Geology, morphology, and speleothems of the Jaskyňa Dezidera Horváta Cave (Western Carpathians)

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Abstract: The Jaskyňa Dezidera Horváta Cave is located in the inner city of the town of Nitra, south of the Kalvária Hill (227.3 m asl.). The Jaskyňa Dezidera Horváta Cave has thus become the longest cave of the karst areas in the Tribeč Mts. It currently reaches a length of 610 m, with a denivelization of 45 m. Several geological, geomorphological, and geochemical methods have been used to clarify the genesis of the cave. The cave evolved in the Jurassic limestones belonging to the Tatric Unit. NW–SE, W–E, and NNE–SSW discontinuities were significant to the genesis of the cave. The raised air and water temperatures in the cave (12.5 – 13.5 °C) and the occurrence of various, not-so-common speleothem types, such as helictites, corraloids, and calcite crystals make this cave unique within the Western Carpathians. The morphology of the cave spaces, together with the increased temperature of the water and cave air, indicates that it could be a hypogenic cave, and even more specifically, a hypogenic-hybrid in origin. During its speleogenesis, the mixing corrosion by mixing of atmospheric waters and groundwater played an important role.

Key words: Western Slovakia, Tribeč Mts., Nitra Karst, Jaskyňa Dezidera Horváta Cave, speleogenesis

1. INTRODUCTION

A residential part of the city of Nitra has been included in the karst inventory (*sensu* Hochmuth, 2008) as a part of the Nitra Karst (Fig. 1). Backfilled entrances to two of the most important caves were localised in 2018. Intensive speleological exploration and research have been conducted there (Drevený lom Cave and Jaskyňa Dezidera Horváta Cave, originally known as Zvislá Cave). The mouth of the Jaskyňa Dezidera Horváta (Dezider Horvát Cave) was discovered in 2018 (Halama & Lačný, 2018) by using the georadar method (Lačný et al., 2022) for its precise localisation. Since 2018, speleologists have uncovered the original part of the cave, which is 60 m long with a total vertical difference of 27 m and have penetrated further from the entrance into the cave for discoveries. At its deepest parts, the cave reaches the groundwater level. Jaskyňa Dezidera Horváta Cave currently reaches a length of 610 m and the vertical difference is 45 m (Fig. 2).

As such, it is the longest cave in the Tribeč Mts. according to the regional geological classification of Slovakia (Vass et al., 1998). From a geomorphological point of view, it is a part of the area of Nitrianske vŕšky Hill, which is a part of the Nitrianska pahorkatina Lowland (Mazúr & Lukniš, 1978). The year-round temperature in the cave is about 12.5°C, making it one of the warmest caves in Slovakia (Lačný et al., 2022). Its water table corresponds with recent conditions of the Nitra River. One of the reasons we began studying this cave was the unclear speleogenesis of the Žibrica caves, which are located nearby (Vlček et al., 2011).

2. GEOLOGICAL SETTINGS

The Tribeč mountain range has an exceptional position in the geological structure of the Western Carpathians, since together with the Nízke Tatry and Žiar Mts., it is the innermost of the crystalline mountain ranges. The mountain is composed of two geologically and tectonically different parts (Zobor and Rázdiel parts). The Zobor Part in the southwest only contains the Tatric Unit. The Rázdiel Part is situated in the northeast and is characterised by the presence of the Tatric, Veporic, Fatric, and Hronic tectonic units (Ivanička et al., 1998a).

The previously mentioned locality where the research was carried out belongs to the Zobor Part of the Tribeč Mts., which is characterised by the metamorphism of the Mesozoic cover sequence of the Tatric Unit. The Zobor Part is divided into two blocks: the Tribeč and Zobor. The Zobor Part consists of granitoid rocks and a Mesozoic cover sequence imbricated into several tectonic duplexes. The stratigraphic range of the cover unit is from the Lower Triassic to the Lower Cretaceous. The bedding planes of Mesozoic sediments of the cover sequence are generally uniform with NE–SW orientation. Folds in sediments of the cover sequence are predominantly overturned, although upright folds are present as well. These represent the final stage of ductile deformation transitioning into conditions of sinistral transpression (Lénárt & Hók, 2013). In the abandoned quarry where the research was conducted, there are variegated probably Middle Jurassic crinoidal sandy limestones, which continue into overlying nodular limestones with cherts, light grey limestones with light

Manuscript received 2022-12-20
Revised version accepted 2023-11-9

Fig. 1. Location of the investigated area (source of the topographic map: https://services.arcgisonline.com/ArcGIS/rest/services/World_Topo_Map/MapServer).

cherts (Lučivná Formation), and Lower Cretaceous light clayey limestones (Ivanička et al., 1998b; Hók et al., 2014, 2019). The Jaskyňa Dezidera Horváta Cave was formed in the Middle Jurassic crinoidal limestones (Fig. 3). These are composed of red, violet, yellow-grey, and light to white crinoidal sandy limestones with quartz laminas (up to 2 cm thick). The limestones are distinctively bedded (10–30 cm). Several meters from the cave entrance, a contact between the crinoidal limestones and light grey cherty limestones of the Lučivná Formation can be found (Fig. 3).

3. METHODS

For the geological mapping of the surface as well as the registration of surface and underground tectonic structures, standard methods of geological research were used. Tectonic structures were documented with the geological compass, Freiberg. The locality is well-exposed because it is situated directly in the area of a former quarry. The measurements aimed to determine which discontinuities played an important role in the speleogenesis of the Jaskyňa Dezidera Horváta Cave. For visualization and subsequent analysis of the tectonic structures, OpenStereo software was used (Grohmann & Campanha, 2010). To verify the lithological sequences, microfacies analysis was used. The depositional textures were determined using the Dunham (1962) classification scheme, and the depositional environment was estimated according to Flügel (2010).

Samples from the quarry surface near the cave entrance, as well as from other sites inside the cave (Pieskovisko, Faun's Labyrinth and Trhlina), were taken for a microfacies analysis for the verification of published information that at least the entrance but also some part of the cave interior should be made in Cretaceous sediments (Ivanička et al., 1998a).

The applied Raman spectroscopy study was performed on a DXR Raman microscope with OMNIC spectroscopic software (Comenius University in Bratislava, Slovakia). The bands from a polystyrene standard were used to calibrate the spectrometer. Carbonates were measured with a 633 nm laser at 8 kW and an aperture of 50 μm pinhole. A magnification of 100× and an exposure time of 2 min were used for all measurements. The measurements had a spectral range of 1,800–100 cm^{-1}, and the resolution was 1 cm^{-1}.

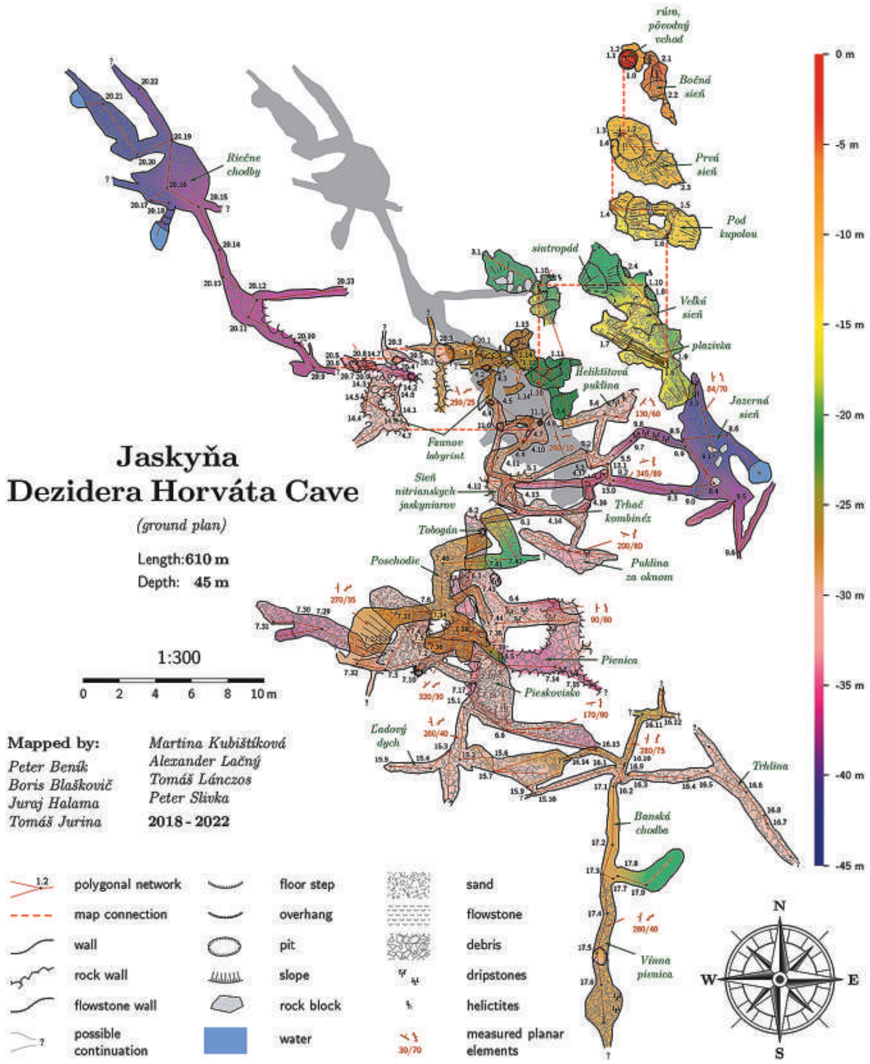

Fig. 2. Map of the Jaskyňa Dezidera Horváta Cave.

