COBISS: 1.01

SPELEOGENESIS ALONG DEEP REGIONAL FAULTS BY ASCENDING WATERS: CASE STUDIES FROM SLOVAKIA AND CZECH REPUBLIC

SPELEOGENEZA OB GLOBOKIH REGIONALNIH PRELOMIH, KOT POSLEDICA DELOVANJA DVIGAJOČIH SE VODNIH TOKOV: PRIMERI IZ REPUBLIKE SLOVAŠKE IN REPUBLIKE ČEŠKE

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Abstract UDC 551.435.84(437.3+437.6)

Pavel Bella & Pavel Bosák: Speleogenesis along deep regional faults by ascending waters: case studies from Slovakia and Czech Republic

The most conspicuous six examples illustrating ascending *(per ascensum)* speleogenesis linked with deep faults/fault systems were selected from Slovakia and Czech Republic. In the past, the caves have been described as product of phreatic, epiphreatic and vadose speleogenesis related to the evolution of local water courses and valley incision, and linked mostly with Pleistocene geomorphic evolution. Our analysis illustrates several common characteristics of caves: (1) they developed along or in close vicinity of deep faults/fault zones, commonly of regional importance; (2) the groundwater ascended due to deep faults/fault systems mostly as results of deep regional circulation of meteoric waters from adjacent karst or nonkarst areas; (3) the 3D mazes and labyrinths dominate in cave morphology; (4) speleogens (e.g., cupolas, slots, ceiling channels, spongework, rugged phreatic morphology especially along slots) indicate ascending speleogenesis in deep phreatic to phreatic environments; (5) they exhibit poor relation to the present landscape; in some of them fluvial sediments are completely missing in spite of surface rivers/streams in the direct vicinity; (6) strong epiphreatic re-modelling is common in general (e.g., subhorizontal passages arranged in cave levels, water-table flat ceilings and notches) and related to the evolution of the recent landscape; (7) recharge structures and correlate surface precipitates are poorly preserved or completely missing (denuded) on the present surface in spite of fact that recent recharges broadly precipitate travertines; (8) caves can be, and some of them are, substantially older than the recent landscape (Pliocene, Miocene), and (9) caves were formed in conditions of slow water

Izvleček UDK 551.435.84(437.3+437.6)

Pavel Bella & Pavel Bosák: Speleogeneza ob globokih regionalnih prelomih, kot posledica delovanja dvigajočih se vodnih tokov: primeri iz Republike Slovaške in Republike Češke

Na Češkem in Slovaškem smo izbrali šest očitnih primerov jam, katerih nastanek je povezan z delovanjem dvigajočih se vodnih tokov ob globokih prelomih. Do sedaj so obravnavane jame povezovali s speleogenezo v freatični, epifreatični in vadozni coni krasa, kot posledica delovanja lokalnih vodnih tokov. Položaj jam pa so povezovali z vrezovanjem dolin in morfogenezo površja v pleistocenu. Naša analiza prikazuje več tipičnih značilnosti opisanih jam: (1) jame so razvite ob oz. v bližini globokih prelomnih con regionalnega pomena; (2) povezane so z dvigajočimi se vodnimi tokovi, ki so del globoke cirkulacije vode iz sosednjih kraških in nekraških območij; (3) tipična morfologiji jam so 3D blodnjaki; (4) različni speleogeni (kupole, zajede, stropni kanali, nepravilna (gobasta/spongework) razporeditev votlin, nepravilne freatične strukture) kažejo na speleogenezo dvigajočih se voda v freatični coni; (5) jame ne kažejo povezave z lokalnim površjem, v nekaterih ni nikakršnih fluvialnih sedimentov, čeprav so površinske reke v bližini; (6) prvotne jame so bile močno preoblikovane v epifreatičnih pogojih, povezanimi z razvojem sedanje pokrajine, na kar kažejo subhorizontalni rovi v več nivojih ter značilni ravni stropi in stenske niše izoblikovani v nivoju nekdanje gladine podtalnice; (7) značilne dotočne strukture in kemični sedimenti na površju so slabo ohranjeni ali pa jih ni (so denudirani), čeprav recentne vode izločajo travertin; (8) nekatere jame so precej starejše od starosti pokrajine (pliocen, miocen) in (9) jame so nastale z delovanjem počasi vzpenjajočih se voda, torej drugače kot v vokluškem speleogenetskem modelu, kjer jih oblikuje relativno hiter tok. Nobena od jam ne kaže, da bi lahko

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Received/Prejeto: 3. 5. 2012

ascent, which differentiate the process from faster vauclusian ascending speleogenetical models. Any of described caves contains clear diagnostic features of real hypogene caves. There are missing evidences that at least heated groundwaters took part during speleogenesis of studied caves, nevertheless, somewhat increased water temperature can be expected during speleogenesis at least in some of caves. Any of described caves cannot be directly characterized as product of thermal waters or hydrothermal process (i.e. as real hyperkarst sensu Cigna 1978), therefore they do not represent hypogenic caves.
Keywords: ascending speleogenesis, hypogene speleogenesis, Belianska Cave, Jasovská Cave, Plavecká Cave and Shaft, Liskovská Cave, Zápoľná Cave, Na Pomezí Cave System.

bil njihov nastanek povezan z delovanjem hidrotermalnih voda (pravi hiperkras v smislu Cigne (1978)). Jame torej niso hipogene.
Ključne besede: vzpenjajoča speleogeneza, hipogena speleogeneza, Belianska jama, Jasovská jama, Plavecká jama in brezno, Liskovská jama, Zápoľná jama, Jamski sistem Na Pomezí.

INTRODUCTION

We present here results of observations obtained from detailed geomorphological studies of caves during extensive sampling of karst sediments for paleomagnetic research and dating in number of central European caves since 1997. We selected the most conspicuous examples illustrating *per ascensum* (ascending) speleogenesis linked with deep faults/fault systems in Slovakia and Czech Republic. Most of caves presented here were described earlier as product of phreatic, epiphreatic and vadose speleogenesis related to (1) the evolution of local water courses and valley incision; (2) some of them were linked with development of river terrace systems, and (3) the cave evolution was mostly connected with climatic changes during upper (even late) Pleistocene eventually with Plio-Quaternary climatic oscillations (base of Quaternary at 1.8 Ma).

Speleogenesis by ascending waters has been described earlier only on few sites both in Slovakia and in the Czech Republic. Bella *et al.* (2009) summarized possible occurrences of products of hypogene or ascending speleogenesis in Slovakia. Except sites presented in case studies here, they mentioned caves between Jasov village and Moldava nad Bodvou town where Seneš (1945–1946) expected speleogenesis by warm groundwater and re-modellation by cold karst waters. Number of boreholes in the Slovenský kras (Slovak Karst) and close vicinity uncovered cavities with warm waters (e.g. Orvan 1973, 1999). The ascending hydrothermal origin of cave near Sklené Teplice Spa (Štiavnické vrchy Mts., central Slovakia) in metamorphosed Middle Triassic carbonates was related to high-temperature processes during the Late Badenian emplacement of granodiorite subvolcanic bodies or the Late Sarmatian activity of the epithermal system in the Štiavnica Stratovolcano. The typical spherical morphology, host-rocks alterations, large calcite and quartz crystals, and clays point to its hypogene origin (Bella *et al.* 2011). Hydrothermal calcite crystals were found in some old caves cut by younger passages in the Nízke Tatry Mts. (Nová stanišovská Cave and some nearby caves: Kalcitová and Silvošova diera; Orvošová & Hurai 2008 and references herein). Calcite crystals indicate possible hydrothermal origin of the Drienka Cave in the Silická planina Plateau, Slovak Karst (Gaál 2008) and the Kryštálová Cave in the Malá Fatra Mts. (Janáčik 1959). Flooded bell-shaped shaft, 38 m deep, at Tornaľa town (the eastern part of Rimavská kotlina Basin) is known as Morské oko (Sea eye). It represents the resurgence of slightly warm (16.2^{o}C) and highly mineralized water of deep artesian waters along NE–SW- and NW–SE-trending faults (for more details see Gaál *et al.* 2007; Gaál 2008). Recently we studied the Skalistý potok Cave with some clear signs of ascending speleogenesis (at least in its subvertical segment) and nearby Drienovská Cave (with possible thermal or sulphuric acid speleogenesis of its upper part); both caves are situated in the southern slope of the Jasovská planina Plateau, Slovak Karst.

In the Czech Republic, there is the classical case of the Zbrašovské Aragonite Caves (Moravia) where Kunský (1957) defined the thermomineral (hydrothermal) karst for the first time in the world karstology literature. Warmer water enriched in juvenile carbon dioxide and helium of upper mantle origin (Meyberg & Rinne 1995) ascends here along deep fault zone from depths over 700 m (Geršl 2009). The hydrothermal speleogenesis cannot be excluded for the Javorka Cave (Žák 2006; Český Karst area between Praha and Beroun cities), lower segments of the Králova Cave and Květnická Chasm (surroundings of Tišnov city, central Moravia; Bosák 1983), and Na Turoldu Cave (Bosák *et al.* 1984). All those caves are related to deep faults. Ascending speleogenesis was proposed for caves in the Koněprusy Devonian (e.g. Koněpruské Caves; Český Karst) by Bosák (1996) and for Na Pomezí

Fig. 1: General location map.

Caves by Altová & Bosák (2011). Similar speleogenesis cannot be excluded also for the Mladečské Caves (central Moravia) and Arnoldka Cave (Český Karst) judging from their general shape and dominant speleogens. Some of those caves have increase radon (^{222}Rn) content (Thinova *et al.* 2010) linked with deep faults. Springs and subsurface occurrence of mineral waters are reported by Pospíšil & Řezníček (1973) along deep faults of the Labe /Elbe/ Zone in the central Moravia. There are both warmer waters (14–16°C) enriched in hydrogen sulphide at Slatinice Spa (between Olomouc city and Javoříčské Caves) or cold mineral waters enriched in carbon dioxide at Horní Moštěnice village (SE from Olomouc city). For position of sites see Fig. 1.

