Acta Mus. Moraviae, Sci. geol.
LXXXVI (2001):111–160, 2001

CENOZOIC HISTORY OF THE MORAVIAN KARST (NORTHERN SEGMENT): CAVE SEDIMENTS AND KARST MORPHOLOGY

JAROSLAV KADLEC, HELENA HERCMAN, VOJTĚCH BENEŠ, PAVEL ŠROUBEK, JIMMY F. DIEHL & DARRYL GRANGER

Abstract

Kadlec, J., Hercman, H., Beneš, V., Šroubek, P., Diehl, J. F., Granger, D., 2001: Cenozoic history of the Moravian Karst Karst (northern segment): cave sediments and karst morphology. Acta Mus. Moraviae, Sci. geol., 86:111–160 (with Czech summary).

Vývoj severní části Moravského krasu v období kenozoika: jeskynní sedimenty a krasová morfologie.

Cave systems of the Moravian Karst were formed by subsurface streams in dependence on the morphology of karst valleys representing a local base level before the Lower Badenian marine transgression. During the Cenozoic, stream activity in the caves alternated with speleothem deposition. Fluvial bodies formed in the Early, Middle and Late Pleistocene are preserved in ponor caves in the N segment of Moravian Karst. However, fluvial sediments filling the caves near resurgences of subsurface streams were deposited only in the Late Pleistocene. Reconstruction of the Cenozoic karst processes was proposed on the basis of the morphology of karst valleys filled with sediments as shown by geophysical survey and cave deposit datings.

Filling of cave corridors with sediments was induced by local events in many cases (e.g., the collapse of the Macocha Chasm roof). These events considerably inhibited the flow of subsurface streams in the cave systems. As a result, bodies of fluvial sediments in the caves of the Moravian Karst cannot be correlated with fluvial terraces formed by surface streams.

Key words: cave sediments, karst morphology, radiometric and paleomagnetic datings, geophysical survey, Moravian Karst

Jaroslav Kadlec, Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 02 Praha 6, Czech Republic

Helena Hercman, Institute of Geological Sciences of the Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland

Vojtěch Beneš, G IMPULS Praha spol. s r. o., Přístavní 24, 170 00 Praha 7, Czech Republic

Pavel Šroubek, Michigan Technological University, Houghton, Michigan, 49931 USA

Jimmy F. Diehl, Michigan Technological University, Houghton, Michigan, 49931 USA

Darryl Granger, Purdue University, West Lafayette, Indiana, 47907 USA

1. Introduction

The Moravian Karst is a typical example of fluviokarst with extensive cave systems formed by subsurface streams. Detrital sediments as well as speleothems are commonly preserved in the caves, deposited in different stages of the development of karst systems.

The earliest systematic studies of sediments in caves of the Moravian Karst started in the second half of the 19th century. The first studies focused largely on detrital sediments deposited in the neighbourhood of cave entrances. The principal aim was to collect paleontological and archeological material preserved in sedimentary strata (e.g., WANKEL,

1868; Kříž, 1891). The break of the 19th/20th century in the Moravian Karst marked the first activities of K. Absolon, who took credit not only for the investigation of cave systems but also for the popularization of this karst area (Absolon, 1905–11, 1912, 1922, 1970a, b). The late 1950s and early 1960s represent a period of intensive studies in the Moravian Karst. Then, a number of papers emerged concentrating largely on the geomorphological history of the karst area and speleogenesis (e.g., Panoš, 1963, 1964; Štelcl, 1962a, b, 1963, 1964). A vigorous impulse for further investigations was the discovery of the Amatérská Cave in 1969; this cave poses a substantial part of a karst system draining the N segment of the Moravian Karst. Information on the character of this cave and its cave sediments were summarized by Pelíšek (1974), Přibyl and Rajman (1980) and Vít (2000). Deposits in other caves were studied by Pelíšek (1940, 1948, 1974, 1975, 1980) and Přibyl (1966, 1972a, b, 1973, 1988) from sedimentological viewpoint. Problems of the genesis of cave systems were dealt with in the papers of Hypr (1980), Bosák et al. (1989), Dvořák (1994) and Dvořák et al. (1993). Problems of provenance, genesis and age of cave sediments in the N segment of the Moravian Karst were solved in recently submitted diploma and dissertation theses: Vít (1990, 1996), Kadlec (1997b) and Kvítková (1999).

In the past, the largest portion of attention was traditionally given to sediments of the so-called entrance facies (see Kukla and Ložek, 1958) often containing abundant paleontological and archeological material permitting to date the individual sedimentary strata and to suggest paleoenvironmental interpretation of sediment genesis (Schmid, 1958). In the Moravian Karst such studies can be exemplified by sedimentary sections exposed in the Kůlna Cave (see Chapter 5.2), which were documented in detail using archeological and paleontological finds, and the stratigraphic conclusions were supplemented by radiocarbon data (Valoch, 1988) and ESR dating (Rink et al., 1996). In contrast, sediments deposited deep in the cave systems are usually free of any fossils. These detrital sediments and speleothems preserved in cave systems of the Moravian Karst have been not dated. Stratigraphic interpretations of cave sediments formulated in older publications are, therefore, questionable. Only a detailed sedimentological study, dating

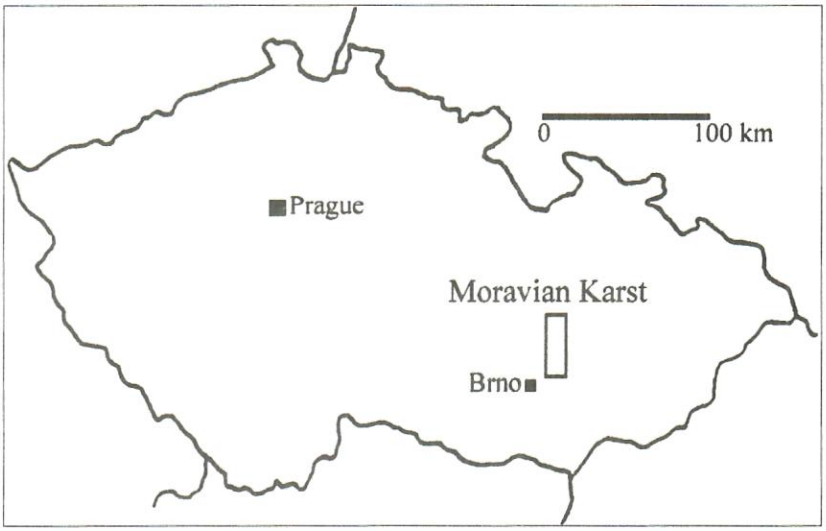

Fig. 1. Location of the Moravian Karst.
Obr. 1. Lokalizace Moravského krasu.

of sediments and knowledge of karst morphology can serve a basis for the correlation of discrete sedimentary sections, reconstruction of depositional conditions and processes, and interpretation of the history of the karst area.

2. Geographic and hydrographic setting

The Moravian Karst represents a part of the Drahanská vrchovina Highland, lying NE of Brno, in the eastern part of the Bohemian Upland (Fig. 1). The preserved limestones form a N-S-trending belt, 3–5 km wide and 25 km long, covering an area of 85 km^2. The surrounding Lower Carboniferous sediments and Proterozoic granitoids of the Brno Massif create relief with maximum altitudes of ca. 600 m. In contrast to the ambient non-karstic rocks, the limestones form a depression with surfaces lying at 490–520 m a.s.l. The limestone surface is dissected by deep valleys, locally adopting the character of karst canyons. The transverse Lažánecké and Křtinské valleys run from SE to NW across the limestone area, thereby subdividing the Moravian Karst into the northern, central and southern segments.

The streams flowing through cave systems spring N and E of the Moravian Karst, in areas built of Lower Carboniferous shales, greywackes and conglomerates. Streams run into depression formed by Devonian limestones and sink under the ground through ponors near the boundary between limestones and non-karstic rocks. Water passes through cave systems and re-appears on the surface at resurgences along the western margin of the karst area. In the form of surface channels again, it merges with rivers forming the base level of the area.

Each of the three segments of the Moravian Karst is characterized by a separate drainage pattern. The N segment (N of the Lažánecké Valley) is drained by the Punkva River to the west, into the Svitava River. The central segment of the Moravian Karst is drained by the Křtinský Creek also to the west, into the Svitava River. The southern segment is drained by the Říčka River into the Svratka River (Fig. 2).

Most of the drainage area of the Punkva River (130.6 km^2) lies on Lower Carboniferous sediments. The drainage area of the stream on karstic rocks is 29 km^2, and the drainage area of its lower reach, downstream of the karstic rocks, is only 10.8 km^2. The Punkva River appears in the Amatérská Cave system at the confluence of the Bílá voda and Sloupský creeks (the latter formed by the Luha and Žďárná creeks – see Fig. 2), which are sinking into ponor caves at the northern margin of the Moravian Karst, i.e. in the Holštejnské Valley and the Sloupské Valley, respectively. With an average discharge of 2 m^{3}s^{-1}, the Punkva River flows through the Amatérská Cave and resurges from the Punkevní Cave near the Macocha Chasm (Fig. 3). The total length of this cave system draining the N segment of the Moravian Karst exceeds 30 km. Other minor streams enter this karst area from the east, unite under the surface and resurge as the Vilémovické vody Creek in the so-called Small Resurgence located south of the Macocha Chasm. The overall drainage area of these tributaries is 9.4 km^2.

3. Geological setting

The Moravian Karst is formed by sediments of Devonian and Lower Carboniferous age. Devonian sedimentation was commenced by the deposition of sandstones and conglomerates, unconformably overlying Proterozoic granitoids of the Brno Massif. Basal clastics are overlain by carbonate reef complex over 1,000 m thick, known as the Macocha Formation (Eifelian to Frasnian). The prevalent back-reef facies is characterized by dark-grey coloured limestones with brachiopods and amphiporids alternating with light-gray stromatoporoid-coral reef banks and bioherms in several megacycles (Hladil,

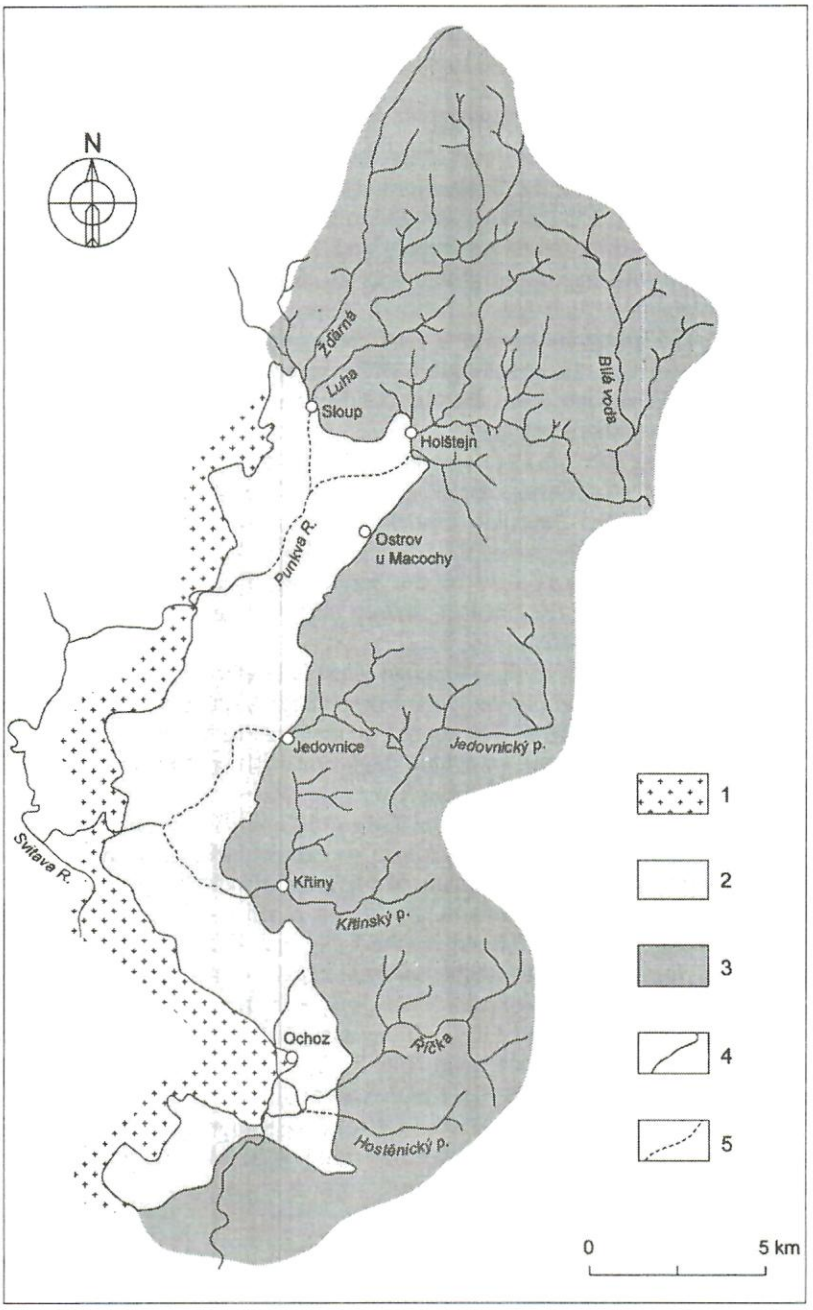

Fig. 2. Modern hydrography of the Moravian Karst. 1 – Proterozoic granitoids; 2 – Devonian to Lower Carboniferous limestones with Devonian basal clastics at the western periphery; 3 – Lower Carboniferous shales, greywackes and conglomerates; 4 – surface reaches of streams; 5 – subsurface reaches of streams.

Obr. 2. Hydrografie Moravského krasu. 1 – proterozoické granitoidy, 2 – devonské až spodnokarbonské vápence s devonskými bazálními klastiky při západním okraji krasu, 3 – spodnokarbonské břidlice, droby a slepence, 4 – povrchové toky, 5 – podpovrchové toky.

