cave is a part of the extensive Stratená Cave System. In the Quaternary, these caves were separated by the collapse of the ceiling (Duča Collapse). This had a significant impact on the conditions of air circulation and thus on the ice formation in the Dobšiná Ice Cave. The volume of cave ice is estimated at over 110,000 m^3 (Bella, 2007; Bella and Zelinka, 2018). This ice can be a source of valuable information about the past because it records the environmental and climate changes of the late Holocene. This record is unique and changes over time because the ice mass slowly melts due to geothermal heat from below and increases from above.

The scientific goal of the research is to interpret the age of ice, ice mass increase, and vegetation reconstruction based on the analysis of pollen grains preserved in individual layers of cave ice. An 11-meter ice profile was selected for the study. The ice section is characterized by clearly defined layers. Ten pieces of organic debris (bats remains) were collected from the ice section. They were dated by the radiocarbon method using the AMS technique. The data showed that the oldest organic remain was 1385±30 years BP (605–676 AD). It confirms earlier interpretations that ice in the cave has been forming at the turn of the Dark Ages Period and the Medieval Warm Period (Gradziński et al., 2016). Properly prepared material for pollen analysis was subjected to quantitative and qualitative analysis. These studies have confirmed the presence of pollen grains in cave ice. There have been identified pollen grains of trees and shrubs, such as *Pinus*, *Alnus*, *Betula*, *Quercus*, *Salix*, *Abies*, *Corylus* and herbaceous plants such as *Plantago*, *Artemisia*, Poaceae, Apiaceae, Asteraceae, Cichorioideae. The diversity of pollen grains was observed in individual layers. This may indicate a change in environmental conditions during the formation of the ice massif in the cave.

Therefore, it can be concluded that the analysis of pollen preserved in individual ice layers reflects the vegetation of the region at that time. Thus, it may prove to be a useful tool for reconstructing climate change in the past millennium.

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CRYOGENIC CALCITE IN 15 CAVES OF THE URALS

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When permafrost in karst area thaws in response to climate warming, its upper boundary (and the 0 °C – isotherm) gradually moves down through the rock and eventually it may intersect a cave. At this point in time, a situation occurs where liquid water infiltrating from Earth' surface enters the still-at-subzero temperature cave and freezes inside. Slow freezing of the infiltrating water in small ponds on ice leads to a cryogenic concentration of the residual solution and eventual formation of cryogenic minerals. For caves in carbonate rock, the most abundant mineral phase is calcite; other minerals, such as gypsum, barite and silica are also found, albeit in accessory amounts. (This type of cryogenic mineralization, forming in response to large-scale climate changes is to be distinguished from cryogenic minerals forming in cave areas with dynamic ventilation/heat exchange, in response to seasonal accumulation of cold; the latter type of cryogenic cave minerals will not be discussed here). Dating cryogenic cave calcite (CCC) by U-Th method affords an opportunity to reconstruct changes in the spatial distribution of permafrost on continents over several of the last glacial-interglacial cycles.

Identification of CCC is based on various criteria, including its location in caves (far from cave entrance, where the temperature is constant; occurrence in patches of several m^2 in size; primarily restricted to upward-facing surfaces) and peculiar morphology (individual grains and aggregates are not attached to each other; sizes ranging from several µm to several cm; abundance of crystal splitting; common spherulitic morphologies). Also, CCCs display characteristic stable isotopic properties. Ice, slowly forming from a limited volume of water preferentially incorporates the 'heavy' isotope ^{18}O; accordingly the residual solution becomes enriched with 'light' ^{16}O, and calcite crystallizing from this solution inherits its isotopic signature. Limited degassing of CO_2 from freezing ponds leads to the progressive enrichment of the residual solution, and calcite crystallizing in it, with the 'heavy' ^{13}C isotope. The characteristic isotope trend capturing the advancing CCC crystallization is that of diminishing δ^{18}O and increasing δ^{13}C.

Early works dedicated to CCCs as an indicator of paleoclimatic (paleocryological) conditions were performed in Central Europe. Cryogenic carbonates were studied from ca. 20 caves in Germany, the Czech Republic, Slovakia, Austria, and Poland. The first finding of cryogenic calcite of this type in Russia was made by E. Dorofeev, who had collected calcite samples with an unusual morphology in the Divya cave in the Northern Ural back in 1968. Samples were stored at the Kungur field station of the Mining Institute of the Ural Branch of the Russian Academy of Sciences; the cryogenic origin of this calcite was recognized only in 2014.

A systematic survey of the Ural caves and their screening for CCCs was initiated by the authors in 2012. In Northern Ural, CCCs were found in three caves, including numerous locations in Divya and Mahnevskaya caves on the western slope of the range, and in the Starateley cave on its western slope. U-Th dating of CCCs (22 dates) showed that over the last 500 ka, permafrost in the Northern Urals was present for long periods, punctuated by repeated thaws. Some of the thawing episodes were associated with interglacials: marine isotope stage (MIS) 13 (ca. 482 ka), MIS 9 (ca. 303 ka), Termination III (ca. 243.5 ka), and MIS 5e (Eemian, 128 ka). In addition, thawing was also caused by relatively short-term warming episodes, Greenland interstadials (GI): GI 24 (106–107 ka), GI 23 (ca. 104 ka), GI 21 (85.4 ka), GI 7 (ca. 34 ka), as well as the *Bølling–Allerød* interstadial (13.2 ka), and the beginning of the Holocene (11.8 ka).

In Central Ural, CCCs were found in seven caves: Kizelovskaya (Viasherskaya), Usvinskaya-1, Geologov-3, Tikhaya, Rossiyskaya, Obvalnaya, and Bolshaya Ponyshskaya. According to the U-Th dating (36 dates), the most ancient episodes of permafrost thawing in this region date back to 650–670 ka and 567–595 ka. These ages are at the limit of applicability of the U-Th method, the precision of the dates are low (60–100 ka); accordingly, these most ancient episodes of permafrost thawing cannot be linked to specific warming periods. Later episodes of thawing were recorded at the Termination V (416–435 ka), MIS 9 (295.7 ka), MIS 7 (198–205.1 ka), and the Termination II–Eemian (128.6–130.0 ka). Similarly to the Northern Ural, permafrost also responded to shorter warming episodes of GI 24 (106–107 ka), GI 23 (ca. 102–104 and 98.7 ka), GI 22 (89.4–90.0 ka), GI 20 (75.4 ka), GI 14 (52.5 ka), GI 12 (47.5 ka), GI 7 (35.8 ka), as well as the *Bølling–Allerød* interstadial (13.1 ka), and the beginning of the Holocene (11.7 ka).

In Southern Ural, we have identified five caves with CCCs: Ignatievskaya, Shulgan-Tash (Kapova), Victoria, Grandioznaya, and Smelovskaya. U-Th dates (20 dates) showed that the permafrost affected the Southern Ural during MIS 3 and MIS 2. The permafrost responded (by thawing) to short-term warming episodes of GI 16 (56.0 ka), GI 14 (53.3 ka), GI 12 (46.6 ka), GI 11-GI 10 (41.9–42.3 ka), GI 8 (36.5–38.5 ka), GI 7 (34.4 ka), GI 6 (33.1ka), GI 4 (29 ka), and pre-GI 2 (25.1 ka). The final demise of permafrost only occurred at the beginning of the Holocene (ca. 11.9 ka).

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NEW RADIOCARBON AGES FROM THE ICE BLOCK OF THE VUKUŠIĆ ICE CAVE, VELEBIT MT., CROATIA

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Introduction

Cave ice deposits have a pronounced paleoenvironmental potential in mid-high latitude areas (Perşoiu et al., 2018) based on their geochemical (Perşoiu et al., 2017; Sancho et al., 2018) and biological records (Rygielski et al., 1995; Feurdean et al., 2011; Gradziński et al., 2016; Leunda et al., 2019) archiving variation in climate, vegetation, and hydrology in their surroundings. Geochronological data are essential to link the variations in these geochemical and biological parameters to time.

The Dinaric Karst hosts numerous cavities with perennial ice and snow accumulations (Barović et al., 2018; Buzjak et al., 2018; Temovski, 2018; Nešić and Ćalić, 2018). However, geochronological evidence from the cave ice deposits of this region are very limited (Horvatinčić and Krajcar-Bronić, 1998; Paar et al., 2013; Kern et al., 2018). The northern part of the Velebit Mt. is a prominent range in the Dinaric Karst due to the high spatial density of ice caves (up to 25 ice caves/km^2; Buzjak et al., 2018) frequently delivering new explorations (Bočić et al., 2014). A recent study showed that the ice accumulation of the bottom ice layer in certain cave ice deposits in the Velebit Mt. is older than 1000 years (Kern et al., 2018). A radiocarbon age suggested that the ice accumulation of the Vukušić Ice Cave can be older than 3500 years, however, this suggestion was based on a single ^{14}C age which needs further confirmation. Therefore, additional samples were collected from the Vukušić Ice Cave and subjected to radiocarbon analysis.

Material and method

Site description and sample collection. The Vukušić Ice Cave (Vukušić snježnica, 44.80N, 14.98E, 1470 m a.s.l.) is located near to the Veliki Zavižan peak (1676 m a.s.l.) in the northern part of the Velebit Mt., ~8 km from the Adriatic coast. The Vukušić Ice Cave formed in Middle Jurassic limestone. This shallow cave (rock overburden ~20 m) consists of an entrance and two chambers filled with permanent ice (Fig. 1). These chambers are connected to the upper entrance via a shaft. The length of the cave is 20 m, and its depth, from the upper entrance to the ice level, is 30 m. The thickness of the ice body is not known exactly, however, it is estimated to be >10 m (Kern et al., 2008).

The cave was revisited on 18–19 August 2018. The ice level remarkably lowered (cca 1–1.3 m) since 2008. This has changed significantly the conditions in the cave. In the current conditions, the western side of the main ice block was accessible through a widened lateral crevasse between the ice and the cave wall. This side was inaccessible during former visits, while the north side of the ice block, providing the best approach to the ice profile with numerous organic layers in 2012 (Kern et al., 2018), was completely blocked by collapsed ice.

Three branches were sticking out from the ice at depths of about 2 and 3 m from the recent ice level along the accessed section of the western side of the ice block (Fig. 1). Samples were sawn from these branches. Due to the thick cover (>8–10 cm) of re-frozen ice, it was not clear whether these samples are representative of that depth or have got to their position subsequently. In addition, the deepest sample (DVK-1/18) showed traces of processing with an axe.

Radiocarbon analysis and calibration. Samples were subjected to the standard AAA chemical treatment (Tans and Mook 1980), then they were converted to benzene using an Atomkomplex Prylad-type benzene synthesis line (Skripkin and Kovaliukh, 1998). LSC measurements were performed by a Quantulus 1220™ ultra low-level beta spectrometer at the Radiocarbon Laboratory, University of Szeged. Sample and background activities were calculated using quench curves generated from mixtures containing a different proportion of standard and scintillation cocktail. Conventional radiocarbon ages were determined using the fundamental assumptions of the method. The δ^{13}C value of samples was taken -24±2 ‰ on the basis of Stuiver and Polach (1977). Calibration of 14C dates was performed using OxCal v.4.3.2 (Bronk Ramsey 2009) in conjunction with the IntCal13 dataset (Reimer et al., 2013). Calibrated ages are reported with 95 % probability.

Results and discussion

Benzene output ranged from 1.26 g to 1.36 g (Table 1). Two samples yielded relatively young ages while the third sample yielded a conventional age of 1829±34 ^{14}C BP. Corresponding calibrated ages are <290 cal BP for the young samples while the age of the third sample was well above these and reached 1635 cal BP (Table 1).

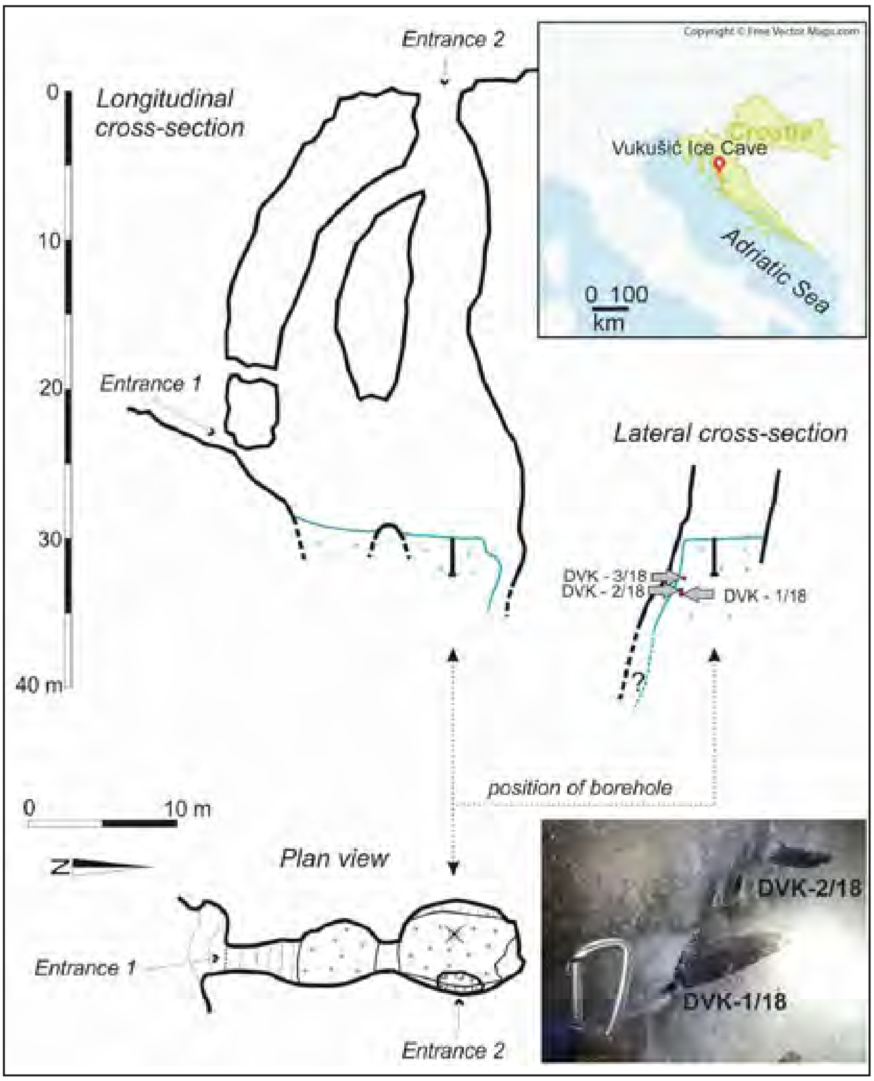

Fig. 1. Map of the Vukušić Ice Cave. The position of the samples is marked on the lateral cross-section. The collection spot of the deeper samples (DVK-1/18, DVK2/18) with a thick cover of congelation ice are shown in the site photo in the lower right corner. Inset map shows the location of the Vukušić Ice Cave in Croatia. Croatia by FreeVectorMaps.com

Regarding the collection depth of the samples, the obtained ages show a contradictory pattern because the samples with young ages were collected ~1 m below the one with the old ^{14}C age. As noted before, signs of human processing were observed on the lowest sample (DVK-1/18). Considering the young ages of the samples collected at the ~3 m depth level (DVK-1/18 and DVK-2/18) it is very likely that their original stratigraphical position does not correspond but rather they are fragments of modern woody debris drifted to the crevasse from the top of the ice block and trapped in the seasonally accreted congelation layer.

A similar situation was observed also in other cave ice deposits. In an ice cave from the Eastern Alps, it was noted that the gap between the host rock and the ice body is a critical zone (Spötl et al., 2014). This gap can widen during melting periods and acts as a trap for organic remains sliding down the lateral slope of the ice body. During subsequent periods of positive mass balances the gap can be closed by young firn and/or congelation ice resulting in complex and possibly inverse stratigraphies when exposed during the next cycle of ice wall retreat (Spötl et al., 2014). Hence radiometric ages of the deeper samples (DVK-1/18, DVK-2/18) are recommended to treat as an outlier if the deposition history of the cave ice deposit is to be reconstructed.

The third sample (DVK-3/18) yielded a much older age (Table 1). It very likely represents an originally entrapped piece of wood in the ice deposit. The age of DVK-3/18 confirms the previously suggested multimillennial age of the lower section of the Vukušić cave ice deposit. Unfortunately, the stratigraphic relationship of the previously dated samples (Kern et al., 2018) to the new set of samples could not be reconstructed due to the changes in the morphology of the ice body.

Table 1. The conventional and calibrated radiocarbon age of wood samples collected in August 2018 from Vukušić Ice Cave.

sample code	depth (m)[a]	Lab code	Benzene yield (g)	C (g)	pMC	^{14}C age (BP) (±1σ)	calibrated (cal BP) (95 % probability)
DVK-1/18	~3	CSZ 133	1.41	1.3	98.19 ±0.96	146 ±32	283–168 (45.7 %) 154–59(33.3 %) 42–1 (16.5 %)
DVK-2/18	~3	CSZ 134	1.47	1.36	98.61 ±0.96	112 ±32	270–186 (31.2 %) 149–11 (64.2 %)
DVK-3/18	~2	CSZ 135	1.37	1.26	79.64 ±0.84	1829 ±34	1865–1696 (93.5 %) 1648–1635 (1.9 %)

a: depth below the 2018 August ice surface

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TESTING CAVE ICE DEPOSITS AS ARCHIVES OF PAST ATMOSPHERIC ^{10}BE DEPOSITION

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Introduction

Depositional records of atmospheric cosmogenic radionuclides play an important role in the reconstruction of fluctuations of the solar activity over millennial timescales (Beer, 2000). However, sedimentary ^{10}Be records reflect partly the local depositional conditions such as precipitation patterns. Therefore, a cross-check of ^{10}Be records obtained from different geographical locations with distinct precipitation regimes is important. To meet this demand, as polar ice cores proved to be invaluable archives of atmospheric ^{10}Be deposition, increasing scientific interest turned to ^{10}Be records of mid-latitude glaciers (Inceoglu et al., 2016). Conversely, while presently surface glaciation

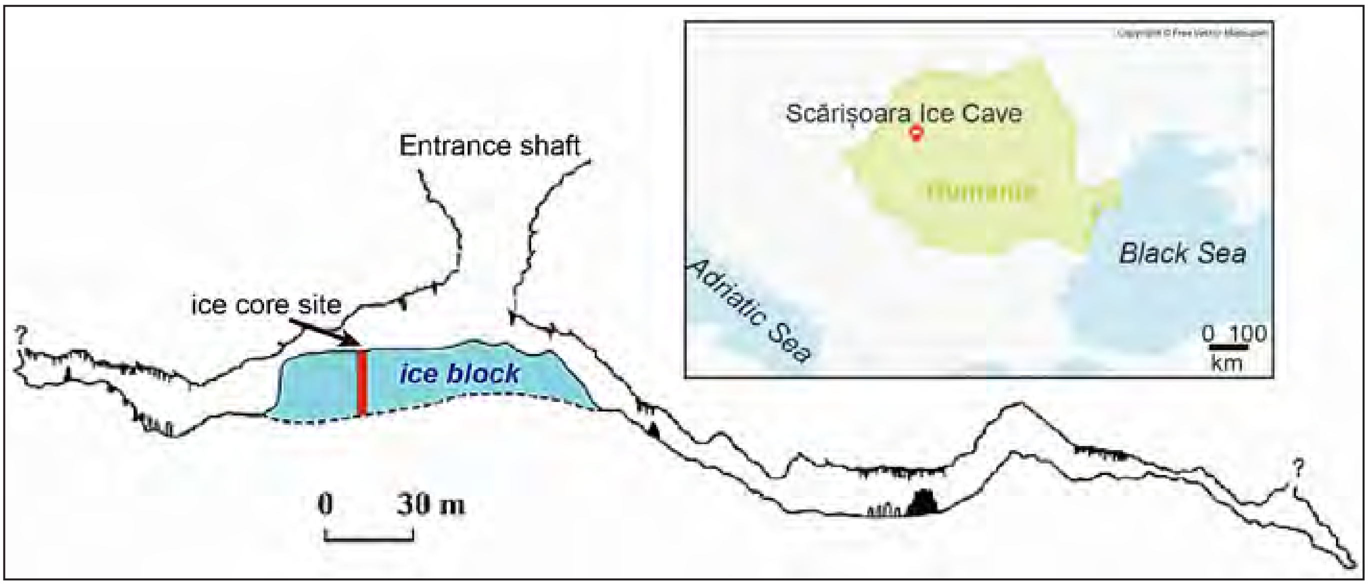

Fig. 1. Cross-section of the Scărişoara Ice Cave. The position of the ice core is marked with a thick vertical line drawn in the ice block. Inset map shows the location of Scărişoara Ice Cave in Romania. Romania by FreeVectorMaps.com.

is mostly absent at mid-latitudes, subterranean glaciation (i.e., ice caves) is a common feature, even on low-elevation karstic areas. Once it forms, cave ice can preserve the deposition record of ^{10}Be similarly to surface ice bodies, so it has the potential to be a useful complementary archive providing comparable records of past atmospheric ^{10}Be deposition.

We present here a record of atmospheric ^{10}Be locked in the millennial old ice deposits from the Scărişoara Ice Cave, Romania. To our knowledge, our project is the very first in measuring atmospherically-produced ^{10}Be in cave ice deposits.

Sampling strategy and methodology

A ~6 m long, 10 cm diameter ice core was extracted from the ice block of the Scărişoara Ice Cave (Apuseni Mts, Romania, Fig. 1) in 2015 in segments each between 5 and 30 cm long. The outer surface of the core was immediately cleaned in the field using sterilized plastic knives, subsequently wrapped in clean plastic bags and stored at temperatures between -20 °C and -40 °C prior to analysis. The ice cores were transported frozen to the Cosmogenic Nuclide Sample Preparation Laboratory in Budapest (http://www.geochem.hu/kozmogen/Lab_en.html) in 2018. Nine ice core sections, each weighing ~300 g, were selected for a pilot study. Radiochemical sample processing including the addition of defined amounts of stable ^{9}Be followed the methodology of Zipf et al. (2016) and was carried out at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR). Accelerator Mass Spectrometry (AMS) measurements of the ^{10}Be/^{9}Be ratio of the samples were also performed there. Data were normalized to SMD-Be-12 (Akhmadaliev et al., 2013), which is traceable to the NIST4325 standard.

The processing and measurement of these pilot samples were successful: all samples provided measurable and distinct ^{10}Be/^{9}Be ratios. The performance of five out of nine samples was excellent. Although the chemical yield of four samples was lower than expected (except for one sample) uncertainties remained below 5 % (range between 2.3 and 5.1 %; mean 3.5 %).

An additional set of nine samples was selected for analysis in 2019, with the aim of using a slightly modified radiochemistry method to achieve increased and more stable chemical yield for all samples and to provide more details of the variations of atmospheric ^{10}Be concentrations along with the core. This sample set was radiochemically processed by the same people but at the University of Vienna. These samples were investigated by AMS out at the Vienna Environmental Research Accelerator (Steier et al., 2019). The data were again normalized to the secondary standard SMD-Be-12 to allow direct comparability between the two datasets.

The age of the ice core was determined by transferring the depth-age model of the Perşoiu et al. (2017) record, based on 26 ^{14}C ages, to the present core. Four ^{14}C measurements of this new core were used as anchor points for the older chronology. The chronological framework has been assigned to the cave ice derived ^{10}Be results following the synchronization of the depth-scales of the two cores.

Results and discussion

Due to successfully-improved chemical preparation, the chemical yield could be increased for all samples, hence, leading to smaller overall uncertainties of the ^{10}Be data of the second sample set (1.9 – 3.6 % [mean 2.7 %]). The measured ^{10}Be/^{9}Be ratio of the samples and processing blanks are in the same range for both sample sets (Fig. 2).

The ^{10}Be concentrations range from (0.52±0.02) × 10^{4} at/g_{ice} to (4.17±0.16) × 10^{4} at/g_{ice} in the combined dataset (Fig. 2). This concentration range is comparable to those found in polar ice cores (Berggren et al., 2009, von Albedyll et al., 2017) but slightly lower than in the high-elevation Asian mountains (Inceoglu et al., 2016).

Based on the ^{14}C measurements, the maximum age of the 6 m core is estimated to be 900 years. The ^{10}Be concentrations of the studied section cover the upper 1.5 m of the ice core and correspond to the ~1630 AD to ~1850 AD time interval.

The main trend in the cave ice derived ^{10}Be concentration mirrors quite well the ^{10}Be concentration profiles obtained from polar ice cores for the same period (von Albedyll et al., 2017; Berggren et al., 2009). The ^{10}Be concentration peak (3.96±0.20) × 10^{4} at/g_{ice}; Fig. 2) in the Dresden data found at the depth range of ~97 – 103 cm below surface corresponding to the late 1680s AD might reflect the Maunder Minimum documented as peak concentration both in the Akademii Nauk ice core (von Albedyll et al., 2017) and the NGRIP ice core (Berggren et al., 2009).

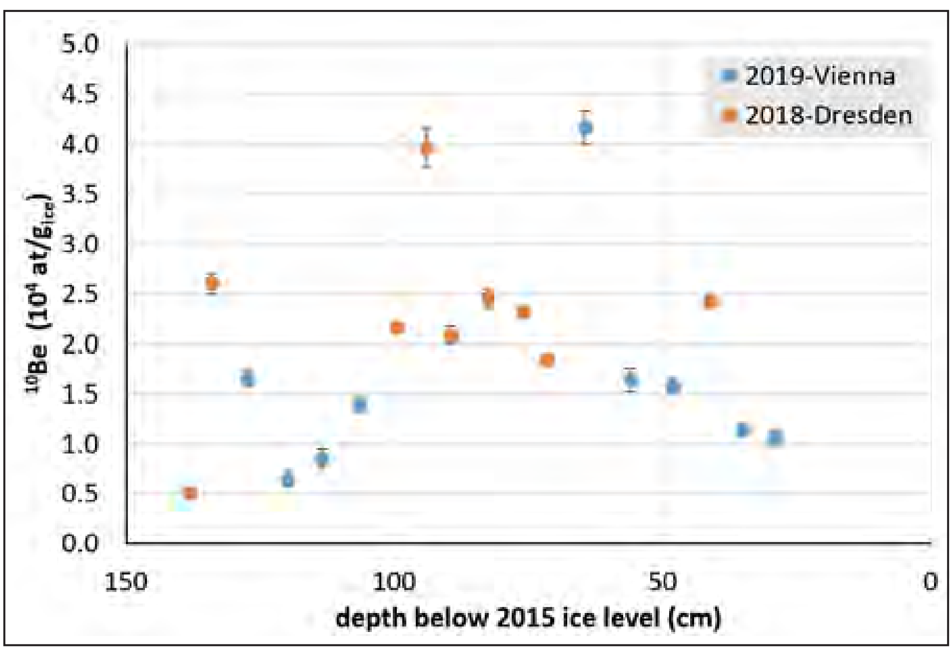

Fig. 2. ^{10}Be concentrations in the upper 150 cm of cave ice deposits of the Scărişoara Ice Cave.

The data looks very promising, but further data evaluation and interpretation are still needed.

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CRYOGENIC CAVE CARBONATES DOCUMENT MUCH MORE EXTENSIVE CAVE ICE AND MULTIPLE THAWING EPISODES IN THE EISRIESENWELT (AUSTRIA) DURING THE LAST GLACIAL PERIOD

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The Eisriesenwelt is a complex cave system with over 40 km of known passages. It has a large lower entrance at an elevation of 1641 m a.s.l., a narrower one at 1838 m a.s.l. and several suspected upper openings on the overlying karst plateau that have not been discovered yet. Due to the presence of multiple entrances, the air circulation of Eisriesenwelt is governed by forced airflow, resulting in large perennial ice deposits in the first ca. 550 m behind the entrance, even though the mean outside annual air temperature at this elevation is about ~4°C. Although the inner passages of the Eisriesenwelt are currently ice-free and show mean temperatures between 1.5 and 2.0°C, the occurrence of coarsely crystalline cryogenic carbonates (CCC coarse) documents that during the past perennial ice was also present deep inside this large cave system.

CCC coarse occurrences have been found in small heaps on and partially beneath breakdown blocks at eight localities, the innermost one being ca. 2.5 km behind the present-day limit of perennial cave ice. CCC coarse crystals and aggregates are up to 5 cm in size, being the largest ones found in the Eastern Alps, and show diverse morphologies from rhombohedral and skeletal crystals to half-spheres and complex aggregates. $\delta^{18}O$ values vary from -29 ‰ to -13 ‰ and $\delta^{13}C$ values range from -1 ‰ to +8 ‰ (both vs. VPDB). Furthermore, stable isotope analyses confirm the presence of cryogenic aragonite at two localities were cryogenic calcite is absent

U-Th dating of 42 samples, the largest database for any ice cave in the Alps, records several episodes of thawing of perennial ice bodies during the last glacial period. The two oldest generations date to MIS 4 (74–73 ka BP) and MIS 3 (54–52 ka BP). The Late Glacial was characterized by several thawing events with the most CCC coarse ages falling into the Allerød and Younger Dryas. None of the samples is Holocene in age, suggesting that wide-spread perennial ice disappeared from the inner parts of the Eisriesenwelt by the end of the Younger Dryas.