WHY ASCENDING AND NOT HYPOGENIC SPELEOGENESIS

The use of prefix *hypogene or hypogenic/hypogenetic* (in the connection with speleogenesis and caves) is recently unclear, especially after summarizing review of Klimchouk (2007 and 2011) and other his contributions on that topics. Klimchouk (2007, 2011) proposed that all products of speleogenesis by ascending waters, especially in artesian or confined hydrogeological settings, have to be classified as hypogene, "regardless of the nature of the water" (as noted fittingly by Palmer & Palmer 2009). To support this approach Klimchouk (2007, 2011, p. 6) wrote: "Hypogenic speleogenesis is defined here, following the recent suggestion of Ford (2006): *as the formation of caves by water that recharges the soluble formation from below, driven by hydrostatic pressure or other sources of energy, independent of recharge from the overlying or immediately adjacent surface*". Unfortunately, the expression in italics cannot be found in the text of Ford (2006) *at al.* Ford (2006, p. 4) distinguished basic three genetic settings for cave origin, where the second one is setting *„hypogene, where water enters the soluble formation from underlying strata which may or may not be soluble"*, nothinng less, nothing more.

According to our approach, concept of A. Klimchouk unfortunately (1) does not reflect traditional and prevailing concept of the hypogenic speleogenesis/caves/process as defined number of times also quite recently in the World karstologic literature: hypogene cave is that formed by water that has derived its solutional capacity (aggressiveness) from sources unrelated to the surface (in depths), waters are of deep-seated origin and/or belong to deep water circulation systems, cave patterns have no relations to (recent) surface karst or recharge, vadose features are generally absent, certain speleothems and minerals are diagnostic, ascending waters are enriched in sulphuric acid, carbon dioxide, hydrocarbons, etc., increased water temperature is common but not necessary (e.g. Ford & Williams 1989, 2007; Palmer 1991, 1995, 2000, 2007; Dublyansky 2000; Palmer & Palmer 2009), but (2) follows one of approaches of a part of Russian karstology schools: hypokarst is formed by dissolution in soluble rocks by waters that are ascending to them from deeper formations (see Ford & Williams 2007, p. 3).

The concept of A. Klimchouk brings subtantial uncertainty to karstology literature and principal understanding of processes; it omits speleogenesis by ascending (resp. deeply circulating) "normal", i.e. *meteoric*, waters in phreatic to bathyphreatic settings ("Four State Model" of Ford 1971 and Ford & Ewers 1978) and disputable includes its products to the category of hypogene products. Also Forti (1996, p. 101) expects deeply circulating meteoric waters as the expression of the "normal" karst. Recently, Palmer (2011) tried to heal this inconsistence expecting the hypogenic cave is formed by "upward flow of *deep-seated* water or by solutional aggressiveness generated at depths below the surface". Nevertheless this compromise does not solve what "deep-seated" water means.

Numbers of caves formed by *ascending meteoric waters* have been described in literature and textbooks, e.g. outlet caves created by basal injection of meteoric waters into sandwich structure of aquitards and aqicludes as specified by Ford & Williams (2007, p. 237). One of the most conspicuous examples is represented by relatively deep-seated caves developed in the western Missouri (Brod 1964), the other one are shallow-seated gypsum maze caves in Ukraine (e.g. Klimchouk 1996, 2000). Speleogenesis of Ukrainean gypsum mazes, in spite that occurs in confined aquifer with ascending water flow paths, depends on evolution of modern landscape (recharge from immediately adjacent surface in regional groundwater circulation), water is clearly meteoric and not deep-seated, no aggressiveness is added from the depth (see details in e.g. Klimchouk 1996); also dissolution principles in sulphate rocks are other than in carbonate rocks (two components phase equilibria in gypsum – rock and water – in comparison with three and more ones in carbonate rock – *cf.* Cigna 1978, i.e. additional aggressiveness is not necessary).

Speleogenesis by meteoric waters, which aggressiveness was not enhanced by some of deep-seated processes cannot be assumed as hypogenic according to original and broadly accepted concept (see definitions also in Palmer 1995, 2007; Palmer & Palmer 2009), even when water is slightly heated above mean annual temperature (geothermic gradient) but without other diagnostic criteria in respective caves (role of carbon dioxide, sulphuric acid, etc.). We describe some such cases in this text.

We apply here the term *per ascensum* (ascending) speleogenesis (1) as it represents non-genetic term (from down up) regardless of attempts to understand this term in some modified meanings and (2) to avoid the necessity of repeated explanation, which model of hypogenic speleogenesis is under the consideration.

CASE STUDIES

BELIANSKA CAVE

The cave is situated in the eastern part of the Belianske Tatry Mts. (Fig. 2A) at the right bank of the Biela River, on the northern slope of the Kobylí vrch Hill (1,109 m a.s.l.). It is developed in the Middle Triassic limestones, in facies of shallow-marine Annaberg Limestone, overlain by the Ramsau Dolomite (Nemčok *et al.* 1994; Pavlarčík 2002; Michalík 2009). Steep NE-inclined fault, which is situated in the area of the cave (Maglay *et al.* 1999), morphologically separates the easternmost middle-mountain part of the Belianske Tatry Mts. from their principal high-mountainous monoclinal ridge in the W. The easternmost segment of the Belianske Tatry Mts. and adjacent Spišská Magura Mts., belong to morphostructural subregion characteristic by less intensive tectonic uplift in the comparison with the Tatry Mts. region (Minár *et al.* 2011).

The cave is 3,829 m long and 168 m deep (ca. 1,025 to 865 m a.s.l.; Fudaly 2008). It consists from two principal northwards-inclined branches connecting subhorizontal passages in upper and lower cave segments (Fig. 2B). Several shafts and chimneys are developed here, too. Lower subhorizontal passages (at 915 and 890 m a.s.l., i.e. 130 to 155 m above recent river bed) is accessible by discovery chimney (entrance at 972 m a.s.l.) and by the artifical tunnel (890 m a.s.l.). The upper cave passages are developed ca 240 to 255 m above the recent river bed (i.e. 1,000 to 980 m a.s.l.)

The speleogenesis was originally connected with subterranean water course (Roth 1882). The cave represents result of Lower Pleistocene erosion activity of the Biela River according to Vitásek (1931). Droppa (1959) supposed that the cave was formed by water infiltrating from the surface when the Kobylí vrch Hill plateau was entrenched by the Biela River Valley. Wójcik (1968) expected Upper Pliocene origin of principal parts of the cave according to the relative position of the cave above

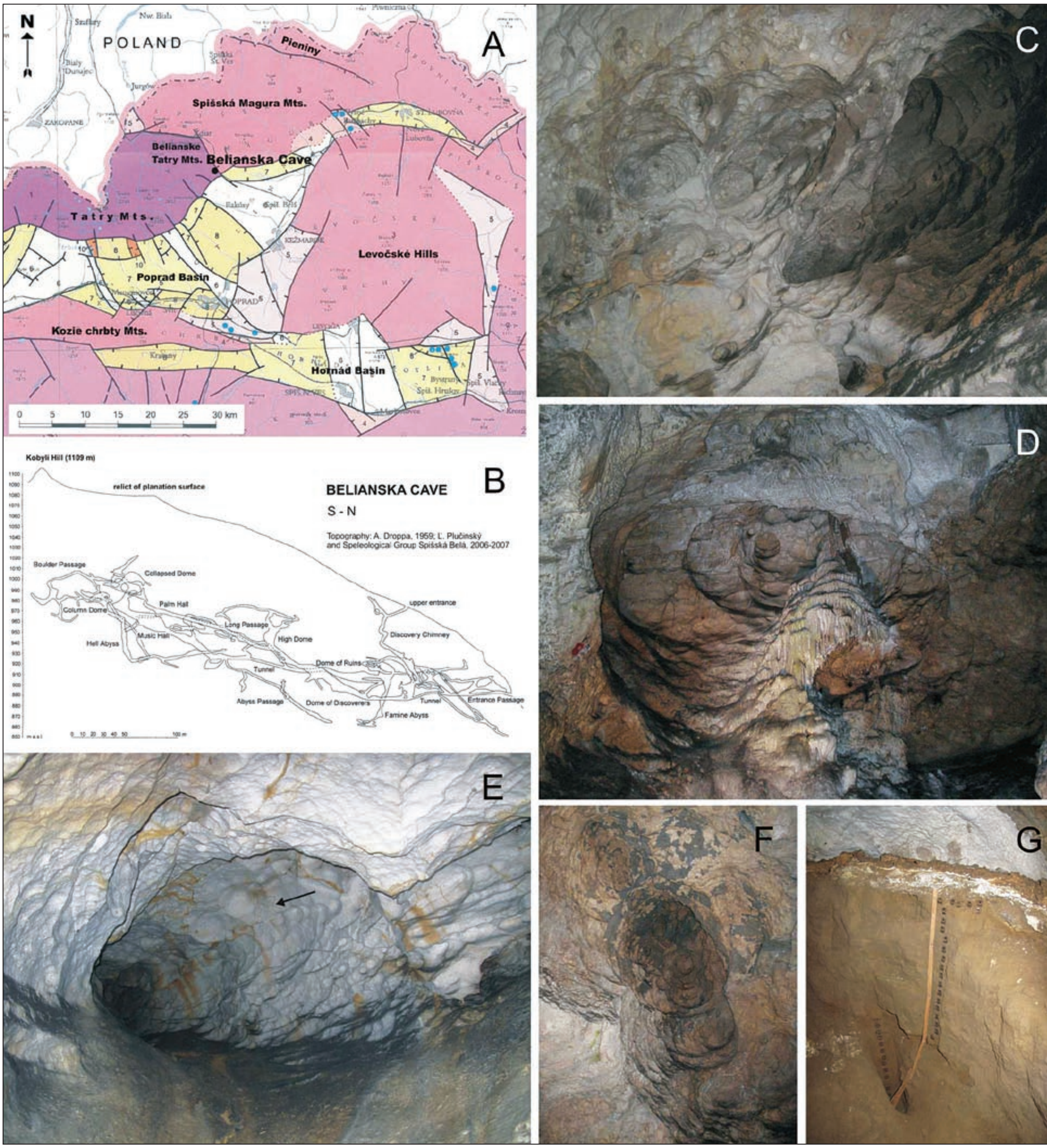

Fig. 2: Belianska Cave. Location map (A; modified from Maglay et al. 1999 with permission), longitudinal projection (B) and photos: C = cupolas, pockets and smaller irregular hollows on the ceiling in the lower part of the cave; D = large cupola in the Dome of Discoverers; E = chimney with scallops as morphological indicators of ascending water flow; F = one of many ceiling pockets; G = sedimentary profile in the Deposit Passage sampled for paleomagnetic research (Photo: P. Bella).

the river bed. Pavlarčík (2002) connected corrosion-erosion origin by authochthonous waters with melting of snow and firn on adjacent parts of the Belianske Tatry Mts. during Pleistocene. The presence of extensive cupolas led Bella & Pavlarčík (2002) to idea on speleogenesis by the mixing of deep circulation waters and infiltration meteoric waters.