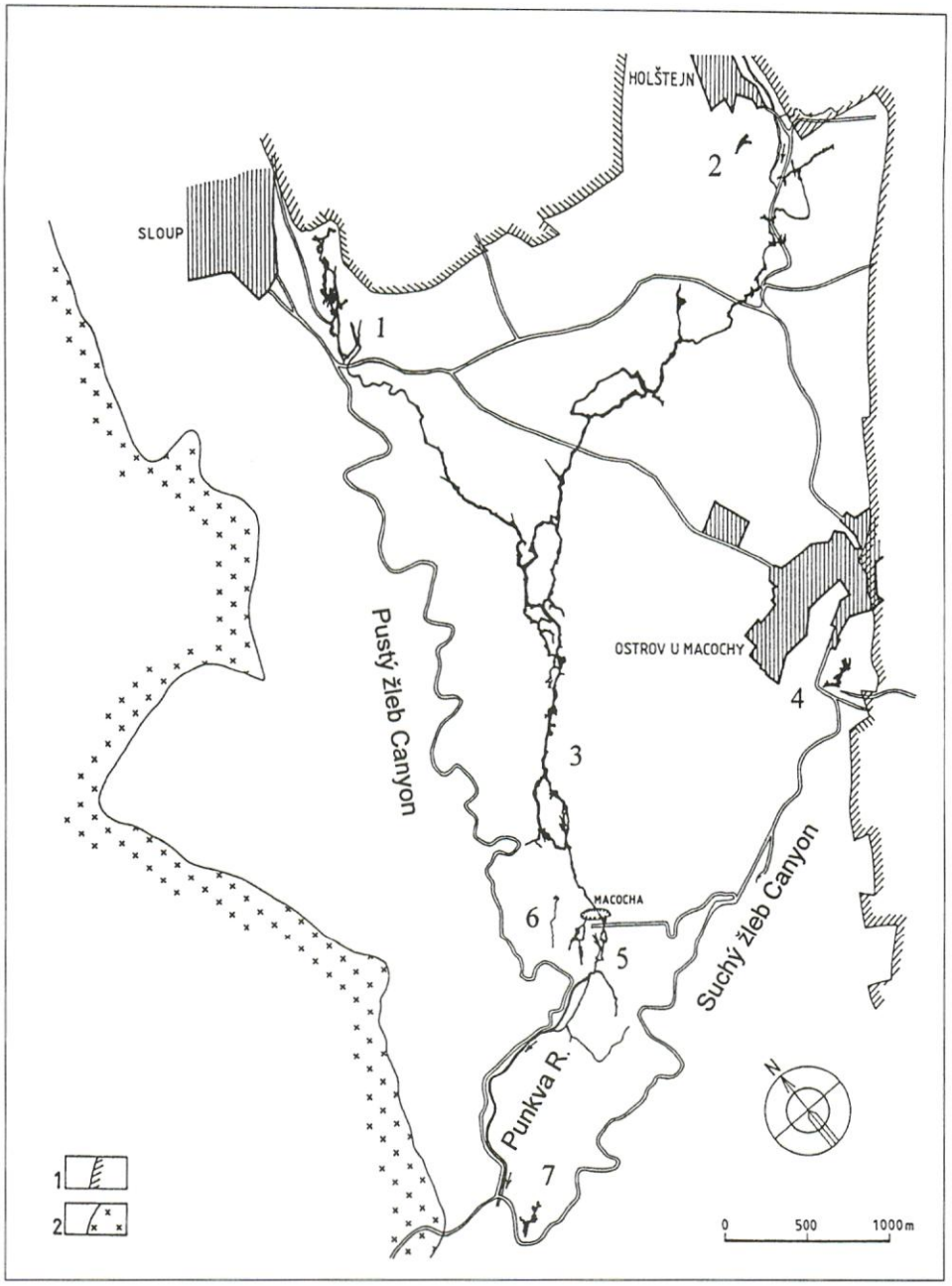

Fig. 3. Large caves in the N segment of the Moravian Karst (modified after PŘIBYL, 1988). 1 – boundary of limestones and Lower Carboniferous non-karstic rocks; 2 – boundary of limestones and Proterozoic granitoids; explanations for caves: 1 – Sloupsko-šošůvská Cave; 2 – Holštejnská Cave; 3 – Amatérská Cave; 4 – Balcarka Cave; 5 – Punkevní Cave; 6 – Zazděná Cave; 7 – Kateřinská Cave.

Obr. 3. Velké jeskynní systémy s. části Moravského krasu (upraveno podle PŘIBYLA 1988). 1 – hranice vápenců a nekrasových spodnokarbonských hornin, 2 – hranice vápenců a proterozoických granitoidů; čísla jeskyní: 1 – Sloupsko-šošůvské jeskyně, 2 – Holštejnská jeskyně, 3 – Amatérská jeskyně, 4 – Balcarka, 5 – Punkevní jeskyně, 6 – Zazděná jeskyně, 7 – Kateřinská jeskyně.

1983). Limestones deposited on top of the Macocha Formation belong to the Líšeň Formation (Famennian to Middle Viséan), they are several tens of metres thick. Intercalations of calcareous shales in their upper part document Early Tournaisian, rarely Early Visean low sea level stages.

Rocks of the Moravian Karst were deformed during the Variscan Orogeny. According to Dvořák et al. (1984), the Late Devonian to Late Carboniferous deformations have largely synsedimentary character, much like displacements along major faults bounding large blocks or plate complexes formed by the old fundament. However, the limestones were mostly deformed by folds with NNE-SSW-trending axes, accompanied by cleavage. These youngest deformations are represented by strike-slip plate movements along NNE-SSW – to NNW-SSE-striking faults linked with the final stage of the Variscan tectogeny (Dvořák and Pták, 1963). Based on modern interpretations, this deformation style originated in the Moravian Shear Zone, being connected with thrust faults and larger displacements of Paleozoic sediments covering the crystalline basement (Hladil et al., 1999).

In the Jurassic (Callovian to Oxfordian), limestones of the Moravian Karst were transgressed by the sea. The sediments deposited, represented by cherty limestones and calcareous sandstones, attain 50 m in thickness (e.g., Bosák, 1978; Hanzlíková and Bosák, 1978). These platform sediments are preserved in the central Moravian Karst, in continuation of the Blansko Graben and in southern segment of the karst at Hády Hill near Brno. Other preserved sediments are the relics of clays, fine-grained quartz sands and sandy gravels, described as the Rudice Member. These terrestrial deposits are probably of Lower Cretaceous age (Kettner, 1960; Panoš, 1963; Bosák, 1977). They were overlain by quartzose sandstones in the early Late Cretaceous (Cenomanian). Originally, the Cretaceous sediments probably covered the whole Moravian Karst area (e.g., Dvořák et al., 1993) but they were almost completely eroded in the Paleogene. Sediments of the last marine transgression covered the whole karst area in the Neogene: relics of fluvial sands and sandy gravels of Ottnangian age and marine calcareous clays of Lower Badenian age are present in the Moravian Karst and its neighbourhood. Now, they are preserved only as fillings of the Lažánecké and Jedovnické valleys in thicknesses of ca. 140 m (Schützneroová-Havelková, 1958; Dvořák, 1994).

4. Methods

The key sections in cave sediments were drawn at the scale 1:10. Lithological terminology of the sediments was based on their grain-size parameters. Grain-size characteristics of silt and clay were specified more exactly by grain-size analyses using the Andreasen method Bezvodová et al. (1985). Based on sedimentary structures the genesis of the individual sediment bodies was interpreted. Geophysical measurements were used for a precise determination of morphologies and architectures of sediment bodies filling subsurface cavities and karst valleys. A combination of two geophysical methods was always applied. Gravity measurements (Scintrex CG-2 gravimeter) were supplemented with vertical electrical sounding (Geoter I and II apparatus), or shallow seismic measurements (NIMBUS apparatus) were combined with vertical electrical sounding.

The ages of the cave sediments were determined by several independent methods. Speleothems (flowstone horizons and stalagmites) were dated using the $^{230}Th/^{234}U$ method (α-particle counting – see e.g., Harmon et al., 1975) in the Uranium-Series Laboratory of the Institute of Geological Sciences of the Polish Academy of Sciences in Warsaw and at the University of Bergen in Norway. Radiocarbon dating of charcoal and bones was commissioned to the Beta Analytic Radiocarbon Dating Laboratory, Florida,

USA. In one case, the age of fluvial sediments was determined by measurement of ^{10}Be and ^{26}Al isotope contents in quartz pebbles. This method allows to recognize the last exposition of pebbles to the cosmic radiation before their transport to the cave (see NISHIIZUMI et al., 1986). The dating was performed at the Purdue University, Indiana, USA. Paleomagnetic record was measured in both detrital and chemogenic deposits for age determination by correlation with paleomagnetic record from sediments with established paleomagnetic time scale. Measurements of oriented samples of unconsolidated sediments and speleothems were performed in the paleomagnetic laboratories of the Institute of Geology AS CR and the Michigan Technological University, USA.

5. Sediments in the cave systems of the northern segment of the Moravian Karst

5.1. Holštejnská Cave

The Holštejnská Cave lies on the N periphery of the Moravian Karst, in the half-blind Holštejnské Valley, which continues southwards to the Suchý žleb Canyon. The entrance to the Holštejnská Cave is located at the foot of the western slope of the valley at 470 m a. s. l. This ponor cave is formed by a horizontal corridor, posing the upper level of a cave system, mostly yet unexplored. Its lower level is the Cave No. 68, lying 60 m deeper (Fig. 4). The two levels are interconnected by vertical cavities filled with sediment. The Holštejnská Cave is a 40–50 m broad corridor filled with several sediment

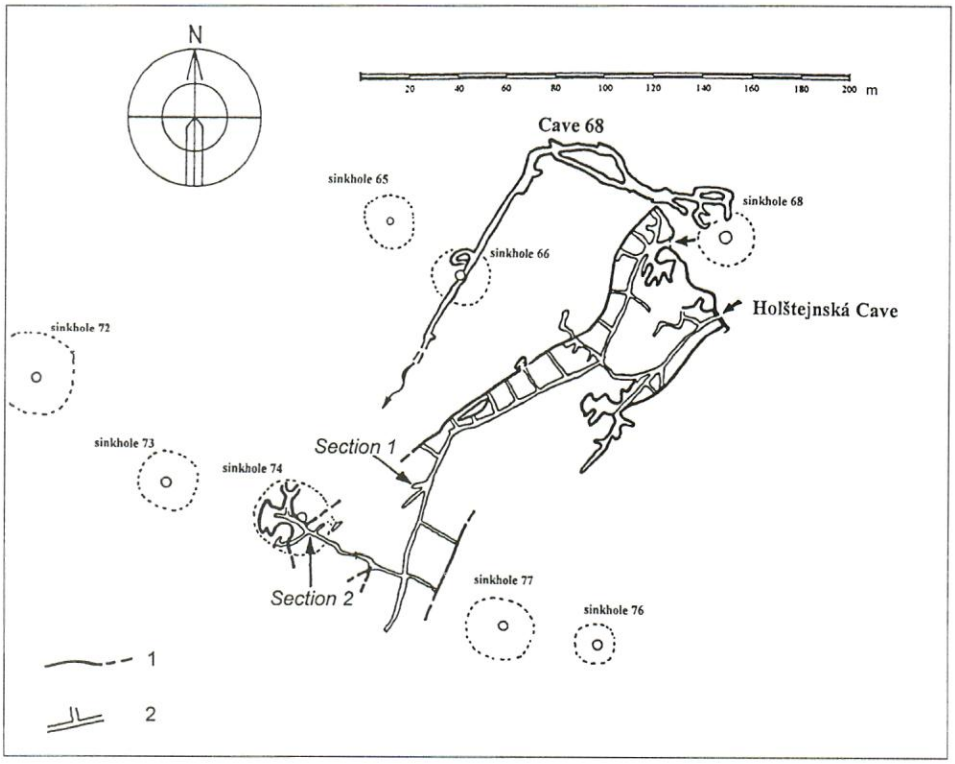

Fig. 4. Sketch-map of the Holštejnská Cave and Cave No. 68 (after ZATLOUKAL et al., 1996). 1 – limestone walls of the cave; 2 – excavated corridors in cave sediments.

Obr. 4. Mapka Holštejnské jeskyně a Jeskyně č. 68 (podle ZATLOUKALA et al. 1996). 1 – vápencové stěny jeskyně, 2 – chodby vykopané v jeskynních sedimentech.

bodies of different ages. Local cavers excavated corridors in sediment fill of the Holštejnská Cave more than 700 m long with the aim to penetrate to yet unknown rooms. Two sections were studied in detail (see Fig. 4).

5.1.1. Lithology of sediments

Section 1, perpendicular to the flow direction of the subsurface stream, shows three sedimentary units (Fig. 5). The oldest sediments are formed by sandy gravel with no bedding, often cemented with carbonate (Unit A). The gravel is dominated by strongly weathered greywacke clasts with average size of 5 cm and max. size of 15 cm. Surface of this sandy gravel is locally overlain by relics of sandy silt. Unit A is covered by flowstone layers. The above lying clayey silt with no bedding (Unit B) occasionally contains lenses of sandy gravel and limestone blocks or flowstone. Surface of this unit is also overlain by relics of flowstone layers (Fig. 5). The youngest sediments are horizontally stratified, locally cross-bedded, medium- to coarse-grained sand to sandy gravel alternating with beds of clayey silt (Unit C – see Fig. 6). Channels filled by Unit C are eroded into both older units. The upper portion of the youngest sediments (Unit C) occasionally contains lenses of sandy gravel with rounded quartz clasts up to 2 cm in size.