4. RESULTS

4.1. Structural analysis

Based on the research, the measured sites were divided into three categories (S_0, S_1, S_2) according to their genesis (Fig. 4). The structural measurements were carried out and measured at 60 sites, of which 22 were in the cave itself (Fig. 5).

Planes S_0 represent bedding (green great circles, Fig. 5). In general, they dip to the NW at an average dip of about 50°. To the SE, however, the dipping of the stratification varies up to 30°. The sites measured in the cave form a separate reference layer (black great circle, Fig. 5).

Perpendicular to the dip direction of the bedding, cleavage was revealed (marked with S_1; red arcs, Fig. 5). These cleavage planes (S_1) represent a significant phenomenon with the same directional orientation as the bedding planes (S_0), but inclined southeastwards. Similar orientations of cleavage planes were documented in the Mesozoic sediments of the cover unit of the Tribeč Mts. (cf. Lénárt & Hók, 2013). Based on the orientation of cleavage planes (S_1) and bedding (S_0), the above mentioned authors assume compression in a NW–SE direction with the formation of fold structures. On the surface, karst activity is associated with the cleavage planes (S_1). On part of these planes, corrosive reworking and partial speleothems were found.

The mentioned structures are disrupted by brittle deformations represented by faults and joints. The analysis of slickenside lineations indicates an extensional tectonic regime with a uniformly oriented principal minimal stress axis in the NW–SE direction. The aforementioned fault systems allowed the individualisation of the Tribeč Horst and participated in the formation of the deposition areas of the Komjatice and Rišňovce depressions during the Miocene (Lénárt & Hók, 2013).

The joints of a third category were (S_2, blue great circle, Fig. 5) oriented generally in an NW–SE direction with a steep inclination to the NE or SW. The ensemble also includes fissures in the approximately west-eastern direction. Due to their low abundance and subvertical trend, there was no reason to treat them separately. The S_2 planes are also significantly evidenced on the surface. They form the walls of the abandoned quarry, on which speleothems are represented by flowstones. We assume that these joints are related to the Holocene neotectonic activity. From the measurements of planar elements in the cave (yellow great circle, (Fig. 5) and the cave map itself, it can be concluded that the S_2 planes with the NW–SE, the E–W, and the NNE–SSW directions significantly contributed to the genesis of the cave.

Two water samples were taken from the small lakes in the Jazerná sieň Hall and the Riečne chodby corridors. The in situ water parameter measurements performed by the GPS Aquameter device fitted with the Aquaread AP-700 electrode unit included water temperature, pH, electrolytic conductivity, redox potential (ORP), and dissolved oxygen concentration values. Dissolved CO_2 and HCO_3^- were analysed in situ by acidobasic titration: the molar concentration of dissolved CO_2 was measured by titration with a 0.1 M NaOH solution and phenolphthalein as an indicator. The molar concentration of HCO_3^- was measured by titration with a 0.1 M HCL solution with a mixed indicator (methyl red and bromocresol green). In the laboratory, chemical analyses of water samples were performed using the Merck Spectroquant® Pharo 300 UV/VIS Spectrophotometer. The concentrations of Ca^{2+}, Mg^{2+}, Fe, Mn, NO_3^-, PO_4^{3-}, SO_4^{2-}, Cl^-, and SiO_2, were measured in this way. The saturation indices for calcite dissolution were calculated using USGS PHREEQC software (Parkhurst & Appelo, 1999).

In the cave, we observed and examined the morphologies that indicated the former hydrographic conditions under which the cave was formed.

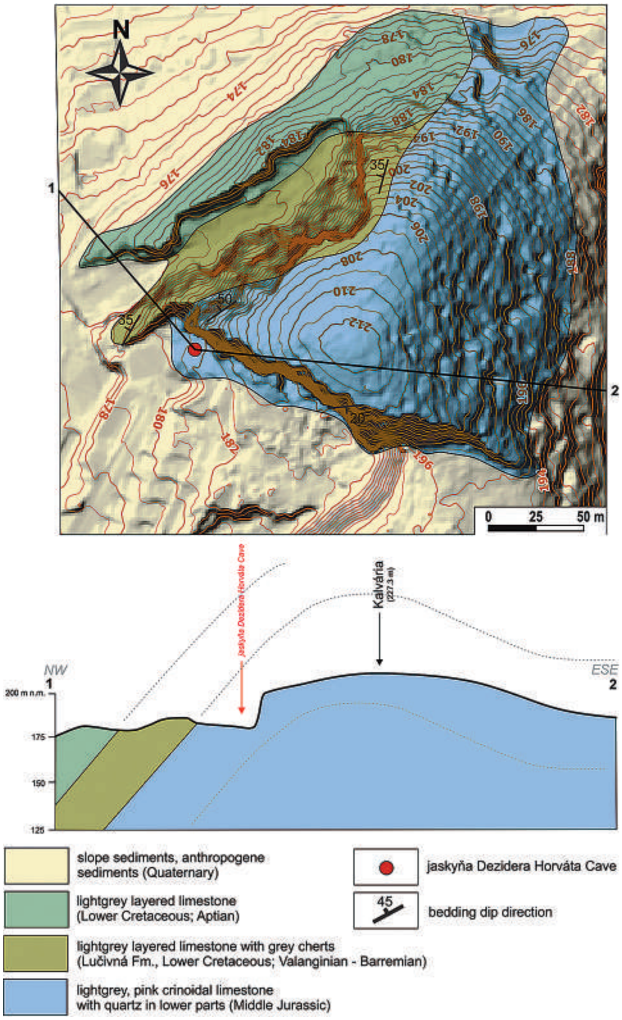

Fig. 3. **Geological map with cross-section of the studied area.**

Fig. 4. **Measured planar structures on the site (Photo: A. Lačný).**

4.2. Microfacies analysis

Samples taken from the quarry surface near the cave entrance and from the Faun's Labyrinth revealed sandy crinoidal packstones. A sample from the Trhlina site yielded crinoidal packestone-grainstone with subangular quartzite lithoclasts (Fig. 6A). The size of the lithoclasts rarely exceeds 2 cm. The constitution of bioclasts in all samples is exclusively made of densely packed and poorly sorted crinoid fragments (Fig. 6B-D). The boundaries between individual grains form a fitted fabric type (grain-to-grain contact) (Fig. 6C). Frequent stylolites swarm with irregular amplitudes (< 1 cm) are noted in samples from Faun's Labyrinth and the surface samples (Fig. 6D). The microfacies analysis confirmed the presence of crinoidal limestones only. By analogy with Tatric sedimentary cover sequences in other mountains of the Central Western Carpathians, the observed lithology is considered as Middle Jurassic in age (Hók et al. 2019). Early Cretaceous microfacies were not observed within the studied samples. Due to the absence of other fossil groups and a strong influence of pressure dissolution caused by tectonic stress and/or overburden pressure, a precise estimation of the sedimentary environment via standard microfacies types (SMF) is difficult. Such monotonous fabrics built exclusively out of crinoid fragments point to mid-ramp deposits and redeposition of bioclastic material from marginal to deeper settings (SMF 12-CRIN) (Flügel, 2010).

4.3. Raman spectroscopy

Representative Raman spectra of calcite from Jazerná sieň Hall (Fig.7) are distinguished by one intense band at 1,086 related to the symmetric stretching of a CO_3 group. Less intense bands at 1,435 and 711 are probably related to asymmetric stretching and asymmetric bending. In the lower wavenumber region, bands at 280 and 154 were found, which are related to external vibration of the groups (translatory oscillations). The obtained Raman spectra correspond to the calcite spectra published by Buzgar & Apopei (2009).

4.4. Water chemical analyses

The analysis results are presented in Table 1. The analyses significantly differ in concentrations of SO_4^{2-} (Jazerná sieň Hall 28.6 mg.l^{-1}, Riečne chodby corridors 72.2 mg.l^{-1}), HCO_3^- (Jazerná sieň Hall 301.42 mg.l^{-1}, Riečne chodby corridors 245.77 mg.l^{-1}), Cl^- (Jazerná sieň Hall 17.5 mg.l^{-1}, Riečne chodby corridors 5 mg.l^{-1}) and Mg^{2+} (Jazerná sieň Hall 7.8 mg.l^{-1}, Riečne chodby corridors 11.5 mg.l^{-1}). The saturation index for calcite dissolution Si_{cc} is almost the same for both locations, 0.61 and 0.64 respectively. Due to the higher saturation index values calcareous mud precipitated at the bottoms of the lakes.