Cave morphology is characteristic by corrosion domes and inclined extensive passages passing into them. Deep corrosion cupolas are developed in ceilings

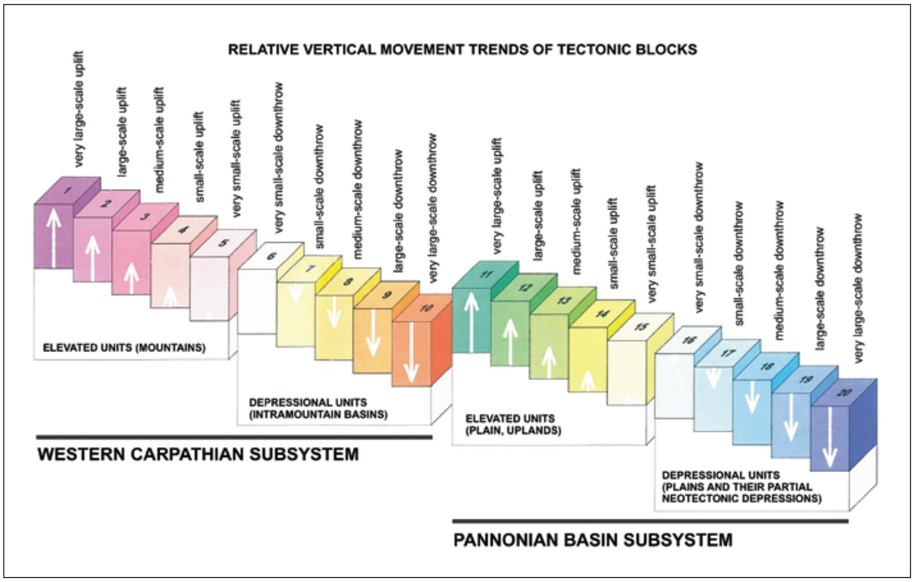

Fig. 3: Explanations to location maps in Figures 2 to 7 based on Neotectonic map of Slovakia (modified from Maglay et al. 1999 with permission).

Fig. 2D). In places of turbulent water flow below oscillating water level, some cupolas were remodeled and partially renewed by smaller cupolas and pockets (Osborne 2009; Fig. 2C). Assymetric scallops, indicating ascending water flow, are developed at places (Fig. 2E). Corrosion oblique smooth facets (so-called *planes of repose* of Lange 1963 or *Facetten* of Kempe *et al.* 1975) in the lower part of halls or passages indicate corrosion in phreatic slowly flowing to stagnant conditions (Bella & Osborne 2008). Lateral water-table notches were developed in number of places between subhorizontal passages during phases of stagnant water table (Bella & Pavlarčík 2002). Morphostratigraphically, older phreatic corrosion domes and inclined passages are cut by horizontal water-table notches at several altitudes.

Any diagnostic minerals for thermal caves were detected until now, in spite of gypsum occurrence in nearby caves (Pavlarčík 1994), presence of foetid and sulfur-rich Annaberg Limestone in the lower segment of the cave, or carbon dioxide-rich waters ascending along Choč-Tatry-Ružbachy fault zone (tectonic line limiting the Západné Tatry, Tatry, Belianske Tatry and Spišská Magura Mts. from the south; Figs. 2A, 6A, 7A), in number of springs (e.g. Vyšné Ružbachy; Jetel 1999).

Fine-grained clastic deposits are preserved in number of places within the cave (Fig. 2G). Clays to silts represent the insoluble residua after selective dissolution of the host rocks and contain up to 90% of dolomite (Zimák *et al.* 2003; Głazek *et al.* 2004). They were deposited in stagnant or slowly moving water. In upper parts of some of sedimentary profiles, fine-grained residua are mixed with clastic allogenic sandy admixture and local autogenic conglomerate bodies. Subaerial flowstone crusts covering most of profiles are older than 1.25 Ma (U-series dating; Bella *et al.* 2007a). Flowstone in the lower part of the Dlhá chodba Passage (935 m a.s.l.) contains *Nyssa* sp. pollen grains typical for Miocene/Lower Pliocene (Bella *et al.* 2011); i.e. fine-grained residua are older than Lower Pliocene in age, which is indicated also by paleomagnetic data (Pruner *et al.* 2000).

The region of the Tatry Mts. was originally covered by thick sequences of Central Carpathian Paleogene (flysch and or flyschoid sediments) deposited during Eocene to Early Miocene (Soták & Starek 1999). The tectonic uplift (exhumation) of the Tatry Mts. started before some 20 to 10 Ma and was followed by their tectonic disintegration and the origin of adjacent tectonic basins (Král' 1977; Kováč *et al.* 1994; Lefeld 2009). The Choč-Tatry-Ružbachy Fault, which tectonically pre-disposed the cave evolution, was activated at the beginning of the Tatry Mts. uplift.

The beginning and principal phase of phreatic cave development can be linked with the ascent of deep waters along the fault, which dissected Sarmatian–Early Pannonian planation surface (Głazek *et al.* 2004; Bella *et al.* 2005, 2007a, 2011). Groundwaters infiltrating in areas of bare Mesozoic carbonate rocks partly penetrated below Central Carpathian Paleogene strata and ascended along fault separating more uplifted Tatry Mts. from less uplifted eastern marginal part of the Belianske Tatry Mts. and the Spišská Magura Mts. In the area of recent cave, groundwater penetrated along steeply inclined bedding planes dissected by the fault(s). The water ascent and intensive corrosion of the host rock can be dated to Miocene (?Upper Miocene) by Lower Pliocene subaerial flowstones (Bella *et al.* 2007a, 2011).

Subhorizontal epiphreatic passages developed during stagnant phases of groundwater level connected with stages of the Biela River Valley entrenchment (Bella *et al.* 2011). The upper subhorizontal passages can be linked with the former slightly oscillating piezometric level developed during the lateral planation (slope undercutting) of (?)Pontian submountain pediment (Bella *et al.* 2011). Epiphreatic re-modellation of original phreatic morphology in the middle and lower parts of the cave and origin of drainage passages were connected with continuing incision of the Biela River Valley in distinct phases (Bella & Pavlarčík 2002). The development of lower subhorizontal passages hydrographically corresponds to the origin of the river level dated to Upper Pliocene and Lower Pleistocene (Gelasian) by palynology of subaerial flowstone crusts in the cave. The cave evolution phases are reflected in the epigenetic part of the Biela River Valley by less steeply inclined slopes and pediments on its both sides at ca 900 m a.s.l. (Košťálik 1999; Bella & Pavlarčík 2002).

JASOVSKÁ CAVE

The cave is situated in eastern part of the Jasovská planina Plateau (the NE part of the Slovak Karst) the western periphery of the Jasov village (Fig. 4B). The area belongs to the western part of the Medzevská pahorkatina Hill Land (within the Košická kotlina Basin). The lower cave entrance is situated in the right bank of the Bodva River at 257 m a.s.l. only 2 m above the river bed. The upper one is at ca 282 m a.s.l. (Droppa 1965, 1971b). The cave is 2,811 m long and 55 m deep (Fig. 4A).

The cave is developed in Middle Triassic limestones and dolomites. The Bodva Valley north of Moldava nad Bodvou town follows the N–S-trending continuation of the Budulov Fault. The valley northeast of the Jasov village is pre-disposed by the NW–SE-trending fault (Elečko & Vass 1997; Zacharov 2000). Passages of the cave follow more W–E-trending fissure and fault lines (e.g. Zacharov 1998). Karst surface on limestone blocks sunkened in respect to the rest of the eastern segment of the Jasovská planina Plateau are exhumed along the Bodva River (a.o. Jakál 1975; Liška 1994; Gaál 2008).

The lower part of the cave is flooded by oscillating groundwater level; floods are not related to changes of the Bodva River level (Orvan 1977). The lowest lake level is situated some 7 m below the river and the lowermost parts of the cave are still water flooded. The river bed was originally in lower position but aggraded recently according to borehole data (Cangár & Karoľ 1987).

Volko-Starohorský (1929), Sekyra (in Ložek *et al.* 1956) and Droppa (1965, 1971b) delimited 3 to 5 evolution levels (Fig. 4A) developed gradually in distinct phases from upper ones to the lowermost one following the incision of the Bodva Valley as a consequence of Quaternary tectonic uplift of the Medzevská pahorkatina Hill Land (Kaličiak *et al.* 1996). But Jakál (1975) and Liška (1994) supposed Pliocene age of the lowermost cave level (the oldest one), i. e. only the middle and upper cave parts were propagated and re-modelled during Quaternary (probably a retrograde cave evolution induced by fluvial aggradation and following multi-phased exhumation of fluvial sediments from the Bodva River bed).

Irregular inclined and step-like spaces (Fig. 4E), different cupola- and sponge-like cavities in lower part of the cave originated by dissolution in slowly circulating water in phreatic conditions. The cave morphology in lower part of the cave is typical by domes and passages with cupolas. Lateral water-table notches and flat ceilings are preserved in different altitudes here and reflect phases of groundwater table stabilization (Bella 2000), when original phreatic morphology was re-modelled in epiphreatic zone. Cupolas and cupola- and chimney-shaped hollows (see Bella & Urata 2002; Fig. 4D) are developed in the lower and middle cave segments. Middle and upper cave segments differ from the lower one. In smaller or larger domes, there are ceiling channels originated by intensively flowing water (Fig. 4C, F). Numerous huge pendants are expressive; some of them are perforated by ascending waters (Fig. 4C).

Passages of the lower segment are filled by fine-grained sediments, sometimes completely up to flat ceilings. They deposited from very slow water flows and/or floods. Sediments are younger than 780 ka (Bella *et al.* 2007b). Coarse-grained fluvial sediments are absent in the cave.

The cave developed along fault margins of limestone block. The evolution of original phreatic cave morphology can be explained by ascending water flow. This model was outlined already by Hevesi (2009), but without any detailed evidence and arguments. Upper Pliocene and Quaternary evolution phases re-modelled the original phreatic morphology in epiphreatic conditions with the origin of cave levels in relation to evolution of the Bodva Valley and stabilization of the groundwater table.