Section 2, oriented parallel to the flow direction, shows only Units A and C (Fig. 7). Unit B was eroded by the subsurface stream in this section. The older Unit A is composed of sandy gravel with greywacke clasts with average size of 3 cm and max. size of 15 cm. These are overlain by Unit C – beds of clayey-sandy silt and medium-grained sand. Surface of this unit has been eroded by waters coming through a karst chimney located above *Section 2*. This chimney connects the Holštejnská Cave with sinkhole No. 74 on the karst plateau (see Fig. 4). A flowstone layer precipitated on the surface of the youngest fluvial sediments after the clastic deposition terminated. The underlying clayey

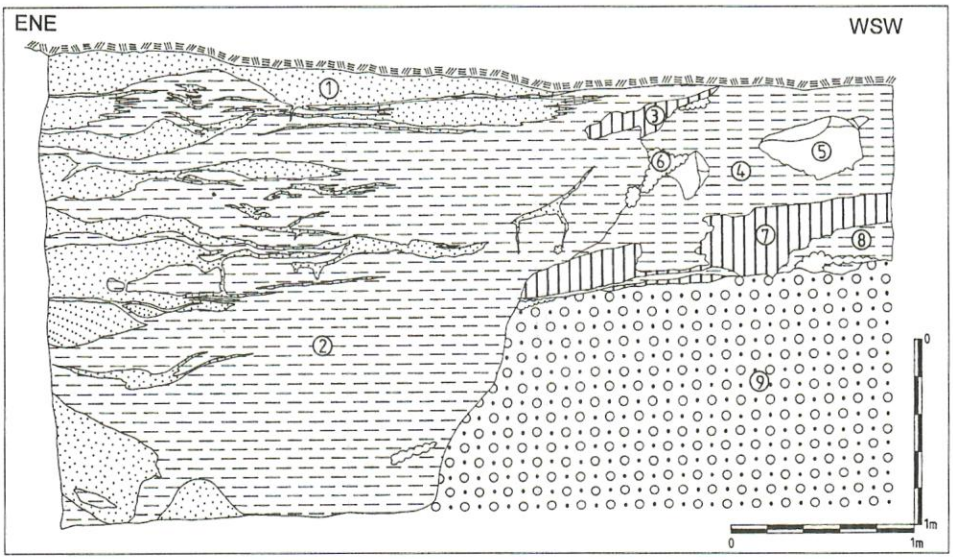

Fig. 5. Section 1, the Holštejnská Cave. Unit C: 1 – medium– to coarse-grained sand; 2 – clayey silt 3 – relic of flowstone layer Unit B: 4 – clayey silt; 5 – limestone block; 6 – calcareous concretion 7 – relic of flowstone layer Unit A: 8 – sandy silt 9 – sandy gravel.

Obr. 5. Profil 1, Holštejnská jeskyně. Jednotka C: 1 – středně až hrubě zrnitý písek, 2 – jílovitý prach, 3 – relikt sintrové vrstvy; jednotka B: 4 – jílovitý prach, 5 – vápencový blok, 6 – karbonátová konkrece, 7 – relikt sintrové vrstvy; jednotka A: 8 – písčitý prach, 9 – písčitý štěrk.

silt was cemented by the carbonate. Stalagmites up to 32 cm long, composed of white carbonate with light grey laminae, were formed atop the flowstone layer.

The youngest sediments in *Section 2* are greyish brown to grey mostly massive clayey silts. These sediments are developed around lower ends of longer soda straw stalactites precipitated beneath the ceiling of the cave corridor (Fig. 7).

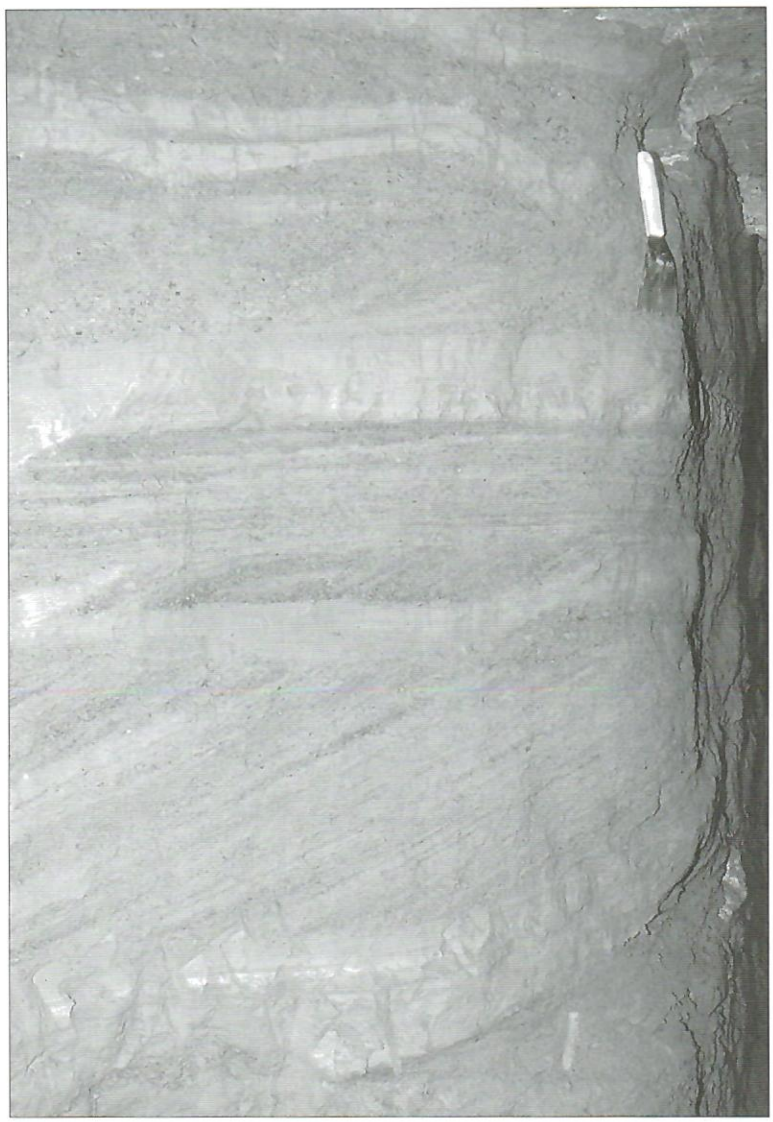

Fig. 6. Holštejnská Cave – fluvial sediments (Unit C). Cross-bedding and horizontal stratification in sand, horizontal stratification in clayey silt following bottom irregularities (Photo by J. Kadlec).

Obr. 6. Holštejnská jeskyně – fluviální sedimenty (jednotka C). Šikmo a horizontálně zvrstvený písek a horizontálně zvrstvený jílovitý prach, vrstvy kopírují nerovnosti v podloží (foto J. Kadlec).

5.1.2. Age of sediments

The oldest fluvial sandy gravel forming Unit A was transported into the cave within the period of 0.8 to 1.1 Ma, as evidenced by the ratios of ^{10}Be and ^{26}Al isotopes measured in quartz pebbles from these deposits (KADLEC et al., 2000). Fluvial sandy silt preserved on the surface of this sandy gravel shows reverse paleomagnetic polarity, thereby indicating higher age of sediments than the Brunhes/Matuyama paleomagnetic boundary – i.e. 780 ka. Flowstone layer preserved in a relic on the surface of Unit A consists of two parts separated by a silt lamina. The lower part of the carbonate bed shows reverse paleomagnetic polarity (ŠROUBEK and DIEHL, 1995) and Th/U age exceeding the limits of this method, i.e. 350 ka (HERCMAN et al., 1997). The $^{234}U/^{238}U$ isotope ratio in the carbonate, however, indicates age lower than 1.2 Ma. This means that the lower part of the flowstone layer and the underlying sandy silt are again older than the Brunhes/Matuyama paleomagnetic boundary. The age of the upper part of the flowstone layer as revealed by Th/U dating is 230 +32/–44 ka and 176 +25/–30 ka. Similar data were produced by older dating of flowstone from the upper part of this flowstone layer: 258 +44/–32 ka and 153 +24/–21 ka (GLAZEK et al., 1995). The above given results suggest that the hiatus in flowstone precipitation lasted ca. 500,000 years.

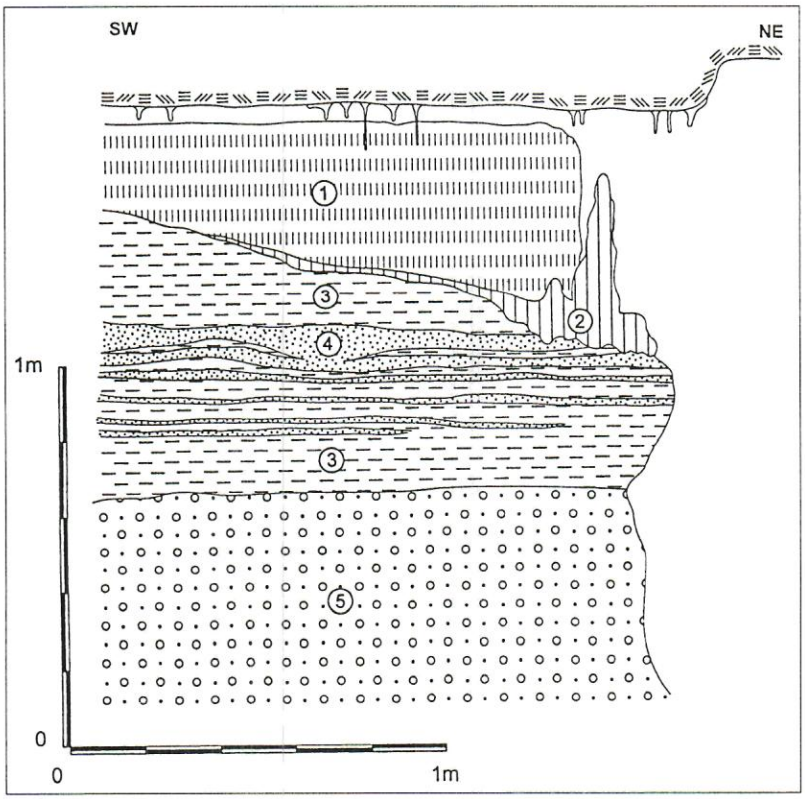

Fig. 7. Section 2, the Holštejnská Cave. 1 – infiltration clayey silt with pottery fragments at the base; 2 – flowstone layer with stalagmite; Unit C: 3 – clayey silt, 4 – sand; Unit A: 5 – sandy gravel.
Obr. 7. Profil 2, Holštejnská jeskyně. 1 – infiltrační jílovitý prach s fragmenty keramiky při bázi polohy, 2 – sintrová vrstva se stalagmitem; jednotka C: 3 – jílovitý prach; jednotka A: 5 – písčitý štěrk.

The relic of a flowstone layer overlying Unit B was dated by the Th/U method at 121 +10/–10 ka. This means that fluvial clayey silt of Unit B was deposited in the penultimate glacial period between 153 +24/–21 and 121 +10/–10 ka. The latter date also gives the maximum age of the base of the fluvial Unit C (see Fig. 5). The end of the deposition of these youngest clayey silt, sand and sandy gravel is defined by the age of the flowstone layer with stalagmites overlying Unit C and exposed in *Section 2* (see Fig. 7). Seven segments from the axial part of 32 cm long stalagmite from *Section 2* were dated by the Th/U method (Tab. 1). The base of the stalagmite was formed at 13.3 +0.3/–0.3 ka, while its apex at 4.7 +1.1/–1.1 ka. The youngest fluvial Unit C, lying below the stalagmite, was therefore deposited in the last glacial period.

Table 1. The $^{230}Th/^{234}U$ ages of stalagmite segments from Section 2.
Tabulka 1. $^{230}Th/^{234}U$ stáří stalagmitu z profilu 2.

distance from stalagmite top (mm)	age (years BP)	1σ error (years)
0– 11	4 700	±1100
12– 31	5 830	±710
90–101	7 600	±900
120–135	7 800	±700
148–163	10 200	±800
231–245	11 300	±750
307–318	13 300	±300

In the youngest infiltration sediments in *Section 2*, a charcoal was sampled from the middle part of the clayey silt bed and dated by radiocarbon method. This dating, corrected by the dendrochronological chart, revealed that the cinder is younger than AD 1665. The pottery the fragments of which were found at the base of these deposits was made in the 14th century (R. Zatloukal, pers. comm. 1995)

5.1.3. Genesis of sediments

Fluvial deposition in the Holštejnská Cave was closely linked with development of the Holštejnské Valley. This half-blind valley has been formed since the Late Paleogene (Panoš, 1963; Štelcl, 1963, 1964). Also horizontal corridor of the Holštejnská Cave probably originated at the end of the Paleogene (Hypr, 1980). During the Lower Miocene (before the Badenian marine transgression), the Holštejnské Valley was deepened and drained by the lower cave level (Cave No. 68) towards the Amatérská Cave system, which originated at the end of the Lower Miocene (Panoš, 1963; Kadlecová and Kadlec, 1995; see Chapter 6.1). The Holštejnská Cave was then located 60 m above the valley bottom (Fig. 24). The Holštejnské Valley was subsequently filled with fluvial sediments up to 60 m thick (Dvořák, 1961; Kadlec, 1996).

The age of the oldest fluvial sediments in the Holštejnská Cave documents that at 0.8–1.1 Ma, the Holštejnské Valley was filled with fluvial sediments and a stream could enter the Holštejnská Cave. Heavy mineral contents of the oldest fluvial deposits (Unit A) in the Holštejnská Cave document their source in greywackes located north of the Holštejnské Valley (Otava and Vít, 1992). During the Early, Middle and Late Pleistocene, the stream repeatedly entered the cave corridor. Water generated vertical karst connections between the Holštejnská Cave (upper level) and Cave No. 68 connected with the Amatérská Cave (lower level). Flowing through the Holštejnská Cave, the stream eroded older fluvial deposits forming channels. As a result, fluvial activity in the cave system documents periods of free vertical connections between the upper and lower cave levels.