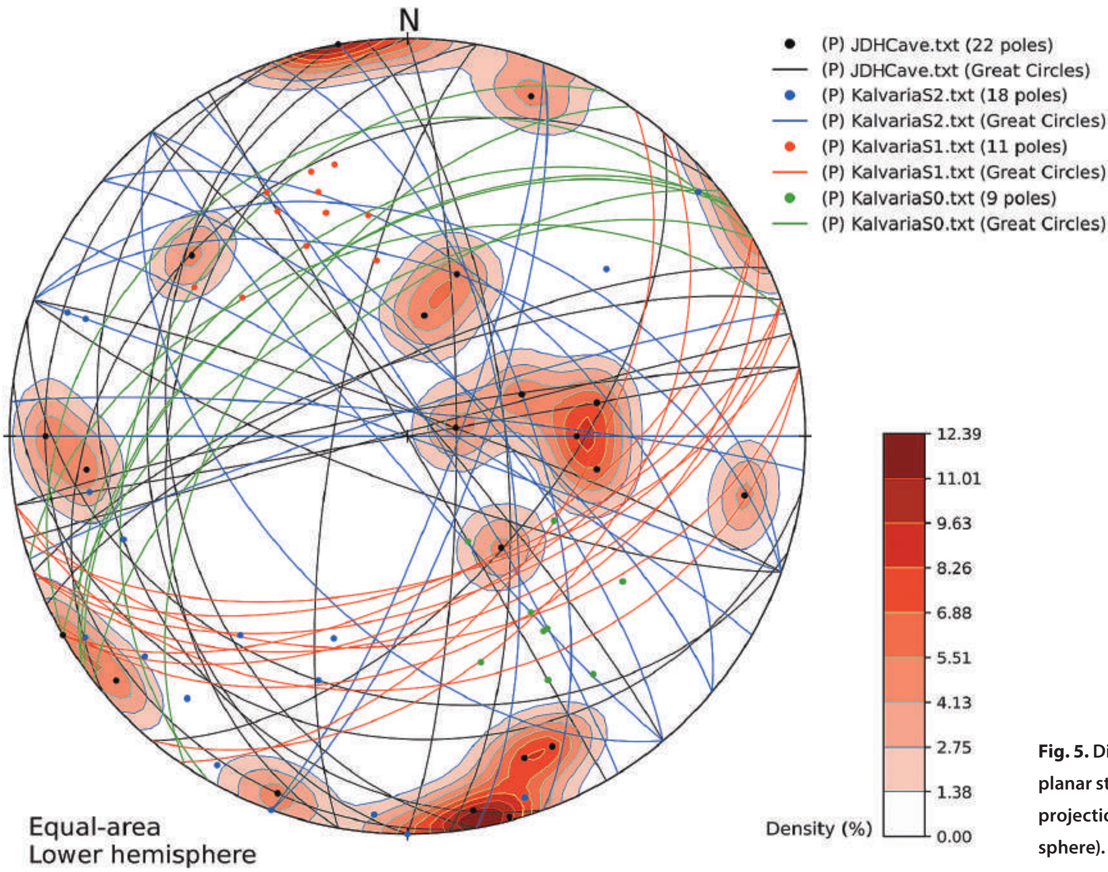

Fig. 5. Diagram of measured planar structures (Lambert projection, lower hemisphere).

4.5. Speleothems description

The cave is considerably poor regarding speleothems occurrence; however, the variety of types is very rich. Some cave parts are almost without any speleothems (the passages Riečne chodby corridors and Trhlina Hall), while others contain them sporadically (the passage Faunov labyrint Hall, halls Sieň nitrianskych jaskyniarov and Poschodie) with few parts being very rich in

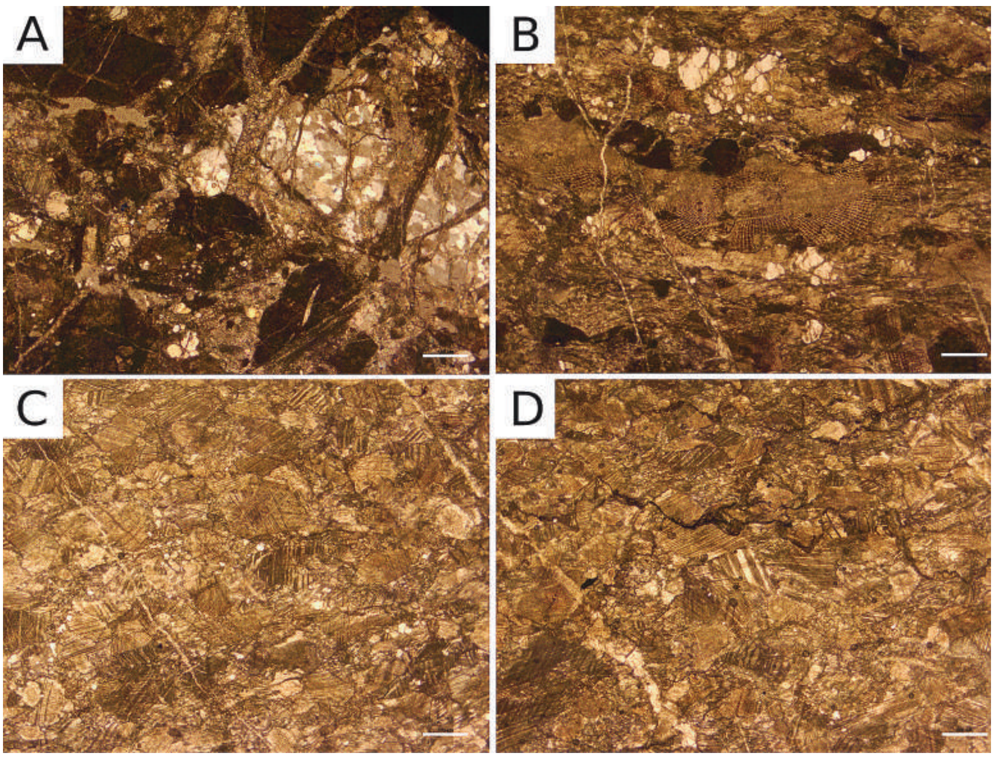

Fig. 6. Microfacies of the crinoidal limestones (Photo: Š. Józsa): (A) Sandy crinoidal packestone with quartz grains and crinoidal wackestone lithoclasts (Trhlina Hall sample). (B) Poorly sorted sandy crinoidal packestone with larger quartz grains (surface sample). (C) Densely-packed crinoidal packestone with fine terrigenous quartz admixture (sample from Faunov labyrint Hall). (D) Densely-packed crinoidal packestone with fine terrigenous quartz admixture and stylolites (sample from Faunov labyrint Hall). Scale bars 500 μm.

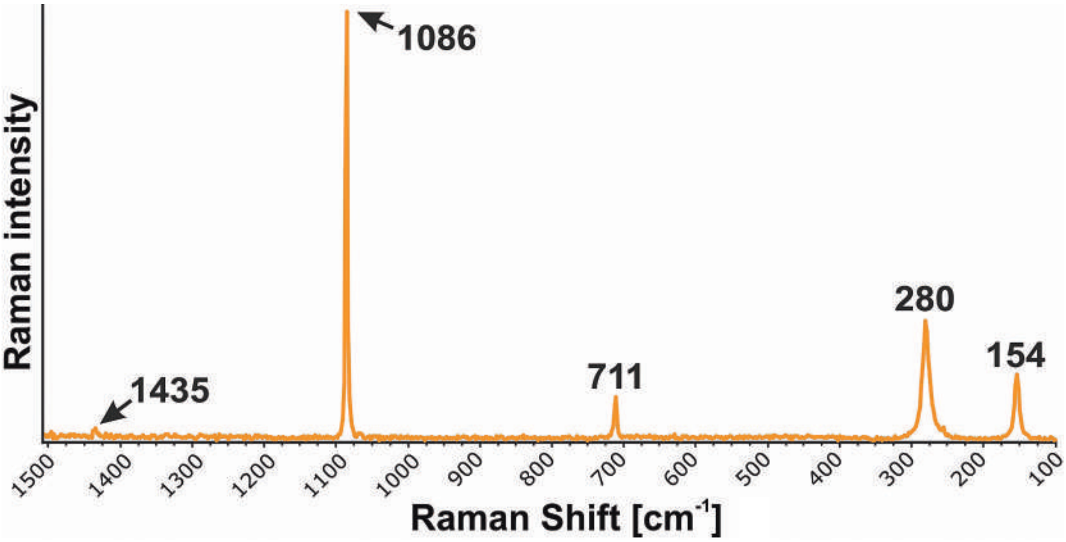

Fig. 7. Typical Raman spectra of calcite from the Jazerná sieň Hall.

them (Jazerná sieň Hall, Puklina za oknom Hall, and Heliktitový komín Chimney).

Helictites represent a considerably rare speleothem type in the caves of Slovakia. In this cave, however, we encounter several morphological varieties of them, depending on the depth of their occurrence. At the depth of 20–25 m below the surface, in the Veľká sieň Hall and the Heliktitový komín Chimney, whitish helictites with a maximum size of up to 2 cm occur. Their shapes resemble teeth, horns, antlers, or fans (Fig. 8A,B), together with smaller transparent straws. They could be encountered mostly in crevasses, hollows, and chimneys. In the Pieskovisko Hall (depth of 30–33 m below surface), in a wide crevasse richly decorated by speleothems of various types, there are comb-like helictite clusters that had formed on the ridges of the blocks (Fig. 8C). They are mostly curved and cone-shaped, some of them form curved sticks. The size of these helictites is up to 4–5 cm. In the Pivnica Hall, below the Pieskovisko Hall at a depth of 35–38 m, short (up to 1 cm), cone-shaped, transparent helictites growing on existing stalagnates in horizontal crevices occur (Fig. 8D). In the deepest part of the cave, in the Jazerná sieň Hall (45 m below the surface), only a few, short (4–5 mm), curved or antler-shaped helictites occur (Fig. 8E).

Another speleothem type more often encountered in the cave is coralloid speleothem. They also occur in different varieties depending on the depth below the surface. Coralloids in deeper parts of the cave, especially in the Jazerná sieň Hall, form dense bunches of tiny (2–3 mm), rounded, often elongated and/or slightly flattened coralloids, sometimes connected to their base by branched stems (Fig. 9A). This morphology was evolved by growing these coralloids directly on tiny, needle-like calcite crystals described below. Their growth starts on the tips of the crystals (Fig. 9B) and then grows along the crystal above and down to the base (Fig. 9C); in this phase, they develop pear-like forms. Coralloids in the upper parts, e.g., in the Poschodie Hall (28–32 m below the entrance), contrarily form clusters of rounded forms, absenting stems lying directly on their bases (Fig. 9D).