CAVES AT PLAVECKÉ PODHRADIE

Plavecká Cave and Plavecká Shaft are situated on the western slope of the Malé Karpaty Mts. under the Plavecký hrad Castle (Fig. 5A). The Plavecká Cave is 837 m long and 33 m deep. The narrow upper entrance is at 236 m a.s.l., but the cave is accessible by the artificial tunnel at 221 m a.s.l. (Tencer 1991; Hubek & Magdolen 2008; Fig. 5C). The Plavecká Shaft with entrance at 270 m a.s.l. is 70 m deep. Its principal dome-shaped cavern parallel to hill slope is about 130 m long (Butaš 2003; Fig. 5B). Any cave sediments have been discovered in both caves.

Caves are developed in Triassic limestones along marginal fault zone of the Malé Karpaty Mts. The fault separates the mountain horst from the Záhorská nížina

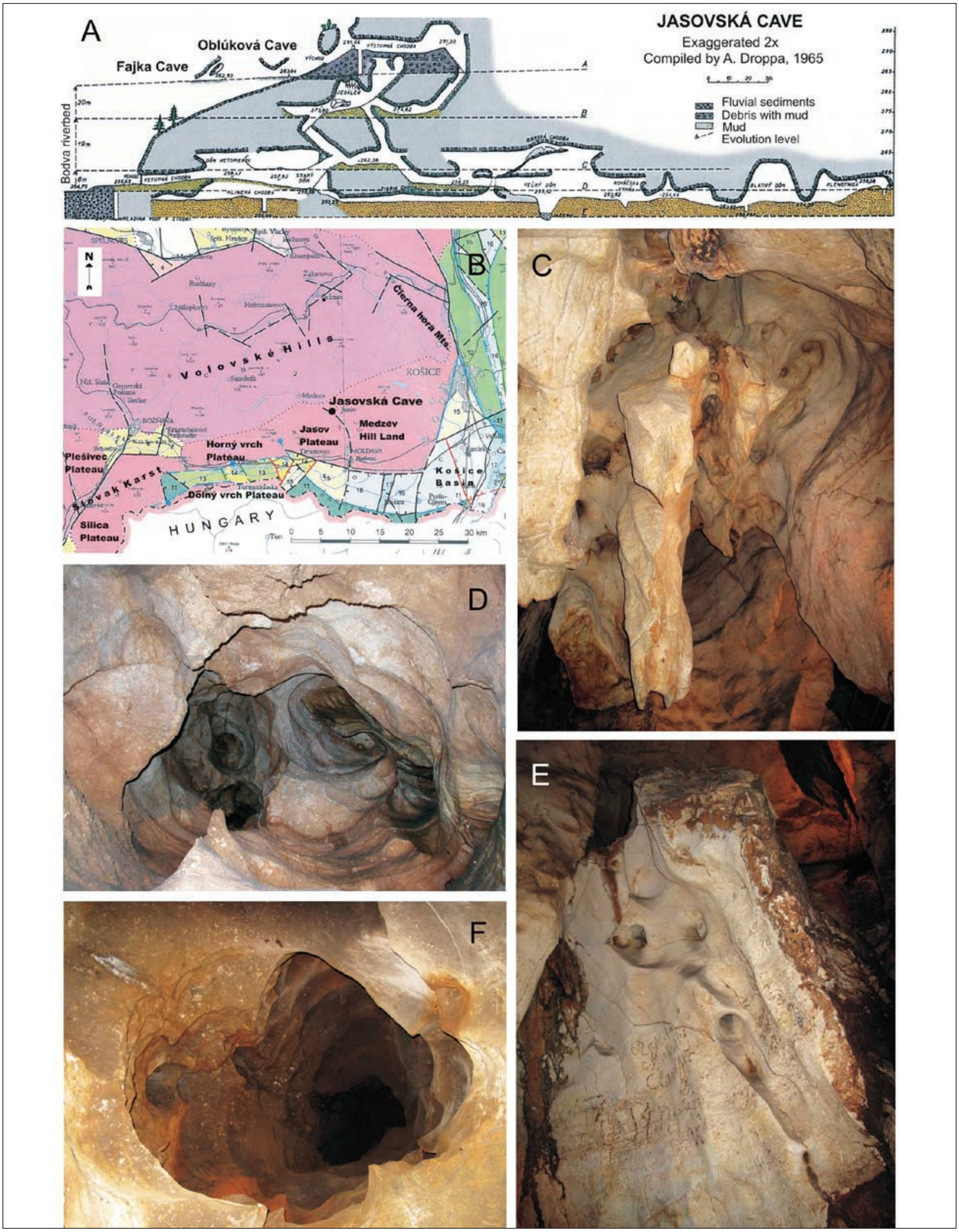

Fig. 4: Jasovská Cave. Longitudinal section (A), location map (B; modified from Maglay et al. 1999 with permission) and photos: C = ceiling half-tube dissected by pockets, rising wall half-tubes and big pendant in the upper part of the cave; D = cupola with ceiling pocket; E = shaft as a feeder in the lower part of the cave; F = one of rising wall half-tubes (Photo: P. Bella).

Lowland, the northeastern part of the Miocene *pull-apart* Vienna Basin (a.o. Royden 1985; Fodor 1995; Marko & Jureňa 1999; Kováč 2000; Marko 2002). Vertical movements over 100 m are situated along the tectonic boundary with the Plavecký Karst (Halouzka *et al.* 1999). The Plavecká Cave is predisposed by NNE–SSW- and NNW–SSE-trending faults (Briestenský & Stemberk 2008).

Droppa (1958, 1973) and Tencer (1991) described the Plavecká Cave as fissure-collapse cavern developed by infiltration meteoric waters along faults and bedding planes.The cave incorporates older paleokarst cavities originated in stagnant waters (Hochmuth 2008). Šmída (2010) described both caves as phreatic developed in resurgence zone with repeating oscillations of groundwater table. The Plavecká Shaft was hydrologically connected with the Plavecká Cave.

Number of springs and water wells yield water with higher temperature (a.o. Hanzel *et al.* 2001) than average annual one (9 to 10°C in lowland margins of the Malé Karpaty Mts. at Plavecké Podhradie; Šťastný *et al.* 2002). Karst spring below the Plavecký hrad Castle with water temperature of 11.6–13.6°C influences the air temperature in the Plavecká Cave (11°C; Briestenský & Stemberk 2008). Underground lake in the Plavecká Shaft has temperature of 13.0–13.1°C, which increases air temperature in cave to 12.7–12.8°C (Košel 2005). Extensive travertine accumulation up to 550 m wide has been deposited from slightly warmer and highly mineralized waters at the fault-limited foothill of the Plavecký Castle Hill (Hanzel *et al.* 2001).

The principal part of the Plavecká Cave is represented by epiphreatic passages and domes developed along the groundwater table in two evolution levels. Its development was influenced by steep faults. Ascending waters of deep karst circulation caused phreatic corrosion of vertical chimney and cupolas. Horizontal levels were influenced by altitude stabilization of karst resurgence in the front of the cave, which position changed according to phases of vertical movements along boundary of the Malé Karpaty Mts. and Záhorská nížina Lowland.

Phreatic speleogens dominate in the morphology of the Plavecká Cave, e.g. chimneys with asymmetric large scallops illustrating ascending water flow (Fig. 5D), ceiling cupolas and irregular corrosion hollows (Fig. 5E, F). Oval halftubes along steep tectonic lines resemble ceiling slots. Floor slots (feeders) along faults occur at places (Fig. 5H). Lateral water-table notches are developed in walls of the horizontal parts of the cave (Bella 2010).

Structural and hydrogeological pre-requisites together with cave morphology indicate the origin of both caves by slightly warmer groundwaters ascending along the fault zone. Waters infiltrated in karst surface deeply circulate along structural discontinuities, warm and ascend at the margin of the horst mountains.

LISKOVSKÁ CAVE

The cave is situated in the eastern suburb of Ružomberok city in the eastern side of the Mních Hill (695 m a.s.l.) near Lisková village in the western part of the Liptovská kotlina Basin (Fig. 6A). The Mních Hill is the tectonic horst composed of Triassic limestones uplifted along ENE–WSW-trending faults since Paleogene. The horst is limited also by younger N–S-trending lines (Gross 1973, 1980). The cave represents the 3D maze with the length of 4,250 m and 72 m deep (Fig. 6B).

In spite of absence of typical fluvial cave morphology, Lóczy (1877, 1878), Janáčik & Šrol (1965), Janáčik (1968), Droppa (1971a, 1975), and Hochmuth (1997) explained cave origin by corrosion and erosion activity of waters connected with nearby Váh River and its side branches, and partly by corrosion of infiltrating meteoric waters.

Oval and mostly irregular corrosion morphology dominates in the cave. Numerous cupolas (Fig. 6C), smaller spherical and sponge-like hollows (Fig. 6E), are developed in walls of cave passages and domes. Upward scalloped channels and local steeply inclined slots along faults indicate ascending water flow (Bella *et al.* 2009; Fig. 6D). In spite of the fact, that the cave is situated on the right bank of the Váh River, and low accumulation terrace is nearby, any typical fluvial cave morphologies with side passages, vadose meandering downcuts or paragenetic ceiling appear in the cave. River sediments (sand, gravels) are also missing here.

The cave was formed by predominant corrosion in slowly moving water of the phreatic zone (Bella 2005). Waters ascending along deep faults most probably took part in the cave origin, as indicating by dominant speleogens. Infiltration areas for waters of deep karst circulation are located on bare carbonate surfaces of adjacent Chočské vrchy Mts. separated from the Mních Horst by parallel faults. Ascending deep waters were drained from cave into the alluvium of the Váh River. The piezometric level of karst groundwater later drawned following the incision of the river bed and evolution of river terraces. This is reflected in epiphreatic re-modellation of pre-existing 3D maze with origin of horizontal cave levels by slowly flowing to stagnant waters (Bella 2005; Fig. 6F) or by injected flood waters of the Váh River by mechanism proposed by Vysoká *et al.* (2012).