Our results document the former presence of cave ice deep inside the Eisriesenwelt since at least 74 ka BP with the abundant formation of cryogenic carbonates during the Late Glacial. While this calls for cooling of even remote parts of this large cave system by at least about 2°C relative to today, the available CCC coarse data demonstrate that thawing events are not related to climate change in a straightforward manner. In fact, there is evidence for the thawing of former ice bodies both during warm intervals such as the Bølling-Allerød and during cold ones such as the Younger Dryas or Greenland stadial 20. This complex pattern is attributed to two processes: (a) the Eisriesenwelt is a large and mostly horizontal cave system with thick overburden and its interior cave air temperature was apparently close to the freezing point during the last glacial period as shown by multiple CCC coarse samples. In other words, this ice was highly sensitive to even small changes in temperature. (b) Such small changes do not necessarily require an outside climate forcing but could have been the result of changes in the pathway and intensity of airflow within this complex cave system. For example, a passage in today's ice-bearing part is known to have been nearly closed by ice a century ago and has opened up since then. Such ice plugs could also have formed in other, currently ice-free parts of the cave, severely affecting the airflow and hence the extent of winter cooling, giving rise to thawing in different parts of the cave and at different times.

It is worth mentioning that only CCC fine is presently forming in today's ice-bearing part, reflecting the pronounced seasonally changing microclimate within the first half kilometer behind the lower cave entrance, which precludes CCC coarse formation.

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UPDATE TO MAPPING OF PERMAFROST IN CRYOGENIC CAVE INDICATORS

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In Slovak caves, we observe various cryogenic phenomena whose origin is related to the permafrost. We provide an update on previous research of Orvošová et al. (2013, 2015). We are mapping the presence of these indicators: cryogenic cave carbonates (CCC), broken stalagmites (BS), broken flowstones (BF), and ice attachments (AI).

The CCC (Žák et al., 2004) are accepted as a tool to detect the presence of ice monolith in the zone of past permafrost. To date, we have collected CCC from 27 localities over large areas of Slovakia. The depth of CCC accumulations is from 20 m (Četníkova jaskyňa Cave) to 285 m (Mesačný tieň Cave) below the surface. The most accumulations we found in Zlomiská Cave, 44 accumulations in depth from 25 to 120 m.

The BS (Luhová et al., 2016) are always found nearby the CCC occurrences, but also in many places without the CCC. They are believed to be broken by ice flow or contraction, the diameter of BS often exceeds 0.5 m. Their fragments are usually scattered on the ground, or partly moved from their base, often with antigravity shift, and now they are cemented to it by a new flowstone. We have sampled special case of BS where the older broken stalagmite is discordantly overgrown by a new phase, often with color contrast. U/Th dated stable isotope profiles suggest that breaking occurred after the buildup of permafrost and before deglaciation about 15 Ka BP. In total, we found BS in 28 caves.

The BF often occur on cave floors, they were cracked by ice, often forming a polygonal mosaic. The thickness of BF is from cm to 0.75 m. The cracks are sometimes sealed by new flowstone, with the same color contrast as overgrown BS (5 localities).

IA represents fragments of speleothems or wall rocks, that were cemented to the inclined substrate in a labile position with the support of ice. This is the scarcest indicator and occurs in 7 caves.

To date, we have recorded and/or sampled 38 occurrences of cryogenic indicators in caves of the Slovak mountains. All they occur north of the line Smolenice – Prievidza – Banská Bystrica – Tisovec – Dobšiná – Tatra Mts., at altitudes 680–1678 m a.s.l. with one exceptional occurrence at 335 m a.s.l. These limits may represent the boundaries of (discontinuous) permafrost at the time of LGM.

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CHEMICAL AND PHYSICAL STRATIGRAPHY OF THE SCHELLENBERGER EISHOLE ICE CORE

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In October 2016 an 8 m depth ice core was drilled in the Schellenberger ice cave (Bavaria, Germany) for the reconstruction of the glacio-chemical records. Major anions and cations were measured to characterize the chemical deposition of the top 8 m of the hypogean glacier to characterize the topmost part of the 900 m depth cave in the Unterberg Massif in southern Bavaria. Visual stratigraphy by ice thin sections permits to evaluate the accumulation mechanism of the topmost part of the ice deposit, showing alternation of clearly snow metamorphism and water pond freezing for the entire 8 m depth. Small tree remains (leaves and wood) and some mineral dust layers with thickness from 0.5 to 4 cm were also observed in the ice core. Radiocarbon dating was done to understand the age/depth relationship of the uppermost part of the Schellenberger ice deposit. A complete record of major ions, conductibility, and pH was reconstructed to understand the possible influence of the natural and anthropogenic impact on the ice deposit.

CAVE SYSTEM OF THE SOUTHERN INYLTCHEK GLACIER

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Since 1980th cave explorers of the former USSR planned to spend speleological expedition on the Southern Inyltchek Glacier – one of the largest glaciers of the Tien Shan (Kyrgyzstan). The glacier has a length of more than 60 km and a width of 2–2,5 km. Cave explorers were interested in the drainage channel with length about 14 km through which once a year, the water of glacier-dammed Mertsbakher Lake flows inside ice to glacier tongue. As during outburst of the lake water stream discharge reached 1000 m^3c^{-1}, it is clear that the arising drainage channel should have an impressive size. And as the channel penetrates the existing central internal drainage network of the glacier, the general extent of cave channels could be much more sizable. Since 1992 different speleo-groups tried to penetrate this channel. As all cavities in a glacier were strongly watered in the summer, all expeditions to glacial caves were spent in autumn, winter, or spring when it is not or not enough quantity of current water on the glacier. Attempts to penetrate the drainage system from different places were undertaken: through the cave on glacier tongue, through moulins closely to Mertsbakher Lake, and through possible cave channels from the lakeside. Penetration from glacier tongue terminated in failure as the channel or quickly closed by roof collapse or has been filled by water. There are data of the channel length in different years about 300 and 800 m. But as topo survey in both cases was absent these data raise the big doubts. Attempts to penetrate the cave system of a glacier closely to Mertsbakher Lake also have not been successful. In different years through moulins, it was possible to go down in ice on different depths from 30 to 105 m. And in all cases in deepest moulins, the channel was finished by lakes. The exception was a find of dead moulins that have no continuation. As the thickness of a glacier in this area changes from 150 to 200 m, it means the glacier drainage system is englacial or drainage system in a cold season dammed and all bottom part of channels was filled by water. Winter drainage of many superficial lakes speaks for this assumption. There were some attempts to find drainage channel entrance from the Mertsbakher Lake but they also been unsuccessful. In the summer of 1991, after lake outburst in its southwest edge already after lowering of an ice dam noise of falling water was heard. However, there was no access to this place because of ice blockage. And in other cases, the penetration of the former channel was not permitted due to ice blockages or the lake filling that spoke about the full closing of the channel existing earlier.

Except for the central drain of the Southern Inyltchek Glacier, there are fragments of marginal channels at its both flanks. But marginal caves have no connection with the central drainage system.

In November 2019 the international group in which staff there were cave explorers from France, Italy, Canada, Russia, and Indonesia, the next attempt to penetrate the cave system of the glacier and waterway from Mertsbakher Lake was undertaken. In spite of the fact that some interesting cavities were found, the penetration of the drainage system was not possible. Some moulins were studied up to depth about 100 m. As some of the cavities at the bottom have lakes there is a desire to try to use divers for the study of them. Perhaps with the help of divers, it will be possible to find out the continuation of moulins and to penetrate the general drainage system of the glacier. The cave system of the Southern Inyltchek Glacier still waits for the pioneers.

TESTING OF A NOVEL MEASURING METHODOLOGY – THE LOGGERNET EXPERIMENT

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In the context of changing climate conditions, ice caves are facing strong melting processes. This is a challenge for ice cave research activities to study this rather unknown part of the subsurface cryosphere in detail before all information is lost. There is a main focus on the processes and dynamics of the subsurface ice bodies in both static and dynamic ice caves. But understanding the specific ice caves climate, the course of the air temperature as well as the airflow regime, and how it is influenced by the exterior atmosphere or how the external temperature signal is transferred into the cave, is still a major issue in ice cave climate research.

During our research activities at the Schellenberger Eishöhle (e.g., Meyer et al., 2014) we began to develop a mathematical approach to clarify open questions and verify hypotheses developed during standard data analysis before. As a consequence of limited energy supply for measuring instruments at this remote study site, we decided to enhance the possibilities to use the given database. The starting was the calcFlow-method for calculating airflow by using air temperature measurements. In this presentation, we present the first results of the testing of a novel measuring methodology based on the calcFlow-method (Meyer et al., 2016), the loggernet experiment. With the calcflow-method, we acquired more detailed knowledge on the transport of the external temperature signal into the cave. For the loggernet-measurements, we use these results and the mathematical model to study the energy exchange through the airflow during the open period of our static ice cave. For the measuring setup, two whole cross-sections at the Schellenberger Eishöhle were equipped with temperature sensors each 30 cm. These sensors measured air temperature in 30 seconds intervals for almost one week, until the memory space of the logger was full. We were lucky that during this time we could record the change between closed and open period and a complete open period. For the analysis of this experiment, we applied calcFlow between a reference sensor and all other sensors of a single net and between both crosssections in order to define the inflowing respectively the outflowing parts of the cross-section. The further computing process will be presented in the presentation. The aim is to compute the energy balance for the cave passage between the two cross-sections on the basis of the temperature differences between them and the air velocities.

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2300 YEARS OF ICE

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The layered ice body in Dobšiná Ice Cave (DIC) is an excellent archive of frozen rainwater, covering several centuries of the historic period. Its parts with monotonous stratigraphy are ideal for high-resolution study of past climate – a high-priority task considering the rarity of cave ice bodies with a long memory and danger of their vanishing with climatic warming.

We traced ice layers across the cave to find a section with the oldest ice, in order to draw a long isotopic profile in a single exposed wall. Totally 1377 cm of ice was sampled in hall 'Pod malou oponou' at 1cm resolution in March to May 2018. Rainwater was sampled at DIC and in Banská Bystrica and measured along with the ice for stable H and O isotope composition. Back-trajectories of air-mass parcels with sampled precipitation were calculated using HYSPLIT tool (NOAA) and processed in R-language. Bat guano for 14C dating was drilled from ice in the same profile, each dating point spanning 5–10 cm, age model was constructed using Bayesian interpolation.

The age range of the measured profile is 2326 to 577 BP, i.e. 376 BC to 1373 AD. The oldest ice in the cave is more than one millennium older than the previous three datings (Gradziński et al., 2016; Clausen et al., 2007). The deposition rate was ca 2.19 cm/y between AD 800 and 1300 (approx. Medieval Warm Period, MWP), contrasting with much lower rates during the preceding Dark Ages Cold Period and subsequent XII-XIV centuries (0.52 and 0.85 cm/y, respectively). High accumulation rate during MWP likely follows from increased precipitation in winter and spring when ice in DIC grows. A slow deposition may be also secondary due to sublimation in harsh winters when cold dry air invades the cave.

Stable H and O isotopes covariate along Global Meteoric Water Line in a compact field (δD / $\delta^{18}O$ = 65 to 45 ‰ / 9.5 to 5.3 ‰ SMOW), averaging much wider range of δD and $\delta^{18}O$ in precipitation (δD / $\delta^{18}O$ = 225 to +20 ‰ / 29.5 to +8.2 ‰ SMOW), with no significant departure, thus representing the real precipitation. Variability of isotope composition from XII to XIV centuries shows a loose periodicity of ca. 25 years. Considering i) the ice growth in DIC exclusively in winter and spring months, ii) large isotope contrast between winter and spring precipitation (33 ‰ δD / 4.5 ‰ $\delta^{18}O$), and iii) unclear influence of moisture origin, we tentatively attribute the isotope variations in profile to the ratio of winter vs. spring precipitation.

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FRACTIONATION TRENDS IN CRYOGENIC CALCITE

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The cryogenic cave carbonates (CCC) are considered as a reliable indicator of cave glaciation formed upon thawing of permafrost during past glacials (Žák et al., 2004). The calcite and aragonite with anomalously light oxygen and heavy carbon and variety of unusual crystal shapes precipitated from supersaturated solution within freezing ice, i.e. in a closed system. Our goal is to find correlations between crystal forms, chemical and isotopic composition, and stage in growth succession.

Morphology of CCC crystals was studied by optical and electron microscopy, chemical composition was determined using an electron microprobe, stable C and O isotopes were measured by mass spectrometry, $CaCO_3$ polymorphism, structural disorder, and presence of substituting ions were studied by Raman spectroscopy.

Crystallization successions were established by common petrographic criteria. CCC crystal habitus evolves in direction: skeletal rhombs – concave rhombs with corner-preferred growth – convex rhombs with face preferred growth – spheroids – aragonite spheroids. This succession is closely followed by stable isotope trend towards lighter oxygen and heavier carbon, in accordance with closed system crystallization during freezing-out of a large amount of water. The span of isotope values is narrow in small halls (2–6 ‰ for both C and O) and wide in large halls (up to 10 and 15 ‰ for C and O, respectively).

Crystals of all the stages are in fact syntaxial aggregates of smaller crystallites with a fractal size distribution, macroscopic crystal faces consist of imbricated single crystallites (5–10 μm) and do not match their orientation. In the first two stages, the crystals are usually clear with parallel single crystallites, in the next stages, progressive rotation of domains causes milky-white color and split ends along the c-axis, resulting in a dumbbell shape. Such fan-shaped ends later dominate and original rhombohedra turn into spheroids. At each stage, the crystal individuals may nucleate, or grow syntaxially on the previous phase, forming complex metacrystals.

Most abundant trace elements believed to influence the crystal morphologies are Mg (up to 1.6 wt. %), Sr (0.5 %), S (0.8 %), and Si (3.6 %), their concentrations rise along the growth succession and isotope fractionation trend. Increasing structural disorder in this trend is expressed in wider Raman peaks, yet without their shifts or splitting. Mg and Sr anticorrelate with Ca, for which they substitute. Sulfur usually anticorrelates with Mg and it has a distinct Raman band of SO_4^{2-} group. Silicon is not pronounced in Raman spectra in the form of SiO_4 tetrahedral vibrations, thus we suppose it substitutes for Ca cation, which vibrates in Raman-inactive mode. These assumptions will be further verified by FTIR and electron diffraction.

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GEOCHEMISTRY AND ISOTOPIC COMPOSITION OF PERENNIAL ICE AND CCCS IN THE WINTER WONDERLAND CAVE, UINTA MOUNTAINS, UTAH, USA

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The Winter Wonderland Cave is a solution cave at an elevation of 3140 m above sea level in Carboniferous-age Madison Limestone on the southern slope of the Uinta Mountains (Utah, USA). Temperature dataloggers reveal that the mean air temperature in the main part of the cave is -0.75°C, whereas the entrance chamber has a mean annual temperature of -2.3°C. The average air temperature outside the cave entrance was +2.8°C between August 2016 and August 2018. The temperature in excess of 0°C was not recorded inside the cave during that 2-year interval. About half of the accessible cave, which has a known length of 245 m, is floored by perennial ice. Ground-penetrating radar surveys with a 400-MHz antenna reveal that this ice has a maximum thickness of ~3 m. GPR results also suggest that the ice mass in the entrance chamber consists of younger ice unconformably overlying an older ice body. Six samples of packrat (*Neotoma*) droppings obtained from the ice in the main part of the cave yielded radiocarbon ages from 40 ± 30 to 285±12 years. These ages exhibit multiple possible calibration ranges, but the median values of the ranges with the greatest probability range from AD 1645 to 1865 providing a minimum limit for the age of the underlying ice. In visits during the summer of 2014 and 2016, the surface of the ice exhibited furrows and ridges with local relief in excess of 20 cm running parallel to the main cave passage. There were presumably formed by sublimation driven by air movement over the ice surface. In contrast, at some point prior to August visits in the summers of 2018 and 2019, liquid water had entered the cave from the rear, flooding over the older ice and freezing to form a new, smoother surface. As a result, the locations of formerly deeper furrows were occupied by isolated pools of water covered with lids of ice. Water samples from these pools are highly enriched, with concentrations of Ca, K, and Mg in excess of 200 ppm. Ice samples (n=84) collected from a ~2 m high exposure at the rear of the cave were analyzed for stable isotopes and glaciochemistry. Values of $\delta^{18}O$ range from -8.6 ‰ to -16.2 ‰, with a mean of -13.8 ‰. Values of δD range from -64.1 ‰ to -118.8 ‰, with a mean of -103.4 ‰. All samples plot on the local water line for winter precipitation and a linear trend fit to these data yields a slope of 7.4 and an intercept of -1.3 ‰. Values for both $\delta^{18}O$ and δD are lowest at the bottom of the exposure and highest at the top. Visual banding in the ice, reflecting concentrations of mineral precipitates, locally correspond with shifts in isotope values, but not in all cases. Calcium has the highest average abundance of cations detectable in the ice (mean of 6050 ppb), followed by Al (2270 ppb), Mg (830 ppb), and K (690 ppb). The surface of the ice is mantled by abundant cryogenic carbonate precipitates (CCCs) with a mean grain size of 30 μm ranging in color from dirty white to orange-brown. Under magnification, these are resolved as planar rafts and botryoidal aggregates of spherical bodies. Stable isotope values in these CCCs range from +1 to +6 for $\delta^{13}C$ and -6 to -21 for $\delta^{18}O$. In contrast, values in the host rock average 2 ‰ for $\delta^{13}C$ and -6 ‰ for $\delta^{18}O$. Although they are finer-grained, the CCCs with the most depleted values of $\delta^{18}O$, therefore, resemble CCC-coarse reported from Alpine caves; the less depleted CCCs are consistent with CCC-fine formed through open-system freezing.

EVIDENCE FOR PACIFIC- AND MONSOON-SOURCED PRECIPITATION VARIABILITY FROM ICE DEPOSITS IN LAVA TUBES (NEW MEXICO, USA)

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The Zuni-Bandera basalt field in western New Mexico (USA), includes lava flows that accumulated from eruptions that occurred between 100,000 to 3000 years ago. El Malpais National Monument (EMNM) encompasses many of these basalt flows in which over 140 lava tube caves have formed. The roof of several of these tubes collapsed providing access to impressive linear or sinuous passages with diameters averaging 10−12 m. Although the galleries are at shallow depths (3−15 m) below surface, all lava tubes with vertical entrances tend to trap cold air during winter becoming natural refrigerators in which perennial ice deposits accumulate. These phenomenon is amplified by the high altitude (over 2000 m) at which the lava tubes within the EMNM are situated. During summer, the cave air is colder and denser than the surface air (warmer/lighter), thus ventilation ceases and the cave temperature remains at, or below 0 °C. The air circulation resumes only in late fall when outside temperature drops below the inside one.

Cave ice builds up from Pacific-sourced rainfall and snow melted water characterized by negative $\delta^{18}O$ values (−9 to −12 ‰) that enter the cave between early winter and late spring, respectively. The summer monsoon-derived precipitations (originating in the Golf of Mexico and California) in the region are characterized by more positive, −8 to −5 ‰ $\delta^{18}O$ values. After major storms, the percolation water reaching the caves melts the topmost ice layer forming a temporarily lake whose water freezes in late fall. Thus, the isotopic signature of cave ice in the southwestern USA can be used to trace the source moisture and qualitatively, its contribution back in time.

The present study focusses on a congelation ice deposit (about 2−2.5 m in thickness) identified in lava tube name Cave 29. Samples for preliminary stable isotope (δ^2H and $\delta^{18}O$) analyses were collected every two centimeters from the upper 50 cm of this ice block. The $\delta^{18}O$ values range between −9.5 and −6.5 ‰, suggesting changes in the source/contribution of moisture arriving either from the Pacific Ocean or the Gulf of Mexico. Fragments of charcoal recovered from various depths in the ice were dated by means of accelerator mass-spectrometry radiocarbon (^{14}C). We interpret the ages to reflect periods when forest fire and human activities happened around or in the cave and not necessarily the exact timing of ice accumulation. Based on ^{14}C ages, the deepest analyzed sample could be as old as AD 165, whereas the top ice layer cannot be younger than AD 930.

The $\delta^{18}O$ time series of ice from Cave 29 exhibits two clear trends between the end samples of the core. The values are becoming progressively more negative between ~AD 165 and ~775 (min. −9.3 ‰) and than start to increase rather abruptly reaching a maximum of −6.5 ‰ at ~AD 931. Similar isotopic trends were noticed in speleothems from southern Arizona and eastern New Mexico. This implies that for almost 600 years the precipitations in the EMNM region were dominantly of Pacific origin, suggesting predominantly cold and wet winters in the southwestern USA under El Niño conditions. Instead the upper part of the ice block records more ^{18}O-enriched water, interpreted to indicate a strengthening of the monsoon and thus more summer rainfall reaching the cave area. This major hydroclimate change could have been controlled by the increase of temperature in the Northern Hemisphere. As a consequence, the Atlantic Multidecadal Oscillation entered in a positive state, known to cause above normal drought conditions throughout the southwestern USA.

Archaeological investigations pointed out the presence of Acoma and Zuni tribes in the area from around AD 800. However, if any of the charcoal samples recovered from ice comes from melting activities to obtain dinking water during hot summers, then the Ancestral Puebloan might have settled in the EMNM area as early as AD 150. Thus, this study also tries to relate the presence of this population with the hydroclimatic conditions (mainly drought) inferred from ice.

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MINERALOGICAL AND PALEOCLIMATIC SIGNIFICANCE OF CAVE ICE DEPOSITS: A REVIEW

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Cave deposits (speleothem, ice, and guano) are unique repositories for paleoclimatic information as they are well protected from destructive processes acting on the surface. Because karst is regionally widespread, climatic data from speleothems have been extensively used over the past three decades to reconstruct environmental conditions and to test space and time-dependent climate processes. A handful of caves worldwide host perennial ice deposits, which are the lesser-known and investigated members of the cryosphere (i.e., the frozen water part of the Earth system). Often, these caves occur at elevations well below those of mountain glaciers and in areas outside the perennial permafrost climatic belt, where no surface glaciation exists. At the same, some caves or lava tubes are located at low latitudes (15 to 35 °N), but at altitudes above 2000 or even 3000 m, a fact that allows ice to build perennial deposits. These deposits hosted under these latter settings are particularly susceptible to melt under the current global warming trend.

The critical condition for ice to build up is that a cooling mechanism, responsible for maintaining the underground temperature at or below freezing, exists. In caves, this can be achieved if they are located in permafrost regions, act as cold or snow traps, or have unidirectional ventilation that causes evaporative cooling to occur. Once one or a combination of these mechanisms are operational, freezing of percolating or snowmelt water induce ice accumulation in caves. To a lesser degree, snow diagenesis (via firn) and sublimation of moisture could also contribute to the total cave ice budget. The incremental thickening over time usually produces large layered cave ice deposits, of whose chronologies, likewise those in the ice sheets and alpine ice caps can be produced by annual-lamina counting. If the ice block structure is less evident, an accurate age-depth model (for the last 10.000 years) is generated using radiocarbon (^{14}C) measurements on organics trapped in the ice. The age of more recent ice deposits (200 years or less) can be established using the short-lived radioactive isotopes ^3H, ^{137}Cs, or ^{210}Pb.

The type of minerals precipitated in limestone ice caves depends on the meroclimate zone. In the periglacial part, where seasonal thawing of ice occurs when temperatures are slightly over 0°C, the most common minerals are calcite, dolomite, and monohydrocalcite ($CaCO_3{\cdot}H_2O$). The latter one usually forms in areas with abundant aerosols generated at the impact of drip water with cave floor or a speleothem. In the glacial zone, where cave air temperature remains below 0 °C, a variety of carbonates are cryogenically precipitated from percolating solutions via rapid or slow freezing. These genetic processes produce either fine (<1 mm) or coarse (>1 mm) crystals and aggregates. The two groups not only differ morphologically, but their isotopic signature ($\delta^{13}C$, $\delta^{18}O$) is also highly characteristic. Depending on the genesis, cave settings, and the isotope fractionation mechanism, the stable isotope composition of cryogenic carbonates fall into three distinct fields, all significantly different from the one that is typical for secondary carbonates precipitated in non-iced caves.

Ikaite, a rare metastable carbonate ($CaCO_3{\cdot}6H_2O$) was positively identified in a handful of ice caves, and at least in Scărişoara (Romania), glendonite aggregates (calcite pseudomorphs after ikaite) were also documented.

Gypsum, as expected, is the dominant mineral phase in gypsum ice caves. The morphology varies with the meroclimate zone of the cave; as such, in the glacial part it occurs as fine-grained powder, sometimes admixed with calcite, dolomite, and other sulfates (e.g., celestine and barite). Sublimation appears to be the main genetic process responsible for the accumulation of cryogenic minerals in the glacial part of gypsum caves. In the periglacial zone, gypsum forms larger aggregates and crystals (sometimes thick crusts). Fibrous sulfates such as mirabilite and blödite precipitate out of the loose sediments covering the cave floor during winter and summertime, respectively. At least two boron minerals (ulexite and inayite) were reported, but they are not primary cryogenic in origin, but freezing plays a role in pre-concentrating the solutions.

Perennial ice deposits in caves contribute significant information needed to decipher past climate and environmental changes at locations where other archives are absent or cover limited time periods. This is because cave ice accumulation and its characteristics are directly linked with Earth's atmosphere and hydrosphere. By far, the most important paleoclimatic data (e.g., amount and composition of meteoric precipitation, air temperature, changes of moisture sources indicating past atmospheric dynamic, etc.) comes from analyzing the stable isotope composition (hydrogen and oxygen) of cave ice layers. The investigation of organic matter (pollen, plant microfossils, and charcoal) trapped within the ice is another source of information that allows reconstructing vegetation dynamics and fire history near the cave entrance. The results of geochemical analysis (major and trace elements) on ice cores are used to identify pollution caused by early mining activities and to infer past changes in local and regional atmospheric circulation.

The presence of cryogenic carbonates, broken speleothems, and sorted sediment patterns, especially when they occur in non-iced caves, are important proxies for recognizing the extent of paleo-permafrost conditions. Due to its limited field of stability, ikaite may serve as a paleothermometer for near-freezing water temperatures. Future work on this mineral may shed light on the relationship between the oxygen isotope values in the ice layers and ikaite's temperature-restricted field of formation. Once this correlation is established, we can exploit the potential of $\delta^{18}O$ in its hydration water to cross-calibrate with the $\delta^{18}O$ obtained from ice layers that contain ikaite.

While all these analyses offer exceptionally important information on their own, the better approach is to use a multi-proxy approach, in which several indicators are used in conjunction to infer a better image of past climatic, environmental and anthropic changes (e.g., chemical analyses could yield information on past pollution, while d-excess analyses could indicate the potential direction of the prevailing winds and thus the source of moisture and/or pollution).

INVERTEBRATES OF THE DOBŠINÁ ICE CAVE AND STRATENÁ CAVE SYSTEM (SLOVAK PARADISE, SLOVAKIA)

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In the cave system of the Stratená Cave 176 invertebrate taxa were identified, while 65 species are known in the Dobšiná Ice Cave. The cave entrances of the entire system are situated on the slopes covered by a mountain spruce forest. The parietal fauna of entrance sections of the Stratená and Psie diery caves consists of a rich dipteran community. The collapsed doline at the entrance of the Dobšiná Ice Cave is the peculiar inverse habitat. It is an important site of several cold-adapted species of the soil fauna. The shallow soil profile at the entrance of the Dobšiná Ice Cave is occupied by recently discovered springtail *Megalothorax dobsinensis*. Its occurrence is limited exclusively to the cold and wet parts of the entrance microclimatic gradient. The cave sections with a permanent glaciation are the poorest in terms of species diversity. Only 4 species were recorded, two of them are the obligate cave springtails *Deuteraphorura kratochvili* and *Protaphorura janosik*. *P. janosik* is a characteristic species of the whole cave system, occasionally with higher population density on the ice surface. Unglaciated parts of the Dobšiná Ice Cave and Stratená Cave System represent an environment with microclimatically more balanced regime with the air temperature between 3–6°C. These parts are the habitat of troglobiotic and eutroglophilic invertebrates such as mites *Pantelozetes cavaticus* and *Cyrtolaelaps mucronatus*, springtails *Pygmarrhopalites aggtelekiensis* and *Megalothorax carpaticus*, isopod *Mesoniscus graniger* and millipede *Allorhiscosoma sphinx*. The Stratená Cave is *locus typicus* of troglobiotic mite *Foveacheles troglodyta* (family Rhagidiidae). The cave system is characteristic of numerous habitats with standing water. For its macroscopic dimensions, *Niphargus tatrensis* is the most striking stygobiotic crustacean in the Stratená Cave System. Another typical aquatic fauna is represented by small crustaceans *Elaphoidella* sp. and *Bathynella natans* occupying pools in unglaciated parts of the Dobšiná Ice Cave. The presence of highly adapted terrestrial and aquatic cave invertebrates, some of them classified as glacial relicts, indicates the stable environmental conditions of the Dobšiná Ice Cave despite its long-term exploitation as a tourist cave.