Speleothems with more "conventional" shapes created by precipitation from oversaturated percolating atmospheric waters also occur in the cave, such as stalagmites, stalactites, columns, soda straws, flowstones, and draperies. These speleothems often occur in smaller clusters, e.g., in Faunov labyrint Hall passage, however, in some places, we may encounter also speleothem accumulations in the area of several square meters, e.g., in the chambers of the Jazerná sieň Hall (Fig. 10A), Pieskovisko Hall, or Puklina za oknom Hall. Often occurring features are ripples on their surface (Fig. 10B), which attest to the periodically high discharge of infiltrating meteoric water (Fairchild & Baker, 2012).

In the Jazerná sieň Hall, a dense cover of tiny (up to 5 mm) needle-like calcite crystal clusters occurs on the floor and walls up to 1–1.5 m. The crystals are often covered by a brownish and/or black coating formed by iron and manganese oxides (Fig. 11A,B).

4.6. The morphology of cave spaces

On the surface, limestones are generally inclined to the SW, with a dip of 40–50°. Similar bedding can be observed in the compact parts of the cave. Bedding planes, combined with variously oriented joints and faults, participated in the formation of cave passages (Fig. 2). Based on the orientation of the corridors, three significant directions can be inferred to which the cave spaces are linked: NW–SE, NNE–SSW, and approximately E–W. A significant fault system of the NW–SE orientation can be assumed (Trhlina Hall, Riečne chodby corridors, but also the Jazerná sieň Hall, Puklina za oknom Hall, Veľká sieň Hall). The second distinctive system is in the NNE–SSW direction, which is reflected in the spaces of the Banská chodba Corridor, Vínna pivnica Hall, as well as partly in the Pieskovisko and Poschodie halls. The connections and narrow corridors are related to subvertical joints with approximately E–W striking (e.g., Heliktitová puklina Corridor). The spaces of the central part are quite neotectonically disintegrated. This applies mainly to parts of Faunov labyrint, Pieskovisko and Pivnica halls. Externally from this sector, the corridors are relatively more compact. These are the Jazerná sieň Hall, Puklina za oknom Hall, Trhlina Hall, and parts of the Pieskovisko Hall, Banská chodba Corridor, and Riečne chodby corridors. In the deepest parts of the cave, in

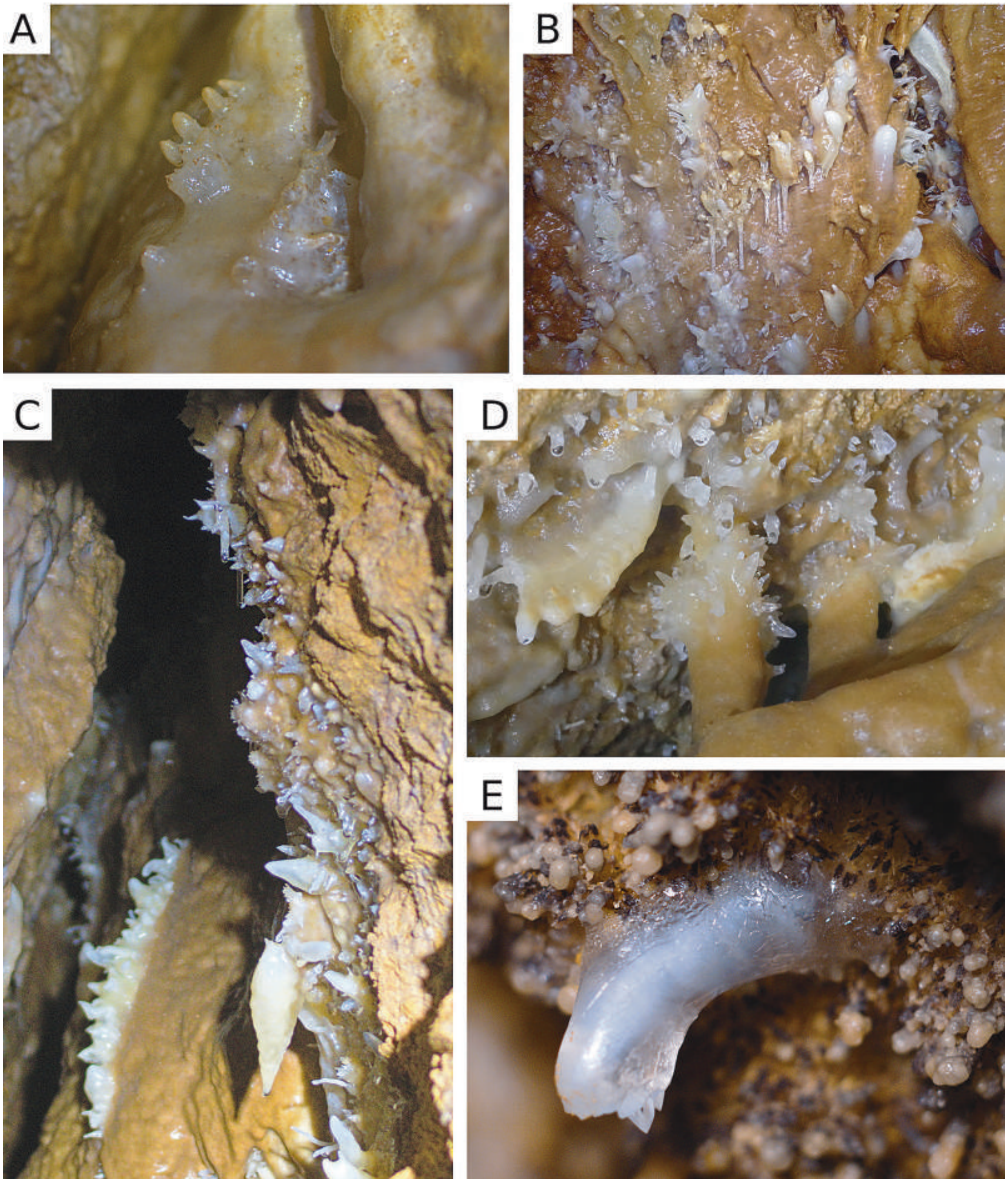

Fig. 8. Helictite type speleothems (Photo: T. Lánczos): (A) Tooth-shaped small helictites (up to 1 cm) in the Veľká sieň Hall, 20-25 m below the surface. (B) Teeth, horns, antlers or fan-shaped helictites (up to 3 cm) together with smaller transparent straws in the upper part of the Heliktitový komín Chimney, 20-25 m below the surface. (C) Comb-like helictite clusters formed on the ridges of the blocks in a wide crevasse in the Pieskovisko Hall (up to 4-5 cm), 30 – 33 m below the surface. (D) Cone-shaped transparent helictites (up to 1 cm) growing on existing stalagnates in horizontal crevices in the Pivnica Hall, depth 35-38 m. (E) Tiny curved helictite (4-5 mm) in the Jazerná sieň Hall (45 m below surface).

the Jazerná sieň Hall and Riečne chodby corridors, the water level in the siphon place (– 45 m) was reached. This water level approximately corresponds to the level of the Nitra River.

In compact parts, ceiling hollows, ceiling pockets, rock holes and other solution morphologies, sometimes decimeters in size (Figs. 12–14), have been preserved on the walls of the cave. In several places of the cave, but especially in the Jazerná sieň Hall, Riečne chodby corridors and Poschodie Hall, they were also identified on the ceilings, indicating the outlet flow of water (Fig. 12A,B). Moreover, in the Jazerná sieň Hall, a narrow, phreatic passage controlled by a steep joint was documented (Fig. 12C). We also documented small ceiling pockets controlled by a joint near the recent water level in the Jazerná sieň Hall, corresponding to mixing corrosion (Fig. 12D).

Right in the Jazerná sieň Hall, there is a steep fissure (like a feeder) (Fig. 13A) and the walls covered with coralloids (Fig. 13B), while the base of walls has needle-like formations of calcite crystals. Such an association suggests the hypogenic origin of the cave (Audra et al., 2002). A significant accumulation of coralloids was documented in aligned interconnected cave spaces with the northwestern-southeastern orientation, i.e., the Jazerná sieň Hall, Pieskovisko Hall, Veľká sieň Hall, and Pod kupolou Hall. The water temperature of the cave pond in the Jazerná sieň Hall was measured; it reached a temperature of 13.3 °C on 12. 2. 2019, and the pond in the Riečne chodby corridors was also 13.3 °C on 13. 2. 2020.

Similar morphologies (ceiling hollows, ceiling pockets) formed by the outlet streams of water can be observed in the Riečne chodby corridors; the height level of which is like that of the Jazerná sieň Hall. Here, too, the water table was reached. However, contrary to the Jazerná sieň Hall, there is no structure that we could unambiguously call a feeder, and coralloids are also absent here. These are located further south, but not directly in the largest space of the Riečne chodby corridors. However, there are pockets on the walls and ceiling, as well as dome-shaped formations on ceiling (Fig. 13C).