ZÁPOĽNÁ CAVE

The cave is situated in the right bank of the Čierny Váh River in the Važecký chrbát Ridge along the tectonic boundary of Kráľova hoľa area (Nízke Tatry Mts.) and

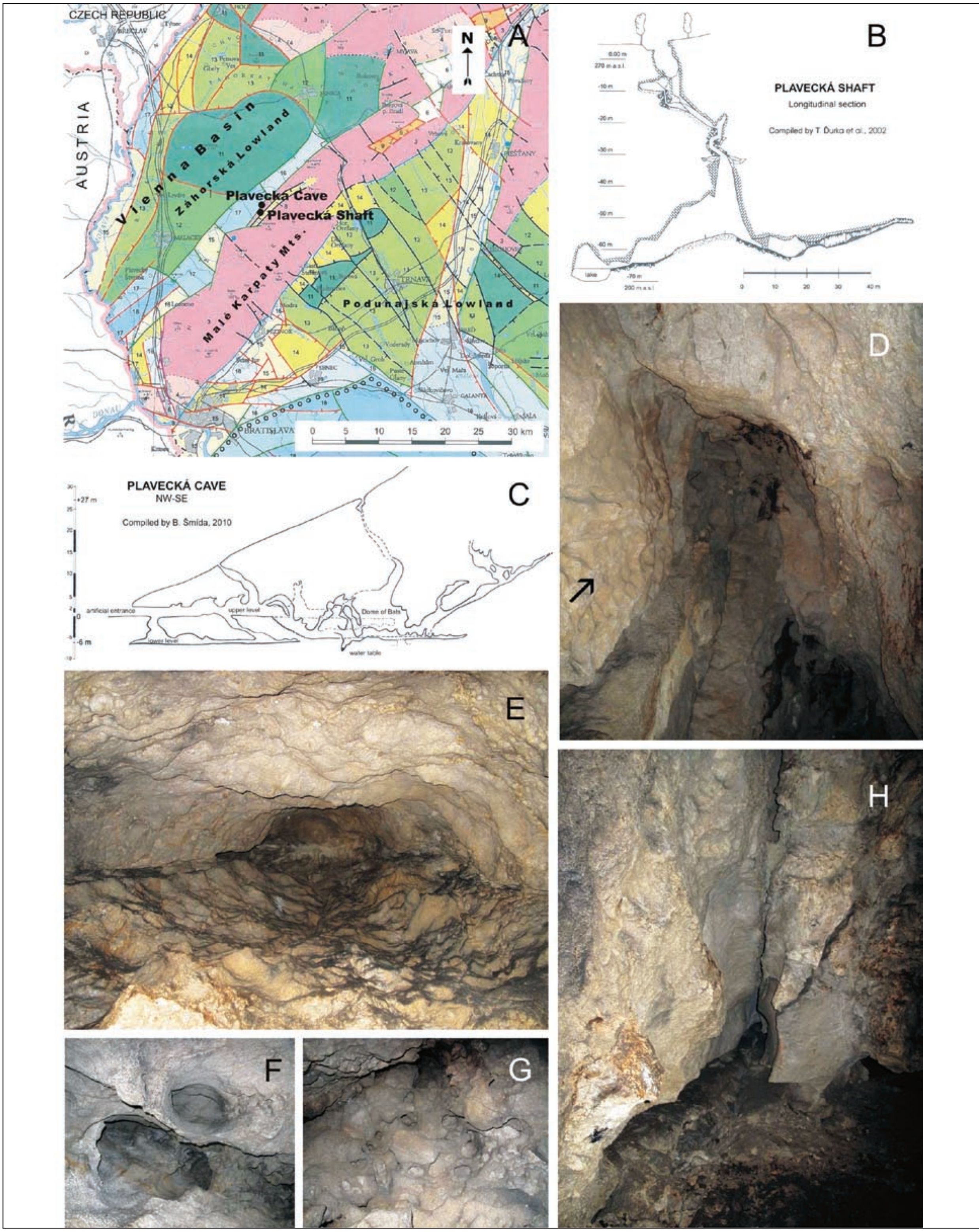

Fig. 5: Caves at Plavecké Podhradie village. Location map (A; modified from Maglay et al. 1999 with permission), longitudinal sections of Plavecká Cave (B) and Plavecká Shaft (C), and photos from the Plavecká Cave: D = rock walls of Bat Dome sculptured by large scallops that indicate an ascending water flow; E = blind chimney controlled by tectonic fracture; F = pocket-like hollows; G = irregular spongework-like hollows; H = discharge floor slot and rising half-tube feeder originated by water ascending along a steep fault (Photo: P. Bella).

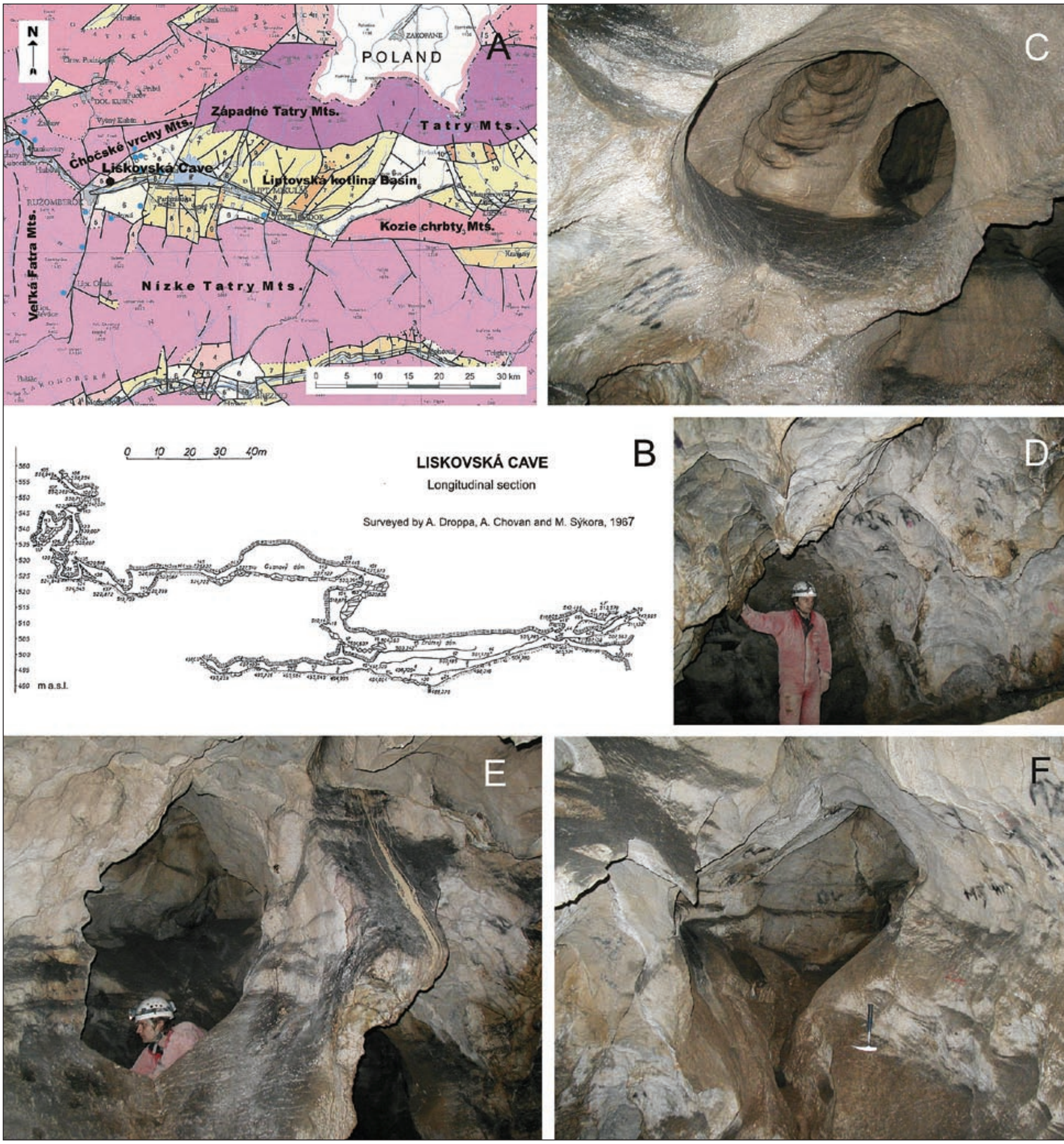

Fig. 6: Liskovská Cave. Location map (A; modified from Maglay et al. 1999 with permission), longitudinal section (B) and photos: C = ceiling pocket and hollows; D = irregular phreatic morphology with large scallops; E = rock window and pillar; F = downward-inclined smooth solution facets so-called Facetten or planes of repose (Photo: P. Bella).

the western part of the Kozie chrbty Mts. (Fig. 7A). The cave is developed mostly in Middle Triassic limestones (Biely 1960; Droppa 1962). The cave (1,813 m long and 59 m deep) has entrance at 755 m a.s.l., i.e. about 50 m above the recent river bed (Fig. 7B). The lower part with sumps is situated 20 m below the river bed; they are flooded time to time, but lake level does not correspond to river fluctuations on the surface. No fluvial sediments can be found in the cave (Holúbek 1998; Holúbek & Kráľ 2001). Hydrogeologic borehole at the confluence of the Čierny Váh River and Ždiarsky potok Creek uncovered karst cavities situated 70 m below the river bed and proved tectonic-influenced karstification in the depth (Hanzel 1977).