CONSTRAINTS ON AN EASTERN MEDITERRANEAN ICE-CAVE TEMPERATURE VARIABILITY: THE CHIONOTRYPA CAVE IN GREECE

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The Chionotrypa Cave (CC) is a 111 m deep alpine cave located at 2080 m a.s.l. at the Falakro Mountain, Northern Greece (Pennos et al., 2018). The cave is accessible through a 50 m wide, 65 m deep shaft, that allows a large amount of snow to accumulate at its base during wintertime. A small opening in the ice approximately 3 m high, 7 m wide close to the eastern wall of the shaft allows access at the lower chambers of the CC. At the bottom of the shaft continuing through the opening, a ca. 30 m snow and ice deposit have accumulated. The upper part of the deposit (~3 m) consists of compacted snow, while the lower part is solid, layered ice, incorporating rocks and organic matter from the surface.

In August 2018, three data loggers (Gemini Tynitag 2) were installed along a vertical profile through the glaciated part of the cave, recording air temperature and relative humidity with an hourly resolution. A fourth data logger was placed in the ice block, at a depth 80 m below the surface to record ice temperature fluctuations with the same resolution. Our goal was to understand the effect of the external temperature variations on the cave temperature and the control on the ice cave mass.

Here we present the results of ice and air temperature measurements between July 2018 and September 2019. CC is a typical snow trap and air temperature variations follow those at the exterior as long as $T_{ext}<T_{int}$ (and below 0 °C) leading to cold air inflow inside the cave. This inflow occurs on time spans between 1–3 hours, being shortest when the temperature amplitude is largest, and *vice versa.* During summer, air temperatures inside the cave are close to 0°C, as a result of slow snow melting and heat absorption during the process. The maximum amplitude of T variations decreases with increased distance from the entrance. Short term variability of T inside the ice mass follows that in the air with no delay (<1 h), suggesting that, contrary to ice formed by the freezing of water, those formed through snow diagenesis allows for a faster transfer of heat.

Our preliminary data suggest that the temperature inside CC has a complex response to external temperature variations and thus the future sustainability of the underground glacier is more difficult to predict compared to surface glaciers.

STABLE ISOTOPES IN CAVE ICE INDICATE SUMMER AND WINTER TEMPERATURES HAD DIFFERENT TRAJECTORIES DURING THE LAST 1000 YEARS

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The climate of East-Central Europe (ECE) is the result of the combination of influences originating in the wider North Atlantic realm, the Mediterranean Sea and Western Asia/Siberia. While some of these influences act throughout the year, others are only active during the summer (e.g., Atlantic Multidecadal Oscillation) or winter (e.g., North Atlantic Oscillation), resulting in a complex picture of climate variability. To understand this variability, precisely disentangled summer and winter climate reconstructions are required. We address this topic by presenting here two high resolution, precisely dated records of winter and summer temperature variations during the last millennium in ECE, based on the stable isotopic analysis performed on ice cores extracted from the Scărişoara Ice Cave and Focul Viu Ice Cave (Western Romanian Carpathians). The data shows little summer temperature differences over the past millennium, but with minima likely occurring during periods of low solar activity. Contrary, winter temperatures were generally high during the Medieval Warm Period and generally low during the subsequent Little Ice Age. Further, summer temperatures fluctuated with a periodicity similar to that of the Atlantic Multidecadal Oscillation, while winter ones were similar to those of Central Asia, controlled by the strength of the Siberian High. Overall, our data suggest that climate variability in Europe during the past 1000 years was likely controlled by winter air temperature changes on centennial scales, while on the decadal-scale, dynamics of the AMO and NAO likely resulted in changes of similar amplitude during both summer and winter.

ACCELERATED LOSS OF CAVE ICE IN SE EUROPE RELATED TO HEAVY SUMMER RAINS

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The recent *IPCC Special Report on the ocean and cryosphere in a changing climate* highlighted the worldwide shrinking of the cryosphere, with ice sheets, mountain glaciers, snow cover and Arctic sea ice all losing mass. Small glaciers are most impacted by this recent melting, climate scenarios suggesting losses up to 80 % by the end of this century for glaciers in several regions, including Central Europe. The cited IPCC report does not include information on the dynamics of perennial ice accumulations in caves. Whereas ice loss in surface glaciers is mostly due to melting related to rising temperatures, cave ice ablation is mostly due to drip water delivering heat to the ice and secondary to rising temperatures. Consequently, whereas the projected increase in air temperature in mountain areas would result in an enhanced mass loss for surface glaciers, the same rising temperatures might only marginally affect ice mass balance in caves. Most of the caves hosting perennial ice are found in Central and South-Eastern Europe, a region that experienced some of the fastest loss of glacier ice over the past decades, but for which climate models suggest a mixed response to the general global warming, with a general decrease in annual precipitation, increase in winter precipitation and increase in the frequency and intensity of extreme summer precipitation events.

In this context, we present here the response cave glaciers in Eastern and South-Eastern Europe to the weather conditions in winter 2018–2019 and summer 2019. We have investigated ice caves in Greece, Croatia, Romania, and Slovenia and analyzed the ice mass balance in response to the climatic conditions in the 2018–2019 winter season (one of the coldest and wettest in the region) and the spring and early summer of 2019 (one of the wettest).

In 2018, we initiated a research program aimed to preserve the climate memory of vanishing Eastern Mediterranean subterranean glaciers. This included the monitoring of cave climate, ice level changes and of the mechanisms by which the climatic information recorded by the stable isotope composition of precipitation is preserved in cave ice. Field trips were conducted regularly in the investigated caves since July 2018.

In the *Scărişoara Ice Cave* (Romania), heavy snowfall in the 2018–2019 winter and subsequent melt in spring 2019 led to rapid infiltration of large volumes of water inside the cave, resulting in ca. 5 cm of ice being formed in the still undercooled cave environment. Between May and July 2019, the ice level in SIC dropped by ca. 35 cm, due to the continuous infiltration of warm water from the surface. This catastrophic melt event spread across the entire upper surface of the 3000 m^2 ice block, resulting in the loss of ca. 1050 m^3 of ice.

In the *Chionotrypa Cave* (Greece), a gradual decrease of the ice volume was evident since 2014, reaching a maximum between July 2018 and September 2019. The ice level at the bottom of the entrance shaft fallen ~3 m and receded ~1 m from the cave walls between July 2018 and September 2019. A rough estimate suggests that >600 m^3 of cave ice was lost during this period.

In the *Crna Ledenica* (Croatia) observations in June 2019 show that following the cold and wet 2018–2019 winter large amounts of fresh snow accumulated below the entrance shafts. However, heavy summer rains and subsequent infiltration of warm water resulted in the complete melting of these ice crusts by September 2019. In some parts of the cave, the ice thickness dropped by up to ~2 m, and the total area covered by perennial ice and snow dropped by ca. 200 m^2, resulting in a loss of about 150–200 m^3 during summer 2019.

In the *Ledena jama v Paradani* (Slovenia) the ice surface lowered by 220 centimeters since 2013, of which 41 centimeters were lost between June 2018 and June 2019. This heavy ice loss in 2019 was the result of low snow accumulation in winter and heavy summer thunderstorm events resulting in large volumes of warm water reaching the ice surface.

Summarizing these observations, two conclusions result: 1) in the summer of 2019, perennial cave deposits throughout SE Europe experienced extensive melting, losing ice volumes that correspond to several years or even decades of accumulation; and 2) the region was battered by heavy late-spring and early summer rains, unprecedented over the past several decades. In contrast, during summer 2019, Western Europe experienced record high temperatures. This precipitation pattern was likely the result of enhanced meridional transport of Mediterranean moisture towards SE Europe, while W Europe was under atmospheric blocking conditions. Climatic models suggest that under ongoing general warming, blocking conditions are set to become more frequent, thus resulting in higher than average precipitation in parts of Europe, while others are going through extreme heatwaves. This atypical distribution of precipitation might lead to the complete loss of cave glaciation in S Europe, taking away with it also the paleoclimatic information stored underground.

ENTRANCES OF ICE CAVES SUPPORT HIGH LOCAL DIVERSITY OF SOIL ARTHROPODS – COLLEMBOLA AS A MODEL GROUP

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The silická ľadnica Ice Cave in the Slovak Karst, Slovakia, is a static cave containing a glacier (213–340 m^3) in its entrance section at 470 m asl and is thus the lowest-lying perennial ice cave in the temperate climatic zone. Its entrance part is a 50-m-deep collapse doline, 351 m^2 in area, with a strong microclimatic gradient where temperatures around zero prevail in the soil in its bottom close to the perennial floor ice, while the upper part of the gradient (karst plateau) may reach soil temperature close to 18°C in the summer. In the period 2005–2007 soil Collembola were investigated at seven sites along a 117.5-m-long transect on the slope from the ice-bearing cave mouth at the bottom of the doline up to the karst plateau at 500 m a.s.l. An exceptionally high species richness of soil Collembola (129 species) was observed, which is about 91 % of the total species richness generated by the Chao1/ACE diversity estimator. Species richness of Collembola positively correlated with soil temperature at the sites. Among the occupants of the karst doline, 10 were Carpathian or Western-Carpathian endemics, and 21 were cold-adapted (psychrophilic) species with montane or boreo-montane disjunctive distribution. A high number and high abundance of endemic species occurred in the middle zone of the gradient slope with rendzina soil type, well developed organic profile and microclimatically favourable conditions. Collembola community near the permafrost zone at the bottom of the doline was similar to polar and mountain tundra communities characteristic with high abundance but low species richness, and very steep rank-dominance curves. The coldest site with primary soil on stony debris is occupied by a cryptic collembolan species of the genus *Folsomia*, morphologically identical with *Folsomia manolachei* Bagnall, 1939, but remarkably differing from typical populations of *F. manolachei* in its ecological requirements. This form has been confirmed by DNA barcoding as cryptic species. The genetic differentiation suggests a scenario of cryptic speciation in the population of '*F. manolachei*' occupying harsh soils near the floor ice. Furthermore, it was the most cold-resistant (lethal dose LD50 of -7.8°C) in laboratory survival tests compared to other *Folsomia* congeners from the close surrounding forest habitats of Silická ľadnica.

The study further showed that cold and wet karst scree slopes in the transition zone between surface habitats and caves may represent borderline habitats for obligate subterranean species. Our results suggest that small-scale microclimatic gradients in low altitude karst in a temperate zone may serve as a reservoir (source) of exceptional soil fauna diversity, providing important climatic microrefugia for endemic and relict taxa. Thus, karst landforms in the temperate zone with strong climatic inversions may harbour high α-diversity and therefore should deserve adequate attention of biodiversity conservation programs. The study was supported by the project of the Slovak Scientific Grant Agency VEGA 1/0346/18.

UNRAVELING 2000 YEARS OF ICE ACCUMULATION IN CAVES OF THE NORTHERN CALCAREOUS ALPS (AUSTRIA)

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Alpine caves locally host ice accumulations derived from the freezing of infiltrated water or drifting and deposition of snow near the entrance. The geometry of the latter 'sag-type' caves acts as a thermal trap during the summer months, allowing perennial ice to build up at elevations far below that of neighbouring surface glaciers. It also provides a natural collector for winter precipitation as well as organic macro-remains derived from the surrounding vegetation. The presence of these 14C-datable layers is essential for establishing the firn accumulation/ablation chronologies.

Results from stratigraphic mapping and radiometric dating of woody macro-remains carried out in several ice caves of the Austrian Northern Calcareous Alps provide new insights into ice-volume fluctuations over the last two millennia.

The oldest deposit dated so far in the Eastern Alps is found in the Eisgruben Eishöhle (Upper Austria). This deposit reaches back to ca. 3600 BC but the start of a well-constrained continuous ice sequence exhibiting wood-rich strata occurred from 350–50 BC onwards. 23 woody macro-remains, as well as stratigraphic relationships, allow the reconstruction of at least seven decadal phases of negative mass-balance from ca. 100 BC–50 AD to 450–650 AD. Major gaps in snow accumulation are recognised during the 9th and 10th century AD, before the onset of sustained ice build-up beginning in the 11th century AD and continuing into the Little Ice Age.

A similar picture emerges from the Guffert Eisschacht (Tyrol) where 6 radiocarbon dates set the bounds of the lowermost 2 m of ice profile between 400–200 BC and 330–530 AD. At least 8 phases of negative mass balance, indicated by inclusion rich layers are recognised in this profile. In addition, 12 wood samples from the overlying 20 m profile point towards a phase of renewed accumulation starting at 1200–1250 AD and continuing well into the LIA.

Thus by volume, Little Ice Age ice makes up the majority of the ice deposits preserved in these two study sites, consistent with data from other 'sag-type' ice caves in the Eastern Alps. All these alpine ice caves have been experiencing a drastic reduction in ice volume in recent decades, which rivals times of negative mass balance during the past two millennia.

TESTING CAVE ICE AS AN ARCHIVE OF HISTORIC MERCURY (Hg) DEPOSITION: THE DOBŠINÁ ICE CAVE PILOT STUDY

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Mercury (Hg) is an important global pollutant emitted into the atmosphere by combustion of fossil fuels, artisanal gold mining, processing of ores, cement production, and some other industrial processes (e.g., electrolytic production of alkaline hydroxides). In the atmosphere, mercury has been dominated by gaseous elemental mercury. Historical levels of atmospheric Hg could be reconstructed using natural archives, e.g., peat bogs, lake sediments, tree rings, or ice cores from continental and mountainous glaciers. Here we test the cave ice as a yet unexplored geochemical archive of Hg deposition.

The Dobšiná Ice Cave was selected for a pilot study since it is located in a pristine forest area of Slovak Paradise National Park, but regional historic mining and processing of ores (including Hg-rich ores) emitted high quantities of Hg into the atmosphere. The oldest date from radiocarbon dating of bat guano found in the cave ice was 2595 years BP (Milovský et al., 2019), which together with earlier studies by Clausen et al. (2007) and Gradziński et al. (2016) indicate a complex history of the cave ice.

The samples for a pilot study were taken by horizontal drilling on the wall of an artificial trench cut into the ice block between the Great Hall and Ruffíny´ Corridor. The sampled ice layers were likely formed by top to bottom freezing of pond water. The top 30 cm layer was omitted from the analysis as it showed signs of post-depositional unconformities and disturbances. Samples were collected in pre-cleaned vials, allowed to melt and transported as liquid water to the laboratory. Mercury was analysed by CV-AFS after filtering, and Hg caught on glass fibre filter was analysed by CV-AAS. For dating purposes, four samples were collected for radiocarbon analysis between 148 and 573 cm below the present-day surface, as well as several additional ones for ^{3}H measurements.

The ^{3}H activity was measured using a Wallac 1220 Quantulus (Perkin Elmer) ultra-low level liquid scintillation spectrometer. Tritium activity was below the detection limit for the topmost 1 m of the profile. Detectable activities (max 7.9±3.5 TU) were observed down to 1.3 m. Below this level ^{3}H activity was again below the detection limit down to 220 cm; however, several samples showed detectable activities in the lower section and, surprisingly, all for the bottom of the profile (below 440 cm).

The organic samples yielded radiocarbon ages between 320 and 2100 BP, suggesting a depositional hiatus (likely as the result of enhanced melting).

Filtered Hg concentrations in the ice sections averaged at 5.1 ng/L and ranged from 1.9 to 11.5 ng/L. Particulate material caught by filtering of the dissolved ice contained 4.9 ng Hg (range 0.5–9.4 ng). Within the studied section (530 cm), concentrations of dissolved and particulate Hg peaked at different depths (200–300 cm and 100–140 cm, respectively). Mercury is strongly bound to dissolved organic material (DOC) and its mobility in suboxic soil is mainly determined by the movement of DOC. Since the cave is located in a densely forested area where seasonal litterfall and subsequent decomposition of organic matter play an important role, this may explain the correlation of Hg concentrations with UV absorbance (254 nm) in melted ice water in the bottom half of cave profile.

We can assume that the observed mercury record has been related to historical mining in the Slovakian Ore Mountains (Slovenské rudohorie) region (the studied cave is located close to this area) which began in the early medieval era and lasted till the end of 20th century. However, we also suggest the record of Hg in cave ice profile was possibly affected by the movement of cryochemically concentrated Hg-DOC rich solutions between growing ice crystals low in Hg.

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GROUND BASED STRUCTURE FROM MOTION (SFM) APPROACH FOR RELIABLE MASS BALANCE CALCULATION OF PERMANENT ICE DEPOSITS IN CAVES

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The study investigates the potential of a photogrammetric approach based on Structure from Motion (SfM) algorithms for monitoring the surface topographic change of a permanent ice deposit in an ice cave located in the Julian Alps (south-eastern European Alps). This allows calculations of volumetric change and both seasonal and annual mass balance. The ground-based photogrammetric approach represents a low-cost method with very limited logistic problems of transportation and human resources particularly important in such extreme environments. This method allows very high-resolution results and makes the use of the Terrestrial Laser Scanner (TLS) survey technique obsolete and inconvenient, especially in such environments. Eight multi-temporal high-resolution Digital terrain model (DTM) were acquired during the ablation seasons 2017 and 2018. The obtained DTM enabled reliable calculation of the topographic changes and mass balance rates during the analyzed period.

ICE DEPOSITS EXPLORATIONS OF THE ASKINSKAYA CAVE AND KINDERLINSKAYA CAVE (SOUTHERN URAL, RUSSIA)

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Two wide known caves with the perennial ice are situated on the Southern Ural: the Askinskaya Ice Cave (371 m/24 m) and Kinderlinskaya Ice Cave (13 km/235 m). Both caverns are characterized by the enormous sizes of their entrances: for the Askinskaya Ice Cave (260 m a.s.l.) it is an arch 20 × 9 m and for the Kinderlinskaya Ice Cave (208 m a.s.l.) it is a trapezium of 12 x 7 m. Underground cavities are located to 10 km from each other, in the boundaries of the same Alutau mountain range (max 650 m a.s.l.).

Geologically, both ice caverns are embedded in the gray limestones of the Upper Devonian. The climate of the territory is continental: the average annual air temperature is 2.2°C and the average annual precipitation reaches 740–750 mm. The height of snow cover achieves 0.7–0.8 m.

According to the origin of coldness and accumulation of snow and ice, both caves are the ones of the sack-shape morphology where the aufeis-layers, ice speleothems, ice crystals as well as the snow-banks are widespread.

In the summer of 2019 three drill cores (diameter 120 cm, length 2.0 m) were extracted from the ice deposits of the Askinskaya Ice Cave (2 cores) and Kinderlinskaya Ice Cave (1 core) using the mechanical ice drill PI-8. Thereupon, the ice cores were cut into separate pieces 20 cm long and were put into double zip plastic packets. The works were realized taking into consideration to minimize the contamination of the ice.

The composition of cave ice (filtered melt ice) for 42 elements was determined by inductively coupled plasma mass spectrometry (Elan 6100 DRC) and inductively coupled plasma atomic emission spectrometry (Optima 3300 RL) for the every 20-cm ice segment. The changes in obtained elements by a depth were considered.

As expected, chemical elements Ca and Mg are characterized by the highest values: Ca in the Askinskaya Ice Cave vary from 17,959 to 48,571 ng g^{-1} and in the Kinderlinskaya Ice Cave vary from 8911 to 42,710 ng g^{-1}; Mg in the Askinskaya Ice Cave change between 302 and 3617 ng g^{-1} and in the Kinderlinskaya Ice Cave change between 1204 and 2772 ng g^{-1}. The analysis of the geochemical data allowed revealing the anthropogenic disturbances in ice caves as well. So, an anomaly of the Zn depth distribution in the Askinskaya ice Cave indicates an anthropogenic pollution zone in this underground cavity between 70 and 110 cm.

Instrumentally the isotope explorations of ice deposits were based on the Piccaro laser analyzer: the $\delta^{18}O$ isotope values for the Askinskaya Ice Cave vary from -11.96 to -12.66 ‰.

Some samples of the wood pieces (branches of the trees) were found in the ice cores; currently, they are in the laboratory of radiocarbon dating.

ICE CAVES IN HAWAII: EARLY RESULTS AND POTENTIAL PALEO-CLIMATE RECORD

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One of the most unusual occurrences of ice caves is on Mauna Loa, Hawaii (19 °N, 155 °W, 4169 m), an active shield volcano in the tropical Pacific with innumerable lava tubes. Historically, high-altitude ice caves have been mentioned repeatedly on the north slope of the volcano, but their scientific study has only begun recently (Pflitsch et al., 2016; Teehera et al., 2018, Schorghofer et al., 2018). Two lava tubes with perennial ice, the Mauna Loa Icecave and the Arsia Cave, have been documented in lava flows 0.2–1.5 kyr old. The Mauna Loa Icecave was first mentioned in 1851. Today, perennial ice blocks the lava tube about 230 m from the entrance, and a large ice floor that was present in 1978 has disappeared (Pflitsch et al., 2016).

Secondary minerals sampled from the deep parts of the caves (Teehera et al., 2018), where temperatures near freezing prevail, are all multi-phase and consist mainly of secondary amorphous silica (SiO_2), cryptocrystalline calcite ($CaCO_3$), and gypsum ($CaSO_4·2H_2O$). Based on carbon and oxygen stable isotope ratios, all sampled calcite is cryogenic. We also found preliminary evidence for the rare mineral ikaite ($CaCO_3·6H_2O$) with a portable Raman spectrometer. The microbial diversity of a silica and calcite deposit was explored by analysis of small subunit ribosomal RNA gene fragments (Teehera et al., 2018). Actinobacteria and Proteobacteria were the most abundant microbial phyla detected, which is largely consistent with studies of other oligotrophic cave environments. The cold, isolated, oligotrophic basaltic lava cave environment in Hawaii may also serve as a potential analog for microbial biogeography on planet Mars.

Several of the paleoclimate proxies commonly used elsewhere are not available in Hawaii: Most trees in Hawaii do not form rings, the written history is only about two centuries long, and there are no known bat guano deposits or speleothems. Cave ice could potentially contain centuries-old annually-resolved paleoclimate information, not available from any other record in the Central Pacific. The isotopic ratios in surface ice falls on the global meteoric line, indicating that little evaporation has occurred, which facilitates the interpretation of H- and O-isotope profiles (Teehera et al., 2018).

With climate warming, the duration of time with air temperatures below freezing has begun to decrease rapidly on Mauna Loa, and less sub-freezing air is available to cool the ice chambers (Schorghofer et al., 2018). The scientific potential of the ice record remains to be explored before it is lost.

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ICE-DAMAGED SPELEOTHEMS IN PREVIOUSLY GLACIATED CAVES: EMPIRICAL OBSERVATIONS AND NUMERICAL SIMULATIONS

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Previous studies have described a number of features in today's ice-free caves attributed to the slow flow of former perennial cave ice causing damage to speleothems. Some of these features have also been interpreted as products of other processes, including strong earthquakes.

Here we report on one of such type of damage, stalagmites which have apparently been sheared off near their base but are still in an upright position. Such stalagmites are present in parts of the Obir Caves in southern Austria along with broken stalagmites and stalactites on the cave floor, as well as coarse crystalline cryogenic cave carbonates (CCC) testifying the former presence of perennial ice deposits during the Last Glacial Maximum. Today these caves are ice-free and their interior air temperature is about 5°C.

We utilized finite-element models for thermo-elasticity and full-Stokes ice flow to identify the relative contributions of these two processes to basal stresses around stalagmites. Initial results show that ice flow, even in case of strong basal sliding, contributes only shear stresses in the order of 0.1 MPa, which is one magnitude lower than the shear strength of the stalagmite calcite (according to preliminary laboratory results). Thermoelastic deformation of the stalagmite in combination with the surrounding ice, however, creates vertical shear and tensile stresses in the order of 1 to 10 MPa, well within the tensile strength range of the stalagmite material.

Our modelling results thus demonstrate that stalagmites are not sheared off their base by lateral ice flow or lateral thermo-elastic expansion and contraction of the ice, but are lifted up as the surrounding ice warms and expands. We suppose that multiple cooling-warming cycles in the sub-zero temperature regime weakened the stalagmites, eventually leading to fracturing. Subsequently, the broken upper part(s) of the stalagmites were displaced laterally by ice flow, later cemented by calcite, or simply fell to the ground.

Pseudo-sheared in-situ stalagmites not only present one of the most diagnostic indicators for the presence of former cave ice; they also indirectly witness substantial sub-zero paleotemperature changes in permafrozen karst rocks, required to break even tall and thick stalagmites. If CCC occur associated with these features, U-series dating can provide minimum age constraints on the presence of cave ice. In the case of the Obir Caves, CCC postdate pseudo-sheared in-situ stalagmites and show that at parts of these caves were heavily glaciated during the Last Glacial Maximum. In the absence of CCC, U-series dating of younger calcite overgrowing and cementing fractures in stalagmites also provides a minimum age estimate for the ice-induced damage.

PREHISTORIC CHARCOAL DRAWINGS IN THE SILICKÁ ĽADNICA CAVE: NEW AMS RADIOCARBON DATES

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The Silická ľadnica Cave (Szilicei jegesbarlang, cadastral territory Silica, district Rožňava, 495 m a.s.l., length 2300 m, depth 117 m, fluviokarst-corrosive-collapsed, ice filling) is located on the Silická planina Plateau 2km west of the Silica village. The upper abyssal part of the cave is partially glaciated. The Silická ľadnica represents the lowest-situated classic ice cave above 50 degrees north latitude of the mild climate zone.

Archaeological finds from the cave come from the Paleolithic?, Neolithic, Bronze, Hallstatt, La Tène period, and even from the Middle Ages (e.g., Böhm and Kunský, 1941; Bárta, 1963, 1965, 1973; Bánesz, 1978; Bárta and Vlček 1990; Romsauer, 1996; Piatničková, 2010; Soják and Wawrczak, 2017; Mirossayová, 2017).

Fig. 1. Charcoal drawing dated to Late Bronze Age/Hallstatt, Silická ľadnica Cave. Photo: F. Engel

Fig. 2. Charcoal drawings dated to Bronze Age, Silická ľadnica Cave. Photo: F. Engel

The first exploratory archaeological research was carried out in 1932–1933 by J. Böhm of the Czechoslovak State Archaeological Institute in Prague after the discovery of the underground areas in the Silická ľadnica Cave. He made two probes and managed to discover thick cultural layers from different periods, such as the Neolithic (Bükk culture) ceramics and other artefacts. He highlighted the ancient charcoal lines from pine tree torches in the back section of the cave and traces of prehistoric tools in the clay. According to the research, the cave gained the greatest importance in the Late Bronze Age (initially it was thought to be a Hallstatt period); and a short-term settlement from the Late La Tène period was also found. Traces of pole pits that remained from hut structures were found to contain a large amount of debris of the Kyjatice Culture pottery.

Recently, the speleologist J. Stankovič reminded again of the traces of black lines on the Silická ľadnica Cave walls, from which six samples were taken in 2009 and 2012. Dating was successful only for two of them – No. 5 and 6(1).

Sample 5 was taken from the carbon lines which look like an anterior part of an animal, perhaps a bear, viewed from the side while the head is oriented to the right (Fig. 1). One more parallel line is visible behind its back. According to dating, the drawing comes from the transition period Late Bronze Age/Halstatt.

Sample 6(1) was taken a few meters to the left from Sample 5 and comes from a carbon sketch found on the giant boulder which blocks the entrance to the area behind the Dome. The smear or sketch consists of numerous simple lines. Two shorter slant lines separate sideways from two almost parallel longer lines (Fig. 2). The sketch looks like a simple human figure. A 'T' shape is drawn on its right side. According to dating, sample 6 is older and dates back to the Bronze Age.

Both samples come from the cave wall in the back part of the Archaeological Dome, close to the original post-war probe mentioned by Bánesz (1962). Their dating confirmed that the cave gained the greatest importance in the Late Bronze Age. Inside this area, a passage leads deeper to the Silica-Gombasek cave system. Maybe that is the reason for the ancient signs there.

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THE FEATURES OF THE WORLD SUBTERRANEAN HERITAGE

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The World Subterranean Heritage (WSH) includes both the natural caves and the artificial underground cavities titled frequent occasions using the term 'cave': the Adjanta Caves, Longmen Grottes, etc.

Nowadays, the WSH of mankind involved 63 properties located in different parts of the globe: 22 in Europe, 22 in Asia, 12 in America, 4 in Africa and 3 in Australia. The sites of exclusive cultural value dominate and account for 34 properties; 24 represent Natural Heritage and 3 are of Mixed (natural and cultural) Heritage and 2 sites are the cultural landscapes with natural caves.

World Subterranean Cultural Heritage is divisible into five groups. *Sites as objects of worship* (12 properties): all 12 cave sanctuaries represent places of four religions pilgrimages: Buddism, Hinduism, Jainism, and Christianity – namely, its Eastern European branch. *Sites with the pre-historical paintings* (10 ones), created starting from the Upper Palaeolithic. The quantities of artworks for one site achieve 30,000 cave decorations. There are both zoomorphic masterpieces with images of local animals of those times and anthropomorphic drawings. *Sites as archaeological objects* (5 ones) include, on the one hand, the properties with underground cavities in which the unique outstanding artifacts were revealed and, on the other hand, the caves that contain the unique evidence throwing the light on the evolution of mankind. *Mining sites* (6 ones) are currently closed for mining operations, but they are used for touristic purposes. The only *cave settlement* was inscribed on the UNESCO List.

World Subterranean Natural Heritage is represented by the caves of different genesis. *Karst (solutional) caves* are the most widespread (22 sites): the world's largest karst underground systems belong to this group as well as the caves with universal karstic manifestations. *Lava caves* (2 properties), defined as lava tubes of considerable length, and *ice caves* inside the framework of cave sites (5 ones). There are 3 properties of Mixed Heritage, described by the natural and cultural criteria, and 2 cultural landscapes, characterized by the cultural criteria only but including the natural caves.