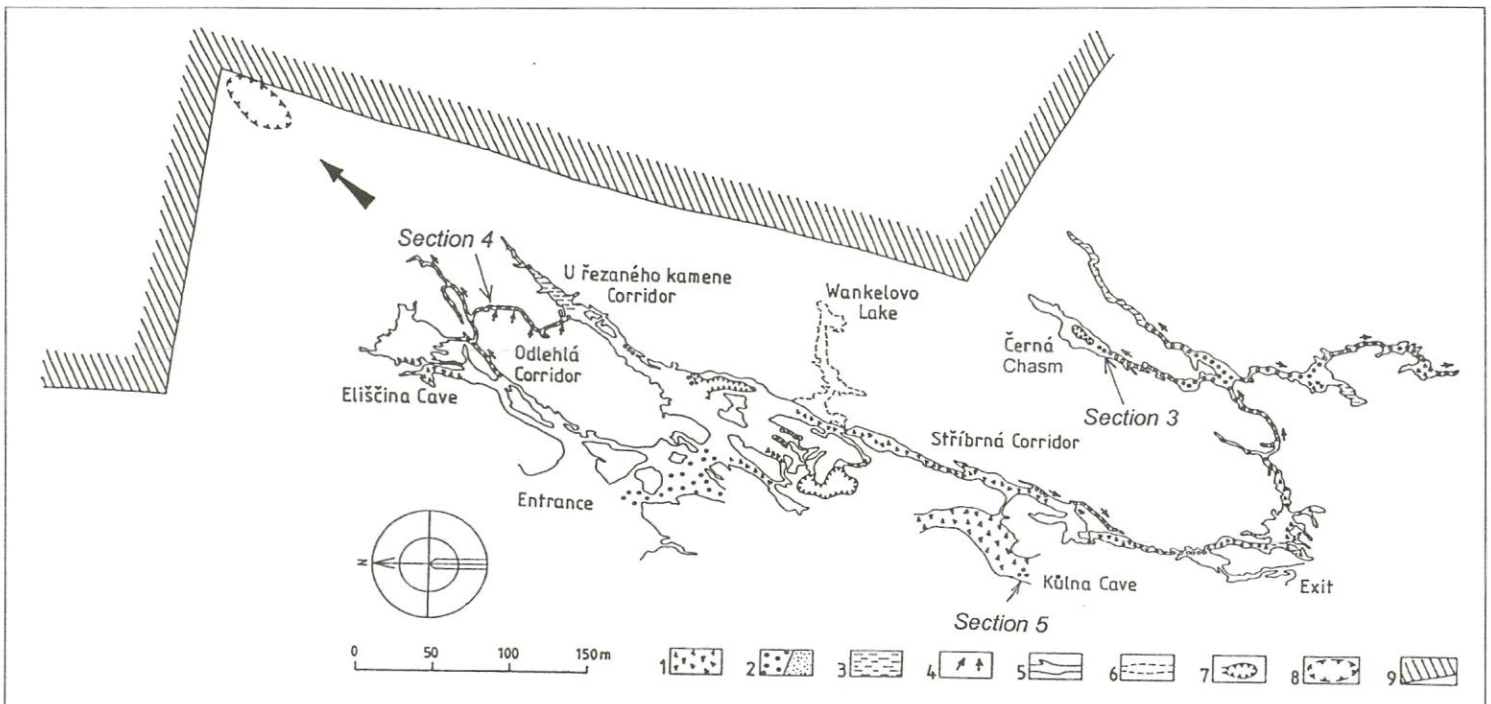

Fig. 8. Sketch-map of the Sloupsko-šošůvská Cave (modified after Absolon, 1970a). 1 – limestone talus; 2 – sandy gravel/sand; 3 – clayey silt; 4 – flow direction of subsurface stream; 5 – upper cave level; 6 – lower cave level; 7 – chasms connecting upper and lower cave levels; 8 – supposed chasm filled with sediments, an arrow indicating sediment transport direction; 9 – boundary of limestone and greywacke.

Obr. 8. Mapka Sloupsko-šošůvských jeskyní. 1 – vápencová suť, 2 – písčitý štěrk/písek, 3 – jílovitý prach, 4 – směr proudění podzemního toku, 5 – horní jeskynní úroveň, 6 – spodní jeskynní úroveň, 7 – propasti spojující horní a spodní úroveň, 8 – předpokládaná propast vyplněná sedimenty, velká šipka ukazuje směr transportu sedimentů, 9 – hranice vápence a droby.

After these paths became blocked, sediments were deposited and the Holštejnská Cave was repeatedly filled with fluvial sediments. After filling of the cave the Holštejnské Valley was drained by surface stream to the south, towards the Suchý žleb Canyon.

The youngest infiltration clayey silt exposed in *Section 2* was vertically transported into the cave by rainwater pouring through sinkhole No. 74 and the chimney from the karst surface above the cave (see Fig. 4). These processes were probably related with the deforestation and agricultural activities in the 17th and 18th centuries, which resulted in increased sediment erosion on the karst surface.

5.2. Sloupsko-šošůvská Cave

The Sloupsko-šošůvská Cave lies on the N periphery of the Moravian Karst, in half-blind Sloupské Valley located 3 km W of the Holštejnské Valley. Morphologically, the Sloupské Valley gradually continues south passing into the Pustý žleb Canyon. The entrance to the Sloupsko-šošůvská Cave lies at the foot of the eastern valley slope at 465 m a. s. l. The cave system comprises the upper and the lower subhorizontal cave levels interconnected by several chasms up to 70 m deep. The length of the whole system exceeds 6 km. The modern stream, known as the Sloupský Creek, disappears in the W part of the upper level, passes through unexplored vertical paths and re-appears at the lower level, then flowing to the Amatérská Cave. Cave sediments of different ages are preserved at a number of locations at the upper level of the cave system. Cave sediments

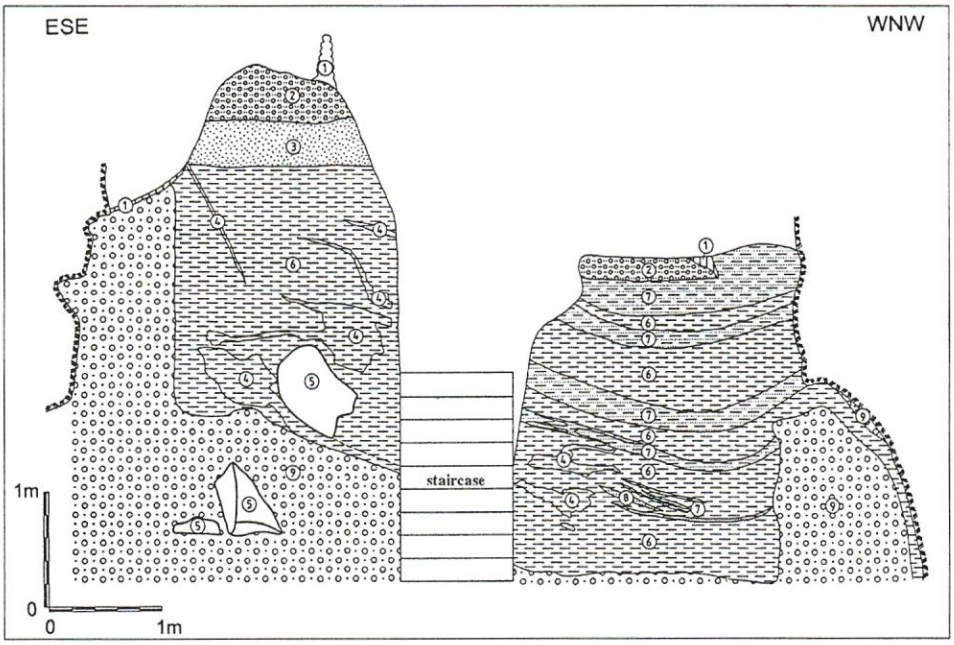

Fig. 9. Section 3, the Sloupsko-šošůvská Cave. 1 – stalagmite; Unit C: 2 – sandy gravel; 3 – sand; 4 – clayey to sandy silt cemented with $CaCO_3$; 5 – limestone blocks; Unit B: 6 – clayey to sandy silt; 7 – laminae of clayey silt and fine-grained sand; 8 – sand; Unit A: 9 – sandy gravel with strongly weathered rounded greywacke clasts.

Obr. 9. Profil 3, Sloupsko-šošůvské jeskyně. 1 – stalagmit; jednotka C: 2 – písčitý štěrk, 3 – písek, 4 – jílovitý až písčitý prach tmelený $CaCO_3$, 5 – bloky vápence; jednotka B: 6 – jílovitý až písčitý prach, 7 – laminy jílovitého prachu a jemnozrnného písku, 8 – písek; jednotka A: 9 – písčitý štěrk se silně zvětralými valouny droby.

near the Černá Chasm, in the Odlehlá Corridor and in the Kůlna Cave were studied in detail – see Fig. 8.

5.2.1. Lithology of sediments

Section 3 with several preserved sedimentary units (Fig. 9) lies near 70 m deep Černá Chasm. The section is oriented perpendicular to the flow direction of the subsurface stream. The basal unit is composed of sandy gravel with rounded greywacke clasts of average size of 3 cm (Unit A). The size of the clasts increases downwards up to 17 cm. Clasts are strongly weathered. Pebbles of red greywacke are frequently included. Occasionally, gravel contains lenses of coarse-grained sand. In Unit A, the subsurface stream eroded a channel with steep banks (see Fig. 9). The channel is filled with light brown clayey silt with laminae of fine sand, 0.5–15 mm thick (Unit B). At boundaries with the ambient less permeable clayey silt, bases and upper surfaces of sand laminae are often accentuated by rusty red lines coloured by Fe-oxides. These fine sediments are incised by another shallow channel filled with sandy gravel with rounded greywacke clasts up to 7 cm in size (Unit C).

Remains of sandy gravel are cemented to limestone walls in the neighbourhood of the section. Gravel consists of rounded greywacke clasts with average size of 3 cm and maximum size of 15 cm (Unit D). Clasts are weakly weathered. No weathered red greywackes frequent in the oldest sandy gravel appear in Unit D. In a cross-section perpendicular to *Section 3*, loose sandy gravel of Unit C are interlayered between cemented gravel (Unit D) and underlying fine sediments (Unit B; Fig. 10). This phenomenon can be called a "stratigraphic sandwich" (sensu Osborne 1984).

An extensive *Section 4* is exposed in the Odlehlá Corridor in the NW part of the upper level of the Sloupsko-šošůvská Cave. The corridor has been excavated in sandy gravel with rounded greywacke clasts of average size of 4 cm and maximum size of 20 cm. Sandy gravel frequently display imbrication of pebbles, indicating northeasterly to easterly flow direction of the subsurface stream – i.e., towards the boundary with non-karstic rocks (see Fig. 8). The same flow direction is also indicated by cross bedding and ripple cross-lamination in rare sand beds. A channel up to 120 cm deep was eroded in the upper

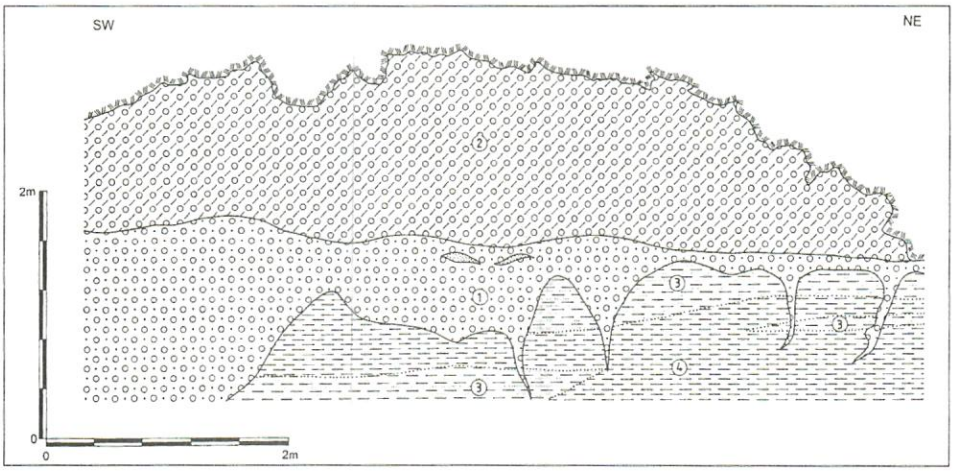

Fig. 10. Section 3 (longitudinal view), the Sloupsko-šošůvská Cave. Unit C: 1 – sandy gravel; Unit D: 2 – sandy gravel cemented to the limestone wall; Unit B: 3 – sandy silt; 4 – clayey silt.

Obr. 10. Profil 3 (podélný pohled), Sloupsko-šošůvské jeskyně. Jednotka C: 1 – písčitý štěrk; jednotka D: 2 – písčitý štěrk přicementovaný k vápencové stěně; jednotka B: 3 – písčitý prach, 4 – jílovitý prach.

part of the sandy gravel by the subsurface stream. It is filled with medium- to coarse-grained cross-bedded sand, rounded greywacke and angular limestone clasts.

The U řezaného kamene Corridor runs parallel to the Odlehlá Corridor. Test-pits excavated under the supervision by WANKEL (1868) and later KŘÍŽ (1900) revealed a sequence with alternating beds of sand- and silt-dominated sediments with beds of clayey silt containing abundant bones of Pleistocene fauna and limestone and greywacke clasts. The whole sequence is subdivided by flowstone horizons and underlain by greywacke gravel (see ABSOLON, 1905–11). Rocky floor of the corridor is inclined towards NE (WANKEL 1882; KŘÍŽ, 1900; SEITL, 1998).

Section 5 is located in the Kůlna Cave, which belongs to the upper level of the Sloupsko-šošůvská Cave system (see Fig. 8). Sediments filling a large, tunnel-shaped corridor are exposed in test-pits excavated during archeological investigations in 1961–1976 (VALOCH, 1988). Grey sandy silt is exposed at the base of the section, being overlain by sandy gravel. The size of rounded greywacke clasts does not exceed 7 cm. Sandy gravel is overlain by beds with variable proportion of limestone talus with clasts up to 50 cm large in sand-silt matrix. The upper part of the section contains talus with a bed of light brown silt with coarse sand laminae in its basal part (Fig. 11).

5.2.2. Age of sediments

Fine silt and sand (Unit B) filling the channel in gravel in *Section 3* shows a reverse paleomagnetic polarity (ŠROUBEK and DIEHL 1995) with an indication of a transition into normal polarity in the upper part of the unit. The sediments are most probably older than the Brunhes/Matuyama paleomagnetic boundary (780 ka); consequently, they were deposited in the Lower Pleistocene or earlier. Lithology and intensity of weathering of sediments in Unit A are comparable with those of the oldest fluvial sediments in the Holštejnská Cave (Unit A). Both units may therefore be of the same age, 0.8–1.1 Ma (see Chapter 5.1.2.). Their similar ages are also suggested by the equal rate of weathering of clay minerals at both localities (VÍT, 1996, 2000).

The age of sandy gravel (Unit D) cemented to the cave walls above the mouth of the Černá Chasm is not reliably documented. They may correspond with fillings exposed in *Section 4*. Here a flowstone layer deposited on the sandy gravel was dated by the Th/U method. The flowstone originated in the last interglacial period at 128 ±12 ka to 112 ±9 ka. Therefore, underlying sandy gravel was deposited not later than in the Middle Pleistocene. Sandy gravel preserved in relics cemented to walls near the mouth of the Černá Chasm (Unit D), if posing a time equivalent of the sandy gravel in the Odlehlá Corridor, was deposited in the period between 780 ka (the age of Unit B) and the last interglacial period, hence also during the Middle Pleistocene. The youngest sandy gravel in *Section 3* (Unit D) was then deposited in the last glacial period and overgrown by stalagmites of probably Holocene age (see Fig. 9).