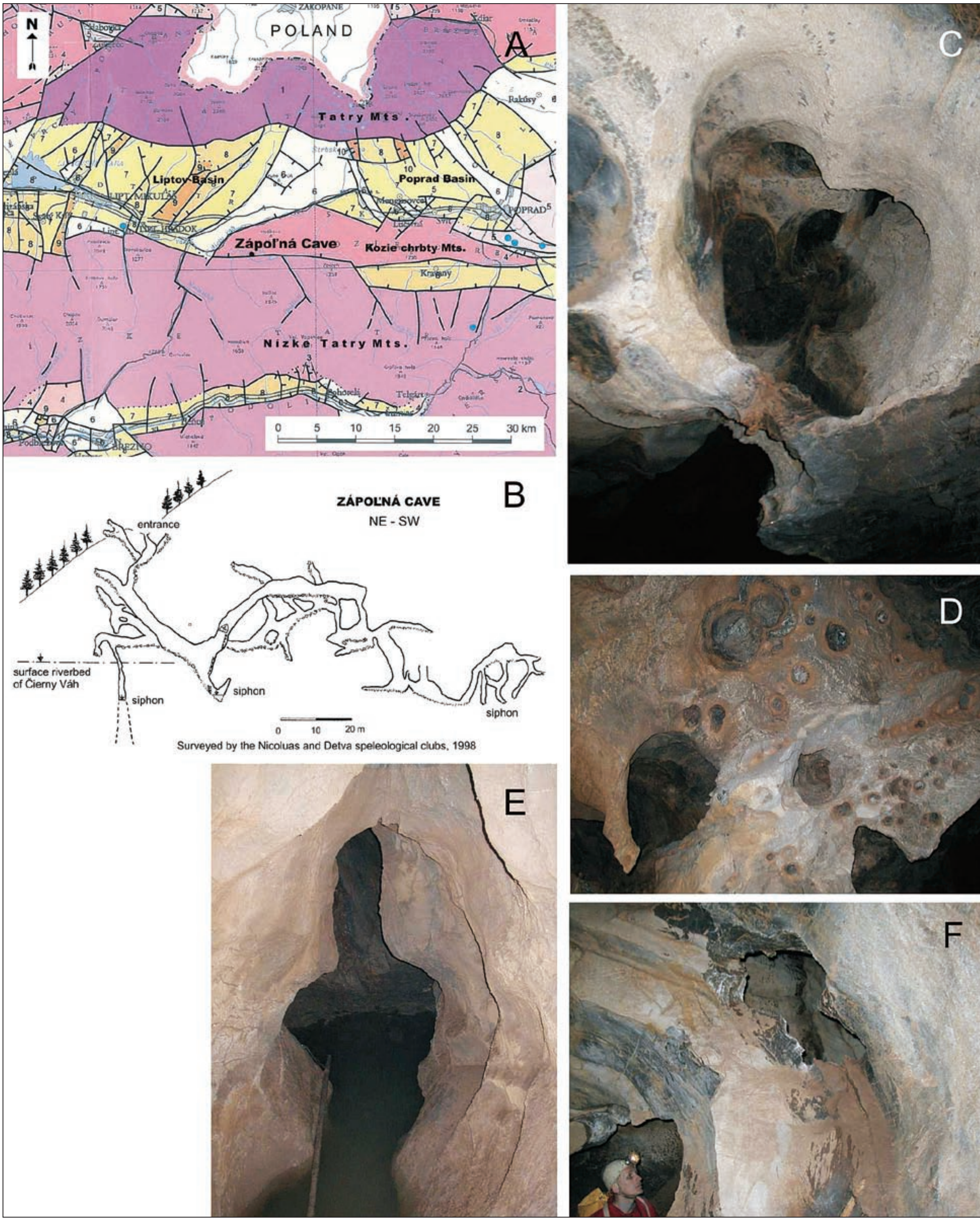

Fig. 7: Zápoľná Cave. Location map (A; modified from Maglay et al. 1999 with permission), longitudinal projection (B) and photos: C= cupola with ceiling pockets; D = ceiling pockets and hollows; E = phreatic passage with solution facets in the lower part of the cave; F = holey wall partition as a result of intense phreatic solution of carbonates (Photo: P. Bella).

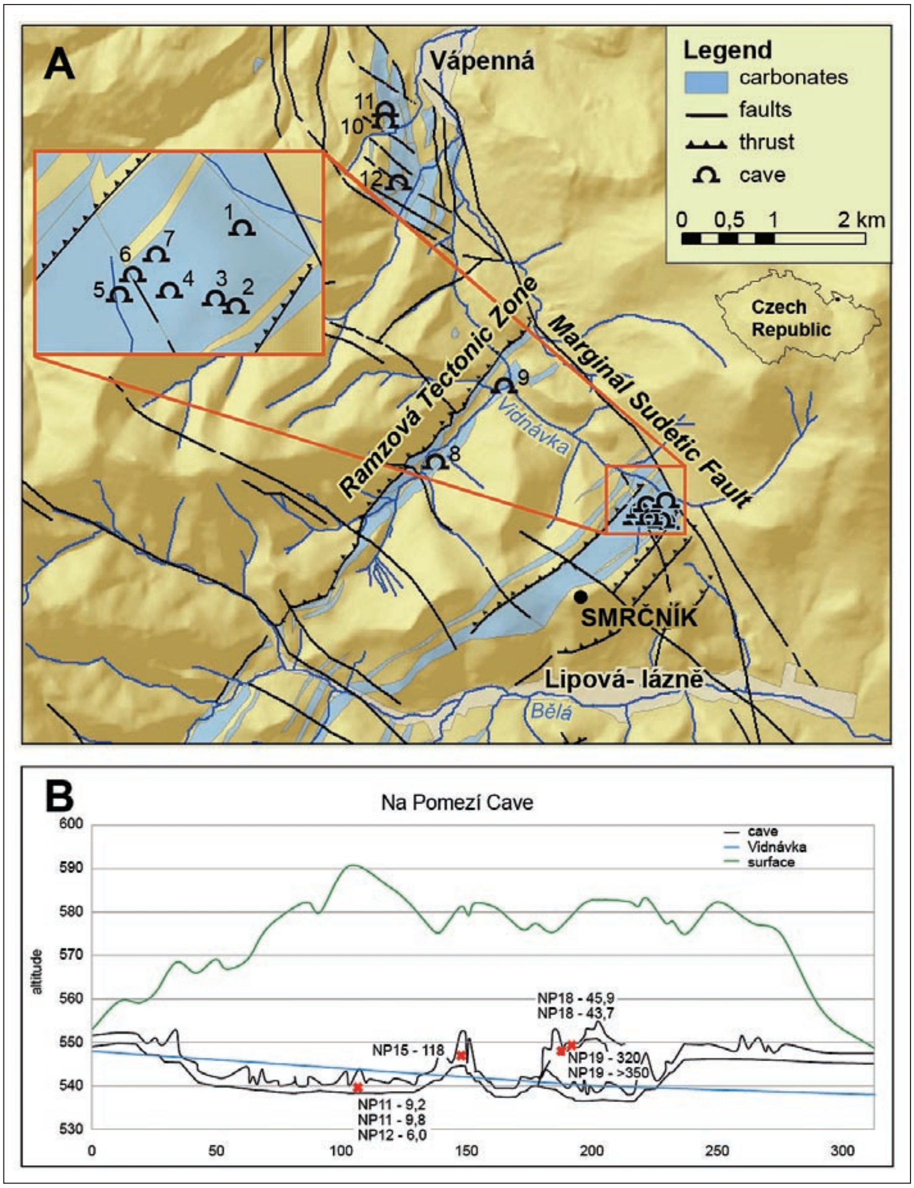

Fig. 8: Na Pomezí Cave. A = Southwestern part of the Rychlebské hory Mts., limestone outcrops, principal tectonic lines and position of caves along the Marginal Sudetic Fault between Lipová-lázně Spas and Vápenná village. Caves: 1-Na Pomezí, 2-Rasovna, 3-Netopýrka, 4-Bezejmenná, 5-Smrčnické propadání, 6-Nová, 7-Liščí díra, 8-U borovice, 9-Za hájovnou, 10-Roušarova, 11-S excentriky. B = Cave profile with some results of Th/U dating of speleothem crusts (modified originals of V. Altová).

Cave with unlevelled longitudinal section consists of more or less iregular inclined passages, shafts, chimneys and connecting tubes forming sponge- to maze-like system (Fig. 7D, E). Parallel passages are often separated by rock walls thick only several centimeters (*wall partitions, sensu* Osborne 2007; Fig. 7F). Cupolas are developed in places (Fig. 7C). Smaller half-spheric hollows resembling ceiling pockets are developed in the lower segment of the cave, where large calcite crystals were found, too. There are missing speleogens indicating fluvial speleogenesis of the cave.

The cave was formed in the phreatic zone with slow water flow and convection (Bella & Holúbek 2002). Waters ascended along W–E-trending fault pre-disposing the nearby segment of the Čierny Váh River Valley (Maglay *et al.* 1999). Lateral water-table notches and local flat ceilings indicate phases of water level stagnation and drawning during younger cave evolution phases (Bella & Holúbek 2002).

NA POMEZÍ CAVE SYSTEM

The Na Pomezí Cave System directly consists of the Na Pomezí Show Cave, Rasovna, Komínová and Netopýrka caves, but 3 other smaller caves can be linked with the system (Panoš 1961; Morávek 2009). Caves are situated on the left bank of the Vidnávka Creek in the eastern steep slope of the Smrčník Hill (799 m a.s.l.) to the north of Lipová-lázně Spas (Fig. 8A). Caves are developed in 200–250 m thick and steeply inclined crystalline limestones forming NE–SW-trending zone within metamorphics of the Branná Group (unclear age: Precambrian or Devonian) with imbricated internal structure. Limestone belt is limited by overthrust on the NW and cut by still tectonically active NW–SE-trending Marginal Sudetes Fault on the NE. The Marginal Sudetes fault zone is composed of several parallel faults which deflected in *en echelon* structure in the area with described caves (see Altová & Štěpančíková 2008).

The Na Pomezí Cave is ca 1 km long and 45 m deep (principal spaces are between ca 538 and 560 m a.s.l.). It is open by artificial tunnels at 545 and 549 m a.s.l. from old quarries. It consists of subvertical caverns with