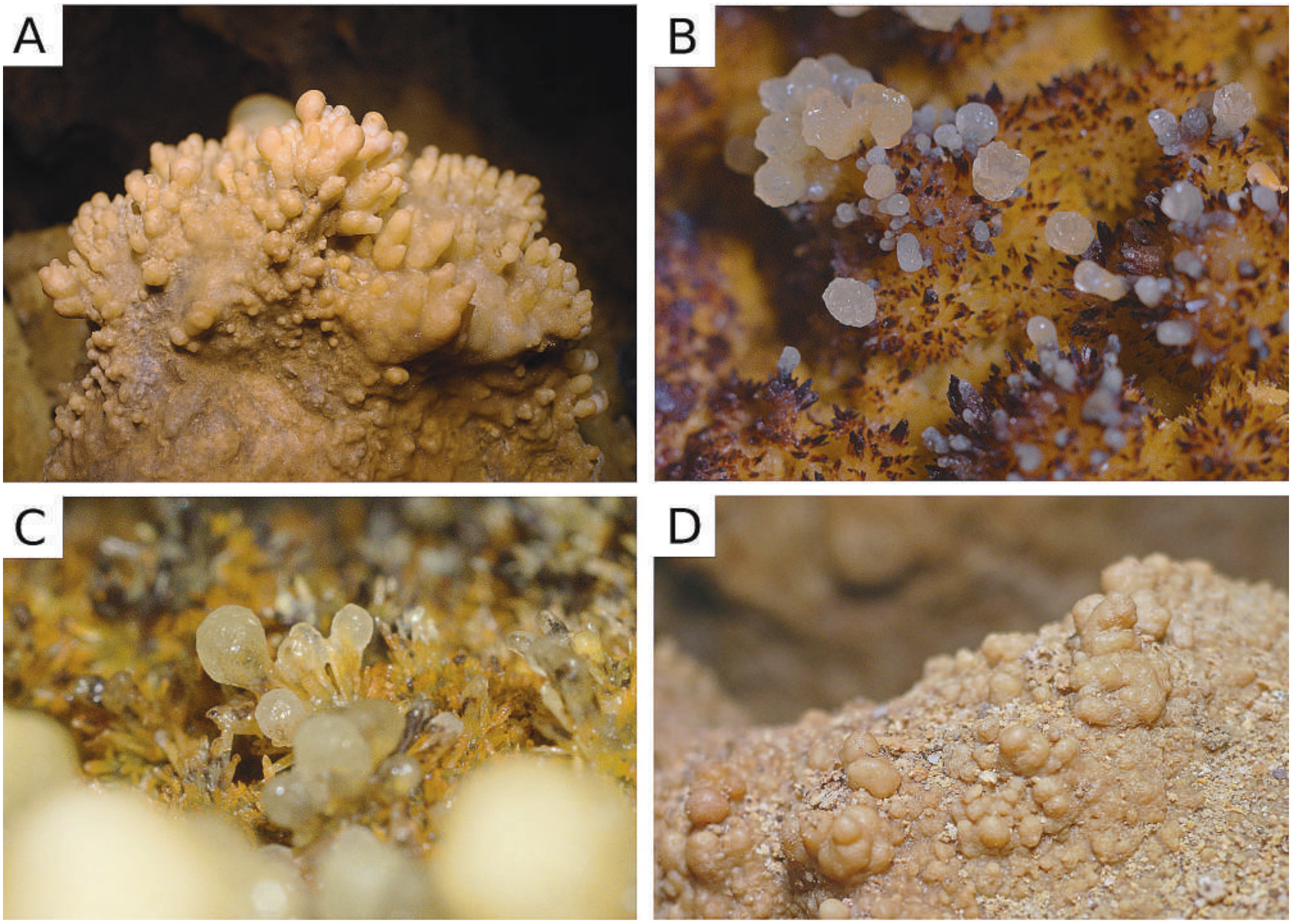

Fig. 9. Coralloid type speleothems (Photo: T. Lánczos): (A) Coralloids in the Jazerná sieň Hall forming dense bunches of tiny (2–3 mm), rounded, often elongated and/or slightly flattened coralloids, sometimes connected with their base by branched stems. (B) Coralloids in the Jazerná sieň Hall, in the early phase of their development, growing on the tips of calcite crystals (1–2 mm). (C) Coralloids in the Jazerná sieň Hall overgrowing the calcite crystals in a pear-like form, 4-5 mm long. (D) Coralloids in the Poschodie Hall (28–32 m below the entrance), absenting stems, forming clusters of low relief rounded shapes.

The intensive crunching of limestone is also indicated by numerous ceiling rock holes and solution hollows in the Pieskovisko Hall and Poschodie Hall (Fig. 14A,B)

5. INTERPRETATION (POSSIBLE SPELEOGENESIS OF THE CAVE)

We can assume that the disturbed parts of the cave are linked to younger processes. In the compact parts, one can speak of fluvio-karstic processes, as reflected also in the deepest parts of the cave flooded with water, as well as the sediments of the autochthonous sand fraction in several parts of the cave. Following the morphological classifications of caves (White, 1988; Palmer, 1991, 2000), the studied cave represents a branched cave, formed by linear and in some places, by crossing passages. These are strictly related to systems of subvertical parallel and intersecting tectonic faults. Cave corridors with parallel tectonic discontinuities (Fig. 2) correspond to the so-called angular maze cave pattern. This pattern is characteristic of hypogenic recharge (Jouves et al., 2017).

Based on the vertical arrangement of the cave, one can express the opinion that the origin and development of the passages relate to subvertical tectonic faults, along which the waters of deeper circulation ascended. Following our observations it is however apparent, that the key process in the cave spaces development is the so-called mixing corrosion. The principle of the mixing corrosion was described by different authors (e.g., Bögli, 1964, Dreybrodt, 1981, Dreybrodt et al. 2010) as a consequence of mixing of two solutions saturated by calcite under different pCO_2 conditions and therefore having different chemical compositions. The resulting solution is undersaturated concerning calcite and thus will tend to dissolve it. In this cave, the infiltrating atmospheric waters are mixing with the groundwater entering the system probably through a feeder-like structure (Fig. 13B) in the Jazerná sieň Hall, in the place where calcite crystals occur exclusively, and the solution process took place on the groundwater level. The Nitra River incision in time caused groundwater decrease in the area. The decreasing groundwater level consequently caused cavities to widen by corrosion enhanced by mixing with percolating precipitation waters (Fig. 15). The relatively bigger space of the Pieskovisko Hall was created probably during a stagnation period of a low groundwater level. The intensive corrosion of limestone is also indicated by numerous rock holes in the ceiling (Fig. 14A) of cave spaces related to subvertical tectonic faults.

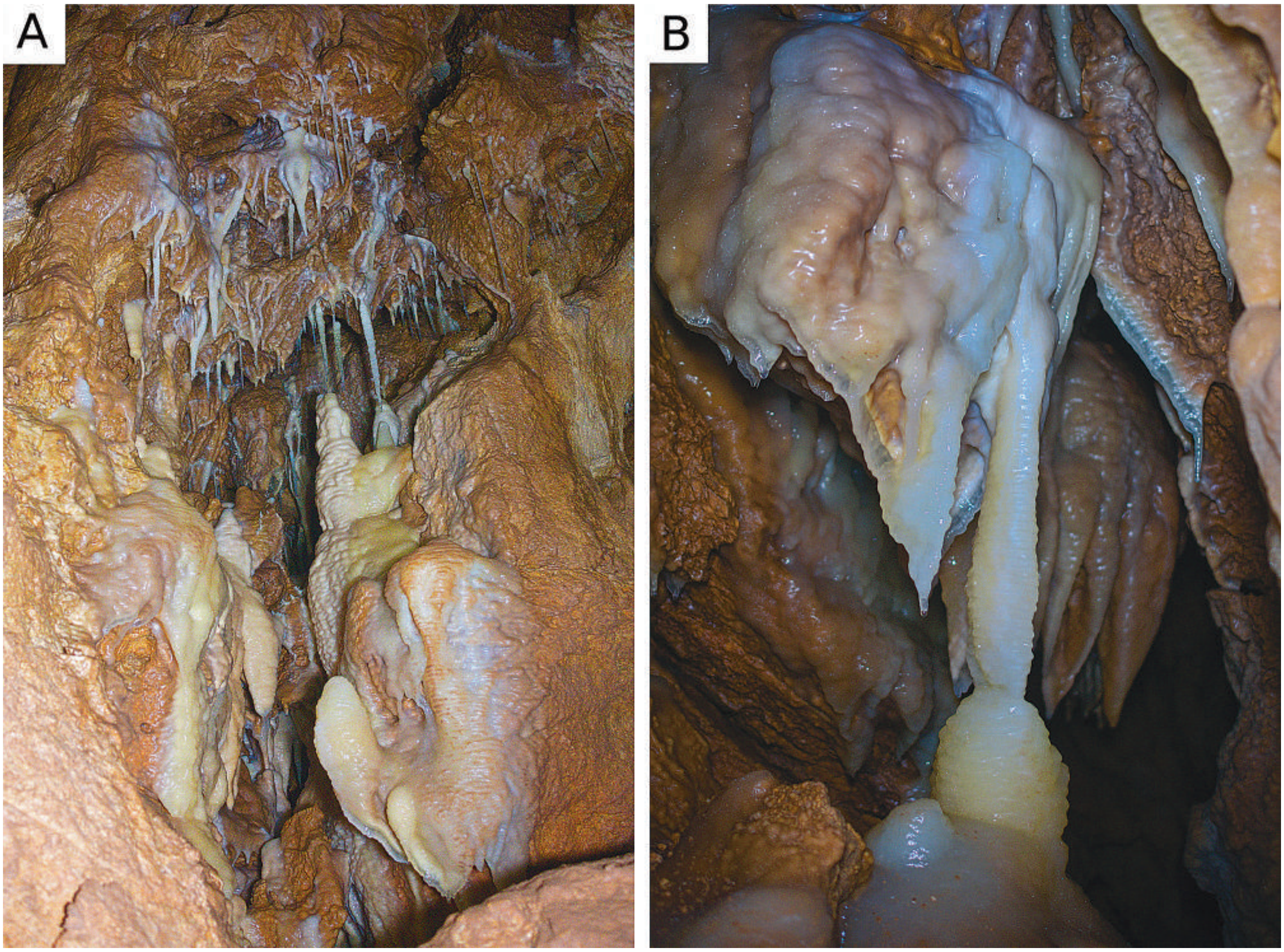

Fig. 10. Speleothemes created by precipitation from oversaturated percolating atmospheric waters (Photo: T. Lánczos): (A) Accumulation of stalagmites, stalactites, columns, soda-straws, flowstones, and draperies in the Jazerná sieň Hall, approx. 3 m high. (B) Ripples on the surface of the speleothems attest to the periodically high discharge of infiltrating meteoric water, Pieskovisko Hall.