Stratigraphy of sediments exposed in sections in the Kůlna Cave has been determined on the basis of archeological and paleontological finds, pollen and malacozoological analyses, and radiocarbon and ESR dating (VALOCH, 1988; RINK et al., 1996). Sandy silt and overlying gravel at the base of the section are dated to the last interglacial period using archeological evidence, while the strata above are dated to the individual stadials and interstadials of the last glacial period (see VALOCH, 1988, 1989). This stratigraphic subdivision was confirmed by magnetic susceptibility variations measured in the sandy-silty matrix of individual strata. Variable magnetic properties of the sediments reflect variations in climatic conditions, which controlled the influx of fine sedimentary material into the cave. Detected magnetic susceptibility variations correlate well with VALOCH's

(1988, 1989) attribution of the strata to the individual stadials and interstadials within the last glacial period (Šroubek et al., in press).

5.2.3. Genesis of sediments

Much like the deposition in the Holštejnská Cave, also the fluvial deposition in the upper level of the Sloupsko-šošůvská Cave was closely linked with development of the Sloupské Valley. The upper level of the Sloupsko-šošůvská Cave probably developed in the latest Paleogene (Panoš, 1963). As indicated by the course of cave corridors, the origin of the cave was significantly controlled by faults developed near the tectonic contact between limestones and greywackes (Fig. 8). During the Lower Miocene (before the Badenian marine transgression), the Sloupské Valley was deepened. The upper level of the Sloupsko-šošůvská Cave was then located 55 m above the valley bottom (Fig. 26). During the Pliocene and Pleistocene, the

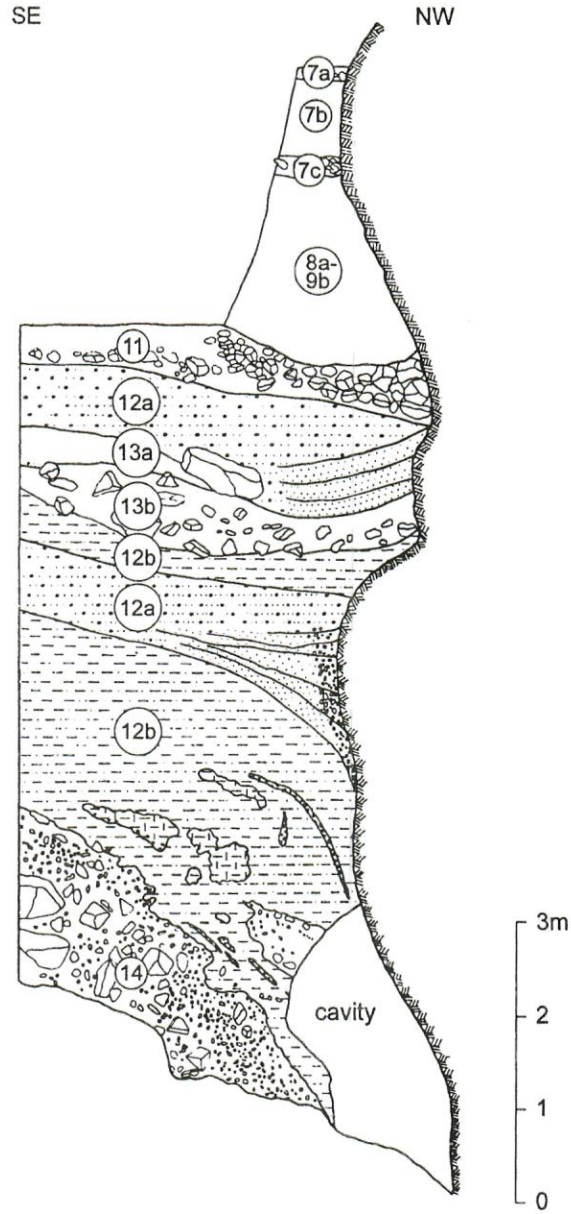

Fig. 11. Section 5, the Kůlna Cave (slightly modified after Valoch, 1988). 7a – limestone talus with sand-silt matrix; 7b – silt with coarse sand laminae in basal part; 7c–11 – complex of beds with variable amount of limestone talus with sandy-silty matrix; 12a – sandy gravel; 13a–13b – limestone talus with sandy-silty matrix; 12b – sandy silt; 14 – coarse limestone talus; beds with limestone talus differing in content of archeological and paleontological remains.

Obr. 11. Profil 5, jeskyně Kůlna (nepatrně upraveno podle Valocha 1988). 7a – vápencová suť v písčito-prachové matrix, 7b – prach, při bázi polohy jsou laminy hrubozrnného písku, 7c–11 – souvrství s kolísajícím množstvím vápencové suti v písčito-prachové matrix, 12a – písčitý štěrk, 13a–13b – vápencová suť v písčito-prachové matrix, 12b – písčitý prach, 14 – hrubá vápencová suť; vrstvy s vápencovou sutí se liší obsahem archeologických a paleontologických pozůstatků.

Sloupské Valley was subsequently filled with fluvial sediments up to 60 m thick (Dvořák, 1961; Kadlec, 1997a).

If the oldest sandy gravel exposed in *Section 3* (Unit A) really correspond to the oldest fluvial sediments in the Holštejnská Cave in their age (0.8–1.1 Ma), in the late Lower Pleistocene the Sloupské Valley had to be filled with fluvial sediments approximately to the present level to allow the stream to enter the upper cave level. At this time, chasms connecting the upper and lower levels were formed, including the Černá Chasm. This vertical connection was filled with fluvial sediments and emptied again several times during the Pleistocene. This is evidenced by the sediments of Unit B filling the channel in Unit A (see Fig. 9). Fine infiltration sediments of Unit B were transported into the cave by rainwater through karst chimneys and joints. Later, they were deposited in stagnant water near the Černá Chasm, which had to be completely filled with sediments. In the Middle Pleistocene, the space above the chasm mouth was filled with fluvial sandy gravel (Unit D) to the height of several metres. Relics of Unit D cemented to the walls evidence a major episode of deposition during which drainage through the lower level was interrupted in the whole cave system, and the chasms as well as a considerable portion of the upper level were filled with fluvial sediments (e.g., Odlehlá Corridor, S part of the Stříbrná Corridor, spaces adjacent to the Černá Chasm, U průsvitných krápníků Corridor). Drainage through some chasms (e.g., the Černá Chasm) was restored later (latest Middle Pleistocene – Upper Pleistocene?). Some chasms connecting the upper and lower levels, however, retained their sediment fill till these days. One of them is located 100–150 m NE of the end of the Odlehlá Corridor, near the tectonic boundary between limestones and greywackes. This chasm was draining the stream which deposited sediments now filling the Odlehlá Corridor (see Fig. 8). Another so far unexplored chasm, completely filled with sediments, lies in the U průsvitných krápníků Corridor, as documented by flow directions indicated by pebble imbrication in the deposits of a subsurface stream flowing towards this chasm as well as by small relics of sandy gravel cemented to limestone walls alike those of Unit D in the Černá Chasm.

The Upper Pleistocene was the period when subsurface stream eroded older fluvial sediments. During flooding episodes, silt- and sand-sized material with frequent limestone clasts and abundant vertebrate bones was transported from the surface or higher located cavities through karst chimneys into corridors of the upper cave level. Such sediments are preserved at a number of locations (e.g., in the U řezaného kamene Corridor and the Stříbrná Corridor) and were ranked within the younger part of the last glacial period by Seitl (1998). These detrital sediments were often overlain by a flowstone layer up to 20 cm thick.

In the Kůlna Cave, conditions for sediment deposition differed, because the cave tunnel is open to the surface at both ends. Large sinkhole leading to the vertical cavities connecting the Kůlna Cave with the lower karst level was formed in the bottom of the southern portion of the corridor. In the last interglacial, a stream was entering the cave through its southern entrance and deposited sandy silt and overlying sandy gravel in the lower part of *Section 5*. The stream descended to the lower cave level through vertical cavities. As shown by sediments exposed in the cave, the proportion of overlying limestone talus increases towards north. The vaulted ceiling of the cave corridor, having an ancient appearance, could not produce many limestone clasts falling down into cave sediments during the last glacial period. Talus filling the corridor was transported through the northern entrance of the Kůlna Cave from a sinkhole. This path was used for the transport of limestone talus and sandy-silty matrix from slopes down to the Kůlna Cave. In the area of the southern entrance, sediments were transported into the cave in the

opposite, i.e., northerly direction. This is evidenced by flow directions revealed by magnetic anisotropy measurements in the matrix of sedimentary beds No. 7–11 in *Section 5* and in neighbouring exposed sections (Šroubek et al., in press). Laminated sandy silt with sand laminae in the lower part of Bed 7b (Fig. 11) are flood sediments, deposited in a shallow depression in the southern entrance to the Kůlna Cave.

5.3. Amatérská Cave

The Amatérská Cave represents the largest segment of the karst system draining the N segment of the Moravian Karst (see Fig. 3). Sumps separate the Amatérská Cave from the ponor caves hosting the Sloupský and Bílá voda streams, as well as from the resurgence Punkevní Cave. This is the main reason why the Amatérská Cave remained inaccessible for such a long time. This situation changed only in 1969, when the 30 m thick fill of sinkhole located 4 km SW of Holštejn was penetrated and the access to the cave was thereby permitted (Šlechta and Ryšavý, 1974; Motyčka et al., 2000). The Amatérská Cave comprises two corridors: lower active corridor and upper flood corridor, the vertical distance between which increases up to 25 m in the downstream direction. These two corridors converge in the upper reach, hosting the Sloupský and Bílá voda streams. Confluence of both streams gives rise to the subsurface Punkva River.

Sediments of subsurface streams are deposited in the Amatérská Cave corridors but, with only a few exceptions, they are not exposed in vertical sections. One of the few sections can be found in the Western Macocha Branch, on the flank of a cave corridor (see Fig. 12). It is a test-ditch excavated in sediments perpendicular to the flow direction of the subsurface stream.

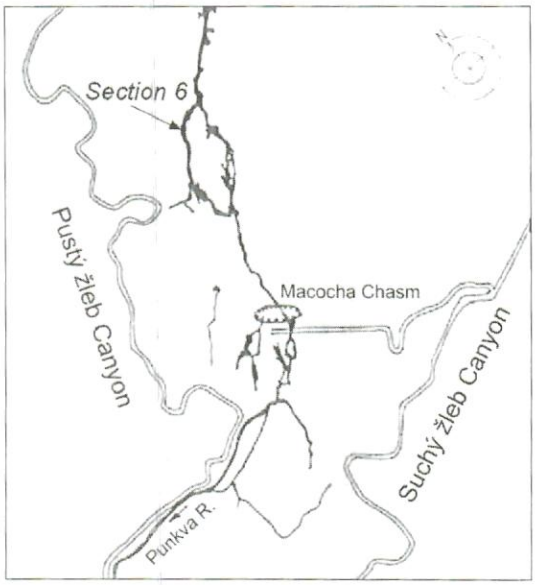

Fig. 12. Position of Section 6 in the Western Macocha Branch in the Amatérská Cave (from Přibyl and Rajman, 1980).

Obr. 12. Pozice profilu 6 v Západní větvi Macošské chodby v Amatérské jeskyni (podle Přibyla a Rajmana 1980).

5.3.1. Lithology of sediments

Sandy gravel containing rather small lens of cross-bedded medium-grained sand is exposed in the lower part of the section. They are overlain by cross-bedded medium-grained sand, and than by sandy gravel containing rounded clasts of Lower Carboniferous rocks up to 1 cm in size. The size of the clasts increases upwards to max. 10 cm. Stalagmites up to 2.5 m long rise from the surface of sandy gravel in the upper part of the slope (ca. 15 m far from the section).

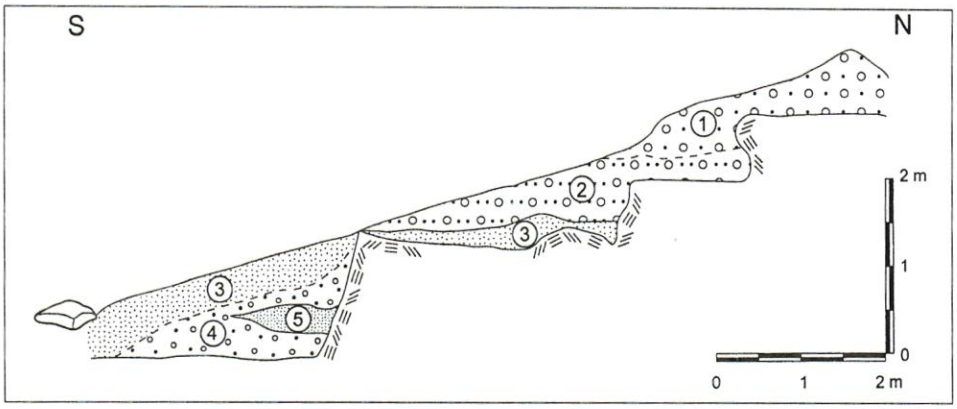

Fig. 13. Section 6, the Amatérská Cave. 1 – sandy gravel with rounded clasts up to 10 cm in size; 2 – sandy gravel with rounded clasts up to 1 cm in size; 3 – cross-bedded medium-grained sand; 4 – sandy gravel with rounded clasts up to 5 cm in size; 5 – cross-bedded medium-grained sand.

Obr. 13. Profil 6, Amatérská jeskyně. 1 – písčitý štěrk s valouny velkými až 10 cm, 2 – písčitý štěrk s valouny velkými až 1 cm, 3 – šikmo zvrstvený středně zrnitý písek, 4 – písčitý štěrk s valouny velkými až 5 cm, 5 – šikmo zvrstvený středně zrnitý písek.

5.3.2. Age of sediments

One of the stalagmites was dated by Th/U method. Its base was dated to 9.42 ±0.75 ka, its middle portion to 5.42 ±0.47 ka and its top to 2.33 ±0.47 ka. Underlying sand and sandy gravel were deposited before the Holocene, most probably during the Late Pleistocene.

5.3.3. Genesis of sediments

Fluvial sand and sandy gravel in the Western Macocha Branch were deposited by a subsurface stream flowing through the corridor towards the Písečná Cave in the Macocha Chasm (see Fig. 30). This path was used by the subsurface stream in times when the lower-lying corridors were blocked due to the roof collapse in near Macocha Chasm (see Chapter 7.7). The Western Macocha Branch was filled with fluvial sediments, reaching to a considerably higher level than today. Now, only relic of fluvial sediments is preserved on the stepwise inclined bottom of the corridor. Fluvial sediments were later eroded by stream. The erosion probably continued till the Holocene, as indicated by undercut flowstone layers of probably Holocene age at several points in the Western Macocha Branch. The Punkva River now flows some 20 m lower through the active level (cf. Přibyl and Rajman, 1980; Motyčka et al., 2000).