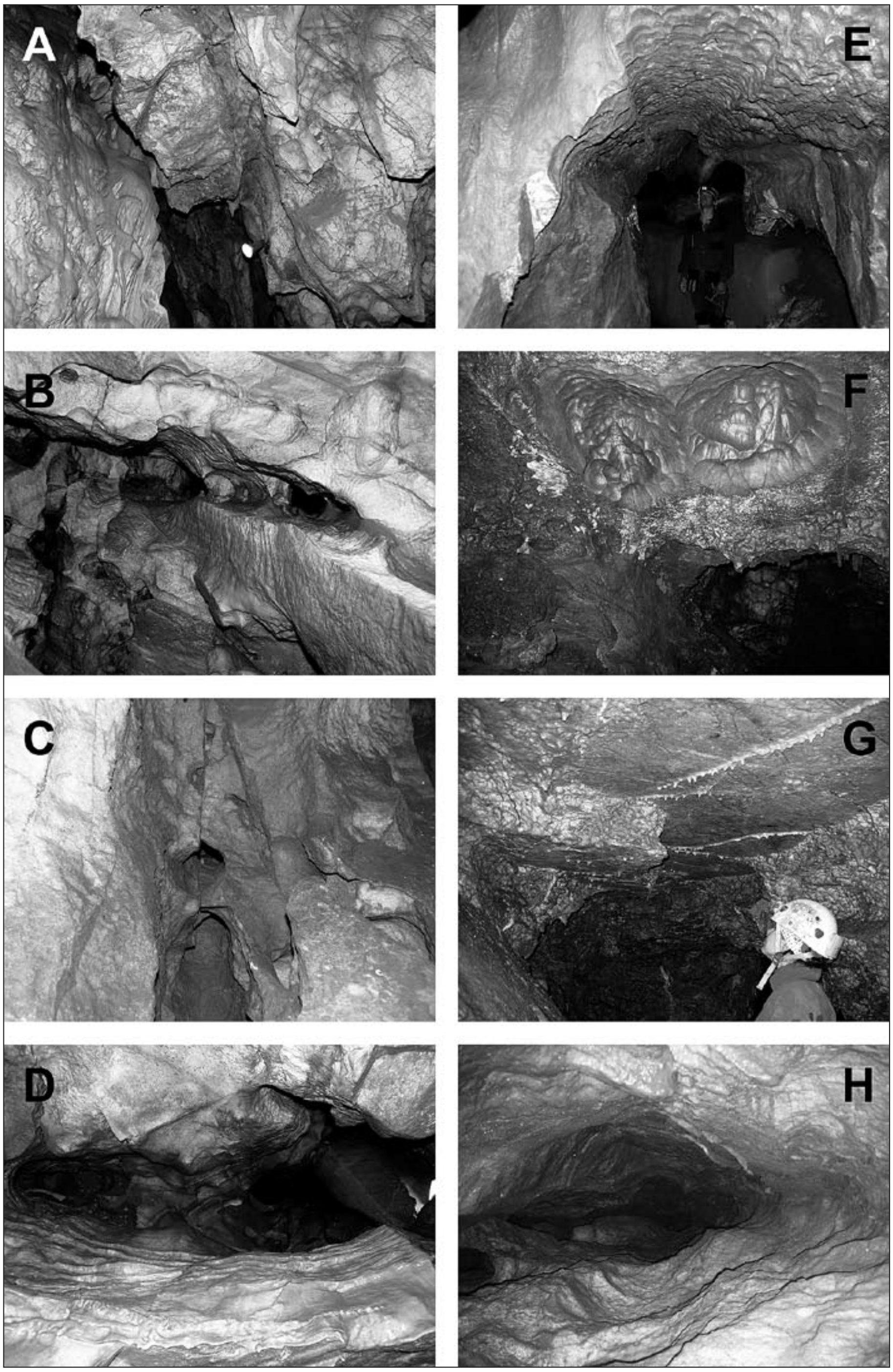

Fig. 9: Photos of cave morphology from the Na Pomezí Cave (A to E; Photo: P. Bosák 2010) and Rasovna Cave (F to G; Photo: V. Altová 2007). A = Rising ceiling channels. B = Scallops of different sizes indicating upward direction of water flow. C = Phreatic forms displaced by fissure. D = Outflow ceiling slot. E = Laugdecke with scalloped ceiling channel. F = Ceiling pockets remodelled by scallops and a lower belt of vertical ribbed flutes. G = Structurally controlled flat ceiling and solution Facetten at left. H = Outflow ceiling slot.

2 indistinct levels of subhorizontal passages. Downward vertical continuation is chocked by cave sediments at ca 536–538 m a.s.l. (Fig. 8B). The Rasovna Cave is subvertical, 632 m long and 76 m deep (596 to 520 m a.s.l.) with entrance in abandoned quarry (590 m a.s.l.). The cave system has total depth over 100 m.

The evolution of the cave system has been connected with the evolution of relief, planation surfaces and the entrenchment of the Vidnávka Valley since Miocene and with Quaternary periglacial processes (Král 1958; Panoš 1961; Morávek 2009). Panoš (1961) expects the Lower Pliocene age of spaces in higher altitutes and Middle Pliocene age of the lower ones. Collapses in caves have been connected with periglacial destructon (a.o. Panoš 1959).

The subvertical system of Na Pomezí–Rasovna caves is arranged in two altitudinal zones. The upper one consists mostly of collapse-modified high, narrow and densely-spaced fissure-like passages with speleogens indicating ascending water flow and strong condensation corrosion. Flat ceiling-like forms in the Rasovna Cave (Fig. 9G) resulted from collapses of limestone block along subhorizontal cleavages rather than from corrosional action of karstwater *(Laugdecken)*.

The lower cave zone is characteristic by floor slots and channels leading to ceiling slots (Fig. 9A, E) situated mostly in open fractures and leading to the upper cave zone. Channels, often with flat ceiling, are covered by two to three generations of relatively small scallops (Fig. 9E). Floor slots are situated mostly at ends of small side passages with floor choked by sediments. Upward narrowing slots have very rugged phreatic morphology with distinct pendants. Ceiling slots (Fig. 9B, D, H) have also very rugged phreatic morphology with abundant pendants, anastomoses; wall forms are partly modified by later mixing/condensation corrosion and collapses, and slightly displaced, in places, along fissures (Fig. 9C). Passage walls indicate also some vadose rocky relief forms, like paragenetically flattened roofs or lateral water-table notches (Fig. 9E). Some of ceiling channels can represent paragenetic feature, when cave passages were filled by sediments.

Speleothem crusts at different positions were dated by Th/U dating (H. Hercman, 2008 pers. comm.). Flowstones over Holocene sediments have age of 6.0–9.8 ka. Crusts in different positions within the system were dated from 43.9 up to over 350 ka ($^{234}U/^{238}U$ ratios indicate that the samples can be older than 1.2 Ma; Fig. 8B). Crusts represent rests after numerous cave fill and exhumation phases, up to different altitudes, as indicated by younger data in higher altitudes than some older ones in lower positions. Sediments at recent cave bottom, along tourist trail, contain subrecent bat bones and magnetization of sediments is normal (younger than 780 ka; Altová & Bosák 2011).

The system Na Pomezí–Rasovna caves is not connected with entrenchment of surface rivers as expected by Král (1958) or Panoš (1959). The age of some speleothem crusts indicate the substantial age (over 350 ka and even 1.2 Ma), which may indicate quite old origin of cavities, which is in accordance with model of Panoš (1961). The system was formed in phreatic to deep phreatic conditions by ascending water of deep circulation; it was later partly re-modelled in epiphreatic conditions connected with the incision phases of the Vidnávka Valley and movements along the Marginal Sudetic Fault. The system, especially its lower zone – Na Pomezí Cave – was several times completely filled with allogenic clastic sediments and subsequently exhumed partially or completely. The recent state represents exhumation period. It is expected that clastic load was transported into the cave system by surface waters in period when groundwater table slowly subsided. Ceiling channels, inflow semichannels and paragenetic features (Fig. 9E) developed when groundwater ascended. Rapid fall of groundwater level resulted in exhumation of cave fill; rests of speleothem crusts indicate the level of the infill phases. The Rasovna Cave is vertical outlet part connecting the cave system, or its part, with the surface. Original surface outlet forms were completely destroyed by the intensive geomorphic processes on surface during Quaternary (e. g. Král 1958; Panoš 1959). The vertical oscillation of groundwater table can be connected with (1) the stress field orientation along the Marginal Sudetes Fault and associated faults and fissures; when in a extension regime, waters were subsiding, when in stress, waters were ascending, and/or (2) with Pliocene–Quaternary climate changes and water supply from the upper zones of the Rychlebské hory Mts. drained by the Marginal Sudetes Fault. Collapses are rather connected with the tectonic unrest, than with climate-driven processes (expected by Panoš 1959), although some fine-grained screes resulted from the frost activity.

DISCUSSION

Caves presented here as case studies represent products of ascending speleogenesis in zones of deep regional faults/fault zones. Any of described caves contains clear diagnostic features of real hypogene caves (as defined before the concept of Klimchouk 2007), expressed e.g. in specific mineral assemblages. On the other hand, number of elements of rocky cave reliefs (speleogens) can be attributed to phreatic and deep phreatic speleogenesis related to slowly rising water flow (e.g. Osborne 2004; Audra *et al.* 2009b); some of them are often expected as typical for hypogenic speleogenesis (sensu Klimchouk 2007) or hyperkarst (sensu Cigna 1978).

There are missing evidences of even slightly heated groundwaters within studied caves, except of the Plavecká Cave and Shaft. Nevertheless, somewhat increased water temperature can be expected during speleogenesis at least in some caves. Numerous springs of thermal waters occur recently in the vicinity of the Belianska and Liskovská caves. Springs discharge along deep regional Choč-Tatry-Ružbachy Fault. Some of them are enriched in carbon dioxide and the temperatures are from 23 to 31.5°C (e.g. Vyšné Ružbachy). Subsurface groundwaters in adjacent deep aquifers of the Liptov and Poprad basins reach temperatures of 24 to 109°C at depths of 250 to 3,600 m (e.g. Jetel 1999, 2000; Remšík *et al.* 2005).

It seems, that any of described caves cannot be directly characterized as product of thermal waters or hydrothermal process, i.e. as real hypogenic caves (hyperkarst sensu Cigna 1978). Water temperatures in described caves of the Plavecký Karst reach only 1.6 to 3.8°C above the mean annual air temperature of the area; nevertheless they indicate the mix of deeply circulating heated waters with meteoric ones or shallower water circulation along marginal fault zone of the Malé Karpaty Mts. Plan *et al.* (2006, 2009) and Pavuza & Plan (2008) described similar caves formed by ascending slightly warmer waters along the southern and eastern fault margins of the Vienna Basin in Austria. Temperatures of water at resurgences from other caves/systems mentioned here recently reach usual values for the respective region.

All caves described in case studies were developed along expressive and important faults or fault zones often of regional importance, which enabled free ascending circulation of groundwater, especially in the extensional regime (Hanzel 1977, 1992 and others). The faults limit (1) extensional sedimentary basins and horst/fault-limited mountains (Plavecká, Liskovská and Skalistý potok caves); (2) tectonic grabens (Mladečské Caves, Květnická Chasm); (3) tectonic blocks with differential uplift in marginal zones of mountains or karst plateau (Belianska, Zápoľná, Jasovská and Na Pomezí caves), or (4) blocks with differential subsidence in the basement of sedimentary basins (Morské oko, spas in central Moravia).