The exploration has been realized in the context of the IGU Karst Commission project 'Preserving World Subterranean Heritage'.

ADVANCED METEOROLOGICAL MONITORING OF TWO SAG-TYPE ICE CAVES IN THE AUSTRIAN ALPS

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Understanding the microclimatic processes in ice caves and their relationship to the surface climate is fundamental for a robust interpretation of snow and ice deposits within these caves. In order to improve the knowledge of associated processes, extensive micrometeorological experiments have been set up in two sag-type ice caves in Tyrol, Austria: the Hundalm ice cave and Guffert ice shaft.

At the Hundalm ice cave, which has been operated as a show cave since 1967, the new instruments (installed in fall 2018 and extended in November 2019) complement a set of longer-term temperature measurements (starting in 2005; Fig. 1). In contrast, the Guffert ice shaft represents an undisturbed natural system with no previous meteorological records. There, instruments were installed in October 2019.

At both caves, the aim is to capture their thermal and dynamic characteristics. Particular emphasis is put on the 'open period' and related cold air intrusions as well as transitions between winter and summer regime. Thus, at both sites, meteorological stations inside and outside the cave allow a comprehensive investigation of the relationships between surface and subsurface environments.

The main stations are equipped with instruments measuring temperature (air, snow/ice, ground, and rock), pressure, humidity, wind speed, and direction (high-frequency and 3-dimensional at Hundalm), precipitation, snow/ice height, and radiation components. To capture the spatial characteristics of air temperature and circulation in more detail, additional wind and temperature (and humidity) sensors are episodically placed at critical locations and along vertical and horizontal transects. The measurements are complemented by time-lapse cameras and stakes drilled into the ice to monitor the seasonal and inter-annual ice dynamics.

The data will also be used to drive and validate models of the mass and energy balance of the ice and airflow within the caves, both serving enhanced interpretation of the investigated paleo-climatic records being retrieved from the ice deposits.

Fig. 1. Meteorological monitoring station at Hundalm ice cave. Photo: C. Spötl

ANALYSIS OF LONG-TERM TEMPERATURE RECORDS AT THE HUNDALM ICE CAVE (AUSTRIA)

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The Hundalm ice cave is a sag-type cave, located in the western part of the Northern Calcareous Alps at an elevation of 1530 m above sea level. Discovered in 1921, the cave was opened as a show cave in 1967. Continuous monitoring at the cave site started in 2005 when three temperature loggers were installed inside the cave. Since 2007 additional loggers have been installed providing information about the stratification of cave air along the main shaft, the temperature below and above the entrance door as well as about rock- and ice temperature (Fig. 1). Complementary, an automatic weather station was monitoring surface conditions in direct proximity to the cave entrance in the years 2008 to 2015.

All these long-term measurements serve as a basis for a comprehensive analysis of the thermal (temporal and spatial) characteristics of the Hundalm ice cave including annual/seasonal trends and shorter-term temperature changes during the last decade. The loggers located along a quasi-vertical profile in the main shaft allow to study the temporal evolution of the air stratification.

Observations show the typical ventilation pattern for sag-type caves with a 'closed period' during summer with prevailing stable stratification inside the cave and an 'open period' during winter, when cold air enters and steadily cools the cave. The strength and duration of this exchange are closely related to the surface conditions. Hence, the special focus of this analysis is placed on cold air intrusions during the 'open period', their onset, duration, timing, and spatial pattern, as well as respective relationships between cave and surface air temperature. Furthermore, the transitions between these seasonal regimes and possible thresholds triggering these transitions are examined.

The ice development in the cave is monitored by means of several stakes and point measurements and put in context to the observed temperature evolution. Alarmingly, the ice body, which plays a crucial role in maintaining the cold microclimate in the cave during summer, shows a continuous decrease in the observation period.

Fig. 1. Location of temperature loggers in Hundalm ice cave (C. Spötl, T. Racine)

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ASSESSMENT OF TOURISTS PERCEPTIONS REGARDING ENVIRONMENTAL ISSUES ON THE AMARNATH CAVE IN INDIA

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Every year, many thousands of religious tourists go to see the Amarnath Cave. The Amarnath cave, located in the Indian state of Kashmir, is one of the most famous shrines in Hinduism. Dedicated to the God Shiva, Inside the main Amarnath cave is an ice stalagmite resembling the Shiva Linga, which waxes during May to August and gradually wanes thereafter. This lingam is said to grow and shrink with the phases of the moon, reaching its height during the summer festival. This poster is based on a questionnaire survey of different tourists to know their perception regarding different environmental issues in these areas. Many tourists blaming global warming is the main environmental issue. Out of two hundred surveys, one hundred seventy-five tourists said that solid waste, degradation of forests, and climate change are the main environmental issues in this area. The study concludes that environmental awareness among the tourists and local communities varies with the educational background, origin, and age and the level can be strengthened through a combination of appropriate community based environmental awareness, with collaborative relationships between government, Non-Government Organizations, and community-based organizations. About 70 % of subjects knew about solid waste management but only 69 % had knowledge about what they have to do in order to save the local environment of the cave. Both man-made and natural forces are difficult to tackle, but awareness and preparedness will help to solve the environmental problem. The people at large must be well-aware of the occurrence of the issues. It should be treated on a priority basis, with long-term planning and preparedness gradually being made part of the process of development planning in Amarnath Cave. Local Non-Governmental Organisation can play an important role to reduce the environmental impacts on Amarnath cave for creating environmental awareness among tourists and the local community by using of social-media, distributing pamphlets, providing training to the local community for their role in saving Amarnath caves and making the environment sustainable.

SULFURIC ACID SPELEOGENESIS IN THE PLAVECKÉ PREDHORIE FOOTHILL OF THE MALÉ KARPATY MOUNTAINS, WESTERN SLOVAKIA

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The morphology of several caves in the Plavecký hradný vrch Hill (431 m a.s.l.), at the western fault edge of the Malé Karpaty Mountains (MKM), near Plavecké Podhradie village, indicates their hypogene origin. They are formed in fractured Triassic carbonates (Hronic Unit) by waters ascending along fissures genetically related to the horst-graben structure at the contact of the MKM and Záhorská nížina Lowland (the NE part of the Vienna Basin). The Plavecká jaskyňa Cave and the upper-lying Pec Cave contain almost horizontal passages and halls/chambers with flat corrosion bedrock floors, feeding fissures, and wall water-table notches that belong to morphological indicators of sulfuric acid speleogenesis. The width of the flat corrosion bedrock floor in the newly discovered part in the upper part of the Plavecká jaskyňa is up to 10–12 m. Other predominant rock sculptures in these caves are shallow cupolas, spherical holes, wall niches, and upward wall channels, as well as vadose vents or small hemispherical corrosion depressions deepened into the overhanging walls and resembling replacement pockets. The subhorizontal cave segments are interconnected by steep to vertical oval feeders (Bella et al., 2019a, b).

In addition to the morphological indicators, the sulfuric low-temperature acid speleogenetical phases of the Plavecká jaskyňa are indicated by the presence of gypsum and jarosite, mainly in its upper part named Herzov dóm Chamber and the access low passage. Also, the isotope alteration O and C in the uppermost thin zone of limestone bedrock on the cave wall resulted from its interaction with hypogene water (the sample taken from the lower part of the Plavecká jaskyňa; Bella et al., 2019b). Flat corrosion bedrock floors truncate fissure discharge feeders, on the edges with wall water-table notches, indicate rapid lateral corrosion by the sulfuric low-thermal waters. The passage of the lowest evolution level of the Plavecká jaskyňa is at about the same elevation as the recent springs of slightly warmer groundwater near the cave (11.6 to 13.6°C; about to 3°C warmer than the regional mean-annual temperature). Subaerial calcite popcorn rims were also precipitated due to H_2O evaporation and CO_2 degassing from condensation water at the edges of feeding fissures that were still active as thermal vents when the water table was dropped (see also De Waele et al., 2016). Hydrogen sulfide involved in the sulfuric acid speleogenesis was probably derived from hydrocarbon reservoirs of adjacent Vienna Basin (Bella et al., 2019b).

Four subhorizontal passages of the Plavecká jaskyňa (at 212 m, 214 m, 220 m, and 225 m a.s.l.) have been developed at former levels of the piezometric surface during water table stagnations corresponding with phases of erosion base level stabilization in relation to the landform evolution during the subsidence of the adjacent part of the Vienna Basin (Bella et al., 2019b). The Pec Cave also consists of three subhorizontal parts (at 283 m, 287 m, and 295 m a.s.l.) that represent the highest-lying and oldest (probably Early Pleistocene or pre-Quaternary) known cave level segments in the Plavecký hradný vrch (Bella et al., 2019a). In order to reconstruct the geochronology of cave level development, U-series dating and paleomagnetic research of calcite flowstones deposited on the flat bedrock floors, as well as paleomagnetic research of fine-grained sediments containing jarosite is realized.

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GEOPHYSICAL MEASUREMENTS USED IN RECONSTRUCTION OF THE DEVELOPMENT OF LEVELLED PASSAGES IN THE DOMICA-BARADLA CAVE SYSTEM (SLOVAKIA, HUNGARY) – PRELIMINARY RESULTS

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In 2018, the Slovakian-Hungarian Interreg project started with the aim to explore and assess the cave environment and build a technical infrastructure for speleotherapy in the Domica-Baradla cave system. In order to determine the stability of cave sediments and limestone basement, the geophysical measurements were realized. They have also markedly contributed to a solution of some problems of the genesis of this well-known multi-level cave system. For the determination of thickness and consistency of pebble-loamy floor sediments, the VES (Vertical Electric Sounding) method was used with the

10–25 m distance between electrodes. Measured data were processed by an IX1D computer programme. The measurements in the cave system were realized by GeoGold Kárpátia Kft in 2018–2020. In the Baradla Cave, the first geophysical research was realized in 1978, in the streambed section planned for the boat tour for its visitors. In the Domica Cave, the first geophysical measurements were done by Géczy and Kucharič (1996) in three selected sections from the Panenská chodba (Virgin Passage) to Gotický dóm (Gothic Chamber). The Gotický dóm is still occasionally used on the boat tour.

In the Domica Cave, another two sections were measured in 2018 and 2019: the inactive Suchá chodba (Dry Passage) of the oldest evolution level and the active streambed in the Panenská chodba belonging to the main lower-lying evolution level. In the measured 70 m long section of the Suchá chodba, the thickness of fine-grained sediments deposited on its floor is approximately the same, in the range of 2–4 m. These brown or reddish-brown clayey sediments are older than 124 ka, and the Brunhes/Matuyama boundary (780 ka), Kamikatsura excursion (~900 ka), Santa Rosa excursion (~932 ka), and Jaramillo magnetozone (~1.001–1.069 Ma) were identified in them (Pruner et al., 2000; Bella et al., 2019). Residues of the allochthonous pebbles are sporadically preserved on the wall of the passage, with a burial age of 3.5 Ma (Bella et al, 2019). They were fluvially transported from the Poltár/Borsod Formation (Late Miocene–Early Pliocene) that was deposited on the subsided tectonic blocks of Triassic carbonates at the southwestern edge of the Silická planina Plateau and Aggtelek Karst.

In the Panenská chodba with a still active aggraded streambed, the 300 m long section was measured from the artificial dam downstream to its central part. In the first part of this section with a length of 60 m, pebble-clayey sediments have a thickness of 2–3 m. In the following part, the limestone floor basement covered by these sediments was detected in a depth of about 20 m. In the eastern part of this section, after 120–130 m, the floor sediments become thinner again, but further to the east its thickness suddenly grows to 10 m. At the eastern end of this section, the sediment thickness is gradually reduced to 4 m.

A lesser extent of the varying thickness of fluvial sediments was detected also in the Baradla Cave. The geophysical research was realized in three sections of the main passage of the Baradla Cave: along the active streambed of the Nádor utca Passage, in the Viasz utca and Nehéz út passages, and near the mouth of Retek-ág branch. In the Nádor utca, also belonging to the main evolution level, 500 m long section was measured. In its first 100 m, the sediment thickness is about 5 m. In the north-eastern part of the passage, the thickness oscillates from 1 to 5 m. In the first 60 m of the higher-lying Viasz utca Passage, the thickness of clayey sediment is 1–2 m. In the continued part of the passage, the thickness rises to 7–8 m. However, at the end of this 100 m long section, the limestone basement suddenly decreases to a depth of 15 m. Smaller differences in the thickness of fluvial sediments were detected in the Nehéz út Passage which is the lower-lying and narrower part of main cave passage below the Viasz utca. The sediment thickness in the first 110 m of this section is 0.5–1 m, however in the ending 20 m is 2–3 m (the total length of this section is 135 m). Similar data was detected in the 300 m long section near the mouth of the Retek-ág inflow lateral passage. The sediments consist of allochthonous pebbles, mostly cemented by calcite or mixed with clay. Its thickness reaches 1–2 m, downstream gradually rising to 2–3 m. The maximum thickness of fluvial sediments in this section is 5 m.

The spatial oscillations of the thickness of fluvial sediments forming the aggraded streambed, which is evident especially in the Panenská chodba of the Domica Cave, indicate the nonlinear, slightly inclined rock basement. It is more likely that the recent passage is mainly a result of the upwards leveling of looped conduits, but in places, it may also include older phreatic cavities or their parts. In the Domica Cave, the distance between supposed phreatic loops is different, from 10 m to 60 m with vertical amplitudes up to 20 m. The borehole in the Panenská chodba, drilled at the artificial dam, directly shows that the thickness of floor sedimentary cover is 18 m (Rak and Ingr, 1964; see also Droppa, 1972). Based on data from this borehole, Jakál (1975) and some others assumed that another evolution level (represented by a slightly inclined rock floor) can occur below the recent aggraded streambed. In the Baradla Cave, the vertical amplitudes of loops are lesser, up to 5–8 m, exceptionally up to 15 m.

Based on obtained data, it can be concluded that the main, downstream slightly inclined levelled passage, mostly with an aggraded streambed, resulted from a former phreatic looped cave or a cave with a mixture of phreatic and water table levelled components originated along the NNE-SSW-striking fracture system. In the Baradla Cave, the origin of phreatic loops was controlled NW-SE-striking bedding plane of Wetterstein limestones with a dip of 20–30° to the south-west (Gaál, 2014). Phreatic loops were filled by allochthonous pebbles and completely remodelled by ceiling erosion mostly in the Early Pleistocene (Bella et al., 2019). If the piezometric surface occurs above the looped cave, and allochthonous sediments are fluvially transported into the drainage conduits, its irregular long section is gradually aligned by the paragenetic ceiling erosion of the downward apex of phreatic loops due to the sediment accumulation or the development of a 'bypass tubes' above the downward apex of phreatic loops completely filled with sediments. As a result of continued alluviation, i.e. the ever-growing sedimentary fill, the paragenetic development of the ceiling parts of cave passages progresses upwards until the piezometric surface is reached (see Pasini, 1967, 1975; as well as Ford, 1965, 2000a; Ford and Ewers, 1978; Farrant and Smart, 2011; and others).

After the partial removal of fluvial sediments (post-paragenetic erosion phase), the large passage with ceiling channel, wall channels, and an aggraded streambed slightly inclined downstream to the former Jósva spring at Jósvafő Village resulted from this long-term cave evolution. Multiple undulating wall channels and meander notches occur in many places as proof of repeated streambed aggradations and lateral wall erosion. According to Ford and Ewers (1978), as well as Ford (2000b), the main passage of the Domica-Baradla cave system represents the so-called 'ideal water table cave'. Due to the later incision of the Jósva Valley, the lower-lying Short and Long Lower caves were developed in the outflow part of this underground hydrological system. This cave is still fluvially active and leads to recent spring. It is featured by phreatic loops with a height range of about 10 m, and horizontal vadose or epiphreatic segments (Ford, 2000). It can be assumed that primary phreatic looped conduits had a similar appearance, from which the modern morphology of the passage of the main evolution level was formed during the multi-phased paragenetic development.

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RESEARCH AND MONITORING OF CAVES IN THE SAMOBORSKO GORJE MT (CROATIA) 2015–2019

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The Samoborsko gorje is a low mountain area between the Žumberak Mt and the Sava river plain in western Croatia. The area is characterized by high geodiversity as a consequence of diverse geological composition, structure, and geomorphological features. The alternation of diverse landscape units of plains, deeply incised valleys, and steep ridges is determined by geological conditions, hydrological features, and geomorphological processes. The karst and fluviokarst of the Samoborsko gorje are developed in two main lithostratigraphic units: Triassic dolomites and Miocene limestones. The main surface indicators and features of karst are solution dolines, ponors, and karst springs connected with shallow karst aquifers.

Caving club Samobor started a project supported by the Public Institution for Management of Protected Areas and Other Protected Natural Values in Zagreb County (Green Ring) in 2010. The goal of this project was to complete the cave database. It consists of cave data in the form of datasheets, cave maps, position maps, and photographs. The database comprises 43 caves. Most of them are simple speleological features with length and depth up to 50 m. The most important cave sites among them are the Grgos Caves (protected as Geomorphological monument of nature) and the Vugrinova Cave (NATURA 2000 site – 8310: Caves not open to the public).

The Samoborsko gorje Cave database served as a basis for a five-year-long monitoring activities in the frame of the project „Protection, promotion and sustainable use of protected areas of Zagreb County" financed by the Public institution Green Ring. The main object of the monitoring was to establish a system of observing ecological conditions of caves, protection from pollution, cleaning of caves, scientific research, and developing cooperation with the local population for protection of fragile karst environment. Some caves were selected for geomorphological, hydrochemical, geochemical, and botanical research performed in cooperation with the Department of Geography (UNIZG) and Croatian Natural History Museum. The ecological condition of the caves depends on anthropogenic pressure and, due to rapid urbanization, the pressure is high. Therefore, important parts of the annual reports were evaluation and directions for actions, protection, and sustainable management.

THE ELEPHANTA CAVES: SUSTAINABILITY AND LAWS

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The Elephanta Caves serve as a great tourist attraction in the vicinity of the large Mumbai metropolis. The Elephanta island is located 10 km away from the Gateway of India at Mumbai in Maharashtra State in India. The Elephanta Caves are a conglomeration of seven caves, out of which the most important is the Mahesa-murti Cave. Environmentally, this cave is under stress due to climate change, the pressure of tourism, degradation of forests, and new urbanization nearby this region. The poster shows that there is an urgent requirement for the government and the local community to understand the importance of caves for the tourism industry in India and also the existence of civilization. The government must make strict laws to protect such type of heritage. And these laws should be executed at local and national levels, strictly for the sustainability of such type of heritage for future perspective. This study is totally based on field observations. Four posters will be prepared to show the status of these caves and that these caves are under stress.

MORPHOLOGICAL AND ISOTOPIC EVIDENCE OF A HYPOGENE ORIGIN OF THE DRIENOVSKÁ CAVE, SLOVAK KARST

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The Drienovská Cave is located on the south-eastern edge of the Jasov Plateau (Palanta hill), Slovak Karst. The cave has a length of 1588 m and a depth of 84 m (Thuróczy et al., 2012) and consists of two dominant vertical levels, the lower feeding an autochthonous stream (Zacharov, 2013b). The Drienovská Cave has been interpreted as a fluviokarst cave with an active stream (Bella et al., 2018), structurally controlled by the Darnó fault zone and the deep-rooted Rožňava fault system (Zacharov, 2008, 2012; Gagyi, 2013). Previous studies reported morphological features including cupolas and low-diameter vertical chimneys, as well as gypsum and large euhedral calcite crystals in the upper cave level (Zacharov and Košuth, 2005; Zacharov, 2013b, 2013a), and the possibility of a hypogene origin of the upper level was already hypothesized.

We identified additional morphological features indicative of a hypogene origin. In the Kruhová Gallery, Laughöhle morphologies are present which are diagnostic of density-driven, slow convection in a hypogene setting (Kempe et al., 1975; Dublyansky, 2013). This phreatic morphology is dissected by a later condensation corrosion vent (cf. Audra et al., 2009). A chimney is present in the corridor between the Kruhová Gallery and Stratený Dome, and in the Sádrovcová Corridor, a condensation corrosion vent is preserved, covered by calcite and gypsum popcorn, respectively. Flowstone with a smoothed surface suggesting subaqueous or subaerial corrosion is present at the junction between the Česká Corridor and Stratený Dome (Fig.1).

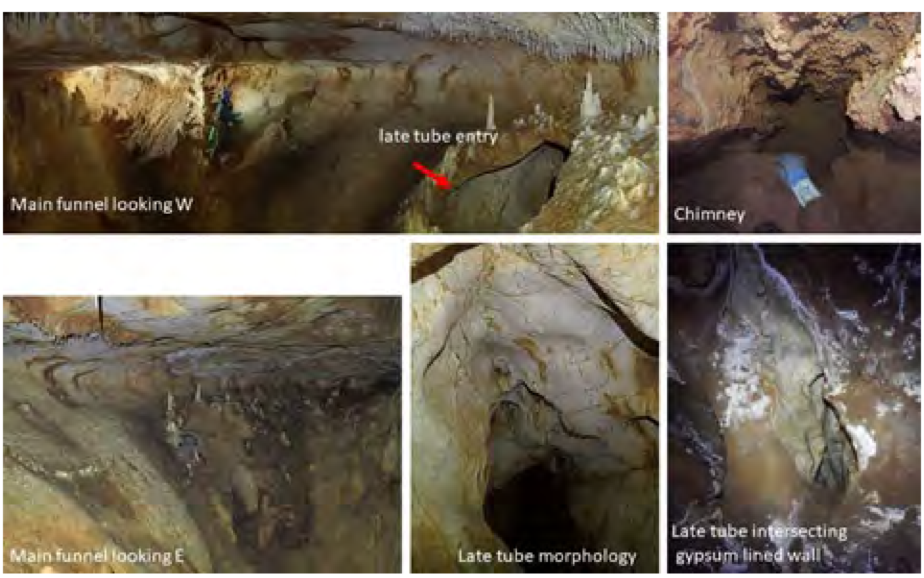

Fig. 1. Laughöhle (left top and bottom) and a close-up of the tube (middle bottom) in the Kruhová Gallery. Chimney wall coated by calcite popcorn (top right) and tube coated by gypsum popcorn in the Sadrovcová Corridor (right bottom).

Two cores were drilled in the wall of the Laughöhle and the vent and microsampled for C and O isotope depth profiles. Samples of euhedral pool spar crystals were obtained from the Hodinková Chamber at the end of the Česká Corridor and in the Horná kryštálka Chamber and investigated for fluid inclusions and stable isotope composition.

Both drill cores consist of light grey to grey-pinkish limestone of the Triassic Waxeneck Formation which is partly marmorized and intersected by veinlets. The uppermost part of the core (the cave wall) is stained white. The limestone of the tube shows $\delta^{13}C$ values of +1.1 to +3.4 ‰ and $\delta^{18}O$ values of -3.5 to -1.5 ‰. These values correspond to the expected bedrock values of this marine (diagenetically stabilized) limestone. Veinlets filled by calcite show a more depleted carbon and oxygen isotope composition diagnostic of deep-burial cementation. In contrast, the Laughöhle core shows carbon and oxygen isotope which are significantly lower than those of the matrix of the tube core. $\delta^{13}C$ and $\delta^{18}O$ values range from -4.9 to -1.1 ‰ and from -5.8 to -4.3 ‰, respectively. There is no clear trend along the 12.5 cm-long core, indicating that the alteration front around the Laughöhle affected the wall rock to more than 12.5 cm depth.

The pool spar crystals contain monophase fluid inclusions indicating crystallization at temperatures below about 50°C. The oxygen isotopic composition of the calcite ranges from -7.7 to -6.5 ‰. Assuming a water $\delta^{18}O$ value corresponding to today's local meteoric precipitation, value of -9.5 ‰ (Holko et al., 2012) yields temperatures of crystallization between about 1 and 6°C (when using the equation of Kim and O´Neil, 1997Cd, Ba) and between about 7 and 13°C (using the equation of Coplen, 2007). This supports the notion that these pool spars formed from non-thermal water.

Our observations and analyses provide evidence for a hypogene origin of the upper level in the Drienovská Cave. The isotope shift in the wall rock of the Laughöhle chamber is consistent with the model of density-driven convection in a hypogene setting, resulting in slow dissolution rates and the development of an alteration 'halo' around the chamber. The $\delta^{18}O$ values of this altered wall rock suggest a low-temperature environment. The lack of an isotopic alteration zone in the tube core is attributed to condensation corrosion that removed the alteration 'halo' during a late hypogenetic stage.

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INTENSITY OF CHEMICAL DENUDATION BY THE LIMESTONE PLATES AT TWO LOCALITIES IN THE SLOVAK KARST (SLOVAKIA)

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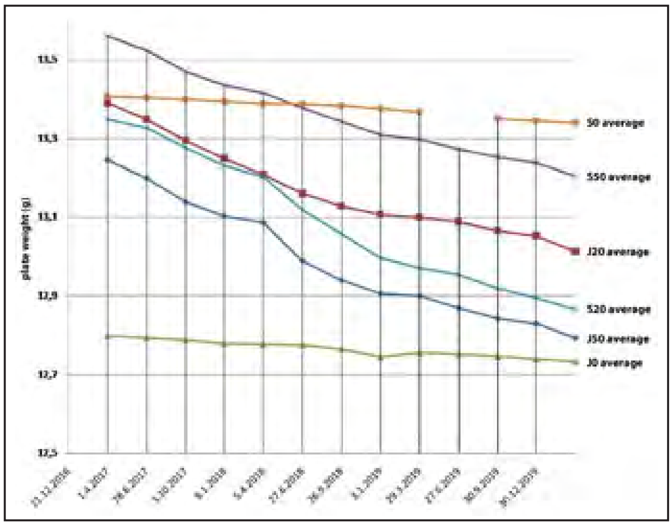
Chemical denudation of karst is one of the basic processes of karst relief formation. That is why it has been the object of exploration in various karst areas for many decades, as evidenced by previously published works (e.g, Gams, 1966; Pulina, 1974; 1999, Himmel, 2000; Gabrovšek, 2007; Galdenzi, 2012; Droppa, 2012). The limestone plate method applied in the past, mainly by Gams (1966, 1985) and later taken over by the Karst Commission of the International Union of Speleology, is also used for its measurement. Hochmuth and Vadelová (2010) dealt with this topic in two karst areas of Slovakia. The principle of the limestone plates method is to measure the weight loss of plates over a period of time during which they are stored in the terrain (on the surface, buried in the soil, etc.) where they are affected by rainwater seeping into the soil and many other factors (Hochmuth et al., 2018; Schwarzová et al., 2019). We applied this method in two localities of the Slovak Karst (one set of platelets was placed on Jasovská plateau and the other on Silická Plateau). Both sites are located in the soil under forest cover at three different depths – on the soil surface, at a depth of 20 cm, and at a depth of 50 cm. At each horizon, 3 control plates are placed from two different types of limestone, namely standardized plates supplied by IRCK in Guilina (China) and local limestone (ie a total of 18 plates at each site). Plate weighing was performed on high-precision analytical scales every three months for three years. After digging the samples from the site, the plates are transferred to the granulometric and hydrological laboratory at the Institute of Geography of the Faculty of Science, UPJŠ in Košice. They are dried for 8 hours at 80 DEG C. and weighed.

The results show an apparent weight loss at all samples of both sites of varying intensity. As expected, the smallest loss was recorded on samples placed on the surface. From the beginning of the measurements, the loss on standardized plates on the Jasovská Plateau reached an average of 0.47 % and 0.49 % on the Silická Plateau. The largest decrease was recorded in the Jasovská Plateau at a depth of 50 cm – 3.40 %, but on the Silická Plateau at a depth of 20 cm – 3.62 % (at a depth of 50 cm it was 2.62 %). When comparing the results measured on our local plates (from 26. 9. 2018) there are no significant differences. More interesting results will certainly be after a long time series of observations. The results are shown in the following table and figure.

	Standardized plates (China)	Local plates
J50 average	0.8662 g	0.6740 g
J20 average	0.7192 g	0.6879 g
J0 average	0.0864 g	0.2408 g
S50 average	0.7917 g	0.8784 g
S20 average	1.0087 g	0.6585 g
S0 average	0.2742 g	0.2103 g



The reason for the differences in denudation intensity may be several and require further observation. One of the most important factors affecting the intensity of denudation is the amount of precipitation in the area and the value of runoff. The quality of the limestone, its purity and porosity allow faster dissolution. The depth of the root system, the chemical and physical properties of the soil, and, last but not least, the CO_2 content of the soil affect the intensity of denudation in the forested area.