5.4. Zazděná Cave

The Zazděná Cave merges into the Pustý žleb Canyon 200 m W of the Macocha Chasm at the altitude of 368 m (see Fig. 3). The cave provides one of the largest expo-

sures of cave sediments in the Moravian Karst. The exposure dates to 1938–1940 when a tunnel 350 m long was excavated in sediments under the supervision of K. Absolon with the aim to penetrate into the then unknown cave system hosting the subsurface Punkva River. These works were, however, left uncompleted (Absolon, 1970b).

5.4.1. Lithology of sediments

Section 7 is exposed in a steep excavated corridor in the NE part of the Zazděná Cave (see Fig. 14). The section is formed by rhythmically alternating beds of sand and clayey silt (Unit A). All beds are sharp-based, consisting of fine silty sand upwards passing into clayey silt. Beds are usually 1–2 cm, exceptionally 5 cm thick (Fig. 15). Sandy portions of the beds are frequently rimmed by rusty red Fe-oxides precipitated at contacts with less permeable clayey silt. Deposition of the rhythmites was interrupted by breaks, during which mud cracks up to 30 cm deep were formed. Other sedimentary structures show sediment deformations due to compaction-related water escape (Fig. 16) or deformations due to fall of limestone blocks (Fig. 17). Coarse limestone talus with sandy-silty matrix is exposed in the central part of excavated corridor (Unit B; see Fig. 14). Limestone clasts have volume up to 1 m^3. The total thickness of sediments exposed in *Section 7* is 33 m.

A 350 m long section exposes detrital sediments with a flowstone horizon in the horizontal tract of the Zazděná Cave. Two test-pits, 8.5 and 5.8 m deep, were excavated in the bottom of the dug out tunnel (Panoš, 1961; Pelíšek, 1975). Nevertheless, none of them reached the rocky bottom and both were later refilled. *Section 8* is situated at the location of test-pit *S1*, now preserved as 1.5 m deep hole. Laminated clayey silt to silty

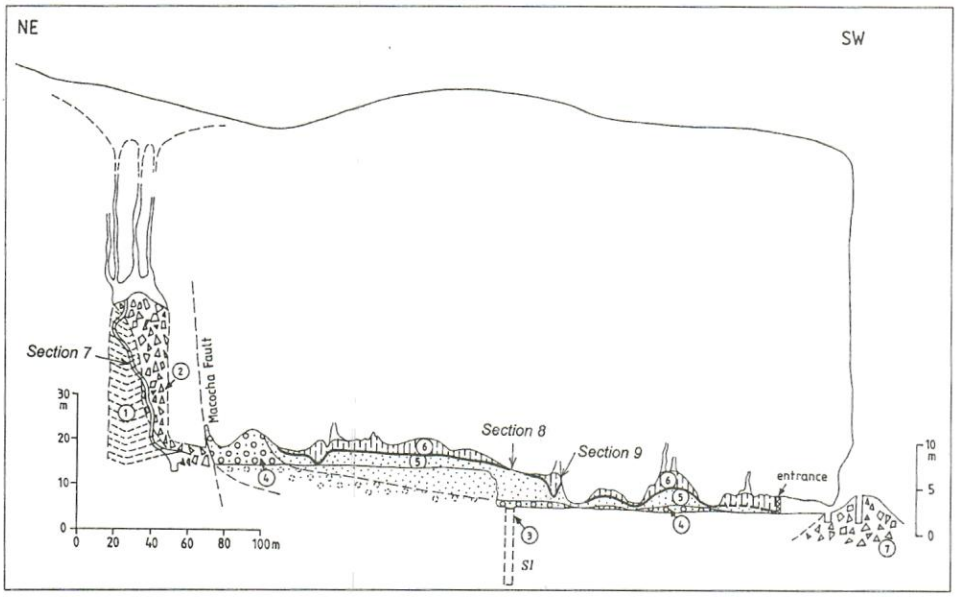

Fig. 14. Zazděná Cave – a longitudinal vertical section. 1 – thinly rhythmically bedded sand and silt (Unit A), 2 – limestone talus with silty matrix (Unit B), 3 – silt and sand exposed in the rest of the test-pit (Unit C), 4 – sandy gravel (Unit D), 5 – sand and clayey silt (Unit D), 6 – laminated clayey silt (Unit E), 7 – limestone talus with sandy matrix (Unit F).

Obr. 14. Zazděná jeskyně, vertikální podélný profil. 1 – tence vrstevnaté písky a prachy (jednotka A), 2 – vápencová suť v prachové matrix (jednotka B), 3 – prach a písek odkrytý ve zbytku sondy (jednotka C), 4 – písčitý štěrk (jednotka D), 5 – písek a jílovitý prach (jednotka D), 6 – laminovaný jílovitý prach (jednotka E), 7 – vápencová suť s pískovou matrix (jednotka F).

Fig. 15. Zazděná Cave – infiltration sediments (Units A). Horizontal stratification in sandy to clayey silt, deformations in the centre represent dripholes (Photo by E. Janoušek).
Obr. 15. Zazděná jeskyně – infiltrační sedimenty (jednotka A). Horizontálně zvrstvený písčitý až jílovitý prach, egutační jamky ve středu obr. porušují horizontální zvrstvení (foto E. Janoušek).

Fig. 16. Zazděná Cave – infiltration sediments (Units A). Sands intercalated with clayey silts. Horizontal stratification is disrupted by compaction induced water escape (the coin diameter is 19 mm; Photo by E. Janoušek).
Obr. 16. Zazděná jeskyně – infiltrační sedimenty (jednotka A). Písky a jílovité prachy. Horizontální zvrstvení porušují textury vzniklé v důsledku úniku vody ze sedimentů v průběhu kompakce (průměr mince je 19 mm, foto E. Janoušek).

clay with occasional beds of medium-grained sand max. 5 cm thick (Unit C) are exposed at the base of the section. Deposits are intersected by numerous clastic dykes filled with sandy gravel, sand and clayey silt from the overlying beds (Fig. 18).

Laminated fine sediments exposed in test-pit *S1* is overlain by sandy gravel with rounded limestone clasts of an average size of 5 cm, occasional rounded clasts of conglomerates of the Devonian basal clastics up to 10 cm in size and angular and oval limestone

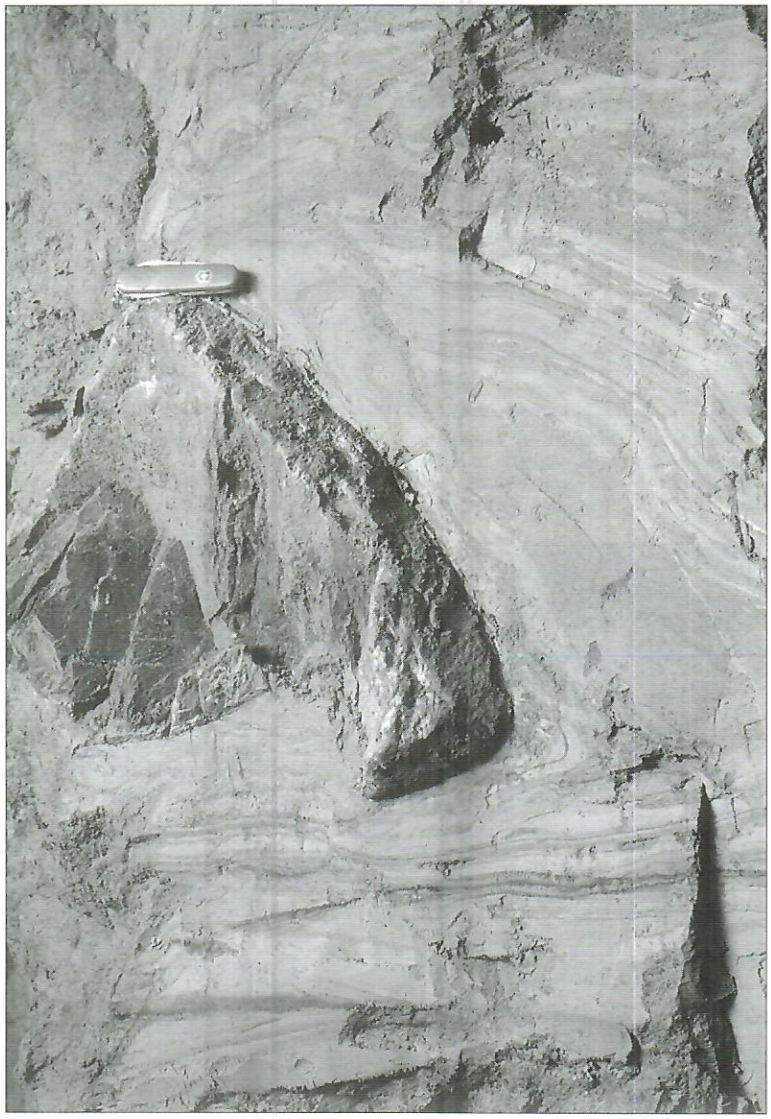

Fig. 17. Zazděná Cave – infiltration sediments (Units A). Primary horizontal stratification in fine sands and clayey silts is deformed by fallen limestone block from a karst chimney 50 m high (Photo by E. Janoušek).

Obr. 17. Zazděná jeskyně – infiltrační sedimenty (jednotka A). Původně horizontálně zvrstvené jemnozrnné písky a jílovité prachy jsou deformovány impaktem vápencového bloku vypadlého z krasového komína (foto E. Janoušek).

boulders reaching up to 50 cm in size. The thickness of the gravel bed (ranked also within Unit C for simplicity reasons) varies between 70 and 160 cm. Gravel is overlain by clayey silt and, above, by sandy gravel with rounded clasts of greywackes, siltstones and shales (Unit D). The average clast size is 2 cm, with the largest clasts reaching 7 cm. Gravel also contains angular clasts of limestones and rare limestone blocks with volume up to 1 m^3. Sedimentation continued with the deposition of laminated clayey silt and medium-grained cross-bedded sand with an erosive base. During the break in deposition, later sand bed (Bed 6 on Fig. 18) was dissected by irregular cracks, max. 60 cm long, which were filled with overlying sandy silt. This sandy silt contains irregular lenses of sandy gravel with rounded quartz and angular limestone clasts. Sedimentation terminated by the deposition of medium–grained sands and sandy silts. Vertical wedge-shaped clastic dykes even several metres long intersect the sediments in *Section 8* (Fig. 18).

Section 9 lies only 25 m far from *Section 8* (see Fig. 14) but it provides important information on the genesis of sediments filling the Zazděná Cave. Sandy gravel with rounded limestone clasts of average size of 5 cm and angular as well as rounded limestone boulders up to 50 cm large (Unit C) is exposed at the base. This sandy gravel is conformably overlain by Unit D formed by sandy gravel with rounded greywacke, siltstone and shale clasts 4 cm in size on average, and with beds of medium- to coarse-grained sand and

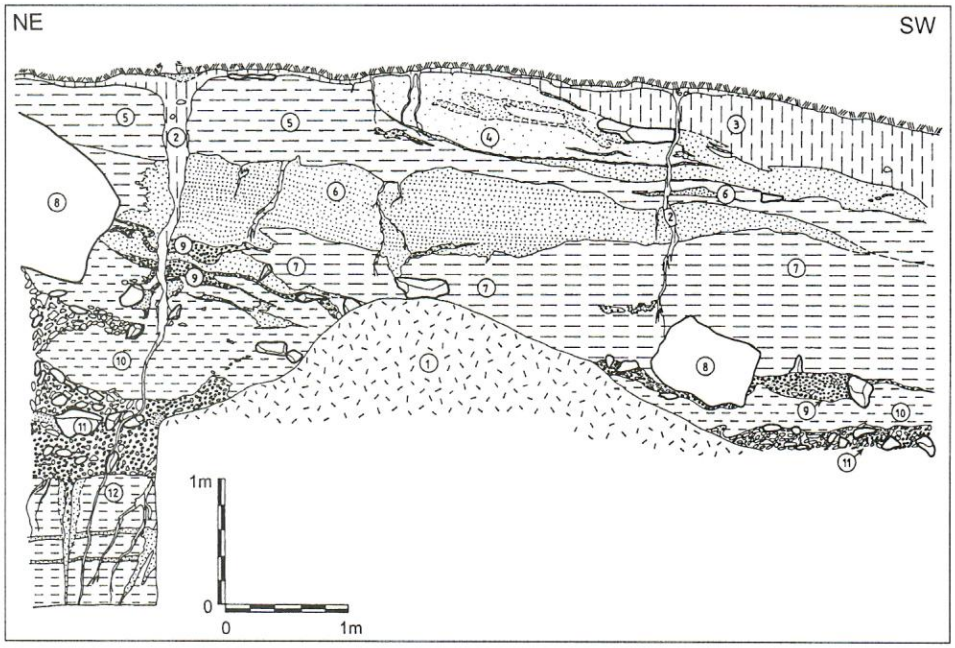

Fig. 18. Section 8, the Zazděná Cave. 1 – material excavated from the test-pit, Unit E: 2 – clayey silt filling clastic dykes, 3 – thin-bedded and laminated clayey silt, Unit D: 4 – sand and sandy silt, 5 – clayey silt, 6 – medium-grained sand, 7 – clayey silt, 8 – limestone blocks, 9 – sandy gravel with rounded clasts of greywackes, shales and limestone, 10 – clayey silt, Unit C: 11 – sandy gravel with limestone clasts, 12 – clayey silt to silty clay with sand beds intersected by clastic dykes filled with silt, sand and sandy gravel.

Obr. 18. Profil 8, Zazděná jeskyně. 1 – materiál vykopaný ze sondy; Unit E: 2 – jílovitý prach vyplňující klastické žíly, 3 – tence vrstevnatý a laminovaný jílovitý prach; Unit D: 4 – písek a písčitý prach, 5 – jílovitý prach, 6 – středně zrnitý písek, 7 – jílovitý prach, 8 – bloky vápence, 9 – písčitý štěrk s valouny droby, břidlice a kameny vápence, 10 – jílovitý prach; Unit C: 11 – písčitý štěrk s vápencovými klasty, 12 – jílovitý prach až prachovitý jíl s pískovými polohami porušený klastickými žilami vyplněnými prachem, pískem a písčitým štěrkem.

clayey silt (Fig. 19). Younger laminated clayey silts (Unit E) fill a funnel-shaped depression in Unit D. Unconformable boundary between both units is accentuated by a layer coloured in black by Mn-oxides. Unconformities are also present within laminated fine sediments of Unit E (Fig. 20). The whole *Section 9* is transected by a vertical wedge-shaped clastic dyke filled with clayey silt (Beds 1–3 on Fig. 19).