Such places can be observed, for example, in Poschodie Hall (Fig. 14B). For example, another cave with mixing corrosion, in connection with a possible hypogenic genesis is Večerná-Čárka Cave System, with a similar geomorphological position, located in the peripheral zone of a mountain range, in this case the Malé Karpaty Mts. (Lačný et al. 2020).

Based on the morphology of the vertical passages and other cave passages located in the depth range of 45–30 m we assume that they were created by phreatic corrosion (Fig. 15). Up to this level, several chimneys are decorated with coralloids (Fig. 13D, Tobogán site). The dissolution of limestones under phreatic conditions also created small irregular corrosion hollows.

The recent waters in the lakes of the Jazerná sieň Hall and Riečne chodby corridors are apparently meteoric waters infiltrated from the surface. Their chemical composition was formed by mineral dissolution in their rock environment. The differences in the chemical compositions of the samples can reflect the lateral or vertical changes in the sediment composition. However, we can't exclude some anthropogenic contamination caused by neighbouring residential areas (Tab. 1). However, the very similar pH, CO_2 concentration and partial pressures, as well as saturation indices for calcite dissolution, prove the same conditions of chemical composition development.

The distribution of the different types of the speleothems would provide us with a hint regarding their origin. The accumulation of calcite crystals exclusively at and near the bottom of the Jazerná sieň Hall is a sign of flooding the chamber in the

Tab. 1: Results of chemical analyses and in situ measurements of water samples from the lakes in the Jazerná sieň Hall and Riečne chodby corridors.

Site	Jazerná sieň Hall	Riečne chodby corridors	Site	Jazerná sieň Hall	Riečne chodby corridors
Twater [°C]	12.7	12.8	pH	7.36	7.36
EC [μS. cm^{-1}]	714	656	TDS [mg.l^{1}]	485.0	444.8
CO_2 [mg.l^{-1}]	7.58	7.7	log P_{CO_2}	−2.08	−2.34
SiO_2 [mg.l^{-1}]	5.91	5.31			
	Cations [mg.l^{-1}]			Anions [mg.l^{-1}]	
Ca^{2+}	109	93	Cl^-	17.5	5.0
Mg^{2+}	7.8	11.5	SO_4^{2-}	28.6	72.2
Fe^{2+}	0.036	0.025	NO_3^-	14.43	11.51
Mn^{2+}	0.17	0.3	HCO_{3-}	301.42	245.77
Al^{3+}	0.041	0.009			
	Saturation indices for calcite dissolution				
Si_{cc}	0.61	0.64			

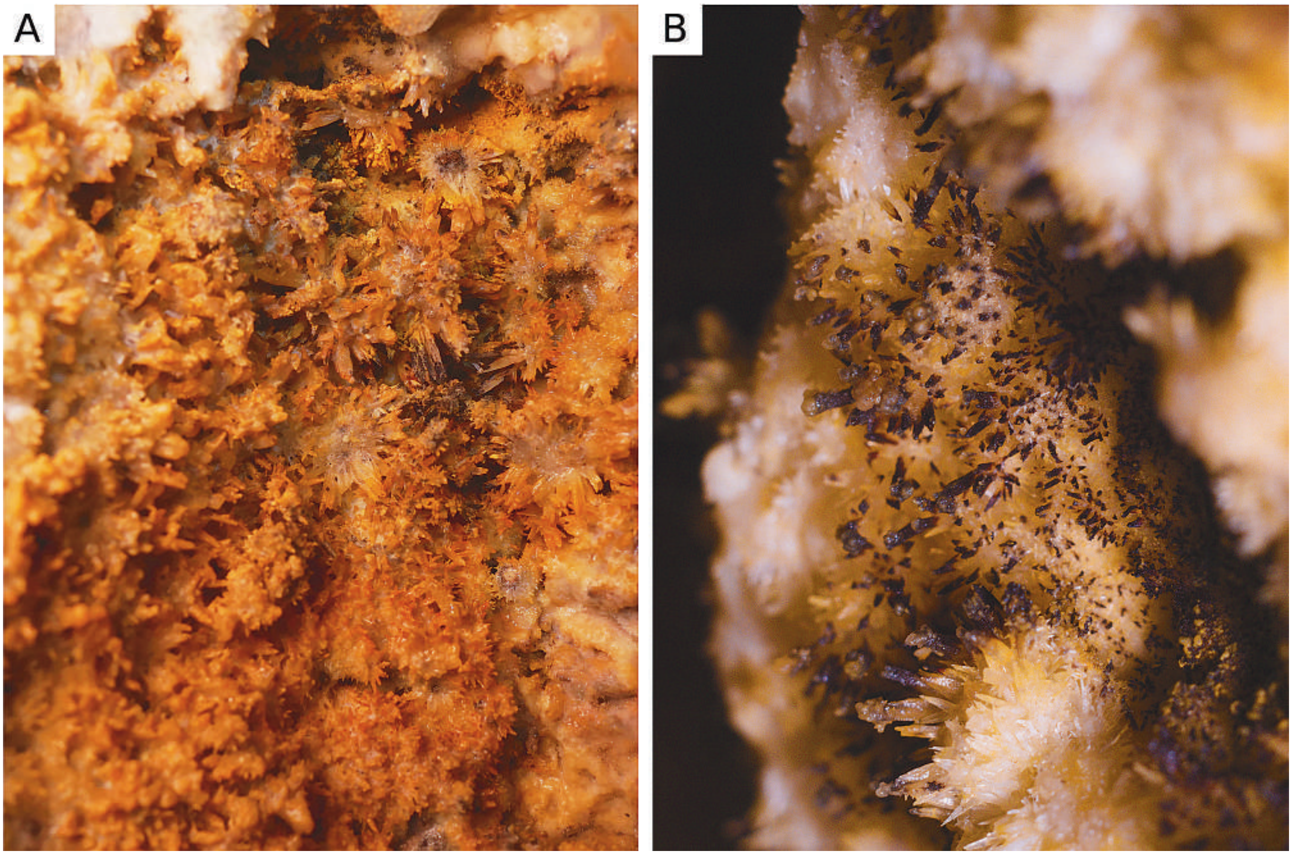

Fig. 11. A dense cover of tiny (up to 5 mm), needle-like calcite crystals in the Jazerná sieň Hall (Photo: T. Lánczos): (A) Calcite crystals covered by iron oxide. (B) Calcite crystals covered with manganese oxide coatings on their tips.

past with water oversaturated to calcite directly from the feeder, where oversaturation was reached through the loss of CO_2. The coralloid speleothems were grown later, after the decrease of the water level, in some cases directly on the calcite crystals. The bacterial activities driving coralloid speleothems growth, based on the studies of Banks et al. (2010), were probably supported by higher temperatures and the presence of some nutrients (like Mn and Fe). This hypothesis needs to be supported by more detailed investigations in the future.

The formation of other speleothem types, including helictites, is dependent on meteoric waters infiltrating from the surface; therefore, they represent a hypergenous phase of speleogenesis. The unusual abundance of helictites was probably caused by higher temperatures boosting microbial activities (Tisato et al. 2015).

6. DISCUSSION

Several morphological features, mineralogical associations, and the air and water temperature of the Jaskyňa Dezidera Horváta Cave indicate that it was likely formed by slightly heated waters rising along the peripheral zone of the mountain range.

A partial analogy can be found with the hypogenic origin of caves with slightly heated waters rising along the faults at the tectonic contact between the Malé Karpaty Mts. and the Záhorská nížina Lowland near Plavecké Podhradie (Bella, 2010; Bella & Bosák, 2012; Bella et al., 2019a, b, Lačný et al., 2022).