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DIVERSITY OF AIRBORNE MICROBIOTA FROM THE ASCUNSÃ CAVE (ROMANIA)

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Caves are thought to be an unfavorable environment for organisms, because of the low temperatures, the permanent darkness, and the scarcity of nutrients. But due to their adaptations to the peculiar underground conditions, to their influence on human/animal health, as well as to their potentially economical valuable metabolic products and/or enzymes, we assist in an ever-increasing interest for the microbes from caves. With the continuous development of tourism in general and the speleological tourism in particular, we observe changes in the underground biocenoses. Microbial communities, being the first to be affected by human activities, fact that hugely impacts on the whole underground ecosystem since microorganisms are at the very base of the trophic net, are often involved in biogeochemical processes resulting in the formation of various mineralogical structures many of them conferring the beauty of the caves. The aim of this study is to assess the diversity of the underground microbiome of the Ascunsă cave (Romania), a non-touristic, difficult to access cave, having its subterranean environment virtually undisturbed, as compared with several other caves in the region, that are either very easy to access or are show-caves and thus, intensively visited. The presence of an underground river, together with the whole morphology of the cave (huge chambers alternating with very narrow passages), and the presence of bats colonies determine the Ascunsă cave to present a variety of subterranean ecological niches, presumably inhabited by different microbial communities. Here we present preliminary results of a sampling campaign carried out in 2016 in the Great Chamber. Airborne microorganisms were collected and incubated in the laboratory. Isolates were then cultivated separately and used for genomic DNA extraction. Specific genes were amplified by PCR and the amplicons sequenced resulting in a 17 species inventory of microorganisms.

PLIO-QUATERNARY CAVE SEDIMENTS IN SLOVENIA

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Cave sediments in different geological and geomorphological settings in Slovenia were systematically sampled during the last 20 years. We used different dating methods which showed that cave sediments in most of the Slovenian karst areas are up to 5 Ma old. Previously they were dated to Pleistocene and that caves themselves are not much older. The majority of sediment studies have been carried out in SW Slovenia (i.e. in the NW part of Dinaric Karst) and at some sites of Alpine karst. More than 4000 samples were taken and analysed in 42 different sections from active, relict, and unroofed caves, and surface sediments. Results from paleomagnetism and magnetostratigraphy were calibrated by U-series, cosmogenic isotopes, radiocarbon, paleontological, and geomorphological dating where possible. Age sequences were compiled from composite sections including different ages during Cenozoic. A robust chronology in the spatially and temporally highly discontinuous sediment record preserved in karst was set up. Calibrated data contributed to the reconstruction of speleogenesis, deposition in caves, and indirectly to the evolution of karst surfaces and succession of tectonic movements. The oldest sediments, about 5 Ma, are now situated in relict caves close to the surface or in unroofed caves, which were exposed to the surface by karst denudation. Sedimentation in caves has also reflected the evolution of the surrounding landscape; i.e. climatic changes with flood events or/and changes of the tectonic regimes during the Neogene and Quaternary.

CHEMICAL COMPOSITION OF UNDERGROUND WATERS IN DEMÄNOVÁ VALLEY AS A TOOL FOR FINDING CONNECTIONS BETWEEN THE ŠTEFANOVÁ AND DEMÄNOVÁ CAVE SYSTEM

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More than two years ago, we have published at the occasion of 11th scientific conference 'Research, use and protection of caves' an abstract in the Aragonit journal (Herich et al., 2017) dealing with the chemical composition of underground waters in the Štefanová Cave. Since then, no significant changes happened in the known extension of the caves of Demänová Valley, yet Štefanová cave is now reaching 18 km in length (Fig. 1).

Accurate chemical analysis of underground waters can be a useful tool for obtaining various data about the studied cave system. We can detect significant changes in chemical composition caused by the mixing of waters with different compositions only due to its different origin.

Our research was based on wide practical speleological knowledge of the karst phenomenon of the Demänová caves and compared with the results of previous tracing experiments (Auxt et al., 2012). The first set of samples was

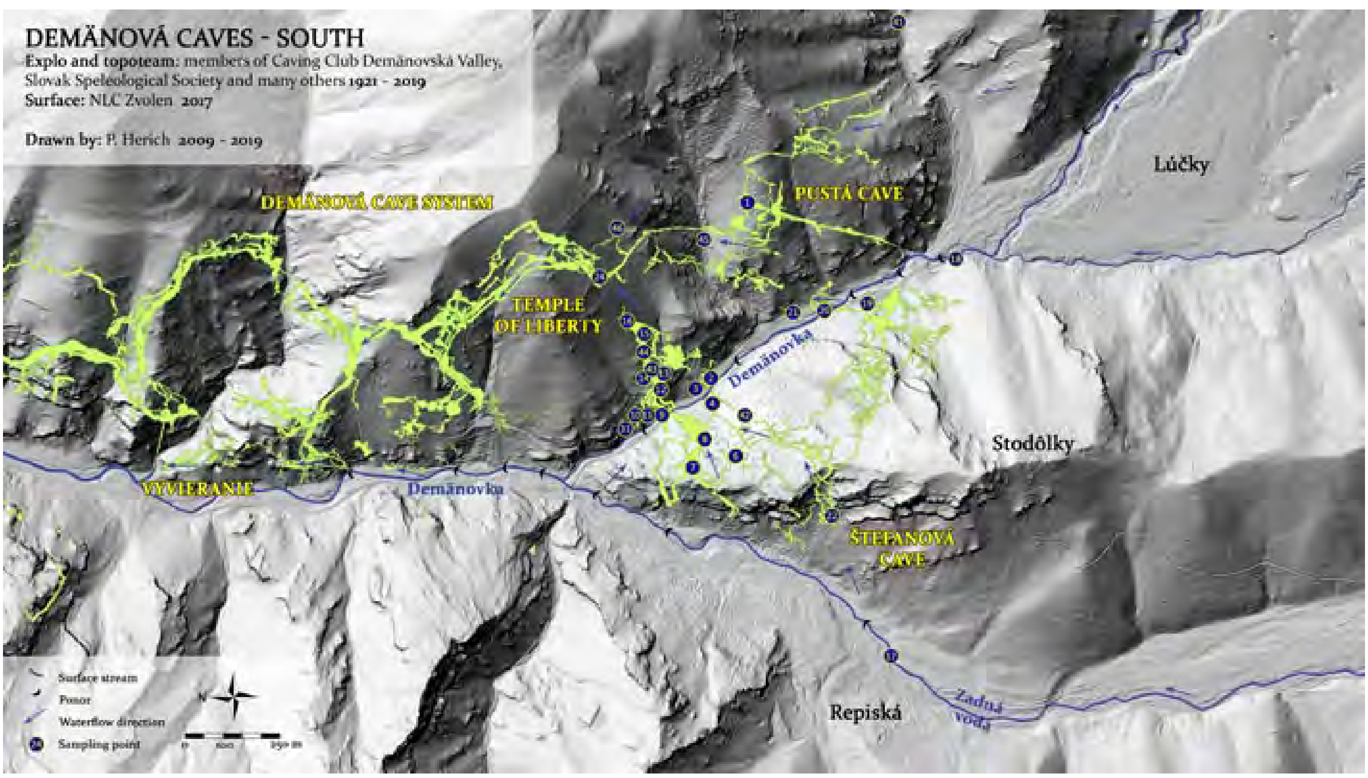

Fig. 1. An overall map of the Demänová Caves (south part) with the location of samples: 1 – Agate Chamber, 14 – inflow from the left, 17 – Zadná voda (surface stream), 18 – Demänovka, 24 – Infernal Chamber of the Temple of Liberty, 41 – Machnatá Valley (surface stream), 43 – streambed between No. 14 and 15, 44 – Lake Chamber, 45 – Pustá Valley (surface stream), 46 – Forgotten Corridor. Author: P. Herich

Tab. 1. The results of chemical analyses.

Sample No.	pH	T. Alk. (mmol·L^{-1})	Ca^{2+} (mg·L^{-1})	K^+ (mg·L^{-1})	Mg^{2+} (mg·L^{-1})	Na^+ (mg·L^{-1})	Cl^- (mg·L^{-1})	N NO_3^- (mg·L^{-1})	S SO_4^{2-} (mg·L^{-1})	Sum Anion (μeq·L^{-1})	Sum Cation (μeq·L^{-1})	Diff. of the sum of cations and anions (%)	Quality Ions balance	Calcd. conductivity (25°C) (μS·cm^{-1})	Measured conductivity (μS·cm^{-1})
1	7.89	1.336	30.13	0.47	8.90	1.23	0.49	0.877	13.61	2261	2301	2	OK	232	227
14	7.35	0.336	7.24	0.54	1.62	1.91	0.57	0.946	2.05	547	591	8	OK	61	61
17	7.25	0.248	5.45	0.52	1.33	1.77	0.74	0.946	2.11	467	472	1	OK	52	52
18	7.48	0.438	8.42	0.63	2.78	2.40	1.60	1.031	2.19	694	770	10	OK	77	76
24	7.82	1.277	24.64	0.49	7.52	1.41	0.59	1.029	8.84	1918	1922	0	OK	193	190
41	8.32	3.238	37.74	0.19	18.64	0.32	0.34	1.347	1.77	3454	3435	-1	OK	305	318
43	7.73	0.821	14.45	0.58	3.66	1.84	0.72	1.065	2.80	1092	1117	2	OK	111	113
44	7.71	0.757	13.66	0.58	3.44	1.93	0.74	1.056	2.69	1021	1063	4	OK	105	107
45	7.98	3.701	44.69	0.17	20.24	0.45	0.38	1.070	1.98	3911	3918	0	OK	343	365
46	7.93	2.968	39.54	0.28	16.17	0.38	0.34	1.142	4.68	3351	3326	-1	OK	302	310

collected in March 2016 and the results were published as mentioned above. When we tried to calculate relative discharges of water in the Agate chamber in the Pustá cave and in the Lake chamber in the Štefanová Cave, using mixing equations from its composition in the Infernal Chamber of the Temple of Liberty, we did not obtain consistent results. It means, that relative discharges calculated from different indicators (cations or anions) significantly varied and some set of equations had no real solution. The chemical composition of the water in the Infernal Chamber could not be compiled only from two sources, waters from the Agate Chamber and Lake Chamber.

Therefore we have organized the new set of sampling in November 2017 to include more possible sources (Fig. 1). Chemical analyses of the collected samples are summarized in Tab. 1.

The main difference in comparison with the spring collection of 2016 is the composition of water in Lake Chamber (sampling place 44). During spring flood in 2017, a new large ponor of the Zadná voda Stream has been opened. This led to a significant change of composition of water in the Lake Chamber in the Štefanová Cave, which is much less mineralized now due to the higher ratio of allochthonous water from the Zadná voda Stream.

Tab. 2 Calculated discharge ratios from mixing equations.

Sample	Hydrogencarbonates (mg·L^{-1})	Calcium (mg·L^{-1})	Magnesium (mg·L^{-1})	Sulphates (mg·L^{-1})	Average discharge ratio
1 Agate Chamber	81.5	30.1	8.9	13.6	–
44 Lake Chamber	46.2	13.7	3.4	2.7	–
46 Forgotten Corridor	181.1	39.5	16.2	4.7	–
24 Infernal Chamber of the Temple of Liberty	77.9	24.6	7.5	8.8	–
Discharges ratio **1/44**	1.52	1.46	1.48	–	1.49
Discharges ratio **1/46**	5.94	7.29	6.34	–	6.52
Dischages ratio **44/46**	3.93	5.01	4.28	–	4.41

The source of nitrates (and partly sulphates) in all the samples is most probably represented by rainwater (acid rains). The average concentration of nitrates in rainwater in the highly polluted area in the Krušné hory Mts. (NW Bohemia) varied between 2 and 3 mg·L^{-1} (Hůnová et al., 2004), while in our samples (area with significantly lower pollution from combustion engines) the average concentration varies in the range between 1 and 2 mg·L^{-1}.

The content of chlorides in all waters is negligible in comparison with spring 2016. Its presence is significant only in winter and spring months due to deicing salt and preparing of artificial snow in ski-resort Jasná.

Comparing the chemical composition in the Machnatá valley and in the Forgotten Corridor leads to the conclusion, that both water types are very similar and water from Machnatá valley most probably goes to the Forgotten Corridor.

In Tab. 2 there are discharge ratios calculated from mixing equations based on four different indicators (hydrogen carbonates, calcium, magnesium, and sulfates). When we accept the model, that the waters in the Infernal Chamber are coming from the Agate Chamber in the Pustá Cave, the Lake Chamber in the Štefanová Cave, and the Forgotten Corridor we will find quite reasonable and consistent results. The average discharge ratio for the Agate Chamber/Lake Chamber is equal to 1.49, which is very close to reality. The calculated discharge in the Forgotten corridor slightly exceeds the reality, which can be explained by another unknown inflow of very similar chemical composition. We have calculated, that it cannot be only water from Pustá Valley due to low sulfate content. So, the conclusion follows: The water in the Infernal Chamber can be compiled from three main different types: 1) water from the Agate Chamber with high sulfate content, 2) water from the Lake Chamber with low mineralization (a large portion of the Zadná voda Stream) and 3) different autochthonous waters of the average composition similar to water from the Forgotten Corridor.

We would like to thank all cavers involved in this research – members of the Slovak Speleological Society (mostly from Demänovská dolina Valley Caving Club) and Czech Speleological Society.

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UIS CAVE RESCUE COMMISSION FOR CAVERS

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Cave Rescue Commission (CRC) is among the first commissions which are actively existing since the first steps of UIS. It was established by Alexis de Martinoff in 1965. The following presidents have continued his job to realize his dream on the field of cave rescue. As the main target, the presidents promoted to organize regular meetings, congresses, or international conferences on the subject of the subterranean help. During the second international meeting held in Mozet/Belgium in 1971, it was decided to organize an international cave rescue conference every four years. The first meeting of cave doctors was held at the Eisriesenwelt/Austria in 1975. Nowadays, CRC held conferences in different countries on four years and held commission meetings on the occasion of ICSes. Those meetings deal with differents topics of rescue activity like medical, technical, communication, responsibility, insurance policy, legal, and other important aspects. The rescue information and experiences are shared among UIS member countries. During international meetings, the participants did occasional demonstrations and common training. On the 11th International Cave Rescue Conference (ICRS) held in Aggtelek-Josvafo/Hungary in 2007, where 110 representatives of the 26 countries created the Aggtelek Agreement which consists of certain basic recommendations concerning cave rescue operations. That document may serve as support in negotiations between rescue manager and administration. Now it is functioning as UIS Governmental Recommendation on Cave Rescues. Only 8 countries were represented on the first international meeting about cave rescue held at Bruxelles and Han-sur-Lesse/Belgium in 1963, but there were 110 participants from 14 countries at the Vaumarcus/Switzerland where the 13th ICRS was held in 2015. The last event was held on the occasion of the 17th ICS in Sydney/Australia, where 23 cave rescuers participated and reviewed the activities of the past 4 years and defined the tasks ahead.

TECTONIC OBSERVATORIES IN THE CAVES OF THE SLOVAK KARST AND THE OCHTINÁ KARST

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A network of six extemensometric gauges was founded to define faulting activity in the southern part of Eastern Slovakia. The local network here is a part of an extensive European network called Eu-TecNet. A high number of far-located sites helps to compare geodynamic regimes not only on a local scale but on a global scale as well. Many of these sites are located in karst caves to decrease the effects of peak-to-peak massive dilatation, which is caused by changes in air temperature and sun exposition. Such an effect is significant at surface sites. All six sites were located in four caves: Skalistý potok Cave (two gauges), Drienovská Cave (two gauges), Krásnohorská Cave, and Ochtinská aragonitová jaskyňa Cave. All monitored faults displayed fault activity and high sensitivity to stress field changes in the Slovenský Karst and Ochtiná Karst. It is not possible to define the magnitude of fault displacement trends for the period 2011-2019, because the trends were interrupted by short-lasting tectonic pulses, which can accelerate the previous trends or bear contradictory displacement mechanisms. Those interruptions can be generated either during increased stress periods, documented by fault closing and thrusting, or during reversal periods, documented by fault openings and subsidence. Moreover, different periods are followed by a different sense of strike-slips as well. We observed three mutual periods with increased stress in half of 2013, 2014/2015, and half of 2017 (Fig. 1). The most significant one was the 2014/2015 period. This period enabled us to compute NW-SE stress orientation at localities: the Drienovská Cave and the Skalistý potok Cave. On the other hand, the long-term regime displayed NE-SW striking extension. It is obvious from prevailing eastern blocks subsidence in the Skalistý potok Cave. The fourth period represents stress relaxation at the end of 2018. It was documented by subsidence at the Skalisty potok 1 and 2 sites, fault opening at the Drienovská 1 site, and subsidence in the Krásnohorská Cave. That relaxing period was preceded by a calm period, without any significant displacements. It was observed at many sites in Europe. Here, it is visible in the Krásnohorská Cave or at the Skalistý potok 1 site too. Furthermore, recent results show that displacements reach a hundredth and tenth of mm. Such faulting does not affect the stability of cave spaces. On the other hand, the faulting represents a significant shaping phenomenon for calcite decoration, damaging its wholeness too.

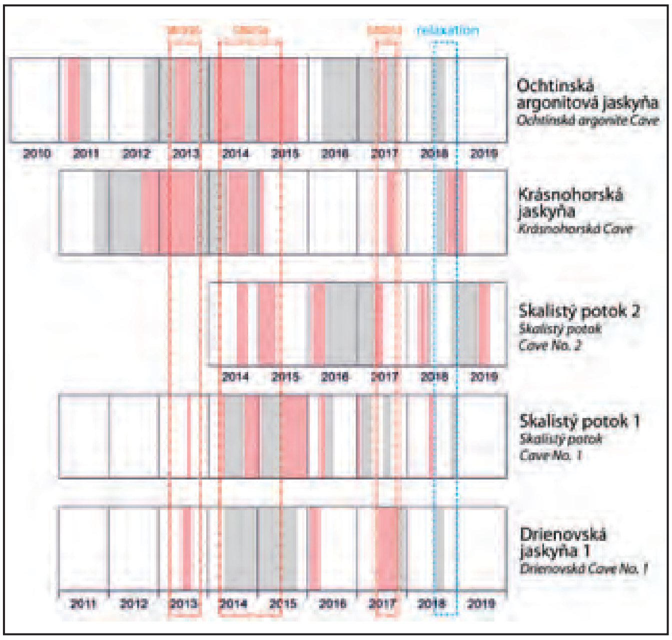

Fig. 1. Episodes with increased stress (pink colour) and stress reversal phases (grey colour). Significant fault displacements occurred during three increased stress periods and one relaxation phase. The relaxation was accompanied by significant vertical microdisplacements and fault opening.

STATUS OF CAVES IN LOWER HIMALAYAN REGION IN INDIA

Gagan Deep – Sagarika Grewal

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The subterranean caves are an interesting geographical feature in the lower Himalaya that is famous for its snow-capped peaks, rivers, and valleys. These could be limestone grottoes hidden in the mountains, ice caverns in the glaciers, or holes created by humans in the fragile pebbled and sandy cliffs of the Trans-Himalaya. For many Buddhist and Hindu monks, these caverns were and are meditative spaces where they lock themselves from the outside world for a specific time, ranging from a few months to many years. At the foothills, 22 km from Rishikesh, on the banks of the tranquil Ganga is the Vasisht Gufa, the holy spot. The spiritual vibrations inside the cave are intensified by the silence that pervades. The fascinating Ice Caves, formed within the glacier bodies, are found in those parts of the Himalaya where the temperature is subzero for most of the year. They are impermanent and can change form and shape according to the weather conditions. In the Trans Himalaya, several man-made caves serve as Buddhist monasteries, the Ajanta of the Himalaya, overlooking the Spiti River. As we know, caves impart poignant scientific information about the geological activities, the sustaining plant and animal life forms, and the art and lifestyle that existed ago. After an intensive field survey, we found that around 80 % of caves are under environmental stress and also geologically very weak. The government and the local community are doing their best for maintaining their natural beauty but some caves are very near to the end of their existence.

MORPHOMETRIC ANALYSIS OF THE SINKHOLES ON THE ČACHTICKÁ PLAIN

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The dominant part of the Čachtice Karst, located in the northern part of the Malé Karpaty Mts., is the Čachtice Plain. Our research was focused on a morphometric analysis of 85 sinkholes located in this plain (Lačný et al., 2019).

Sinkholes rarely occur individually but are often clustered into lines. They are found in the bottom of dry valleys, or on tectonically predisposed lines directly on the plain. Often they contain small tributary grooves. There are also connected sinkholes, mostly occurring as a group of two sinkholes. Several sinkholes can be described as maternal and subsidiary, also referred to as parasitic sinkholes or depressions. According to the methodology of Jakál (1975), on the basis of the slopes of sinkholes, the kettle-shaped (38) and funnel-shaped ones predominate. Ring-shaped (6) and cup-shaped (5) sinkholes have minor representation. We use the methodology of Petrvalská (2010) to differentiate them according to the shape of a footprint. Irregular sinkholes (52) dominated, followed by the oval (30), and least represented were symmetrical – round sinkholes (3). However, this classification could be biased due to the subjectivity of mappers.

Three major directions of sinkhole lines have been identified: WNW-ESE, NNE-SSW, and NE-SW. The most significant direction is WNW-ESE. It showed a significant relationship between sinkhole lines and dominant fault courses.

The Čachtice Plain is relatively heterogeneous in size of sinkholes. There are sinkholes whose circumference reaches several hundred meters. There are five (Sinkhole Megero, Springer´s Pits 1,2,3, Jesenský Oaks). Up to 51 bores reach a perimeter of 10 to 40 m. The largest described sinkholes reach depths of 15 to 28 m. The largest group of sinkholes reached a depth of 1–2 m (29), followed by a group of 0–1 m (16). In twelve sinkholes, their depths reached the range of 2–3 m and 4–5 m. The mapped longest axes of the sinkholes are more variable than the previous data. Sinkholes with the longest axis in the range of 3 to 15 m are the most represented. Also significant is the group with lengths from 16 to 25 m.

Based on the altitude, two significant horizons can be traced, on which sinkholes originate. The first horizon ranges from 314 to 361 a.s.l., and the second at an altitude of 498 to 550 m. These significant horizons may be related to the alignment of the platform in multiple phases (Mitter, 1974).

With the number of four sinkholes per km^2, the area ranks rather to the karst areas of lower representation. Compared to the Koniar Plain (15 sinkholes per km^2), Plešivecká Plain (45–50 sinkholes per km^2) or Silická Plain (55 sinkholes per km^2) (Hochmuth, 2004), this number is low. For the not so well-developed karst of the Malé Karpaty Mts., these sinkholes and the cave space connected to them, are sharply inscribed in the character of the Čachtice Plain.

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EUROPEAN TROGLOBIONTS ON THE NORTHERN RANGE LIMIT – DIVERSIFICATION OF CAVE *PSEUDOSINELLA* IN THE WESTERN CARPATHIANS

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The observations from the recent period revealed that the Western Carpathians, a part of the Carpathian mountain chain, is the northernmost region in Europe with the occurrence of the troglomorphic cave fauna. The collembolan genus *Pseudosinella* Schäffer, 1897 is an artificial, polyphyletic taxon derived from the genus *Lepidocyrtus* Bourlet, 1839 from which it differs in the reduced number of eyes. It covers about 350 species with predominantly Holarctic distribution of which about 39 % are confined to caves. We studied morphology and molecular traits to identify cave species of the genus *Pseudosinella* occupying the Western Carpathian caves and clarify their phylogenetic relationships. Based on morphological traits, we hypothesized that *Pseudosinella aggtelekiensis* (Stach, 1929) and *P. paclti* Rusek, 1961 are descendants of the different phyletic lineages, the former species lacking morphologically related edaphic species. On the other hand, several species related to *P. paclti* were found in caves, superficial subterranean habitats, and in the soil. Molecular phylogeny analysis has shown two distinct groups of cave species following a pattern of allopatric distribution. The first group consisted of populations of *P. aggtelekienis* from the Slovak Karst and an undescribed species from fragmented and isolated karst in eastern Slovakia. In the second group, different populations of *P. paclti* occupying caves of the central karst regions were incorporated together with a new highly troglomorphic species confined to a small karst area. After an approximate estimate of the geological timing of the species isolation (RelTime), the two distinct *Pseudosinella* lineages separated approx. 9.54 mya, followed by subsequent diversification in *P. paclti* lineage 8.36 mya and in *P. aggtelekiensis* lineage 6.99 mya i.e., during the Late Miocene. This study contributed to the assumption that the Western Carpathian Mts. played an important role as a speciation centre of the obligate cave fauna in Central Europe.

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POSTCARDS AS A FORM OF PROMOTION OF SHOW CAVES IN AUSTRO-HUNGARIAN MONARCHY

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Postcard – 'outdoor letter', 'card with a view' – appeared for the first time in the world on October 1, 1869, in Austro-Hungary. Dr. Emanuel Hermann, a professor of economics at the military academy in Wiener-Neustadt, is considered to be its inventor. The first page had no illustrations yet, only inscriptions in German and Hungarian. A stamp with the image of Emperor Franz Josef was also printed. In the 1870s, the Austro-Hungarian post office issued cards in local languages, including Polish. In 1872, an illustration appeared on the card where the content was saved – the other side was the address. At the end of the 19th century, postcards gained tremendous popularity, which was associated with the development of modern tourism, including cave tourism. The period from the end of the nineteenth century to the end of the First World War is called its 'golden period'. At that time, the postcard was not only useful, it was also the object of a collector's passion in a large part of society. Exhibitions were organized around the world, specialist magazines were issued and collectors' clubs were associated. Around 1890, the first cave-related postcards appeared. Initially, they were mainly lithographs. Postcards with caves from the Karst area in current Slovenia were very popular – in 1899, the first post office inside the cave was opened in the Adelsberger Grotte (now the Postojna Cave). In addition, postcards from the Moravian Karst, Austria, Polish-Hungarian borderland were popular too. The aim of the paper is to analyze and present cave-related postcards and their impact on tourism development in 1890–1918.

NEW RECORDS OF RHAGIDIID MITES (ACARI: PROSTIGMATA: RHAGIDIIDAE) IN SLOVAKIA

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Mites of the family Rhagidiidae are relatively scarce predators of the soil invertebrates. Several rhagidiids are closely associated with caves in Slovakia. From 34 species known from Slovakia, nine were found in caves. Among them also the Western Carpathian endemic troglobiont *Foveacheles (Spelaeocheles) troglodyta* (Zacharda, 1988) and glacial relict *Poecilophysis (Procerocheles) spelaea* (Wankel, 1861) (Kalúz, 2017; Kováč et al., 2014; M. Zacharda, unpublished data, 1980, 1988).

All records of both species are from seven caves and abysses situated in five regions, namely Horehronské podolie Valley, Great Fatra Mts., Hornádska kotlina Basin, and Low and Western Tatras Mts. Most mites were collected directly by hand or infrequently also captured in traps as part of comprehensive surveys of terrestrial or aquatic fauna in caves. New records of the cave Rhagidiidae date from the period 2018–2020.

Troglobiont *Foveacheles troglodyta* have distinct morphological adaptations to subterranean life. It was originally described from Stratená Cave System in the Slovak Paradise (Zacharda, 1988). Additional individuals have been found in caves of the Slovak Paradise, Muránska planina Plateau, and Western and Low Tatras (M. Zacharda det.; Kováč et al., 2001, 2002, 2014). Glacial relict and troglophilous species *Poecilophysis spelaea*, also considered a troglobite, at the stage 'in statu nascendi' is a predator of Collembola (Zacharda, 1980). It is distributed in several European countries, in Slovakia it has been recorded in caves of the Slovak Karst, Muránska planina Plateau, Liptovská kotlina Basin, Kozie chrbty Mts., Low and Western Tatras Mts., Slovak Paradise, and Great Fatra Mts. (M. Zacharda det.; Kováč et al., 2001, 2002a, 2002b, 2014; Košel, 1994).

New records of *Foveacheles troglodyta* come from the hind part of the Márnikova Cave (Horehronské podolie Valley), where two females and one male were collected by hand from the surface of water pool. *Poecilophysis spelaea* has been recently registered in six caves. One male was collected by hand from the rock surface in the hind part of the Dreveník Ice Cave (Hornádska kotlina Basin). This mite was similarly also hand collecting on the surface of water pools in the Dolná Túfna Cave (Great Fatra Mts.), namely two tritonymphs and seven females. In the Brestovská Cave (Western Tatras Mts.) one tritonymph was found on the surface of water pool. The species has been found also in several caves of the Jánska dolina Valley (Low Tatras Mts.). Two females and one tritonymph were detected on the surface of water pools in the Malá Stanišovská Cave, and six females and one male in the same habitat of the Veľká Stanišovská Cave, while one male was caught by a pitfall trap in the Medvedia Cave. In the nearby Demänová Valley, two females were detected on the surface of water pool in the Okno Cave. The new records complement the current distribution range of these rhagidiid mites, while confirm their geographic distribution in caves of the Central Carpathian and the Bůkk-Gemer-Spiš regions (Košel, 2009).

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MICROBIAL CONTAMINATION OF THE UNDERGROUND STREAM STYX IN THE BARADLA CAVE, HUNGARY

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Microbial contamination was recorded on the touristic trail Hoszutúra (Baradla-Jósvafő) in November 2018. The underground stream Styx went dry or turned to residual pools as a result of a longterm period of drought. Some of them were with unpolluted water, but gradually downstream, we found pools with orange to black coloured water/sediment in the term of microbial contamination, as well as orange coloured sediment on the bottom of completely dried pools. From water and sediment samples, we isolated completely different communities of microbiota (bacteria and filamentous microscopic fungi) in comparison with the results of previous studies on microbiota in this cave system and also with control samplings in October 2019. The expansion of these microbial species was brought by contamination of the underground stream.