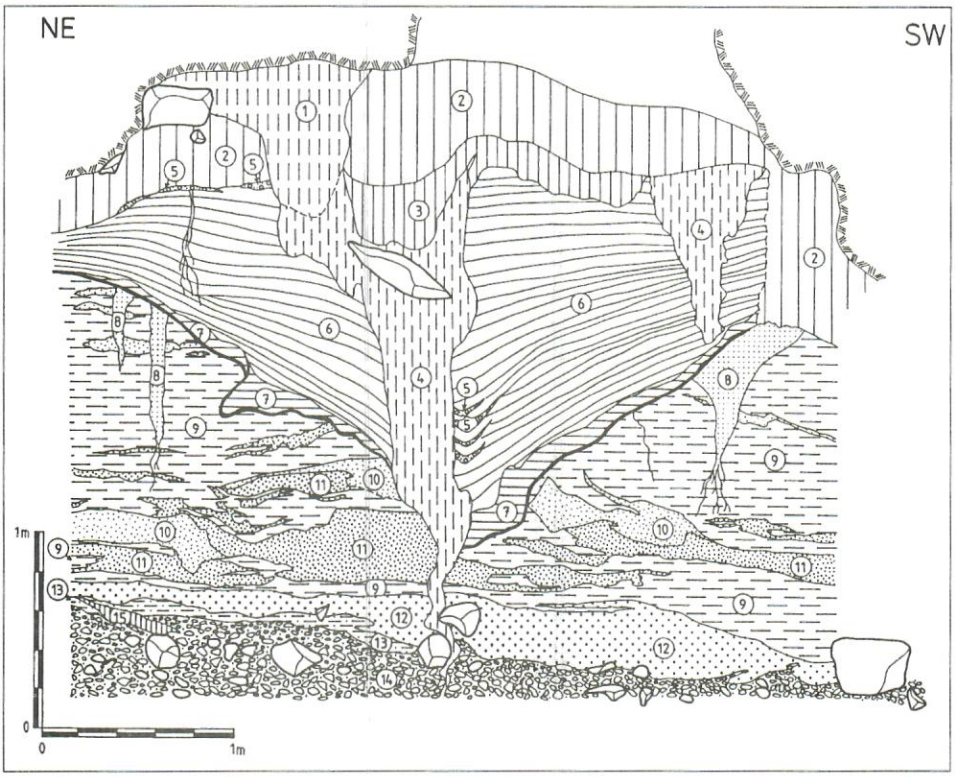

Fig. 19. Section 9, the Zazděná Cave. Unit E: 1 – dark brown massive clayey silt, 2 – light brown clayey silt with beds of grey silt max. 2 cm thick, 3 – brown silt with indistinct lamination, 4 – brown-grey massive clayey silt with limestone block, 5 – lenticular beds of coarse-grained sand to sandy gravel with rounded quartz clasts max. 3 mm in size, 6 – laminated clayey silt, 7 – remains of older fill of the depression formed by thin beds of yellow sandy silt and rusty fine-grained sand bounded by rusty contours of precipitated limonite a layer coloured in black by Mn-oxides at the base of Unit E, 8 – coarse-grained sand to sandy gravel with quartz granules, Unit D: 9 – clayey silt with lenses of fine-grained sand, 10 – medium-grained sand, 11 – medium-grained sand with abundant clasts of clayey silt, 12 – medium- to coarse-grained sand, passing to sandy gravel near the base, 13 – medium-grained sand, 14 – sandy gravel – upper portion of the bed is composed of pebbles of greywacke, siltstone and shale, lower portion of the bed is composed of limestone pebbles and boulders, 15 – redeposited fragment of weathered flowstone.

Obr. 19. Profil 9, Zazděná jeskyně. Jednotka E: 1 – tmavě hnědý masivní jílovitý prach, 2 – světle hnědý jílovitý prach s vrstvičkami šedého prachu o mocnosti do 2 cm, 3 – hnědý prach s náznaky laminace, 4 – hnědošedý masivní jílovitý prach s vápencovým blokem, 5 – čočkovité polohy hrubozrnného písku až písčitého štěrku s valounky křemene velkými do 3 mm, 6 – laminovaný jílovitý prach, 7 – zbytky starší výplně nálevkovité deprese tvořené vrstvičkami žlutého písčitého prachu a rezavého jemnozrnného písku ohraničenými rezavými konturami vysráženého limonitu na bázi jednotky E je vrstvička černě zbarvená Mn-oxidy, 8 – hrubozrnný písek až drobnozrnný písčitý štěrk s valounky křemene; jednotka D: 9 – jílovitý prach s čočkami jemnozrnného písku, 10 – středně zrnitý písek, 11 – středně zrnitý písek s hojnými útržky jílovitého prachu, 12 – středně až hrubě zrnitý písek, při bázi polohy až drobnozrnný písčitý štěrk s valounky břidlice a křemene, 13 – středně zrnitý písek, 14 – písčitý štěrk – svrchní část polohy tvořena valouny droby, prachovce a břidlice, spodní část polohy tvoří valouny a balvany vápence, 15 – redeponovaný fragment zvětralého sintru.

Sandy gravel with quartz granules and angular limestone clasts forms irregular lenses in Unit E. They were deposited into the underlying fluvial sediments at some places (KADLEC, 1994). Concentrations of this gravel and talus bodies are the highest around chimneys leading to the horizontal corridor. This sandy gravel is characterized by the high contents of staurolite in heavy mineral assemblages (VÍT, 1990).

Flowstone horizon up to 20 cm thick was deposited on surface of Unit D in the NE part of the horizontal corridor during the break in deposition between Unit D and Unit E. Calcite forms white and grey laminae 1–6 mm thick (maximum thickness is 28 mm), being recrystallized into crystals perpendicular to the original laminar structure. The youngest part of the flowstone layer is coloured in grey by Mn-oxides.

5.4.2. Age of sediments

The age of rhythmites in *Section 7* was determined by measurements of paleomagnetic record in sediments. Oriented samples were taken in 30 cm intervals from the lower and upper parts of the section. In the upper part, reverse paleomagnetic polarity was recorded in an interval 2 m thick. Most of the sediments in *Section 7* are therefore older than the Brunhes/Matuyama paleomagnetic boundary, i.e., 780 ka. This means that the rhythmites were deposited not later than in the Lower Pleistocene. However, their Tertiary age can not been excluded.

Basal, middle and surficial parts of the flowstone horizon on the surface of Unit D in the NE part of the Zazděná Cave horizontal corridor was dated by the Th/U method. (Tab. 2).

Fig. 20. Zazděná Cave – infiltration sediments (Unit E). Unconformities in laminated clayey silt filling the funnel-shaped depression in Section 9 (Photo by E. Janoušek).

Obr. 20. Zazděná jeskyně – infiltrační sedimenty (jednotka E). Diskordance v laminovaném jílovitém prachu vyplňujícím nálevkovitou depresi v profilu 9 (foto E. Janoušek).

Table 2. The $^{230}Th/^{234}U$ ages of flowstone layer from the Zazděná Cave.
Tabulka 2. $^{230}Th/^{234}U$ stáří sintrové vrstvy ze Zazděné jeskyně.

distance from flowstone layer top (mm)	age (ka BP)	1σ error (ka)
0–15	99.85	+3.30/–3.21
29–45	112.50	+4.55/–4.17
79–89	114.37	+5.05/–4.85

Flowstone was deposited at the beginning of the last Glacial. Clastics of underlying Unit D deposited probably in the last Interglacial. Laminated clayey silts (Unit E) overlying by flowstone were deposited during the last glacial period.

5.4.3. Genesis of sediments

The Zazděná Cave consists of two parts, in which sediments were deposited under different conditions. Vertical cavity in the NE part of the cave passes down into a horizontal corridor leading to the cave entrance (see Fig. 14). The cavity has about 30 m in diameter. It is filled with rhythmically bedded infiltration sand and clayey silt of Unit A exposed in *Section 7*. They were probably derived from filled sinkholes connecting surface of the karst plateau with cavity through large chimneys. Fine sediments were vertically transported by rainwater into the cave where they were deposited in a low-energy environment not affected by flow. Deposition of rhythmites was marked by breaks, characterized by the formation of mud cracks. Rainwater coming from chimneys also eroded the sediment fill of the vertical cavity. As a result, sediments are not deposited horizontally but they dip NE to E at an angle of 5–20°. Vertically circulating water produced minute dripholes in rhythmites (see Fig. 15).

Below huge karst chimneys, rhythmites were eroded by vertically falling waters loaded by limestone talus with clasts reaching volume of 1 m^3 (Unit B) from higher-positioned cavities. The coarse talus with sandy-silty matrix partly filled vertical cavity and it is now exposed in the middle part of steep corridor dug out through sediments.

The oldest sediments in the horizontal corridor of the Zazděná Cave are represented by Unit B, exposed in test-pit *S1* (see Panoš, 1961). Heavy mineral assemblages in the sand (dominant epidote-group minerals and amphibole, low garnet content) correspond with those of sand in Unit A (Vít, 1990, 1996). Both sedimentary bodies are probably derived from sediments filling sinkholes on the surface of the karst and were vertically transported into the cave by rainwater. In the horizontal corridor these infiltration sediments are overlain by bed of sandy gravel with rounded and angular clasts of limestone. The absence of clasts of greywacke, siltstone and shale evidences that the material is of local character and it was transported into cave from higher-positioned, unknown cavities by gravity flows.

Sediments of Unit D in the horizontal corridor were deposited by subsurface stream, as evidenced by clast roundness in sandy gravel and by current-generated structures in sand. Erosional boundaries between individual beds and mud cracks filled with clayey silt indicate that fluvial sedimentation proceeded periodically and intermittently. Cross-bedding and ripple cross-lamination in sand-dominated beds indicate southwesterly flow, i.e. towards the cave entrance. Heavy mineral assemblages of fluvial sandy gravel (Fig. 18 – Bed 9) are dominated by garnet (46 %) prevailing over epidote-group minerals (27 %) and zircon (15 %). Less frequent heavy minerals are amphibole (6 %), apatite, rutile, tourmaline and alterites. This assemblage is characteristic for fluvial sedi-

ments transported into the karst area by streams from areas of non-karstic rocks, such as greywackes, siltstones and shales.

Fluvial sandy gravel with pebbles of Lower Carboniferous rocks forms a wedge-shaped body in the cave corridor (see Fig. 14). In the SW part, close to the cave entrance, this sandy gravel directly overlies psephites with limestone clasts. Further inside the cave, both lithologically distinct bodies are separated by bed of clayey silt. In the NE part of the cave, fluvial sandy gravel is hidden beneath overlying sands and silts and re-appear again at a distance of 300–350 m from the cave entrance. The surface of sandy gravel is rising here; further on, the whole corridor is dug out in these psephites. Fluvial sediments locally contain "floating" limestone blocks up to 1 m^3 in volume. The occurrence of sandy gravel with pebbles of Lower Carboniferous rocks abruptly terminates where the horizontal corridor of the Zazděná Cave is transected by fault, which crosses the near Macocha Chasm (see Fig. 14).

Fluvial sediments were transported into the cave at an anomalous situation probably caused by the collapse of the roof of the Macocha Chasm (see Chapter 7.7). The fall of Macocha Chasm roof resulted in the rise of the subsurface stream level. The Punkva River began to flow through the Amatérská Cave at a higher level and it developed a new path into the Písečná Cave in the Macocha Chasm. After the subsurface stream reached the karstified Macocha Fault, periodical inrushes of waters loaded with sediment into the Zazděná Cave horizontal corridor took place. The same fluvial sandy gravel is preserved in the Amatérská Cave (390 m a. s. l.), the Písečná Cave in the Macocha (400 m a. s. l.) as well as in the Zazděná Cave (370 m a. s. l.).

Fluvial sedimentation was followed by a break, during which only rainwaters entered the cave corridor. These vertically circulating waters eroded fluvial sediments, and funnel-shaped depressions and unusual cylindrical "dripholes" were locally produced and later filled with younger sediments (see Fig. 19). The rainwater contained dissolved $CaCO_3$, which precipitated on the surface of fluvial sediments. A flowstone layer developed on the surface of fluvial sediments in places at the beginning of the last glacial period.

The last glacial period in the Zazděná Cave was characterized by the deposition of Unit E filling horizontal cave corridor up to the ceiling. These fine laminated infiltration sediments were transported by rainwater from karst surface or from higher-positioned cavities fissures and karst chimneys, by mechanism described by Bull (1981). Water periodically penetrating through chimneys eroded even the proper fill of the funnel-shaped depression in *Section 9*, producing a vertical channel filled with massive clayey silt in its central part (Fig. 19). The erosion was associated with formation of minor unconformities, slumps and deformations of laminated sediments in the proximity of the vertical channel.

At many places of the horizontal corridor, the boundary between Unit D and the overlying Unit E is accentuated by Mn-rich horizon precipitated on geochemical barrier of the surface of fluvial sediments.

Fluvial and infiltration sediments were periodically subjected to liquefaction and fluidization during their deposition. Water escaping from pores during sediment compaction produced characteristic water escape structures (e.g., Lowe, 1975). Channels filled with sand grains and clayey silt, as well as minute folds were formed in the sediments perpendicular to the stratification. Fluidized sand locally penetrated into the overlying silt (Fig. 16).

Sections in the horizontal corridor of the Zazděná Cave are commonly intersected by clastic dykes of several generations (see Fig. 18). Their genesis is linked with the subsi-

dence of the sediment fill. Basal part of the sedimentary body is formed by coarse limestone talus (PANOŠ, 1961). Dissolution of limestone blocks resulted in uneven subsidence of overlying clastic sediments and in the deformation of the fill by minute faults. Movements along these dislocations produced minor normal faults as well as reverse faults. Some of them were later widened by flowing water into wedge-shaped forms and filled with younger sediments.