Within the framework of studying various conditions and processes of speleogenesis in the karst territories of the Western Carpathians, the Jaskyňa Dezidera Horváta Cave can be included in the group of corrosion caves with indications of hypogenic origin (Bella & Gaál, 2012). This is confirmed by chimneys and domes created upwards by flowing water, significant faults in cave spaces, half-tubular or tubular outlets of waters rising along subvertical faults, the occurrence of ponds with slightly heated water, a warmer microclimate due to the heating of the cave environment by low thermal water, the absence of allochthonous sediments, and the position of the cave in the mountain front. These traits can be classified as typical for dissolution hypogenic caves or hypogenic-hybrid caves (Bella, 2016). Such caves were formed by the dissolution of carbonates and silicates by hydrothermal or other waters of underground origin (hypogenic caves), or by groundwater mixed with atmospheric waters (hybrid hypogenic-hypergenic caves (e.g., Ford & Williams, 1989, 2007; Palmer, 1991; Klimchouk, 2007, 2009; Dreybrodt et al., 2010; Sauro et al., 2014). In addition to the outlet water currents, condensation corrosion of carbonates can also be considered when CO_2 or H_2S leakage into the environment occurs (Audra et al., 2002). One sign of this is the presence of coralloids, which points to its connection with hypogenic caves (Plan et al., 2009). During the later phases of speleogenesis, we have to take into account also the corrosion of limestone by atmospheric waters. This is evidenced

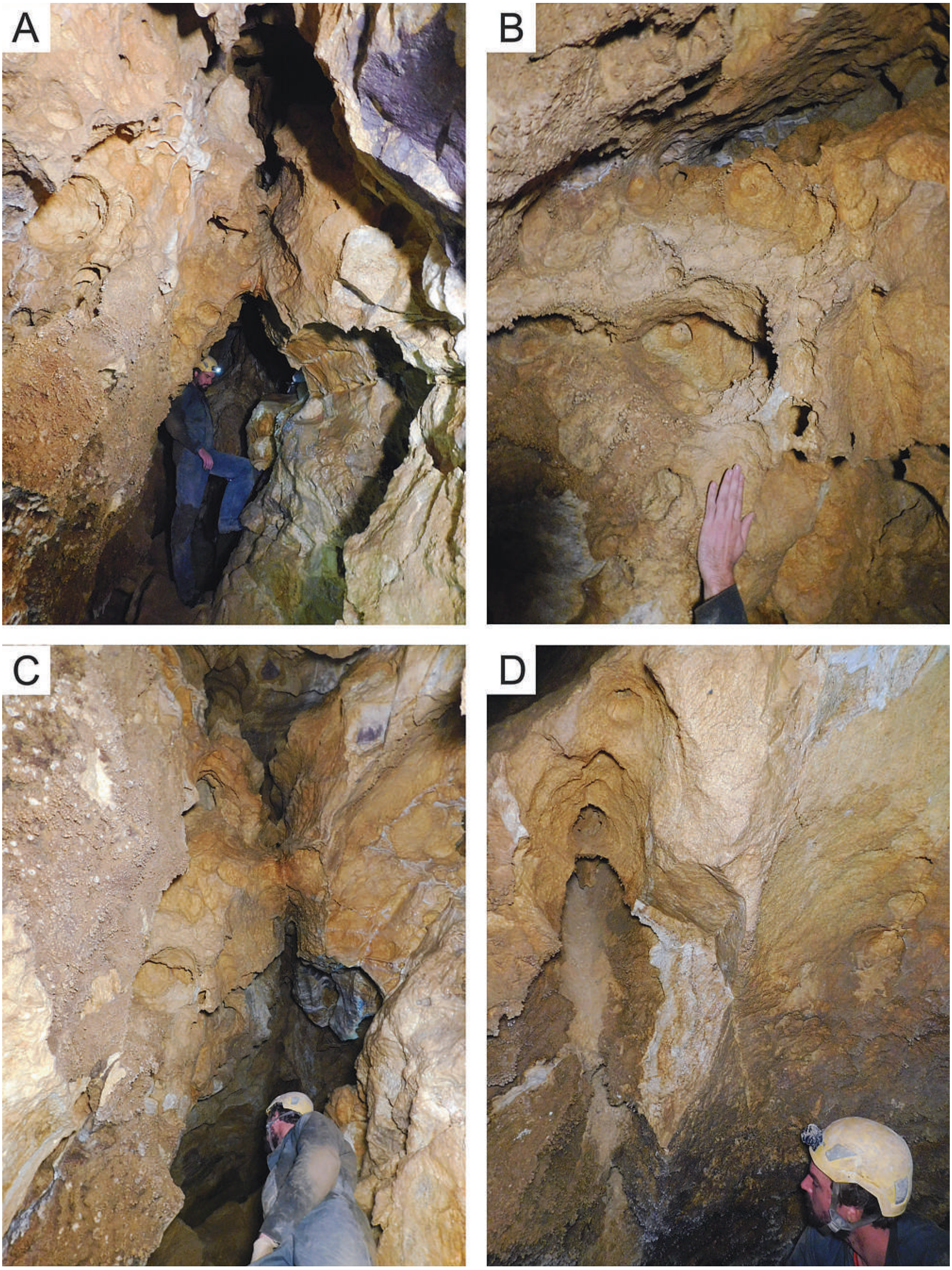

Fig. 12. Cave morphologies (Photo: A. Lačný): (A) Phreatic morphology of the Jazerná sieň Hall with ceiling hollows. (B) Small solution hollows on the ceiling of the Jazerná sieň Hall. (C) Narrow phreatic passage controlled by steep joint. (D) Small ceiling pockets controlled by joint (left side), near the recent water level in the Jazerná sieň Hall.

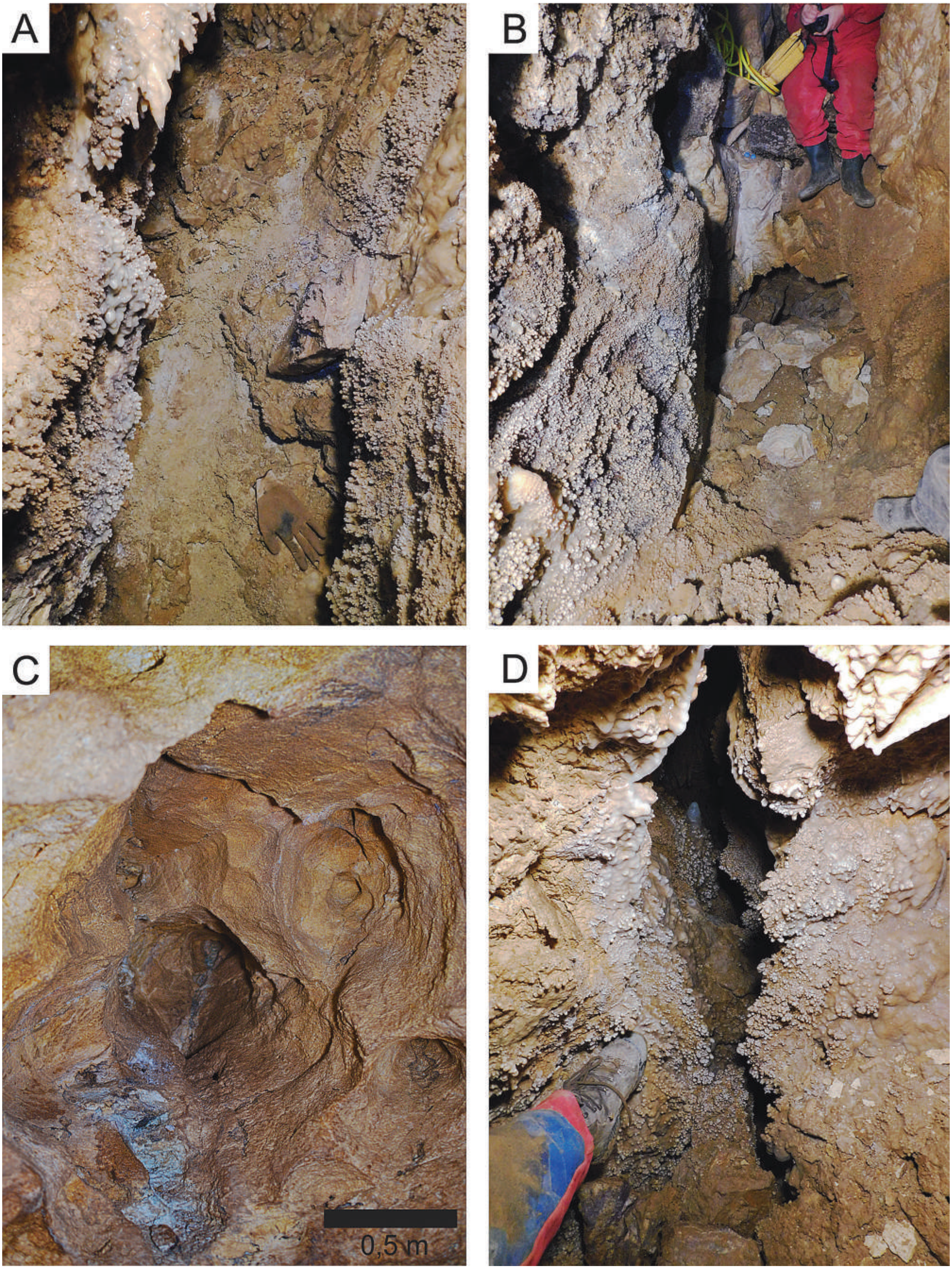

Fig. 13. Cave morphologies (Photo: A. Lačný): (A) Steep fissure structure in the Jazerná sieň Hall, where coralloids are found on the walls. (B) A wider feeder-like structure with the occurrence of coralloids. (C) Ceiling pockets in the Riečne chodby corridors. (D) Fissure at the bottom of the Pieskovisko Hall (loc. Tobogán) with coralloids.