Based on the examined data the question emerges, how the muddy contamination got into the cave. If we take into account that the first mud sediment has been examined below the Törökmecset branch, i.e. eastward, most likely the mud came into underground passages from the Aggtelek lake. It is a typical marginal karst lake, originally a sinkhole that has been filled up by clay. South from the cave system on the border of karstic (Triassic limestone) and nonkarstic (Late Miocenian-Pliocenian pebble and clay of Poltár Formation) rocks many other small lakes can be found which have been filled up with clay and muddy sediments have origin in Poltár Formation. The mud got most likely into the cave during the 2018 summer rains (mainly rainfalls in June 2018) via the Törökmecset branch.

MICROBIOLOGICAL CONTROL OF AIR IN THE DOMICA, BARADLA AND BÉKE CAVES USED FOR SPELEOTHERAPY

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Studies about microscopic fungi and bacteria in the Béke, Baradla, and Domica caves, which will be used for speleotherapy, were predominantly focussed on air-borne microorganisms. Samples were collected 6 times overall during the period between 2018 and 2020 by using the gravity settling technique or isolation of microorganisms with an air sampler. Colony-forming units (CFU) per cubic meter were obtained by cultivating them on growth media. Isolated microorganisms were determined microscopically, or by molecular techniques (isolation of DNA, sequenation of specific genes).

The highest counts of CFU were found in Béke Cave – New sanatorium (1.7×10^3 in August 2018 and 5.8×10^3 in November 2018 for microscopic fungi, and 4×10^3 for bacteria on average). Due to the ongoing reconstruction of this site, numbers of microfungal and bacterial particles in cave air artificially increased to exceed the European norm value for indoor air severalfold (500 CFU/m^3 of air in case of absence of pathogenic species). In spite of these facts, no important pathogenic microfungi were isolated, with the exception of *Aspergilli* of the section *Versicolores* which belong to allergenic species. Commonly, species of the genus *Aspergillus* belong to potential agens important for human and veterinary medicine in regard to the production of various secondary metabolites. Rich microfungal spectrum was obtained in August 2018, *Trichothecium roseum* was found as the most frequent microscopic species. This species was found in one case as an agent of dermatomycosis. Other fungal species found in Béke cave were *Cladosporium cladosporioides* group, *Cladosporium herbarum* group, *Cylindrocarpon candidum, Lecanicillium muscarium*, and *Mucor hiemalis.* From Bacteria, mainly environmental taxa were isolated, e.g. *Cellvibrio* sp., *Streptophyta* sp., *Nocardioides* sp., *Caulobacter* sp., *Bradyrhizobium* sp., *Comamonas* sp., and *Phenylobacterium* sp. Bacteria which may cause diseases, like *Staphylococcus* sp., *Acinetobacter* sp., or *Propionibacterium* sp. were also isolated in small quantities. The occurrence of only a few colonies of these microorganisms is negligible. In addition, from the walls, yellow colonies as *Paeniglutamicibacter* sp. and white colonies as *Arthrobacter* sp., both from the class *Actinomycetes* (family *Micrococcaceae*) were identified.

In Baradla Cave, a place called the Róka ág was selected for speleotherapy. The CFU counts of air-borne microfungi were 56.8 CFU/m^3 in June 2018, 35.0 CFU/m^3 in August 2018, and CFU was increased in October 2019 during the reconstruction (3.5×10^3). Average numbers of bacteria were higher in winter (5×10^3 CFU/m^3) than in summer months (3×10^2 CFU/m^3) and most of the time bacteria reached higher numbers than in the Concert halls open for public (1.3×10^3 CFU/m^3). The most often isolated air-borne microfungi, from this sampling site, were *Cladosporium herbarum* group, *Penicillium polonicum*, and *Scopulariopsis asperula*. From bacteria, dominant taxa were *Arthrobacter* sp., *Micrococcus* sp., *Paenibacillus* sp., *Sphingobacterium* sp., *Pseudomonas* sp., *Rhodococcus* sp., *Planomicrobium* sp., and *Kocuria* sp.

In Domica Cave, a place selected for speleotherapy was monitored is not open for the public yet. Air-borne microfungi reached 178.5 CFU/m^3 in June 2018, and 210.3 CFU/m^3 in August 2018. During the sampling period, bacterial counts ranged from 7×10^2 CFU/m^3 to 6×10^3 CFU/m^3. From domain Fungi, following taxa were isolated: *Alternaria* sp. Sect. *Alternata*, *Cephalotrichum microsporum*, *Cladosporium cladosporioides* group, *Cladosporium herbarum* group, *Cladosporium sphaerospermum* group, *Cylindrocarpon candidum, Fusarium* sp., *Penicillium ochrochloron*, *Phoma* sp., *Pochonia chlamydosporia* var. *catenulata*, *Talaromyces alboverticillius*. From the group of Bacteria, mainly environmental taxa were isolated, e.g. *Bacillus* sp., *Arthrobacter* sp., *Terribacillus* sp., *Peaniglutamicibacter* sp., *Curtobacterium* sp., *Luteimonas* sp. Isolated bacterial species like *Micrococcus luteus* and *Bacillus cereus* are common airborne bacteria, but in some cases can be opportunistic pathogens.

LASER SCANNING INTENSITY DATA – LIMITATION AND APPLICATION IN MAPPING OF THE CAVE ENVIRONMENT

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In recent years, the advantage of terrestrial laser scanning (TLS) has been also exploited in the mapping of the underground forms. Cave systems, formed in various geological settings with variable dimensions extending from narrow passages to grand domes, represent an exceptional environment for studying tectonic and geological structures. However, using conventional methods for mapping complex geological geometries and identifying lithological contacts in such a specific environment is a challenging task, mainly due to inaccessibility and limited light conditions. Contactless, light-independent, and highly detailed cave surveying with TLS generates millions of 3D coordinates of cave surface, by which mapping of features difficult to be reached and studied directly is possible. As an additional attribute of laser scanning, the intensity of the backscattered laser pulse is recorded. Intensity values are influenced by factors associated with the scanning geometry and spectral properties of the surface material. Case study of intensity correction was focused on data initially acquired for geological mapping using TLS Riegl VZ-1000 during the expedition in the Gouffre Georges cave in the French Pyrenees, which formed on the contact of marble and lherzolite. After elimination of the influencing factors of scanning range and incidence angle of the transmitted laser beam, taking into account the character and contours of the cave wall surface as a set of facets and effect of the atmospheric attenuation, the resulting corrected intensity values depend mostly on the spectral surface properties. Derived reflectance values reveal different lithological layers allowing their structural properties to be analysed. Resulting data derived by proposed intensity correction methodology are also applicable in the field of speleology, biospeleological, and archeological studies. Application of the corrected intensity is demonstrated on the example of datasets from Domica Cave and Silická ľadnica Cave in Slovak Karst for detection of ice occurrence, wet surfaces indicating active karst processes, for mapping and quantification of cave fauna, and even for identification of cave paintings.

VARIABILITY OF CAVE DRIPWATER DROP SIZE: AN EXAMPLE FROM MORAVIAN KARST

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When discussing dripwater hydrology, there are generally two ways of measuring and quantifying water discharge: (1) the dripwater is collected and the accumulated discharge volume is periodically measured or (2) the number of discharged drops over a time period is counted. Droplet counting seems to be the prevalent method, probably due to the often very low discharge rate. However, using drip rates expressed in drip counts over time must in some correlations and comparisons depend on a few basic assumptions. For example, that (a) the drop volume is constant or with insignificant variations, that (b) the drop volume is independent with respect to other dripwater parameters (temperature, pH, mineralization) or (c) that the drops formed on various speleothems have a similar size. This study presents the results of field measurements of drop sizes in the Punkva Caves (Moravian Karst, Czech Republic) compared to basic hydrogeochemical properties and speleothem width. In addition, the dataset was compared with a laboratory experiment simulating various drip discharges.

A set of 57 drop samples was collected from twelve speleothems in four sampling events from July 2017 to April 2018. The drop volume ranged from 0.1343 to 0.0499 ml with an average volume of a drop being 0.0994 ± 0.0194 ml. The variation coefficient is 19.5 % and it shows that the drop volume variability between individual drips is quite substantial. The strongest correlation of drop volume was determined to the drip rate (R2 = 0.6264) and the speleothem diameter (R2 = 0.5575) and the relations seem to be linear. However, the relation to the drip rate is almost non-existent for slow drip rates below 4 drops min^{-1} (R2 = 0.0002). The drop volume also negatively correlates with CO_2 content in water and pH, which is given by the effect of faster CO_2 degassing from smaller drops. Other correlations of drop volume (with temperature, specific conductivity, and atmospheric CO_2) are statistically insignificant. The laboratory experiment sampled 18 various drip rates (3–54 drops min^{-1}) and 72 drop volumes (average is 0.0581 ± 0.0031 ml). The observed positive linear correlation was statistically significant (R2 = 0.907). The most important parameter determining drop volume is the diameter of the speleothem, while the only seasonally variable parameter with observed influence is the drip rate. It seems that although variability in individual drips might be considered negligible, there might be substantial differences in drop volumes between speleothems within one cave system.

SIX MONTHS OF EXPLORING INVERTEBRATE COMMUNITIES INHABITING EPIKARST OF THE DEMÄNOVÁ VALLEY (SLOVAKIA): WHAT HAVE WE LEARNED SO FAR?

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Epikarst represents the uppermost layer of the karst landscape, at the soil-rock interface. Specifically, it is located within the top vadose zone of the karst aquifers and consists of an extensive network of fractures and voids. These are generally characterized by down to capillary dimension and are mostly filled with water, having vertical circulation. Thus, the epikarst comprises a voluminous reservoir of water, coming mostly from precipitation, which gradually drains to the water table in the underlying cave environment. So far, the knowledge of invertebrates inhabiting the network of epikarst voids has been completely absent in Central Europe. Since May 2019, we have been sampling water dripping permanently from the cave ceilings, along with therein occurring aquatic invertebrates, by means of 27 filtering devices laid out at Okno Cave (5 devices deployed), Beníková Cave (5 devices), Demänovská jaskyňa mieru Cave (5 devices), and Demänovská jaskyňa slobody Cave (12 devices). Each of the filtering devices comprises a plastic funnel that directs dripping water into a cubic-shaped plastic vessel supplemented with a fine mesh (size 60 µm) fixed on its two sides. A perforated plastic container is commonly used to stabilize the above-mentioned components. Invertebrates were collected from the filtration vessels at monthly intervals. At each visit to the caves, we also measured the basic chemical and physical properties of dripping water such as pH, specific electrical conductivity, temperature, and others. In total, nearly 600 individuals of 9 different higher invertebrate taxa were sampled during the six-month period. Epikarst of the Demänová Valley is inhabited by eudominant harpacticoid Copepoda (62.5 %), followed by Collembola (25.3 %), Acarina (3.7 %), Diptera (1.8 %), Oligochaeta (1.3 %), and Amphipoda (1.2 %). The dominance of the remaining taxa did not exceed 1 %. Among the so far sorted invertebrates, two subterranean crustaceans of the genus *Bathynella* and *Niphargus* have been found. The study has been supported by FAN B grant.

DEPICTION OF CAVES ON POSTAGE STAMPS AND OTHER PHILATELIC MATERIALS

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Postage stamps are used since 1840 when the use of them was established firstly in Great Britain – the first stamp, the 'Penny black', as well as two days later issued 'Two penny blue', included an engraving of the young Queen Victoria. They were originally used to indicate that postage had been paid on a mailed item. During the 21st century, the use of postage stamps has reduced in the world because of electronic mail and other technological innovations. In regard to their beauty and historical significance, stamps with other philatelic materials (First Day Issue, First Day Cover, souvenir, and mini sheets, etc.) present currently more collectible values for stamps collectors than an item for the postage rate considering their illustrations and association with the social and political realities of the time of their issue.

The Tasman´s arch was the first illustration depicted on the cave-thematic stamp, which was issued in 1889. A historical overview is presented from the start to nowadays, including issued individual stamps, sheets of stamps, First Day Issues, First Day Covers, souvenir sheets, mini sheets, envelops with stamps, cinderella stamps, and postcards. Illustrations comprise a view into caves, speleothems, underground lakes, cave inhabitants, and cave art paintings from various cave types in the world.

TEMPORAL AND SPATIAL VARIATION OF RADON AND CO_2 CONCENTRATION IN THE VAŽECKÁ CAVE (SLOVAKIA)

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The Važecká Cave is located in the Northern part of the Low Tatra Mountains on the northern edge of the Važec Karst area, at the contact of the Kozie chrbty Mountains and the Podtatranská Basin. The cave is developed in the Middle Triassic dark-grey Limestones of the Gutenstein Formation of the Hronic Unit and is characterized by subhorizontal halls, without a significant vertical segmentation. A large part of the cave floor is covered by water-transported sediments.

The continuous monitoring of ^{222}Rn activity concentration started in 2012 and is still being carried out. Three monitoring stations are situated in the cave: Gallery (operates from May 2012), Lake Hall (operates from November 2015), and Entrance Hall (operated from November 2015 to March 2018, re-opened from September 2019). Besides radon, CO_2 concentration, internal air temperature, and relative humidity are continuously measured at each station. Radon is registered using passive alpha particle detector Barasol BMC2 (Algade, France). The cave is also equipped with the external meteorological station. Atmospheric pressure data was taken from the meteorological station operated by the Earth Science Institute of Slovak Academy of Sciences in Stará Lesná, 40 km NE from Važec village. Data is collected with a sampling period of 10-minutes.

Radon activity concentration and CO_2 concentration in the Važecká Cave atmosphere exhibited annual, non-periodic multi-day, and periodic daily variations. The spatial differences in radon activities among stations were confirmed. The highest radon levels were found in the Gallery, the most distant station from the cave entrance. The daily average of radon concentration ranged from 3600 to 42,200 Bq/m^3 at the Gallery station and from 1300 to 27,700 Bq/m^3 at the Lake Hall station. The lowest radon activities were measured at the Entrance Hall station. Radon reached its maximum in summer months, from June to September. The annual maximum of CO_2 concentration is registered approximately one month later than radon maximum. Annual variation of radon and CO_2 is controlled by the seasonal change of ventilation regime associated with the seasonal variation of the difference between the temperature measured inside the cave and atmospheric temperature.

Multi-day radon variations lasting up to 15 days were observed at all three stations. Most of them were registered simultaneously at the Lake Hall and the Gallery station and they coincided with CO_2 multi-day variations.

Daily variations were observed at all three stations, but the position of daily maximum and minimum was not identical. During a whole year, radon maximum in the Gallery corresponds to radon minimum in the Lake Hall and the Entrance Hall. The highest daily radon amplitude in all stations is observed from May to September.

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GEOMORPHOLOGY & NATURAL HAZARDS: A CASE STUDY OF THE AMARNATH CAVE REGION IN INDIA

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Mountain belts created by continental collision represent the most dominant geologic features on the surface of the Earth. The Rockies and the Appalachian belt in North America, the Andes in South America, the Ural mountains in central Eurasia, the Alps of Europe, and the Himalayas are some of the best examples, each extending for thousands of kilometers. A great deal of attention has been paid to the evolution of these mountain belts since the advent of plate tectonics. The youngest and perhaps the most impressing of all the continent-continent collision belts on the Earth is the Himalayan origin; its evolution has long been the subject of discussions (Gansser, 1964; Molnar and Tapponnier, 1975; Bhat, 1987; Treloar and Searle, 1993).

The Amarnath cave, located in the Indian state of Kashmir, is one of the most famous shrines in Hinduism. Dedicated to the god Shiva, the shrine is claimed to be over 5000 years old and forms an important part of ancient Hindu mythology. Inside the main Amarnath cave is an ice stalagmite resembling the Shiva Linga, which waxes during May to August and gradually wanes thereafter. This lingam is said to grow and shrink with the phases of the moon, reaching its height during the summer festival. According to Hindu mythology, this is the cave where Shiva explained the secret of life and eternity to his divine consort Parvati. There are two other ice formations representing Parvati and Shiva's son, Ganesha. The cave is situated at an altitude of 3888 m (12,760 ft), about 141 km (88 mi) from Srinagar, the capital of Kashmir. During the past fifty years, the ice Shiv-lingam has shrunk in size. While weather does affect its shape and size, many environmentalists blame global warming for the condition.

The Amarnath Cave has special significance. The cave is quite large. Its entrance is about forty yards horizontally and in height, it is about 75 feet and is sloping 80 feet deep down inside the mountain. In the cave is an ice-lingam of about five feet high and at the top, it forms a cone. This is The Cave which was chosen by Bhole Shankar for narrating the secrets of immortality and creation of Universe to Maa Parvati ji. The story goes like this. Centuries ago Maa Parvati asked Shiv ji to let her know why and when he started wearing the beads of heads (Mund Mala). Bhole Shankar replied whenever you are born I add one more head in my beads. Maa Parvati said, 'My Lord, my body is destroyed every time and I die again and again, but you are Immortal. Please let me know the secret of this.' Bhole Shankar replied that it is due to Amar Katha.

History of different disasters in the Amarnath region: *(1) Amarnath Yatra tragedy (1996)*. 1996 Amarnath Yatra tragedy is referred to the deaths of over 250 pilgrims in 1996 in Jammu and Kashmir State in India due to weather conditions. The pilgrims were on annual pilgrimage (Yatra) to the Amarnath shrine. During this period, there was unusually heavy snowfall along with severe blizzards along the yatra route. Yatris lost their lives due to exhaustion, exposure, freezing, etc. *(2) Cloudburst (2015)*. Three people were killed and 11 injured after a cloudburst triggered flash floods and landslides near the Baltal base camp of the Amarnath yatra in Central Kashmir's Ganderbal district on July 25, 2015. At least 50 tents and shops, as well as the parking area outside the main gate of the base camp, were affected. *(3) Road accident (2012)*. On July 27, 2012, sixteen Amarnath pilgrims were killed and 16 others injured when a truck carrying them plunged into a deep gorge in Samba district of Jammu and Kashmir. The truck carrying 34 pilgrims, who were engaged in setting a community kitchen at Amarnath, was returning when it skidded off the road and rolled down deep into the gorge near Zamoorha Morh in Mansar belt of Samba district, about 50 kilometres from Jammu city.

Possible Natural Hazards and disasters in Amarnath Cave Region. Considering the geomorphology, weather conditions, etc., there is an apprehension of any one or more of the following types of natural hazards and disasters, during the Amarnath Cave travel period: Avalanche, Earthquake, Cloud Burst, Flash floods, Heavy snowfall, Shooting stones, Landslides, Fire, Stampede, Sudden Drop in Temperature, Slippery Path, etc.

Impacts of Natural Hazards on the Amarnath Caves Region. Lakhs of great men and common men, both old and young, have undertaken the hazardous and exhausting trekking to the cave for centuries. India is prone to a large number of natural as well as man-made disasters. 58.6 per cent of the landmass is prone to earthquakes of moderate to very high intensity; over 40 million hectares (12 per cent of land) is prone to floods and river erosion; of the 7516 km long coastline, close to 5700 km is prone to cyclones and tsunamis; 68 per cent of the cultivable area is vulnerable to drought and hilly areas are at risk from landslides and avalanches.

This research paper shows that there is a high possibility of natural hazards and disasters when traveling to Amarnath Caves every year. The main risk is due to seismicity, as the this cave is located within seismic zone IV, which is a very high-risk zone, and it further leads to landslides and other different natural hazards in this region. There is a wake-up call for all travelers, to understand the importance of disaster preparedness for different natural hazard issues in the Amarnath Caves region. Otherwise, the day is not so far when we all will be faced with a big disaster in this area. Proper training for the travelers, appropriate management of the Amarnath Caves area, and strong policy by the government, can make a difference to reduce the impact of any natural hazards in the future.

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MAPPING OF KARST PHENOMENA ON THE SURFACE OF THE JAVOŘÍČKO KARST – JOURNEY THROUGH SPACE AND TIME

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At the beginning of this journey, there were some points on the map of the Javořîčko karst, some names of caves, little information. I had got one basic book, one article in an older magazine, and one Bachelor thesis at my disposal. The aim of my work was to correct coordinates of caves' entrances and to add other karst phenomena – ponors, springs, and sinkholes in this area. I had got information about ca. 50 caves and 10 hydrologic objects.

The Javořîčko karst is situated in Devonian limestones about 25 km north-west of the town Olomouc. Its territory covers approximately 20 km^2 and consists of four parts. The available data about karst phenomena were sometimes incomplete or inaccurate. So I searched for the correct information. I was asking local cavers about their knowledge. With their help, I was looking for speleological objects in the field, I recorded objects´ coordinates by GPS device and compared this data with older records. When I thought that my work was finishing, my colleague found an old manuscript describing this area that was ready for publication in the 1950s. But that never happened and this manuscript waited for its time for almost 70 years. Our organization published this book at the end of 2017 (name of this book is Kras Severomoravský – topografie a popis krasového území mezi Konicí a Litovlí and its author is Dr. Ing. Karel Kostroň). There was some new information and I started to search for more speleological objects. And not only outdoors, but it was also necessary to search in archives for some older articles and maps (some of them date back to the beginning of the 20thcentury). I compared this old data with the current state. Many of these caves and hydrologic objects were traced. Sometimes it was simple, sometimes more difficult. It depended on the accuracy of their description and also on the changes in the landscape.

In addition to GPS, I used map services Digital Terrain Model of the Czech Republic of the 5th generation (DMR 5G), ortophotomaps, geological map of the Czech Republic, and Fundamental Base of Geographic Data of the Czech Republic (ZABAGED®). The result is data about 72 caves (out of these, 12 caves no longer exist), 15 ponors, 14 springs, and 34 sinkholes. The obtained information was stored in the Unified Database of Speleological Objects (https://jeso.nature.cz). But some questions still remain.

'REDISCOVERY' OF AN ELEPHANTID (PROBOSCIDA, MAMMALIA) TOOTH FROM THE LISKOVSKÁ CAVE, SLOVAKIA

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The Liskovská Cave (Liptovská Basin) is one of the oldest known and most extensively studied caves in Slovakia. The most famous material from this cave is a man skull fragment with some archaic morphological features, found together with three mammoth tooth fragments (Majláth, 1873). Numerous short reports about the mammoth remains from the mentioned cave can be found in the literature, but without any specific data (Lalkovič, 2007). Unfortunately, almost all paleontological and paleoanthropological material is lost, most probably destroyed. An original drawing of the elephantid tooth was found in the handwriting collection by Majláth, deposited in the State archive in Žilina with the seat in Bytča.

The anterior fragment (probably m^2 or m^3 dext.) consists of 4 plates, but the last one seems to be incorrectly reconstructed. The anterior root is excellently preserved. All plates are considerably worn, so a large part of the original features is changed or missing. Moreover, the interpretation of some problematic features depends also on the precision of the drawing. Rectangular crown shape, thick enamel, broad and slightly rhombus like plates indicate the species *Palaeoloxodon antiquus* (Palombo and Ferretti, 2005). One outstanding feature of tooth drawing is the total absence of enamel crenulation and thus corresponds to teeth of the genus *Mammuthus*. However, this feature is practically missing on extensively abraded plates in all elephantid species.

In Slovakia, *Palaeoloxodon antiquus* is known from 9 localities, but only the presented one was found in the cave deposit. Precise stratigraphy of the tooth from Liskovská cave is dubious. It was collected from redeposited sediment, together with mixed osteological and archaeological material of the Pleistocene and Holocene age. In Slovakian territory, *P. antiquus* was stratigraphically proved sporadically from Middle to early Late Pleistocene. The morphology of a tooth from the Liskovská Cave is more resembling to the material from Eemian (OIS 5e) locality Gánovce. Thus, the studied tooth most probably belongs to the Last Interglacial but early interstadials of the Last Glacial Period are not ruled out (Stuart, 2005).

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ARAGONITE BRIDGE AND KARSTIC PHENOMENA OF THE ASEMANSARA MOUNTAIN, IRAN

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The Asemansara karstic area located in the Alborz range of northern (36°45′26.33″N – 36°47′51.07″N and 49°27′2.32″E – 49°30′25.45″E) Iran with numerous karstic features as well as a network of karst cavities. The morphology of this karstic region and subsequently its hydraulic features and conditions changed in the long term and influenced by tectonic movements and especially ongoing active faults. This Karstic area contains sinkholes, funnel-shaped holes, caverns, caves, and underground rivers. One of the underground rivers come out of the outlet of the Cheshmehbad Cave. In this study, a new karstic feature is introduced as the Aragonite Bridge. A discussion is held on the process on which the Aragonite Bridge evolved. The Manjil and Harzavil towns are located around the southern vicinity of the karstic area and rely heavily upon numerous springs of the karstic area for their freshwater supply. Karst regions contain aquifers that are capable of providing large supplies of water. More than 80 percent of the Harzavil town population obtains its water from karst aquifers. Increased demand for water resources of karstic aquifers is an ongoing social problem. The formation of karstic features depends on the internal and external processes. The internal process created folding and fractures of the area and the density of faults in calcareous rocks needs a large-scale, well-prepared geologic map. So this study was carried out by a prepared geologic map and description of morphologic features. A new layer of sinkholes and other surface karstic locations was compiled on the geologic map.

Karst's development took place in the Dorud and Ruteh Formations of the Permian period, which arecharacterized by the occurrence of caves, springs, and other karstic phenomena. Karst landforms are strongly influenced by lithological variations, joint sets, fault patterns, and dolomitization. Clastic sediments played a key role in the determination of the history of the Cheshmehbad Cave, which enables us to describe the formation pattern of underground spaces. These underground spaces network are linked to freshwater resources of the area and karst management must be an ongoing concern. This area is a valuable speleo-tourism heritage because of its attractive karstic features, cave, and the Aragonite Bridge.

WATER QUALITY IN THE KRÁSNOHORSKÁ JASKYŇA CAVE: MICROBIOLOGY, SUSPENDED PARTICLES, AND VISITORS

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Krásnohorská jaskyňa Cave (Slovakia) is 1550 m long cave in Triassic limestones of the Slovenský kras Mts., open for visitors in guided tours. Entering the cave, visitors have to pass some 400 m along the perennial underground stream which, after passing 70 m long siphon appears on the ground surface as the Buzgó karstic spring. The Buzgó spring represents a terminal water outlet from the underground hydrological system of the Krásnohorská jaskyňa Cave. In the study period, its discharge was ranging between 8.50 and 1215.1 $L \cdot s^{-1}$, with an average value of 46.3 $L \cdot s^{-1}$ (median of 22.5 $L \cdot s^{-1}$).

Monitoring device recording groundwater quality parameters in 5-minute intervals was installed here by the end of 2016. The tested monitoring device consisted of an optical system, a laser system, and a multi-parameter probe for measuring individual parameters, and was also equipped with a back-up power supply, control unit, software, and data logger, as well as with wireless data transmission and warning equipment. Xylem Analytics multiparametric probe YSI EXO20 was applied for turbidity, water temperature, and specific electrical conductivity (EC) measurements. Combined digital optical immersion Xylem Analytics probe NiCaVis 705®IQ NI was used for chemical oxygen demand (COD), total organic carbon (TOC), and nitrate content dissolved in water (NO_3^-) measurements. The number of suspended particles was recorded for the particle size categories of ≤ 0.9 µm, 0.9–1.5 µm, and 1.5–2.5 µm by the TCC LOS 30/30 Markus Klotz laser system. Data collection was performed in a 5-minute interval by a separate PLC datalogger Allen Bradley PV PLUS 400 COLOR and data transmission was conducted by GPRS modem Conel ER 75i.

To correlate monitored and microbiological parameters, in 2017, 65 water samples were taken for microbiological analysis (Fig. 1). Presence of coliforms, Escherichia coli, enterococci, and microorganisms cultivable at 22 °C and 36 °C was inspected in approximately weekly intervals. Microorganisms/parameters as Clostridium perfringens, colourless flagellates, nonliving organisms, living organisms, filamentous bacteria, micromycetes, iron and manganese bacteria were not identified in any samples. The presence of abioseston was of average values of 1.8 % (median of 2 %) and was found between 1 % and 3 % in all 33 cases. Total organic carbon (TOC) content was raising mainly at the end of summer and during autumn of 2017, starting from 0.25 $mg \cdot l^{-1}$ and reaching its maximum 3.07 $mg \cdot l^{-1}$. It seems as if the waters in the underground hydrologic system were gradually enriched by TOC generated on the land surface due to the increased air temperatures, in approximately three months lag. Any TOC dependence on the Buzgó spring discharge was observed. TOC content was in the interval between 0.25 and 3.07 $mg \cdot l^{-1}$; average and median TOC values were 0.43/0.60 $mg \cdot l^{-1}$.

The most observable correlation of their population with the Buzgó spring discharge is found in the cases of microorganism cultivable at 22 °C and 36 °C (KM22 and KM36 – psychrophilic and mesophilic microorganisms. Their population visibly increases at high water stages and decreases in dry periods. Radical increase of both populations is supposed to be linked with cave conduits and fracture walls washing by water inrushes. In the Buzgó spring case, the dominance of KM22 over KM36 microorganisms is typical in the ratio of 2:1. This is caused by the usual physiological conditions of cave biotopes in Central Europe, acting in favour of microorganisms growing at lower temperatures. Limited sources of organic substrate needed for their life cycle are then reflected in the low population of both types of microorganisms. The population of one to 64 KTJ/ml was found in the case of microorganism cultivable at 22 °C (KM22). KM22 population average was 16 KTJ/ml and median 8 KTJ/ml. For KM36, the population average was seven KTJ/ml and a median 3 KTJ/ml. These were ranging from one to 28 KTJ/ml. Small and sporadic rises of both KM22 and KM36 populations were also observed, apart from the regular significant peaks coinciding with flooding. It seems that these sporadic small KM22/KM36 population peaks appear after previous warm periods of air temperatures in the area.