The indisctinct or low connection of nearly all caves with the recent surface represents another common feature for case studies. Discharge structures, like paleosprings and related negative relief forms or spring precipitates (travertines, tuffas), are not preserved in spite of the fact that the recent discharges, especially in Slovakia, are characterized by thick travertine deposits. The Choč-Tatry-Ružbachy Fault between Liskovská and Belianska caves (and around them; also in boreholes) is marked on the surface by number of springs discharging warm to hot water and precipitating travertine mounds and cascades (e.g. Vyšné Ružbachy; a.o. Maheľ 1952; Kullman & Zakovič 1974; Hanzel 1992; Franko & Hanzel 1980; Remšík *et al.* 2005). The original discharge structures are highly destructed by Quaternary (base at 2.6 Ma) surface landforming processes mostly due to substantial age of some of caves: Miocene speleogenesis is expected for the Belianska Cave (Bella *et al.* 2010) and Koněpruské Caves (Bosák 1996); Pliocene age is interpreted for the Na Pomezí Cave (Panoš 1961) and the Jasovská Cave (Jakál 1975; Liška 1994).

The reasons for ascending speleogenesis in most caves mentioned here can be related to the evolution of tectonic basins and river valleys, i.e. subsidence and deep erosion was followed by basin fill or fluvial aggradation due to change of tectonic regime and/or related to transgressions.

In the Czech Republic, the origin of the Mladečské Caves was clearly related to subsidence/aggradation/erosion history of the Mio-Pleistocene Hornomoravský úval Basin (continuation of the Labe Zone; for details of sedimentary history see Růžička 1989), causing water ascent along deep marginal faults at least in one of evolution stages. Springs of warm and cold waters enriched in hydrogen sulphide and/or carbon dioxide in the Slatinice Spa and at Horní Moštěnice village represent some of recent outflows of ascending waters in the region.

In the region of the Slovak Karst, the intensive valley incision and fill by fluvial sediments during the Pontian has been explained only by differential tectonic movements – uplift and following subsidence (e.g. Jakál 2001; Gaál 2008). Nevertheless the late Miocene history of the area was closely related especially to the evolution of the Pannonian Lake (e.g. Magyar *et al.* 1999; Kováč *et al.* 2011). Lake paleotributaries from the N/NW came through the Slovak Karst from uplifting mountains farther to the N of it. Lake-level oscillations and deep erosion (up to 1,000 m in seismic profiles in Hungary) are recently related to the Messinian crisis (Csato *et al.* 2007). Pontian fluvial and fluvio-lacustrine Poltár Formation later filled deeply eroded karst canyons and subsided blocks in adjacent sedimentary basins and covered at least marginal zones of karst plateaus due to sediment aggradation. The recent thickness of the Poltár Formation in karst canyons of the Slovak Karst is 120 to 125 m (Vass *et al.* 1989), but the position of the Poltár sediments in some of adjacent tectonic basins (e.g. Jakál 2001; Gaál & Bella 2005; Gaál 2008) and on some of plateaus of the Slovak Karst (e.g. Horný vrch Plateau; Janáček 1940; Láng 1955; Elečko & Vass 1997) proves original thickness possibly up to 465 m. The rising flow of the groundwater up to the surface along sediment/limestone interface and/or along marginal faults followed the sediment aggradation. Zacharov (2011) recently reported favourable tectonic structures enabling the deep groungwater circulation and ascent in the eastern part of the Slovak Karst. The possibility of paragenesis or speleogenesis caused by rising water flow at the Plešivská planina Plateau was noted already by Skřivánek (1966). Speleogenesis of the upper part of Skalistý potok Cave and of the Jasovská Cave we relate to aggradation-induced rising water flow along deep faults.

The ascending speleogenesis along steep faults in our case studies and in most of examples mentioned in the introduction was characterized by dominant slowly rising water flow. Well-organized drainage pattern with deep loops and sediment transport is known only in the case of the Mladečské Caves, being a part of regional Třesín aquifer with well-defined ponor and outflow regions (Panoš 1990). Most of other caves mentioned here are relics (paleokarst s.l.) with fragmentary preserved drainage pattern (Koněpruské Caves), unknown drainage pattern (Na Pomezí Caves) or depending on very deep groundwater circulation on long distances with hardly tracable paths (most of Slovak case studies). This characteristic differentiate our cases from the faster flow of meteoric waters through well-organized conduit drains and "vauclusian" water outflow to spring due to base level rise by sediment aggradation, i.e. from the *per ascensum speleogenetical model* of Audra *et al.* (2004, 2009a) and Mocochain *et al.* (2006, 2011) described in the Mediterranean region of southern France. Unfortunately, the attempts to distinguish between *slow per ascensum* and *fast per ascensum* speleogenesis is not correct, as the latin term *per ascensum* is non-genetical and cannot include any limiting conditions; it characterizes any kind of ascending process. More, ascending spelogenesis was described from the region with the Koněpruské Caves (Český Karst, Czech Republic) already by Bosák (1996, p. 58). We propose to characterize the *per ascendum speleogenetical model* proposed by Audra *et al.* (2004, 2009a) and Mocochain *et al.* (2006, 2011) by the expression: *vauclusian ascending speleogenesis* or *vauclusian type of per ascensum speleogenesis*.

Phreatic and deep phreatic morphologies are typical as primary forms of most of described caves. Nevertheless all caves show secondary epiphreatic re-modellation linked with the evolution of the recent hydrographic network after the origin of the phreatic cavern itself. Valley incisions were mostly related to differential uplift/subsidence of individual fault-limited blocks and temporary stabilization of the local base level. Some of caves show up to several subhorizontal outflow levels developed along subsiding groundwater table (e.g. Belianska, Jasovská, Plavecká, Liskovská, Na Pomezí, Koněpruské caves); the original phreatic morphology is sometimes obscured to more or less unreadable levels. This secondary modified morphology led previous authors to link such caves with predominant epiphreatic and vadose speleogenesis related to the evolution of present landscapes but not with deep-seated processes in the phreatic zone. This approach was supported also by the lack of cave fill or by the fact that preserved cave sediments are young, mostly Pleistocene or even Holocene in age (e.g. Koněpruské Caves – Bosák 1996; Jasovská Cave – Bella *et al.* 2007b; Na Pomezí Cave – Altová & Bosák 2011; Liskovská Cave – Bella *et al.* 2009; P. Pruner, pers. comm. 2011).

Collapses of blocks are typical feature of some of caves. We mention here especially the upper zones both of Na Pomezí Cave and Jasovská Cave, which morphology is strikingly similar in general. Mechanic weakening was caused by intensive phreatic corrosion of densely-spaced fissures/faults at zones of outflow slots, also by later condensation corrosion in places. Sediments in the Liskovská Cave (younger than 780 ka) fill a steep tube or bottom slot originated in the fault zone and show highly variable paleomagnetic parametres in different profiles and their layers (P. Pruner, pers. comm. 2011), indicating young tectonic-affected movements and subsidence of sediments to lower cave segment. Recent tectonic activity of the Marginal Sudetes Fault is proved by measurements on TM71 deformeters (for review see Altová & Štěpančíková 2008). Therefore, the collapses can be connected rather to (neo)tectonic activity of deep faults, than to climate-driven effects.

CONCLUSIONS

Extensive research of cave morphologies and sediments in number of central European caves brought surprising results concerning the speleogenesis of some of Slovak and Czech/Moravian caves. Speleogenesis of selected caves has been originally connected with (1) phreatic and epiphreatic environments in relation to the neotectonic differentiation of horst mountains and grabens or sedimentary basins, and the evolution of local water courses and their incision along faults, some cave parts were linked with development of river terrace systems, and (2) Plio-Quaternary climatic oscillations or even climatic changes during late Pleistocene.

The analysis of cave settings and morphologies illustrates ascending *(per ascensum)* speleogenesis linked with deep faults/fault systems. Decribed caves have several common characteristics, especially: (1) they developed along or in close vicinity of deep faults/fault zones, commonly of regional importance; (2) the groundwater ascended due to deep faults/fault systems mostly as results of deep regional circulation of meteoric waters from adjacent karst or nonkarst areas; (3) 3D mazes and labyrinths dominate in cave morphology; (4) speleogens (e.g. cupolas, slots, ceiling channels, spongework, rugged phreatic morphology especially along slots) indicate ascending speleogenesis in deep phreatic to phreatic environments; (5) they exhibit poor relation to the present landscape; in some of them fluvial sediments are completely missing in spite of surface rivers/streams in the direct vicinity; (6) strong epiphreatic re-modelling is common in general (e.g. subhorizontal passages arranged in cave levels, water-table flat ceilings and notches) and related to the evolution of the recent landscape; (7) recharge structures and correlate surface precipitates are poorly preserved or completely missing (denuded) on the present surface in spite of fact that recent recharges broadly precipitate travertines; (8) caves can be, and some of them are, substantially older than the recent landscape, and (9) caves were formed in conditions of slow water ascent, which differentiate the process from faster vauclusian ascending speleogenetical models.

Any of described caves contains clear diagnostic features of real ("true") hypogene caves, expressed e.g. in specific mineral assemblages. On the other hand, number of elements of rocky cave reliefs (speleogens) can be attributed to phreatic and deep phreatic speleogenesis, or to ascending speleogenesis. There are missing evidences that even slightly heated groundwaters took part during speleogenesis of studied caves, except of the Plavecká Cave and Shaft. Nevertheless, somewhat increased water temperature can be assumed during speleogenesis at least in some of caves. It seems, that any of described caves cannot be directly characterized as product of thermal waters or hydrothermal process, i.e. as real hypogenic caves or hyperkarst.

ACKNOWLEDGEMENTS

We acknowledge the field assistance of V. Altová, J. Bachleda, P. Holúbek, Z. Hochmuth, J. Hromas, J. Kovália, P. Kubalák, J. Menda, P. Pruner, S. Šlechta, L. Vlček, and consultations of Ľ. Gaál, H. Hercman, J. Janočko, M. Kučera, Ľ. Petro, V. Pruner, M. Zacharov, K. Žák. Figs. 7 and 8 were drawn by Mrs. J. Rajlichová. The reprint of sections from the Neotectonic map of Slovakia (Figs. 2 to 7) was allowed by the permission of the copyright holder. Useful comments and suggestions of reviewers are acknowledged as well.

The study is result of Grant Project of Ministry of Education of the Slovak Republic VEGA No. 1/0030/12 *Hypogenic caves in Slovakia: speleogenesis and morphogenetic types;* Grant Project of the Grant Agency of the Academy of Sciences of the Czech Republic No. IAA300130701 *Paleomagnetic research of karst sediments: paleotectonic and geomorphological implications,* and the Institutional Research Plan of the Institute of Geology AS CR, v. v. i. No. CEZ AV0Z30130516.

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