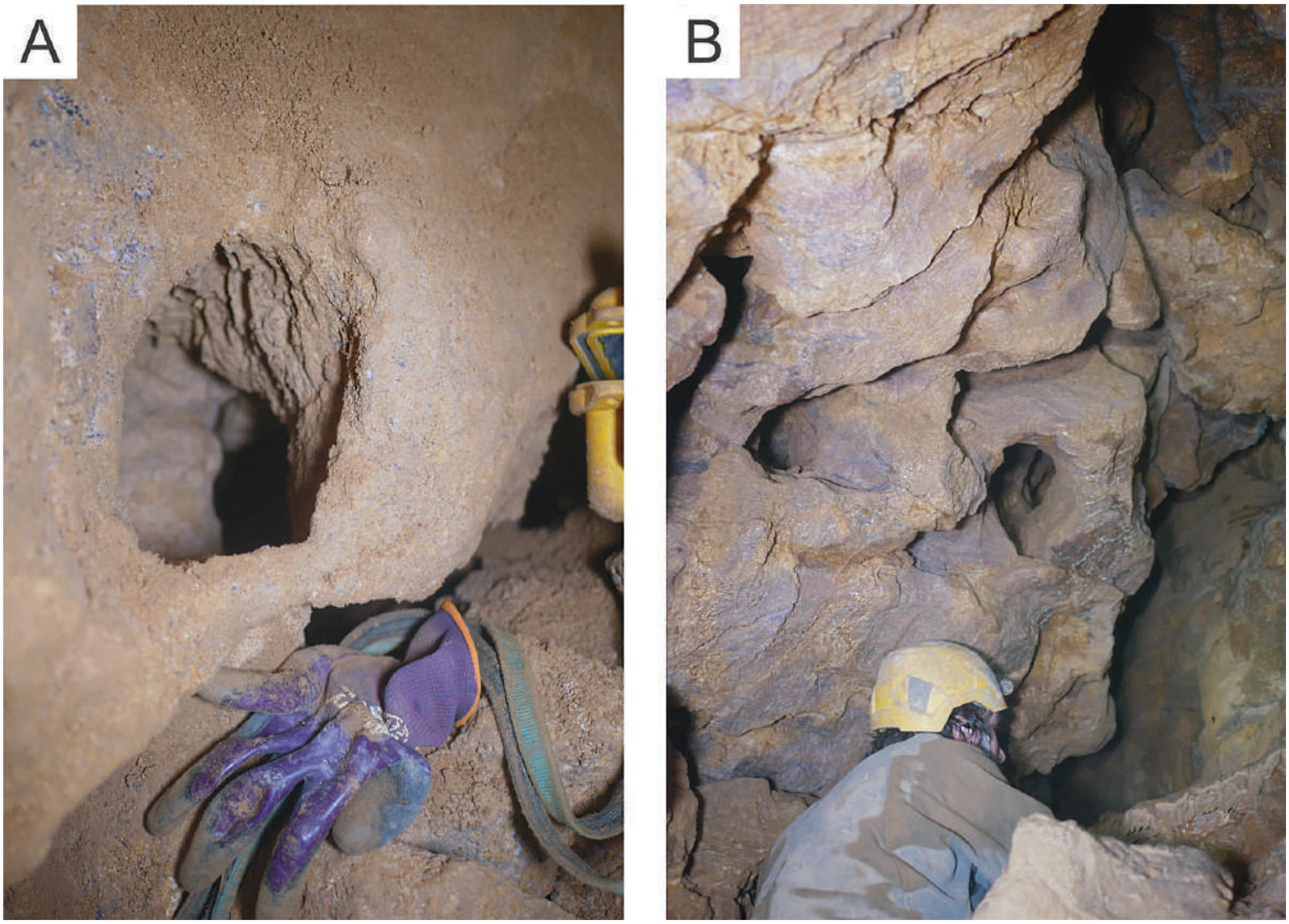

Fig. 14. **Cave morphologies (Photo: A. Lačný): (A) Rock holes located in an area of mixing corrosion (Pieskovisko Hall). (B) Rock holes and other solution hollows in an area of mixed corrosion (Poschodie Hall).**

by ripples on the surface of speleothems (e.g., in Pieskovisko Hall, Fig. 10B), which arise as a result of periodic changes in the amount of infiltrating atmospheric water (Fairchild & Baker, 2012). In the close neighbourhood (Žibrica Hill), also situated on the edge of the mountain range, other caves with the same coralloid speleothems are known. Based on several similarities, we assume that their speleogenesis is very probably similar to Jaskyňa Dezidera Horváta Cave.

There are several hypotheses regarding the origin of the helictite and coralloid types of speleothems. According to the widely accepted ones, the shapes of the helictites are influenced by airflow or capillary forces in combination with evaporation (Fairchild & Baker, 2012). More recent hypotheses propose microbial mediation. Some authors propose that microbially-influenced mineralization proceeds within a gliding biofilm, which serves as a nucleation site for $CaCO_3$, and where chemotaxis influences the trajectory of mineral growth, determining the macroscopic morphology of the speleothems (e.g., Tisato et al., 2015).

For the coralloid type of speleothems, their formation in the splash zones is widely accepted (e.g., Fairchild & Baker, 2012). However, this hypothesis is not valid in the case of their occurrence in narrower crevasses and hollows. According to Banks et al. (2010), their formation is driven by bacteria's need to remove Ca^{2+} ions from their cell, which reacts with CO_2 and results in calcification.

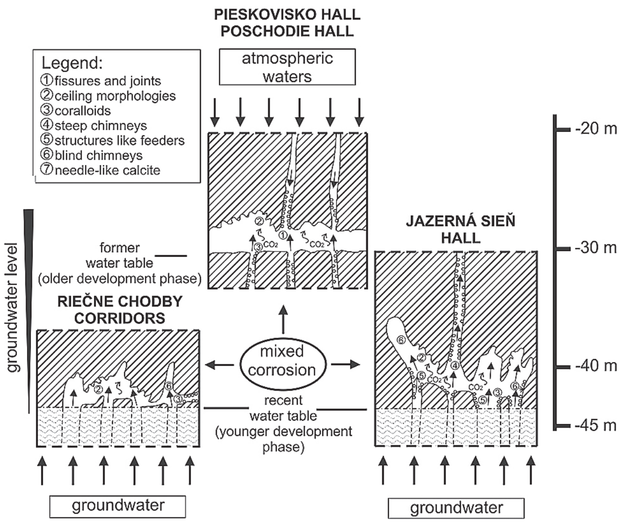

Fig. 15. **A possible model (cross section) of the formation of the Jaskyňa Dezidera Horváta Cave.**

Raman spectroscopy performed on the needle-like crystals did not confirm the presence of aragonite, and all measured spectra corresponded to calcite. Based on morphological observations, it is clear that the studied crystals have a scalenohedral habit and evident trigonal symmetry. Therefore, it is possible to exclude the recrystallization or pseudomorphosis of calcite on aragonite.

The occurrence of these crystals is crucial for the speleogenetic explanation as they occur exclusively in the vicinity of the feeder-like structure within the Jazerná sieň Hall, in the area of a few square meters. Therefore we can assume that they crystallized from groundwater flowing from the feeder into the hall, as a consequence of CO_2 loss, since CO_2 partial pressure in the inflowing groundwater equilibrated with the conditions in the hall. The presence of iron and manganese oxide coatings refers to oxidation-reduction potential changes toward higher Eh values in the hall.

To confirm the presented results and assumptions more accurately, it is necessary to conduct detailed sedimentological and mineralogical research on the cave. The dating of cave sediments is also needed, as it would give a complete picture of speleogenesis on the tectonically disrupted part of the Tribeč Mts.

7. CONCLUSION

The Jaskyňa Dezidera Horváta Cave originated in the crinoidal sandy limestones of the Middle Jurassic age, belonging to the cover sequences of the Tatric Unit. The formation of the cave was mainly due to brittle structures, represented by two main systems of sub-vertically oriented joints, partially in combination with bedding surfaces. The most pronounced are the joints with an NE–SW orientation, which were involved in the evolution of significant cave spaces (Riečne chodby corridors, Jazerná sieň Hall, Trhlina Hall, and Veľká sieň Hall). These joints arose in an extensional tectonic regime with the orientation of the extensional component in an NW–SE trend. The second important joint system has a NNE–SSW orientation. These joints dominate the central part of the cave (Faunov labyrint Hall, Poschodie, Pieskovisko and Pivnica halls). For the speleogenesis, the joints with the E–W orientation and cleavage planes were the least important.

The morphology of the cave spaces and the higher temperature of the water and air in the cave indicate that it could be of hypogenic origin, or more specifically, of hypogenic-hybrid origin, in which mixing corrosion caused by groundwater and atmospheric waters was also involved. However, without mineralogical and isotopic evidence, it should not be classified as a “true” hypogene cave (Bella & Bosák, 2012).

In principle, the labyrinth of passages can continue in several places and any direction. The cave can easily reach several kilometres in length also by possible connection with the nearby Jaskyňa v Drevenom lome Cave, or with the backfilled caves that were previously described from the quarry area or the nearby Jaskyňa v Stračej ceste Cave. The basement here is karstic, as documented by the engineering-geological survey, which was carried out in several parts of the Nitra urban area during the building activities, even just a few hundred meters from the cave. Such a basement complicates construction work. Therefore, the potential of the cave is quite large. Discovery of further cave spaces could help with clarification of the genesis of the cave.

Acknowledgement: The geological and geomorphological research was carried out within the framework of the scientific grant projects: APVV-21-281, VEGA 1/0115/18, VEGA 1/0346/20 and the Plan of main tasks of the State Nature Conservation of the Slovak Republic for 2023. We thank the editor Ján Schlögl, as well as the reviewers Rastislav Vojtko and an anonymous reviewer for their valuable advice and comments.

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