Indicators of faecal contamination were regularly found in Buzgó spring water, contrary to the results of previous investigations. Faecal contamination indicators were analysed in all samples. The number of coliform bacteria was ranging between zero (in three cases) up to 494 colony forming units per 100 ml (KTJ/100 ml), the median value was seven KTJ/100 ml. Thermotolerant coliform bacteria (Escherichia coli) were absent in nearly one half of samples. The median of their presence was 1 KTJ/100 ml and they reached a maximum of 95 KTJ/100 ml. Recorded maximum here seems not to correspond to high discharges, high air temperatures, nor precipitation, namely in the case of coliform bacteria. For enterococci, another faecal contamination indicator, signs of their raising numbers were identified after each of the local discharge maxima in the hydrological year of 2017. Another sporadic smaller enterococci peaks appeared as well, unrelated to hydrologic or meteorological circumstances. Enterococci were not present in 1/3 samples, the median of their presence was two KTJ/100 ml and they reached the maximum of 119 KTJ/100 ml. The presence of coliform bacteria, *Escherichia coli*, and enterococci points to immediate water contamination. We suppose that two independent factors are responsible for their appearance in the Buzgó spring water. Occasional presence of humans in the underground hydrological system of the Krásnohorská jaskyňa Cave is the first and more important factor. The influence of high water stages is less observable and is particularly pronounced in the growth of enterococci population (Fig. 2), in a lesser extent also *Escherichia coli*. No correlation with the hydrological situation was found for coliform bacteria.

Correlation of the results obtained from microbiological analyses of water samples with the results obtained by monitoring device prototype during its operation was difficult to establish. However, it appears that the number of suspended particles of the ≤ 0.9 µm size category as well as the total organic carbon (TOC) detected by monitoring equipment may correspond to the presence of coliform bacteria in the Buzgó spring water. Of all the parameter values evaluated, the coliform population was most closely related to the maximal number of suspended particles of the ≤ 0.9 µm size, detected during the period of 6 hours prior to sampling. The water turbidity value measured by the multiparametric probe of the monitoring device, in turn, had the most significant correlation with the *Escherichia coli* population present in the water of the Buzgó karst spring. Finally, the enterococci population seemed to have a relationship with the average number of suspended particles of the 1.5–2.5 µm size detected during the period of 6 hours prior to sampling.

The influence of spring's high water stages is visible on the population of microorganisms cultivable at 22 °C and 36 °C, to a lesser extent also on enterococci and *Escherichia coli* populations. No correlation with discharge or other hydrological data was found for coliform bacteria. The presence of faecal contamination indicators that were found in the Buzgó springs' water seems to be influenced by occasional human visits to the cave.

Fig. 1. The Buzgó karstic spring orifice – both sampling location and also the place from where the water is conducted to the probes of the monitoring device. Photo: E. Kováčová

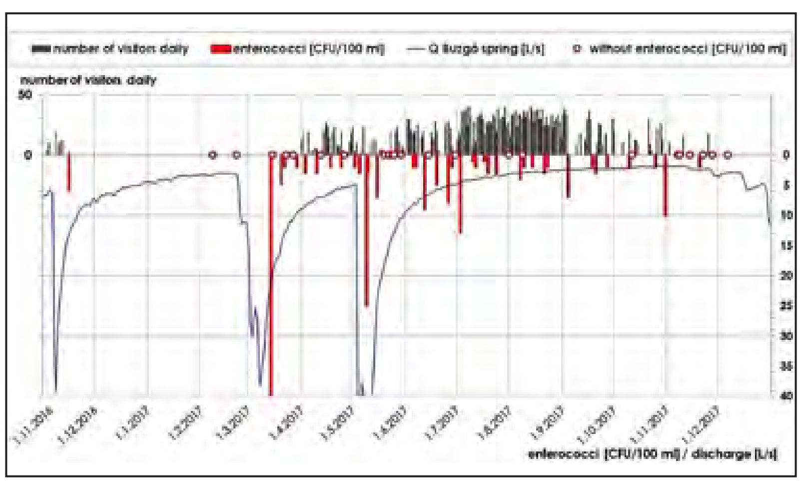

Fig. 2. The presence of enterococci in karstic groundwater of Buzgó spring in Krásnohorská Dlhá Lúka, correlated with its water stages and number of visitors of the Krásnohorská jaskyňa Cave

EXCURSION GUIDE

9th INTERNATIONAL WORKSHOP ON ICE CAVES (IWIC-IX)
Liptovský Mikuláš, Slovakia, May 12–15, 2020
postponed due to the COVID–19 pandemic

Pavel Bella – Ľudovít Gaál – Péter Gruber – Dagmar Haviarová – Juraj Littva – Vladimír Papáč – Zuzana Višňovská – Ján Zelinka

THURSDAY
May 14, 2020

Trip route: Liptovský Mikuláš – Važecká jaskyňa Cave – Belianska jaskyňa Cave – Liptovský Mikuláš

VAŽECKÁ JASKYŇA CAVE

The cave is located in the Važec Karst at the contact of the Kozie chrbty Mountains with the Liptovská kotlina Basin, on the western edge of Važec Village between Liptovský Mikuláš and Poprad towns. The cave entrance, lying 8 m above the bottom of the Biely Váh River, is at an elevation of 784 m.

The cave is formed in the rock scarp composed of the dark-grey Middle Triassic bedded Gutenstein Limestones of the Hronic Unit. It is a subhorizontal branchwork cave, partially with a network rhombic pattern guided by several intersected discontinuities, with the main set being parallel to the scarp and several sets with perpendicular/oblique orientation. Folding also plays an important role, with the widest cave passages being situated withing the hinge of a large gentle fold (Bella et al., 2016).

The cave originated mainly by the inflow of aggressive allochthonous waters and flood-water injections from the Biely Váh River into exposed and fractured carbonates on the left side of the valley (Kozie chrbty Mountains). Its formation was enhanced by waters seeping from precipitation and circulating through karst aquifer to the valley of Biely Váh River, also by surface waters sinking into the underground at the end of the Priepadlá semi-blind Valley located the southeast of the cave, at the contact of non-karst and karst area (Droppa, 1962a, b; Bella et al., 2016). At present, no stream flows through the cave. The solution origin of the cave is evidenced by several morphological features (bedding-plane anastomoses, ceiling pockets, phreatic tubes, and oval conduits) preserved mainly in cave parts not opened to the public (Bella et al., 2016). Original solution morphologies were remodelled by slab and block breakdown, forced by frost weathering during the last-glacial stadials.

The cave is situated at the level of the river terrace T-II (Riss 2 / Late Saalian) developed just in front of the cave (8 m above the recent river bed; Droppa, 1962a, b). Allochthonous gravels and sands with granite pebbles were transported into the cave during its fluvial sculpturing. Consequently, they were covered by unsorted sediments that besides prevailing loam contain mainly slightly rounded limestone clasts, along with Paleogene sandstone, weathered granite pebbles, and fossil faunal remains. The age of cave bear bones (*Ursus* ex gr. *spelaeus*) was dated to over 40 ka by the radiocarbon method (Sabol and Višňovská, 2007; Laughlan et al., 2012). Above unsorted sediments, fine-grained sediments were deposited in several sequences as a result


Dripstone decoration, Važecká jaskyňa Cave. Photo: P. Staník

of repeated flood-water injections from the surface river and floods caused by waters circulating through adjacent karstified limestones (slackwater facies from the suspension in slow water flow to stagnant water). These fine-grained sediments have the normal magnetic polarity (Brunhes chron, younger than 0.78 Ma; Bella et al., 2016).

The passages and halls of the cave are decorated mostly by dripstones and rimstone dams that as calcite barriers obstruct shallow pools (Volko-Starohorský, 1930; Havránek, 1935; Droppa, 1962a, b; and others). After heavy rains or snow melting, the lower parts of the cave are occasionally flooded.

In the cave, air temperature ranges between 6.5 to 7.1 °C, relative humidity between 94 to 96 %. Its entrance parts are influenced by annual climatic variations from the surface, where the effect of frost weathering is manifested (Zelinka, 2002).

The Važecká jaskyňa Cave has the highest natural radioactivity of the rock environment (on average Middle Triassic carbonates 498 Bq/kg, calcite speleothems 385 Bq/kg, and allochthonous fluvial sediments 722 Bq/kg) of all show caves in Slovakia (Zimák et al., 2002, 2003). The radon activity concentration and CO_2 concentration in its atmosphere exhibited annual, non-periodic short-term, and periodic daily variations. Radon reached its maximum in the summer months. The highest radon and CO_2 levels are in the most distant parts from the cave entrance, where a daily average of radon concentration radon reached up to 43 kBq/m^3 and CO_2 concentration up to 7600 ppm (Smetanová et al., 2019).

The Važecká jaskyňa Cave represents an important palaeontological finding place. Fossil bone remains of cave bears (*Ursus spelaeus*-group) and the cave lion (*Panthera spelaea*) were found in the Kostnica and some other cave parts (Droppa, 1962a, b; Sabol and Struhár, 2002; Sabol et al., 2011; Laughlan et al., 2012; and others).

The occasional presence of bats, most often of the northern bat (*Eptesicus nilssonii*) and the lesser horseshoe bat (*Rhinolophus hipposideros*) has been recorded in the cave during winter periods. From among cave invertebrates, several obligate cave and endemic species live in the cave. The occurrence of troglobiotic palpigrade *Eukoenenia spelaea*, situated at the latitude of roughly 49° N, is remarkable and unique and represents the northernmost known occurrence of a representative of this peculiar group of arachnids in the world (Kováč et al., 2002). The cave is notable also by the occurrence of two cave springtails *Deuteraphorura kratochvili* and *Pseudosinella paclti* that do not occur outside the Western Carpathians (Mock et al., 2002). This cave represents the type locality (*locus typicus*) of troglobiotic springtail *Megalothorax hipmani*, which was described only recently from a surface of water pools and is characteristic by highly troglomorphic traits (Papáč and Kováč, 2013). This ranks the Važecká jaskyňa Cave among the biospeleological localities of the European importance.

The entrance hall was known to local people since long ago as the hole under the Small Hills ('diera pod Vŕškami' in Slovak). Other cave passages and halls were discovered by O. A. Húska with the assistance of A. Somr in 1922. Thanks to F. Havránek, the cave was provisionally opened to the public as early as 1928 (Lalkovič, 1998). F. Havránek and members of the Speleological Club in Brno discovered the passage behind the Zrútený dóm Chamber in 1952 (Ondroušek, 1952). After the reconstruction of the visitor pathway and the installation of electric lighting, which was done by Turista National Enterprise, the cave has been in operation since 1954. The length of the accessible cave part is 235 m.

Sceleton of a cave bear (*Ursus spelaeus*), Važecká jaskyňa Cave. Photo: Z. Višňovská

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BELIANSKA JASKYŇA CAVE

The cave is located in the eastern part of the Belianske Tatry Mountains (the north-eastern part of the Tatra National Park), in the Tatranská Lomnica cadastral area (Poprad district). The main cave entrance lies on the northern slope of the Mt. Kobylí vrch (1109 m), at an elevation of 890 m, 130 m above the bottom of the Biela River valley.

The Belianske Tatry Mountains rank among the most significant karst areas in the Tatra Mountains and their highest positions above the timber-line belong to the high-mountain karst. The eastern part of the Belianske Tatry Mountains represents mid-mountain karst dissected mostly by the gorge-like valley of the Biela River.

The Belianska jaskyňa Cave was formed in the Middle Triassic dark-grey Gutenstein Formation of the Fatricum Unit (Pavlarčík, 2002). The rock is permeated by NE–SW-trending joints that, together with similarly oriented faults, exert a major influence on the orientation of the cave spaces. Their total length is 4051 m with a vertical span of 174 m. It represents a vertical-horizontal multi-branched cave composed of two irregularly north-south trending inclined branches. They are joined in the lower, northern part of the cave. Phreatic oval corrosion chambers, halls, and large inclined passages, with ceilings dissected by high cupolas, represent the dominant morphological features sculptured by ascending deep phreatic waters (Głazek et al., 2004; Bella et al., 2007, 2011; Osborne, 2009). Downward-inclined smooth facets ('planes of repose' after Lange, 1963), developed in the lower parts of the walls of halls and inclined passages, are additional morphological indicators for the genesis of major segments of the cave in former slowly moving or standing water with an accumulation of insoluble fine-grained sediments (Bella and Osborne, 2008) as residues from the dissolution of carbonate rocks (Zimák et al., 2003; Głazek et al., 2004; Hlaváč et al., 2004; Kicińska and Głazek, 2005). The main inclined cave branches are vertically dissected by several vertical and steeply sloping chimneys and shafts. Subhorizontal segments in the upper and lower parts of the cave developed during long-lasting phases of water table lowering in the cave related to phases of entrenchment of the Biela River Valley (Bella and Pavlarčík, 2002). Facets developed below lateral water-level notches reflecting younger epiphreatic phases of cave development (Bella and Osborne, 2008).

Oribatid mite *Pantelozetes cavaticus* (Acari). Photo: Ľ. Kováč and P. Ľuptáčik

Palmová sieň Hall, Belianska jaskyňa Cave. Photo: M. Rengevič

Later meteoric water inflows into the cave partially remodelled primary phreatic morphologies or formed some conduits hydrographically inclined to the paleovalley of Biela River. At present, meteoric waters seeping into the cave are cumulating into occasional streamlets mostly at the bottom of shafts in the lower parts of the cave. In several cave parts, original phreatic solution morphologies were remodelled by slab and block breakdown.

The cave was significantly filled with fine-grained clastic sediments, mainly during the phreatic phase of its development. These deposits were largely washed out during younger epiphreatic and vadose phases. Normal and reverse magnetized zones alternate in remnants of the sediments (Pruner et al., 2000; Pruner and Bosák, 2001). Their magnetostratigraphy indicates age older than 1.77 Ma (the upper boundary of the Olduvai epoch), but the sediments can be related to Gilbert epoch (ca 4.18–6.15 Ma). Speleothem crusts on the surface of some profiles are older than 1.25 Ma (Bella et al., 2011). Palynospectra of Miocene and Lower Pliocene age are included in these speleothems (Komar and Bosák, 2013). The age of subaerial speleothems deposited on the eroded surface of the fine-grained clastic sediments is approximately 4–5 Ma (Bella et al., 2007, 2011).

The upper cave parts of phreatic origin reach the relative altitude of 65–80 m below the small plateau near the top of the Mt. Kobylí Hill at 1080 m a.s.l. that presents a remnant of mid-mountain planation surface (Sarmatian–Early Pannonian). Before the main tectonic uplift of the Tatra Region, subhorizontal epiphreatic segments in the upper part of the cave, oscillating at 1000–1015 m a.s.l. (240–255 m above the recent river bed), have originated along a piezometric surface and spring level of deep phreatic waters. The waters ascended along the steep fault between the central and edge eastern part of the Belianske Tatry Mts., probably during the formation of the sub-mountain pediment (Pontian?). The development of younger phreatic and subhorizontal epiphreatic conduits in the lower part of the cave at 915 m a.s.l. (Late Pliocene) and 890 m a.s.l. (Early Pleistocene) is correlated with developmental phases of the Biela River Valley. These outflow conduits, developed during phases of slight or interrupted entrenchment of the valley, occur 155 m and 130 m above the recent river bed of Biela River (Bella et al., 2011; Bella and Bosák, 2012).

From the calcite decoration, waterfall-like flowstones and pagoda-like stalagmites are the most attractive. Draperies and several stalactite types are also present, as well as subaqueous coralloids. Some cave pearls have been found in the occasional streamlet at the bottom of Hladová priepasť Abyss.

Air temperature in the cave, except for its entrance parts, ranges between 5.0 to 5.8 °C, and the relative humidity is from 90 to 97 %. Due to increased air circulation in winter, air temperature cools down the cave entrance parts, which results in forming ice fill not melting until late spring. Air temperature fluctuations during summer range between -2.2 °C and + 5.1 °C (Droppa, 1959). A multiannual attempt to restore glaciation in the lower cave part began in 1936. Its entrance, which in some places is seasonally filled with ice, connects with the outside atmosphere through two entrances in a vertical span of 81 m, exposed to the north. During winter, both entrances were open and cold air flowed into the cave where the air temperature reached -25 °C and in May -3 °C. When the outside air temperature rose above zero, both entrances were closed, and the dynamic cave was changed to a static one. In the artificially cooled part of the cave, ice stalactites up to 1.5 m long, ice columns up to 3 m high, and ice crusts with thicknesses up to 1.5 m were occasionally formed (Lutonský, 1934; Paloncy, 1934; Kunský, 1935–36, 1937, 1940, 1943). However, these conditions were not sustainable, and therefore the failed attempt to restore glaciation in the lower part of the cave caused enhanced frost weathering of bedrock, flowstones, and dripstones (Benický, 1951; Zelinka, 1997).

So far, nine bat species have been recorded to hibernate in the cave, out of which the greater mouse-eared bat (*Myotis myotis)* is the dominant species, together with the whiskered bat (*Myotis mystacinus)* and Brandt's bat (*Myotis brandtii*). Other species, such as the brown long-eared bat (*Plecotus auritus*), northern bat (*Eptesicus nilssonii*), also the lesser horseshoe bat (*Rhinolopus hipposideros*) and Geoffroy's bat (*Myotis emarginatus*), occur irregularly in low numbers here. A maximum known abundance of bats hibernating in the cave is ca 300 individuals (Višňovská, 2008, 2013). Tiny genuine cave invertebrates are represented by springtail *Protaphorura janosik* and mites *Vulgarogamasus maschkeae* and *Pantelozetes cavaticus*. Rare stygobiotic crustaceans *Synurella intermedia* and *Bathynella natans* inhabit cave pools (Kováč et al., 2002; Višňovská and Papáč, 2010).

The cave entrance has long been known as can be seen from a number of names left on cave walls by treasure seekers from years 1713 and 1731. However, it remained hidden for many years. L. Gulden from Spišská Belá, and Fabry, gold prospector from Kežmarok, found the entrance in 1826, however, they were unable to enter deeper into the cave. In 1881, the place was accidentally found by J. Husz and J. Britz, who glimpsed a narrow opening barricaded with decayed wooden logs. They dared to explore the obscurity of unknown subterranean spaces some days later. Through the upper opening, they descended to current entry parts and then continued until they reached what is now known as Dóm objaviteľov Chamber (Explorer's Chamber). Further discoveries in 1881–1882 as far as the Dóm trosiek Chamber (Chamber of Ruins) were shared by A. Kaltstein, I. Verbovszky, and J. Britz. The cave was opened to the public through the original entrance with the financial support of the Spišská Belá town and thanks to A. Kaltstein in 1882. They thirled the current tunnel entrance at the end of that year. The light came from tar torches and later candles in chandeliers. Electric light was installed in 1896, which was among the first electrically lighted caves in Europe (Droppa, 1959; Hazslinszky, 1999; Lalkovič, 2002; and others). At present, more than 1000 m with a vertical span of 125 m is accessible for the public.

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Sprintail *Pseudosinela aggtelekiensis* (Collembola). Photo: Ľ. Kováč and P. Ľuptáčik

FRIDAY
May 15, 2020

Trip route: Liptovský Mikuláš – Ochtiná Aragonite Cave – Silická ľadnica Cave – Domica Cave – Baradla Cave – Liptovský Mikuláš

OCHTINÁ ARAGONITE CAVE

The Ochtiná Aragonite Cave (‘Ochtinská aragonitová jaskyňa’ in Slovak) is a world-famous karst locality, significant from a geological, morphological, speleogenetic, and mineralogical point of view (a part of World Heritage within the Property No. 725: ‘Caves of Aggtelek Karst and Slovak Karst’). It represents a unique natural phenomenon of underground karst attracting attention for both the richness and variability of its aragonite fill and the original genesis and development of its underground spaces. It is located in the Ochtinský cryptokarst on the north-western slope of the Hrádok Hill (809 m) in the Revúcka vrchovina Mountains between Jelšava and Štítnik towns.

The cave is formed in the Lower Devonian grey laminated crystalline limestone, white crystalline limestone (marble), ankerite, and ochres of Drnava Formation (Gelnica Group). They are exposed on the surface only in their small parts. Three carbonate lenses in the Hrádok Hill are bounded by insoluble sericite-graphitic and sericite-chloritic phyllites, which are partly covered by Permian metamorphic sandstone and conglomerate. The carbonate lens was primarily originated on the neritic shelf from lime mud and reef, which slid as olistolith to deeper sea with flyschoidal sedimentation. During the Variscian orogeny, the limestones were folded, metamorphosed, and metasomatically altered by warm Fe-solutions to the ankerite. More than 40 % of underground spaces are formed in the ankerite. Some tectonic structures, mainly folds, normal dip-slip faults, strike-slip faults, cleavage, fold-thrust faults, and others were uncovered on the cave walls. The thickness of the lenses is about 50 m and its total length is 800 m (Ševčík and Kantor, 1956; Homza et al., 1970; Gaál, 2004). The artificial entrance tunnel enters the cave at an elevation of 642 m.

Morphologically, the Ochtiná Aragonite Cave consists of linear fissure passages and elongated halls, with fissure-narrow ceiling parts, that are interconnected with irregular spongework labyrinth-like parts. From a medium-scale morphology, mainly solution flat ceilings (*Laugdecken*), inward-sloping smooth walls (*Facetten*, solution facets, planes of repose), numerous ceiling pocket- and cupola-like hollows, and some other phreatic and epiphreatic solution shapes originated in slowly moving or standing water are typical features for this remarkable cave (Bella, 1998, 2004; Bosák et al., 2002). In several places, facets are associated with horizontal ceilings and together create triangular cross-sections (*Laughöhle* profile after Biese, 1931; see also Kempe et al., 1975; and others) or trapezoidal cross-sections. Ford and Williams (2007) point out that the Ochtiná Aragonite Cave is an excellent example of ‘notch caves’ originated by lateral corrosion along the standing water table in the lens of metamorphosed limestone enclosed by phyllites.

Meteoric water, seeping along steep faults, caused limestone dissolution and ankerite weathering with a production of ochres (goethite). The limestone dissolution was enhanced due to CO_2 produced during the oxidation of ankerite and siderite. Horizontal passages and halls, which are located between parallel

Solution flat ceiling and inward inclined facets, Ochtiná Aragonite Cave. Photo: P. Bella

Rich aragonite decoration, Ochtiná Aragonite Cave. Photo: P. Bella

faults and featured by phreatic morphologies (small cupola- and pocket-like hollows, and irregular spongwork cavities), originated mostly by corrosion of slowly mowing water as a result of the mixing of waters of various temperatures and chemical compositions. Facets (planes of repose) are observed not only below the solution flat ceiling but also in phreatic conduits with an oval ceiling part. According to Lange (1963), they developed in flooded or partly flooded cavities by the solution of the limestone during slow water circulation when insoluble fine-grained particles accumulating on the floor and sloping walls (approximately up to 45° slopes). The sediments protect the floor and the walls from solutional widening (sedimentation proceeds concurrently with solution). The origin of younger wall horizontal notches is associated with the stagnation of the former water table level. Several solution flat ceilings, that cut the lower part of some cupola-like hollows, occur at the same height position.

At present, lakes with oscillating water table occur at the bottom of Hlboký dóm Chamber and in the lateral cavity of Vstupná sieň Hall (its floor is repeatedly flooded). The water table of the lake in Hlboký dóm Chamber oscillates within 9 m. The highest levels are in spring during snow melting and after heavy rain. The water temperature of the lake is close to the air temperature, its average value is between 7.5 and 7.7 °C. The small lake, filled with dripping water, occurs in the southern edge of Hviezdna sieň Hall. In recent times, dripping water in the cave is mainly Ca-Mg-HCO_3 type. From the 1950s, the underground hydrology of the cave vicinity is influenced by mine adits. The northwestern slope of Hrádok Hill is drained by the Ochtinský potok Brook in the Banská dolina Valley. Springs, hydrologically connected with adjacent mine adits, occur at an altitude about 100 m lower than the cave.

Aragonite is formed in closed underground cavities from water solutions with high contents of Mg-, Fe-, and Mn- ions under conditions of stable microclimate. It occurs in places of capillary rising or very slowly percolating water as well as above the wet sediments, which slowly release moisture. The isotopic values of d^{13}C from -7.4 to -6.0 ‰ and d^{18}O from -7.0 to -6.3 ‰ indicate a slow and equilibrium leakage of CO_2 from the solution (Cílek et al., 1998). Three generations of aragonite were determined in the cave (see Rajman et al. 1990, 1993; Cílek et al., 1998; Bosák et al., 2002). The oldest are milky translucent kidney-shaped formations and their corroded remains (dated age of 121–138 ka) with partially recrystallized aragonite, in places metamorphosed to calcite. The second generation of aragonite prevails and occurs mostly in the form of several cm-long needles and spiral helictites (dated age of 14 ka). These form cluster or dendritic formations (including so-called iron flower or anthodite), which are most attractive for visitors. Aragonite of the second generation is still growing, which enables it to maintain its white colour and clean appearance. The youngest generation of aragonite, which is being formed at present on sediments and iron ochres makes tiny fans (2–4 mm in size and sometimes even bigger), sporadically creating miniature helictites (Cílek et al., 1998).

The air temperature in the cave is between 7.1 and 8.5 °C (increased values up to 9.2– 10.0 °C are caused by visitors), while relative humidity is between 92 and 99 % (Rajman et al., 1990; Zelinka, 2002, 2004). The entrance part of the cave (Vstupná sieň Hall – Hlavná chodba Passage – Mramorová sieň Hall) is relatively colder and wetter than its central (Sieň mliečnej cesty Hall) and more distant part (Hlboký dóm Chamber) (Klaučo et al., 1998). Stabilization of the cave microclimate is caused by iron ochres (containing 47–56 vol. % of water) since they are able to absorb and release water vapour (Cílek et al., 1998). Rajman and Roda (1972) pointed out the possible negative impact of microclimatic changes on the aragonite (risk of corrosion) due to the condensation of water vapor and increased content of CO_2 exhaled by visitors. Based on the microclimatic monitoring realized by Klaučo et al. (1998), a maximum of 45 visitors per entry and a time interval of at least 20 minutes between entries was established (Bella et al., 2000).

In the Ochtiná Aragonite Cave, a natural radioactivity of the rock environment is relatively high due to the relatively high uranium content – on average Paleozoic crystalline limestones 251 Bq/kg, ankerite 227 Bq/kg, goethite 303 Bq/kg, aragonite 403 Bq/kg, and clay 339 Bq/kg (Zimák et al., 2002, 2004).

The cave is characterized by the absence of bats. The invertebrate fauna is also relatively poor. Mostly springtails (Collembola), mites (Acarina), and dipterans (Diptera) occur here. The obligate cave springtails *Pseudosinella aggtelekiensis* and *Deuteraphorura kratochvili* are typical inhabitants of the caves within the Slovak Karst. On the organic residues in the cave, the larvae of rare dipteran species *Camptochaeta ofenkaulis* develop, which are known only from a few cave localities in Slovakia (Kováč et al., 2004).

The cave was discovered by chance by M. Cangár and J. Prošek, employees of the East-Slovakian Ore Survey in Jelšava, while drilling the geological survey Kapusta Adit in 1954. The cave protection was secured after finishing the geological survey in the Horný Hrádok locality. Cave development works started in 1966 by drilling the access adit 145 m long, which enabled the opening of the cave to the public in 1972 (Lalkovič, 2004; and others). The length of the accessible part is 230 m.

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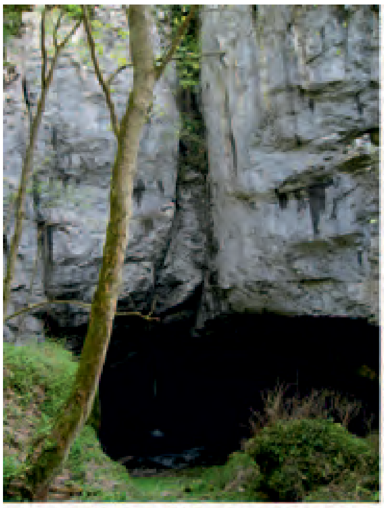
SILICKÁ ĽADNICA CAVE (SILICA ICE CAVE)

This remarkable ice-filled cave is located on the Silická planina Plateau in the Slovak Karst, 2 km to the west of the Silica Village. Its entrance lies at an elevation of 470 m, north-facing in a leafy forest (the upper edge of the collapsed doline-like depression extends to a height of 503 m a.s.l.). The surface area is in the warm, moderately humid subregion with cool winters (January ≤−3 °C, mean annual precipitation total 600–700 mm) (according to Lapin et al., 2002; Faško and Šťastný, 2002). The Silica Ice Cave is the lowest-lying perennial ice cave up to the latitude of 50 degrees north, in the temperate



Entrance part of the Silická ľadnica Cave. Photo: P. Bella

Carabid beetle *Duvalius bokori* (Coleoptera). Photo: Ľ. Kováč and A. Mock

climatic zone. Among the lowest-lying ice caves is also the French Grotte de la Glacière Cave in the Jura Mountains, whose entrance is at an altitude of 525 m. Among the better-known ice caves, only the Kungur Ice Cave is in the lower altitude (its entrance is at 118 m a.s.l.). However, this cave is located farther north (latitude 57 degrees north), in the continental part of the temperate climatic zone (Russia, Perm Region, the western foothills of the Ural Mountains).

The Silica Ice Cave was formed in the Middle Triassic Wetterstein limestones of the Silicicum Unit. Morphologically, it consists of two different parts. The upper part presents a steeply inclined spacious cavity with a large opening to the surface (corrosive-collapsed abyss, *light hole*) (Vitásek, 1930; Roth, 1940a, b; Droppa, 1962, 1964). The lower, mostly subhorizontal fluvially modeled passages were formed by the underground stream, Čierny potok (Black Brook). In 1931 J. Majko entered the Archeologický dóm (Archaeological Chamber) through a hole dug in the bottom of the abyss, which was filled by clastic sediments, mainly debris. Other passages and halls along the Black Brook were discovered by Czech speleodivers in 1988. The cave is 2300 m long with a vertical span of 117 m. The Black Brook flows from the Silica Ice Cave into the Gombasecká jaskyňa Cave and the Čierna vyvieračka (Black Spring). Hydrological connection of these sites was proven by several tracing tests (Roda et al., 1986; Stankovič and Horváth, 2004; and others). The water quality of Black Brook in the Silica Ice Cave is negatively influenced by agricultural activities (Tereková, 1983; Haviarová et al., 2012).

The upper abyss of the cave (from the entrance to the depth of 50 m) is partially filled with ice (at 425–465 m a.s.l.). The drawdown spacious cavity with an accumulation of cold air was glaciated as a result of the restriction of airflow between the upper and lower parts of the cave because of debris that blocked the connecting section. The air temperature in the ice-filled part oscillates between −10.4 °C and +1.0 °C and in the lower Archaeological Chamber (without cave ice) between +3.0 °C and +5.8 °C (Rajman et al., 1987).

Roda et al. (1974) reported an ice surface ranging from 710 to 970 m^2 and an ice volume ranging from 213 to 340 m^3. The surface and volume of the ground ice vary depending on the temperature and precipitation conditions during individual years. During 2016–2018, the highest difference in ice volume in the range of about 70 m^3 was observed between summer 2016 and spring 2017, as well as between spring 2017 and autumn 2017 (Šupinský et al., 2019). Ice increments in the cave occur mainly during the transition phase. During the summer and winter phases, there is a decrease in the volume of ice. In the summer phase, the melting of ice is due to the higher temperature of the ambient air and warm water penetrating into the cave. Ice degradation in winter is mainly caused by sublimation.

The floor ice mass is moving downward on an inclined rock basement, but in the lower part of the abyss, ice is melting because of warmer air circulating through the debris plug (Rajman et al., 1985). An ice stalactite about 7 m long, curving inward (in the direction of warmer air flow), formed in the cave's entrance during colder periods (Kunský, 1939; Roda and Rajman, 1971). During the past several decades, only shorter ice stalactites have occurred seasonally on the cave ceiling.

Originally (before the discovery of the lower parts along the Black Brook), the Silica Ice Cave presented a static cave with congelation ice (in the sense of Leutscher and Jeannin, 2004). Recent thermodynamic conditions for the origin of ice (during winter, transitional, and summer phases) were studied by Rajman et al. (1987).

During winter, warmer deeper parts of the cave have been occupied mostly by the greater mouse-eared bat (*Myotis myotis*) and the lesser horseshoe bat (*Rhinolophus hipposideros*). Occasionally, also the rare Natterer's bat (*Myotis nattereri*) was found here (Hapl et al., 2002). The collapse doline of the Silica Ice Cave is a unique phenomenon with a strongly inverted microclimate gradient within a small area, which means that montane and alpine species occur at lower altitudes. A characteristic example is the occurrence of Western Carpathian endemic diplopod *Hylebainosoma tatranum* (Gulička, 1985). Detailed studies documented that area of the collapse doline supports an exceptional diversity of springtails (Collembola) with more than 120 species and distinct communities of soil Collembola at individual sites of the doline slope (Raschmanová et al., 2013, 2015, 2018). Endogeic beetles *Duvalius bokori* and *D. hungaricus* are among the rare species of the entrance habitat (Hůrka et al., 1989). Obligate cave species were confirmed in deeper parts of the cave and are represented by palpigrade *Eukoenenia spelaea* and springtails *Pygmarrhopalites aggtelekiensis* and *Pseudosinella aggtelekiensis*.

The cave was settled several times before the beginning of its cave ice. Archaeological findings in the lower part of the cave (Archaeological Chamber with the Black Brook) are dated from the Neolithic Age, the Bronze Age, and the La Tene Age. Findings of cinders suggest possible Early Palaeolithic settlement (Böhm and Kunský, 1938, 1941; Bánesz, 1962; Bárta, 1995; and others). Based on archaeological findings, the formation of ice in the upper part of the cave started around 400 BC to 0 BC (Roth, 1940a; Bárta, 1995). Böhm and Kunský (1938, 1941), as well as Kunský (1943, 1950), proposed the origin of the cave ice to be ca. 2000 years ago.

The first information about the Silica Ice Cave was published in the first half of the 18th century. A sketch of underground spaces of the cave, elaborated by J. Buchholtz, dates to 1719. He wrote about this cave to M. Bel, who published the data on the Silica Ice Cave in 1723 and from 1739 to 1741 (Prikryl, 1985; Lalkovič, 1992, 1993; and others). At that time, the Silica Ice Cave was one of the most famous caves in the Slovak Karst. The first measurement of air temperature in the cave was done by the English scientist, R. Townson, in 1793 (he described it in a travel book in 1797). French geologist F. S. Beaudant visited the Silica Ice Cave in 1818; he published a description of the cave, including an explanation of the ice's origin in 1822. E. J. Terlanday dealt with measurements of air temperature and the observation of the cave ice from 1892 to 1894. The Silica Ice Cave is a part of the site Caves of Aggtelek and Slovak Karst inscribed in the World Heritage List in 1995.

The Silica Ice Cave was used to cool beer from the brewery that existed in front of the cave portal (in the eastern part of collapsed doline) from 1863 to 1867 (Szontág, 1871). The smoke from the brewery polluted the cave (Derfiňák, 2001). After the discovery of the Archaeological Chamber in the lower part of the cave in 1931, temperature conditions were disrupted by an upward circulation of warmer air to the upper ice-filled part. This negative human impact was eliminated by filling the excavated connecting hole in 1938 (Roth, 1940a). The gate between the ice-filled part and the lower part (without ice) of the cave was reconstructed or changed several times (during the 1950s, 1960s, and 1980s). The effect of the upward circulation of warmer air was enhanced by partially opening the outflow siphon in the Archaeological Chamber, through which new passages along the Black Brook were discovered by Czech speleodivers in 1988 (Hovorka, 1989). Authorities decided that the cave must be closed, and the next speleological exploration of lower parts was paused (Mitter, 1991). In 1998, when the new and more airtight gate was installed, the decrease in ice volume was reduced and more or less stopped, and climatic conditions were restored almost to the original thermodynamic regime (Zelinka, 1999). Another reason for the gradual decrease in cave ice has been the higher evapotranspiration from a nonindigenous black pine forest above the cave, thus the amount of water seeping into the underground has been gradually reduced (Rajman et al., 1987). The reduction of this nonindigenous forest to 50 % canopy of all trees was realized in 2007 (Gaál and Zelinka, 2008).

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DOMICA-BARADLA CAVE SYSTEM

The well-known trans-boundary Slovak-Hungarian Domica-Baradla cave system (Slovak and Aggtelek karsts) is more than 29 km long. Its catchment area covers over 40 km^2 (one third in Slovakia, two thirds in Hungary). It is drained by the allogenic underground Styx Stream flowing through main fluvial passage slightly inclined from ponors near the Čertova diera Cave (Devil´s Hole), ponor under the Líščia diera Cave, at the end of Hančiná Valley and other blind valleys towards the outflow in Jósvafő Village (Jósva Valley, Hungary). The Domica and Baradla caves are included in the List of Wetlands of International Importance (Ramsar List).

Developmentally, the Domica-Baradla cave system consists of evolution levels that have been formed by headward erosion in relation to the long-stagnant base level of erosion in the Jósva Valley during its multi-phased incision. The upper level of the cave system originated in, or before, the Middle Pliocene – burial ages of allochthonous fluvial gravels are 3.47 ± 0.78 Ma and 2.94 ± 0.50 Ma. The lower evolution level, located 12–18 m below the upper level, originated in the Early Pleistocene – the burial age of allochthonous fluvial gravels is 1.92 ± 0.25 Ma (Bella et al., 2019). The main passage of the Domica-Baradla cave system, belonging to the lower evolution level, represents the so-called 'ideal water table cave' (Ford and Ewers, 1978; Ford, 2000).

Low pre-burial denudation rates (3.1–5.6 m/Ma) correspond with the slowdown or interruption of tectonic uplift of the area and the long-term stabilized erosion base level during the formation of these cave levels. Their origin was linked with the formation of large pediments, of which remnants are preserved on both sides of the Jósva Valley in Hungary (Bella et al., 2019).

Domica Cave

The cave is located on the south-western edge of the Silická planina Plateau, close to the state border between Slovakia and Hungary. The cave entrance lies at the southern foothills of the homonymous hill at an elevation of 339 m. Apart from its significant geomorphological features, the cave is unique for its archaeological findings, abundant occurrence of shields as well as by the multiple species of bats.

The Domica Cave is connected with the Čertova diera Cave and together they reach a length of 8027 m. It is formed in the Middle Triassic pale massive Wetterstein limestones of the Silicicum Unit (Mello, 2004; Gaál, 2008). Its passages developed by corrosion and abrasion of several streams (Styx, Domický potok, and their smaller tributaries), which drain mainly the waters sinking into the underground from a non-karst part of the catchment area (Droppa, 1961 and others). Developmentally, these slightly inclined, almost horizontal passages with ceiling channels, wall channels, and aggraded streambed represent typical fluvially modelled cave levels (Roth, 1937; Droppa, 1972; Jakál, 1975; and others). The morphology and origin of ceilings channels in the Domica Cave were described by Zdeněk Roth in 1937 as the first cave in the world (Bella and Bosák, 2015). Near the state boundary, the meandering canyon-like passage of Styx is undercut by recent streambed. The cave passages are enlarged into chambers and halls, mostly in places of crossing tectonic discontinuities. Directions of the main tectonic discontinuities are NE-SW and ESE-WNW (Gaál and Vlček, 2011).

The surface river network in the catchment area of Domica Cave is due to geological and geomorphologic settings transferred underground through several ponors. The main underground hydrologic artery of the cave is the Styx Stream with its allogenic tributaries, flowing mostly from the south. The biggest one is the Domický potok Brook. The flow rate of the Styx fluctuates from 0–120 L/s (and more) during a year. It becomes active mostly in the springtime (snow melting) and during periods of intensive and longer-term precipitation. Sometimes it stays dry throughout the year. The average flow rate of Styx at the time of its activity does not exceed 1–2 L/s. The Domický potok is a permanent brook with very small discharge (average only to 0.1 L/s), with very quick response to rainfall activity in its basin and with the rapid but short increase in the flow.

Underground canyon of the Styx Stream, Domica Cave. Photo: P. Staník

Pre-hibernation colony of the Mediterranean horseshoe bat (Rhinolophus euryale), Domica Cave. Photo: E. Maxinová

The cave water represents the water of atmospheric origin, with petrogenous mineralization (water with carbonate mineralization). Cave waters of horizontal circulation (Styx, Domický Brook) are characterized by Ca-Mg-HCO_3 types. Dripping water represented Ca-HCO_3 type (Haviarová et al., 2010).

The Domica Cave is rich in calcite speleothems, from which the most typical are shields and drums, rimstone dams, onion-like stalactites, and pagoda-like stalagmites (Kettner, 1938; Kašpar, 1941; Roth, 1948; Droppa, 1961; and others). More than 450 shields and drums are observed in many morphological forms, especially on the walls and ceilings (Bella, 1999). Sporadically, they also occur in the form of so-called 'stegamite' growing up from the floor (Gaál et al., 2014). The Domica Cave is one of the internationally important localities in terms of the occurrence of shields and drums.

The cave air temperature mostly ranges from 9.4 to 11.1 °C and relative humidity from 95 to 98 % (Zelinka and Stieber, 2014; and others). The annual regime of cave microclimate is influenced by repeated air circulation from the surface through seasonally opened water siphons of occasional sinking streams and artificial tunnel draining floodwater from the ponor of Domický potok Brook, the inflow of cold water from melting snow, as well as by long-lasting accumulation of cold water in two artificial dams constructed for a boat tour for visitors (Zelinka, 2002, 2003).

The Domica-Baradla cave system represents a unique underground ecosystem, with 503 invertebrate taxa and 101 species of unicellular organisms, and from the biological point of view ranked among the most important worldwide (Culver and Pipan, 2009, Papáč et al., 2014; Salamon et al., 2014). In the Domica Cave, 271 aquatic and terrestrial invertebrate species, were recorded. Some of them are limited to the caves of the Western Carpathians (palpigrade *Eukoenenia spelaea,* springtail *Deuteraphorura kratochvili*) or caves in the orographic unit Slovak and Aggtelek karsts (diplopod *Typhloiulus* sp., springtails *Pseudosinella aggtelekiensis*, *Pygmarrhopalites aggtelekiensis*, *P. slovacicus*). Interesting is the blind cave diplopod *Typhloiulus* sp., which with a length of 2.6 cm and 147 pairs of legs is the largest terrestrial troglobiont and animals with the largest number of legs in Slovakia (Mock et al., 2002). The Domica Cave has a special position in terms of aquatic fauna in caves in Slovakia. Crustaceans have the largest representation but predominate species passively transported from the surface. Significant is the occurrence of 8 specialized aquatic subterranean forms, among them polychaete *Troglochaetus beranecki*, copepods *Acanthocyclops venustus*, *Diacyclops languidoides*, or amphipod *Niphargus aggtelekiensis*.

Fossil bone remains of the cave bear (*Ursus spelaeus*) were dug out in the Suchá chodba Passage (Hokr, 1946). The Domica-Baradla cave system is one of the most important underground habitats for bats in both Slovakia and Hungary. Sixteen bat species have been observed in the Domica Cave and Čertova diera Cave up to now. The most valuable of them are the Mediterranean and thermophilic species *Miniopterus schreibersii*, *Rhinolophus euryale*, *Rhinolophus ferrumequinum*, and *Rhinolophus hipposideros*. These species have used or exploited this site not only in winter for hibernation, but also in summer as a hiding place or place of reproduction. Just in this area, the Mediterranean horseshoe bat (*Rhinolophus euryale*) and Schreiber's bent-winged bat (*Miniopterus schreibersii*) reach the northern boundary of their distribution area. Recently, the largest populations (an estimated total maximum of about 5000 individuals) in the cave system are recorded in the species *R. euryale*, the only one of such a kind in Slovakia (Uhrin et al., 1996, 2014). The surroundings of the cave entrances are important places in the social and reproductive communication of bats in a time of autumn flying of bats (Bihari and Gombkötő, 1993).

Thick layers, smaller and larger heaps of bat guano in several places are evidence of their long-term presence inside the cave. Based on an analysis of a 105 cm high guano heap in the Domica Cave using the ^{14}C isotopes, its oldest layers were dated to 1055 ± 30 years (Krištůfek et al., 2008). The water leaking from the rainfall affects the guano and causes specific geochemical and mineralogical processes. They resulted in the formation of guano minerals such as gypsum, hydroxylapatite (colophanite), brushite, secondary calcite (Kašpar, 1934, 1940; Cílek, 1999; Audra et al., 2019) as well as guano pots developed by biochemical corrosion (Kettner, 1948).

The Domica Cave offered short-term shelter to the oldest Neolithic inhabitants of eastern Slovakia – the creators of the Eastern Linear Pottery Culture – its local branch the so-called Gemer Linear Pottery. However, it was settled mainly by the Neolithic people of the Beech (Bükk) Mountain culture. Later the original entrance to the cave was choked by debris and the cave became inaccessible. Post holes from dwelling objects and fireplaces were discovered in several places in the cave. Many reconstructed containers from sherds as well as a terrace-dug slope in a fine-grained loam on the Styx bank with imprints of stone axes are evidence of pottery manufacture. Irons, awls, arrows, a comb, ring, decorated cylinder bracelet, and fishhook represent the peak of Neolithic processing of bones. Pendants made from shells and animal teeth were also preserved. Stone instruments comprise polished axes, wedges, and mallets with drilled holes and split stone tools – knives and scrapers. The evidence of fabric production is the finding of a thick fabric imprint in the loam (the oldest one in Slovakia), clay whorls as well as a fragment of the conic weaving weight unit. The rear parts of the cave probably served as a sacred and cult place where charcoal drawings were preserved. The Domica Cave is one of the most important finding places of the Bükk Mountain Culture in Slovakia (Eisner, 1932; Bárta, 1965; Lichardus, 1968; Gradziński et al., 2005; and others).

The Stará Domica Cave (Old Domica) was known for a long time. J. Majko entered in 1926 from its bottom through an abyss into the large underground cave spaces of the Domica, where many diverse archaeological discoveries were found. The westernmost part of the cave system, close to the edge ponor dolines, is formed by the Čertova diera Cave (Devil's Hole). Its underground spaces descend from the opening down to the Styx riverbed. The easily accessible parts near the entrance to the cave have been known for a long time. L. Bartolomeides wrote about the cave in 1801. The presumed connection of the Domica Cave with the Čertova diera Cave was proved by J. Majko in 1929. The Club of Czechoslovak Tourists dug out the lower entrance in 1930 and opened the cave to the public, including electric lighting and damming up the Styx in 1932 for the underground boat tour for visitors (Benický, 1932, 1935; Lalkovič, 1996; and others). At present, the public has access to 1315 m, including the 140 m long underground boat tour.

Recently, only occasional underground streams flow through the cave. The cave was several times catastrophically flooded during intensive storms in the past. Hence it is necessary to manage the agricultural activities to prevent accelerated runoff and soil erosion in the catchment area (Jakál, 1979 and others).

Baradla Cave

The most famous of the entrances of Baradla Cave is the natural one near Aggtelek, located under a spectacular 50-m high rock wall and open since ancient times. Beyond this can be found the Csipke-terem (Lace Hall) entrance, the Kis-Baradla sinkhole, the Denevér-ág (Bat Branch) entrance at Aggtelek, as well as the so-called 'Ereszke' established due to the configuration of nearby buildings. Two more artificial entrances open in Red Lake and next to Jósvafő were established to make the cave easier to visit. The length of the Baradla Cave is 21,819 m.

The Baradla cave was formed in the Middle Triassic Wetterstein and Steinalm light grey limestone, while the Jósvafő section formed in Gutenstein limestone of the Silica Unit (Kovács et al., 1988; Piros, 2002). The 7-km long main passage, between the villages of Aggtelek and Jósvafő, is an underground streambed. The passage is on average 10 m wide and 7–8 m high, and in some places widens into a huge hall. Many side branches connect to the main passage of which the most important are the Csernai Branch (700 m), the Retek (Radish) Branch (2750 m), and the Törökmecset (Turkish Mosque) Branch (1130 m).

The Styx Stream, from the direction of the Domica Cave, and the Acheron waters, flowing from the Acheron ponor near Aggtelek, merge in the Hangverseny-terem (Concert Hall). Today, water flows only during floods in the main passage. The water goes through the cave's ponors into the lower caves which lie at the depth of 30–40 m (Kessler, 1938; Gruber and Haviarová, 2014). It was known from water-tracing monitoring that there are two existing levels independent from each other. One of them was reached along a 1 km section following the pumping of water out from the Short Lower Cave discovered in 1982 (Szilágyi, 1982; Gyuricza and Sásdi, 2009). The largest amount of water is drained through the Long Lower Cave and the Short Lower Cave. The underground streams rise to the surface in the group of springs near village Jósvafő (named Táró, Cső, and Medence). The average discharge of Táró Spring (the outflow from the Short Lower Cave) is 0.01 m^3/s, however, its estimated discharge during floods can reach more than 16 m^3/s. The total discharge of nearby Cső and Medence springs (hydrologically connected with the Long Lower Cave) is approximately 0.17 m^3/s, but it rises to 3.33 m^3/s during floods (Gruber et al., 2012).

Its passages exhibit various colours and shapes, and a unique spectacle is provided by stalactite columns, stalactites and stalagmites, flowstones and draperies. The largest stalagmite, the Csillagvizsgáló (Planetarium), has a height of 17 m and is found in the Jósvafő section, and among the best-known are Minerva's helmet, the Dragon's Head, and the Column of St. László.

New Stone Age man found shelter in the Baradla's ancient natural entrance, and most of the thousands of findings unearthed during excavations originate from the Neolithic era (Nyáry, 1881; Rezi Kató, 2014; and others). Besides a large number of fragments, several intact items of pottery belonging to the Bükk culture were discovered. Man, living six or seven thousand years ago, made thin-walled vessels by hand, without any potter's wheel, and embellished them with parallel lines. Many other findings were unearthed from later times, from the early Iron Age, and from the time of the Mongol invasion in the 13th century (Holl, 2007; Csengeri, 2010).

The cave's temperature is almost constantly around 10 °C and the humidity is 95–100 %. From the 1950s onwards, regular climatological studies have shown that due to the cave's special climate and the air's hygiene/microbiological status, it has a curative effect for those suffering from respiratory diseases.

The most striking cave creatures, the bats, were noticed by the first Baradla researchers, but purposeful biological research began only in the middle of the 19th century. The illustrious figure of the country's cave biology, János Frivaldszky, described the cave's most distinctive animals, the *Mesoniscus graniger*. The most prominent researcher of the Baradla Cave's fauna was Endre Dudich, whose work strove to define the cave as the habitat of animals in a hierarchical system, to determine the specific environmental factors and discover the relationships within the biome. In his German-language work on the cave, which is registered in international scientific literature and was published in Vienna in 1932, the number of animal species, subspecies, and varieties he described numbered 262. Dudich conducted his cave biology work from 1958 until his death, working in the Fox-branch designed biology laboratory. By the late 1960s, about 435 animal species had been detected in the Baradla Cave, among them some characteristically native species: dipterans, springtails, nematodes, annelids, unicellular organisms, crabs. The following species have outstanding importance: the beetle *Duvalius hungaricus*, described by Ernő Csiki, which only lives in the caves of the region, is 6–8 mm in size and light reddish-brown in colour. Also of significant value is the Aggtelek well shrimp *Niphargus aggtelekiensis* named after the cave, as well as the worm species *Helodrilus mozsaryorum*, which lives constantly in water covered mud and has been found only in Baradla's Short Lower cave. Several other endemic and obligate cave species have been described from Baradla Cave and thus represent *locus typicus* for protozoans *Amoeba cavicola*, *Diffugia baradlana*, rotifers *Proales baradlana*, *Habrotrocha baradlana*, dipluran *Plusiocampa spelaea*, spider *Porrhomma profundum*, springtails *Pseudosinella aggtelekiensis*, *Pygmarrhopalites aggtelekiensis*. The most prominent of the Baradla's animals, which use the cave only for a period of their life (trogloxene species), are the bats. The once spectacular bat masses disappeared by the beginning of the 20th century. Their decline could be explained by the negative effects of human civilization. Among the more interference-tolerant species, the cave is a favoured place for the lesser horseshoe bat (*Rhinolophus hipposideros*), the greater horseshoe bat (*Rhinolophus ferrumequinum*), and the Mediterranean horseshoe bat (*Rhinolophus euryale*), which not only visits to hibernate but also for breeding. The latter sometimes can be observed in numbers of over a thousand specimens (Salamon et al., 2014).

The green vegetation (lamp-flora), which has appeared under the effect of artificial lighting and has caused much damage to other caves in recent decades, has not spread to any significant extent in the Baradla Cave. While in the late 1970s, about 22 moss and polypody species had been identified, today the polypody species have disappeared and for the mosses, only presettlement can be observed.

The Baradla Cave is Hungary's oldest visited cave. The first written mention of the cave originates from 1549, and the first survey was conducted by József Sartory in 1794. It was known only to be 1.8 km in length until 1825, as shown by the map made by Keresztély Raisz in 1802 when the cave's first map appeared in print. To facilitate the cave tour, first deployment was carried out in 1806, on the occasion of palatine Joseph's visit. In 1825, Imre Vass

Underground streambed, Baradla Cave. Photo: Cs. Egri

crossed through the Iron Gate's water, beyond the previous endpoint, and revealed the continuation of the cave's main branch to be about 5 km long. A description and an accurate map of the cave and the surface was made by Vass and published in 1831 in Hungarian and German (Vass, 1831). In 1890, an artificial entrance was established at the Red Lake, which is still the starting point of the Red Lake tours. In 1922, in the Stage's continuation, which was the endpoint for almost 100 years, Peter Kaffka revealed a new 500-m long section, to which a passage was forced in 1927–1928 from Jósvafő. Electric lights were installed in 1935 along the sections open to visitors.

The connection between the Domica and the Baradla caves was proved by Huber Kessler in 1932 by traversing the Styx stream's siphons. These two caves were separated on a subterranean boundary grid, which was dismantled after Hungary's accession to the Schengen Agreement (Cholnoky, 1930; Jakucs, 1952; Székely, 2005).

In order to develop tourism, several stages of development were made in some sections of the cave. The current state of the Aggtelek and Red Lake sections is thanks to reconstruction work between 1990–1994 and 2004–2005. The concrete pavement and the electric network of the cave were renovated, and new stainless steel barriers were installed to help guide the visitors. In 2012, the cave applied for and received a modern, energy-efficient LED lighting system. Nowadays, Baradla Cave attracts easily the most visitors among the caves utilised for tourism in Hungary.

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INTERNATIONAL WORKSHOPS ON ICE CAVES

The peculiar presence of ice in caves, especially in regions with "warm" climatic conditions (e.g., in countries bordering the Mediterranean Sea) attracted the attention of both local entrepreneurs (who were mining ice to preserve food and sell ice cream during hot summers) and scientists (who were trying to understand how ice could survive underground). The later endeavors led to the accumulation of an enormous body of literature on ice caves, but it was only in 2004 when a small group of cavers gathered in Căpuș (Romania) to systematically discuss their (and their predecessor's) findings. IWIC (International Workshop on Ice Caves) was born and since than a continuously enlarging "ice cave community" gathers every two years two discuss old and novel findings, establish new research directions and, most importantly, visit ice caves. Following IWIC I, in 2006 the Ján Zelinka, Pavel Bella and their colleagues at the Slovak Caves Administration (SSJ) organized IWIC II at Liptovský Mikuláš – Demänovská Dolina (Slovakia), a meeting where a *Working Group on Ice Caves* was established, as part of the International Union of Speleology (UIS). In 2008, Bulat Mavlyudov and Olga Kadebskaya led IWIC III, when participants finally got a view of the famous Kungur Ice Cave in the Ural Mountains, Russia. In 2010, it was the turn of the Austrian giant ice caves to be visited during IWIC IV, organized by Christoph Spötl and his colleagues at Obertraun. IWIC V, led by Valter Maggi and his research group in Milano (Italy) saw the first helicopter ride to an ice cave in the Grigna Settentrionale-Moncodeno Massif. Two years later, in 2012, our travelling group left Europe for the first time, for IWIC VI, held at Idaho Falls under the organizational skills of George Veni. It was for the first time that IWIC was held under the auspices of the newly formed (in 2013) *Glacier, Firn and Ice Caves Commission* of the UIS. Following this intermezzo in the New World, in 2016 IWIC returned to Europe, in Postojna, Slovenia. Andrej Mihevc and his colleagues showed us their ice caves, as well as parts of the Classical Karst, where most of the karst features were first described and their names originated. Two years later, guided by Enrique Serrano and his colleagues in Valladolid and Zaragoza, IWIC VIII was held in Potes (Spain), in the Cantabrian Moutains. Perhaps for the first time in centuries, scientists gathered where they maybe did centuries ago – in a 14th century church. Finally, in 2020, in times of pandemic and global turbulence, Pavel Bella and SSJ the once again took upon themselves the organization of IWIC in Slovakia – this time, also to celebrate 150 years since the discovery of the world's largest ice caves (by volume) – Dobšinská ľadová jaskyňa.

During these past 16 years, numerous articles were published; special issues in journals were edited and most of our knowledge on tice caves was published (2017) in a dedicated volume (*Ice caves*, edited by Aurel Perșoiu and Stein-Erik Lauritzen at Elsevier).

While we do science and exploration and discuss these at IWICs, these meeting are first about people and their passion. IWICs started as gathering of people bond by their shared love of underground glaciation and metamorphosed from the beginning into a group of friends regularly meeting to discuss their passion. We saw people coming regularly, new people drawn in and never to leave and sadly, people leaving us, only to find peace beyond this world. We dedicate our work to their enthusiasm, hard work and devotion to ice caves.

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IWIC I, excursion to Scărişoara Ice Cave, Romania. Photo: J. Zelinka

IWIC V, Barzio, Italy. Photo: J. Zelinka

IWIC IV, Eisriesenwelt, Austria. Photo: J. Zelinka

IWIC III, Kungur, Russia. Photo: P. Bella

San Vicente Church (14th century), IWIC VIII, Potes, Spain. Photo: A. Perșoiu