Deposition of fine sediments of Unit D and Unit E indicates that the cave mouth was blocked, preventing water flow away from the horizontal corridor. Pools with stagnant water were established here and fine sediments were deposited. Blockage of the cave mouth can be explained by its closure with fluvial sediments filling the lower course of the Pustý žleb Canyon. However, a more probable explanation is in filling of the mouth by limestone talus, the relics of which are preserved cemented to the ceiling and walls. Talus of the same kind, fallen from the limestone wall above the cave mouth, now forms the portal mound (Unit F). According to molluscs, the age of the upper part of the talus was stated to second half of the Upper Pleistocene and Holocene (LOŽEK and CÍLEK, 1995).

5.5. Kateřinská Cave

Where the valleys of Pustý žleb and Suchý žleb merge together, a narrow limestone crest called Chobot is formed between both canyons. The entrance to the Kateřinská Cave lies in the SW extension of the limestone crest at the altitude of 345 m a. s. l., 8 m above the bottom of the Suchý žleb Canyon. The entrance and the frontal part of the cave (Main Hall) have been known for a long time, while the NE part of the subsurface system was discovered only in 1910 (ABSOLON, 1912).

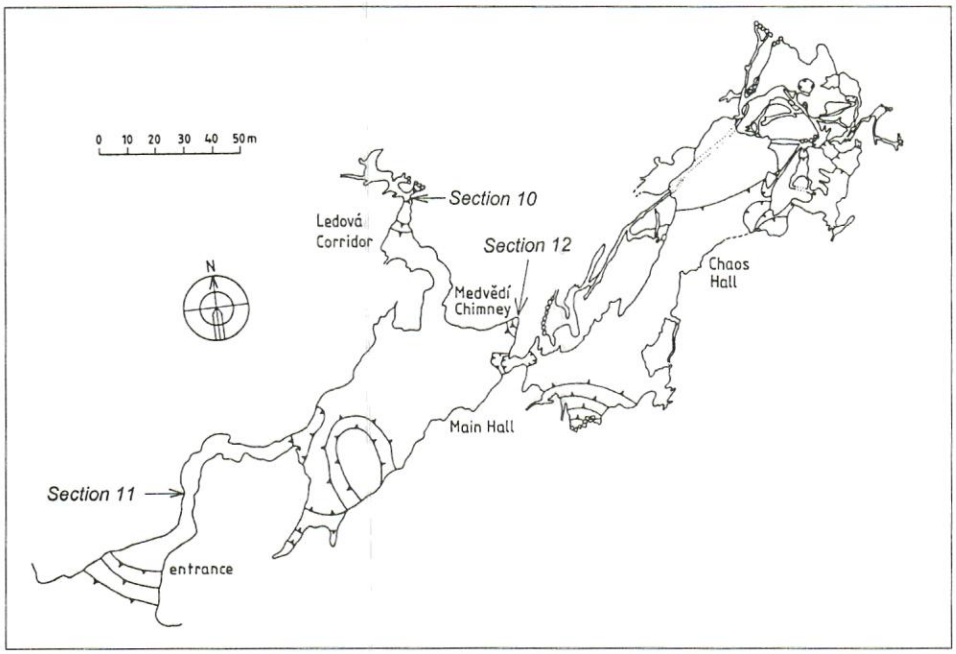

Fig. 21. Sketch-map of the Kateřinská Cave (after ABSOLON 1970a).
Obr. 21. Mapka Kateřinské jeskyně (podle ABSOLONA 1970a).

5.5.1. Lithology of sediments

The most widely distributed sediment in the Kateřinská Cave is limestone talus of different particle size. Limestone blocks cover the bottoms of both large halls (Main Hall, Chaos Hall). Coarse limestone talus also forms large chokes in upper parts of the cave.

Section 10 formed by beds of limestone talus of different particle size with sandy matrix is preserved in inclined chimney leading to the Ledová Corridor (see Fig. 22). Beds of fine talus to coarse sand alternate with beds containing limestone clasts up to 30 cm large. The youngest coarse–grained bed is cemented with carbonate. Beyond the limits of the section, the flowstone forms a layer up to 10 cm thick.

A relic of sandy gravel is preserved near the western wall of the corridor beyond the entrance to the Kateřinská Cave – *Section 11*. Its basal part is composed of limestone peb-

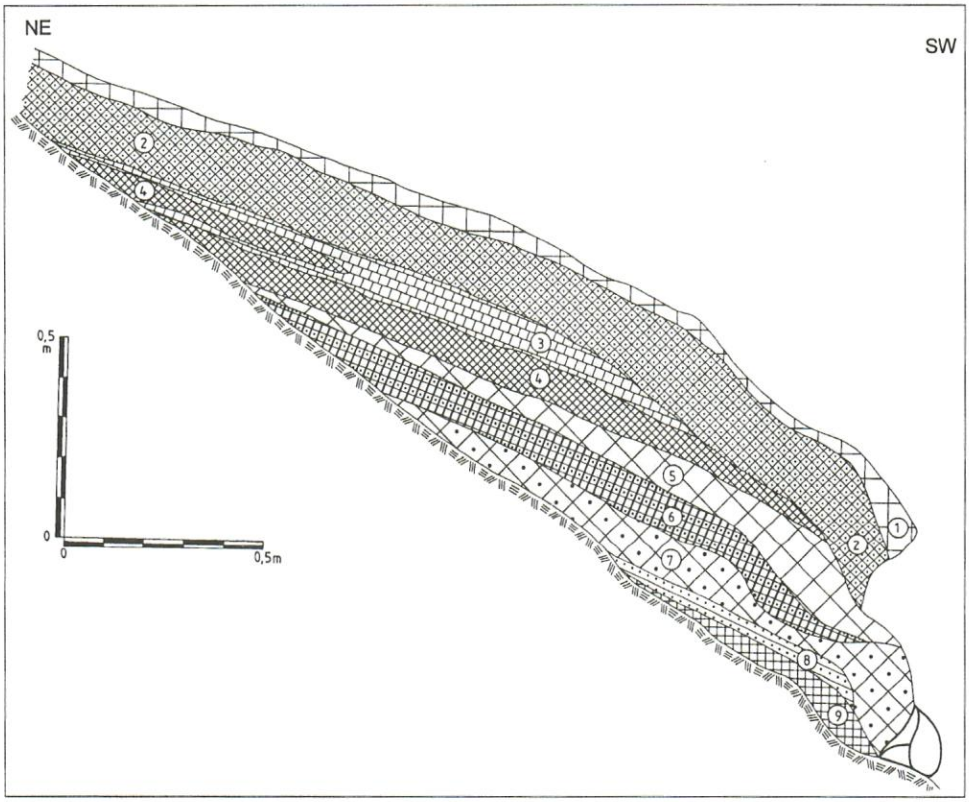

Fig. 22. Section 10, the Kateřinská Cave. 1 – limestone talus with sandy matrix (clast size max. 15 cm), 2 – coarse sand with beds of fine limestone talus 1–2 cm thick, 3 – fine limestone talus with sand matrix (clast size max. 5 cm), 4 – fine limestone talus with sand matrix (clast size max. 2 cm), 5 – limestone talus with sand matrix (clast size max. 10 cm), 6 – fine limestone talus with sandy matrix (clast size max. 2 cm), 7 – limestone talus with sandy matrix (clast size max. 30 cm), 8 – fine limestone talus with sand matrix, 9 – limestone talus with sandy matrix (clast size max. 10 cm).

Obr. 22. Profil 10, Kateřinská jeskyně. 1 – vápencová suť v písčité matrix (klasty velké do 15 cm), 2 – hrubozrnný písek s vrstvičkami drobné vápencové suti o mocnosti 1–2 cm, 3 – drobná vápencová suť v písčité matrix (velikost klastů do 5 cm), 4 – drobná vápencová suť v písčité matrix (klasty velké do 2 cm), 5 – vápencová suť v písčité matrix (klasty velké do 10 cm), 6 – drobná vápencová suť v písčité matrix (klasty velké do 2 cm), 7 – vápencová suť v písčité matrix (velikost klastů až 30 cm), 8 – drobná vápencová suť v písčité matrix, 9 – vápencová suť v písčité matrix (velikost klastů do 10 cm).

bles of an average size of 10 cm, max. 20 cm. Sandy matrix contains significant amounts of bone fragments of large mammals. The proportion of angular limestone clasts up to 20 cm large increases upwards. Sediments of the total thickness of 60 cm are cemented with carbonate.

Section 12 is located in a small corridor in the upper part of the Medvědí Chimney 11 m above the bottom of the Main Hall (see Fig. 21). Relic of fine- to medium-grained sand and sandy gravel is preserved here, filling depressions in limestone wall. It is dominated by greywacke pebbles; pebbles of limestone, siltstones and shales are less common. The average size of greywacke pebbles is 4 cm, the size of limestone pebbles is 2–10 cm. Forty greywacke pebbles from the size interval of 16–31,5 mm were measured for their roundness and shape by the method of Dobkins and Folk (1970). The resulting values are expressed by the median of the whole set. Roundness of greywacke pebbles in *Section 12* is characterized by the value of 0.46, while their shape can be expressed by the value of –0.3.

5.5.2. Age of sediments

Flowstone cementing the youngest talus bed in *Section 10* (Bed 1 on Fig. 22) was dated by Th/U method: the base of the flowstone layer at 12.7 ±4.3 ka, its surface at 4.5 ±1.2 ka. The carbonate was precipitated at the end of the last glacial period and in the Holocene. The underlying beds of the limestone talus were deposited probably during the last glacial period.

No specific data exist on the age of the detrital sediments exposed in *Sections 11* and *12*.

5.5.3. Genesis of sediments

The course of the Kateřinská Cave was predisposed by NE-SW-striking faults. Considerable tectonic deformation of limestones resulted in the formation of vast blocky chokes in the area of the cave. Limestone talus from these chokes was transported into caves by meteoric water and gravity.

Alternation of beds with different particle size in *Section 10* may reflect changing intensity of precipitation diverted from the surface into the cave through karst chimneys. The transport ability of rainwater depends on volume of precipitation and vegetation cover of karst surface. In general terms, coarser limestone talus was deposited in karst areas in warmer periods of the Pleistocene, alternating with the deposition of rather finer talus sediments in the coldest periods poor in precipitation (Ložek, 1963, 1973).

Sandy gravel with bones preserved in *Section 11* was redeposited from chimneys above the Main Hall. A large number of skeletons of cave bear accumulated in one of these chimneys (the so-called Medvědí Chimney; see Absolon, 1970a). Limestone pebbles worn by corrosion and angular limestone talus were transported together with bones from chimneys as gravity flows. As the sediments contain pebbles of greywacke, siltstone or shale, which can be found in fluvial sediments of *Section 12*, sandy gravel with limestone clasts was obviously deposited sooner than the stream transporting greywacke pebbles penetrated to the Kateřinská Cave (see below). Sediments in *Section 11* are genetically identical with sandy gravel with limestone clasts in *Section 8* in the Zazděná Cave (see Chapter 4.4).

The occurrence of fluvial sandy gravel (*Section 12*) in the Kateřinská Cave led Absolon (1970a) to the idea that the cave was connected with ponor caves in the Holštejnské Valley through unknown cave system in the past, and that the Bílá voda Creek was flowing through the cave. Roundness of greywacke pebbles from the Kateřinská Cave, ho-

wever, do not suggest that these fluvial sediments were transported through underground paths all the way from the N margin of the Moravian Karst to the Kateřinská Cave 6 km away. If they were, the greywacke pebbles would have been perfectly rounded (cf. KADLEC, 1997c). It is more probable that the Bílá voda Creek transported fluvial sediments from the Holštejnské Valley through karst valleys on the surface and penetrated to the Chobot crest along karstified tectonics. By this way sediments could reach the upper portions of the Bear Chimney. Later, greywacke pebbles were redeposited by rainwater from the chimney to the talus on the Main Hall. Such pebbles were reported from test-pits in the Main Hall by Wankel (in ABSOLON 1970a) and KNIES (1895). In times when the surface stream was penetrating through the Chobot massif into the Bear Chimney, the lower part of the Suchý žleb Canyon had to be filled with fluvial sediments of the Bílá voda Creek up to the height of min. 15 m above the present bottom. If this was true, the fill of the canyon was later eroded. Periods of repeated aggradation and erosion of sediments in the Pustý žleb and Suchý žleb canyons were also suggested by PANOŠ (1961).

6. Morphology of karst valleys and Macocha Chasm

Half-blind valleys drained through cave systems were formed by streams sinking near the boundary of limestones and non-karstic rocks. On the northern periphery of the Moravian Karst, the Bílá voda and Sloupský creeks sink under the ground in the Holštejnské and Sloupské valleys, respectively. Both these streams unite to form the Punkva River in the Amatérská Cave. Both ponor valleys are filled with fluvial sediments. Gravity and resistivity measurements allowed to reconstruct morphologies of their rocky bottoms. The same methods were applied to determine the rocky bottom morphology of the Lažánecké Valley, which separates the northern and the central segments of the Moravian Karst. Geophysical methods were also employed to specify more exactly the bottom morphology of the Macocha Chasm.

6.1. Morphology of the Holštejnské Valley

Half-blind Holštejnské Valley is drained by the Bílá voda Creek. A broad valley tract trending N-S passes into a narrow tract, where the Bílá voda Creek sinks in the Rasovna Cave. The valley is filled with fluvial sediments up to the altitude of 470 m a. s. l.; these sediments were documented by three boreholes in 1959, which reached the limestone bottom (DVOŘÁK, 1961; see Fig. 23).

Four transverse gravimetric profiles were measured across the valley (25 m intervals between measurement points) and a longitudinal gravimetric profile (50 m intervals between measurement points). The courses of profiles were selected to cross borehole sites with known total sediment thickness. In some cases, the courses of profiles were restricted by the extent of urban areas. Altogether 12 points of vertical electrical sounding were measured along the longitudinal gravimetric profile, extending to the southern closure of the half-blind valley (see Fig. 23).

Geophysical data illustrate valley morphology (BENEŠ, 1994). A 3-D image of the valley without sedimentary fill was modelled by Surfer and Microstation computer programs (Fig. 24). The valley reaches its highest depths in its western part. A relic of a narrow canyon-like valley is present here with its bottom at 400–410 m a. s. l. Here, the thickness of sedimentary fill reaches 60–70 m. The stream which gave rise to this half-blind canyon-like valley with an almost 100 m high terminal wall flowed horizontally to the cave system. The eastern part of the valley is rimmed by a ramp-like limestone plateau, the surface of which lies at 430 m a. s. l. The thickness of sedimentary fill above the plateau varies between 20 and 30 m. The surface of the limestone plateau gra-

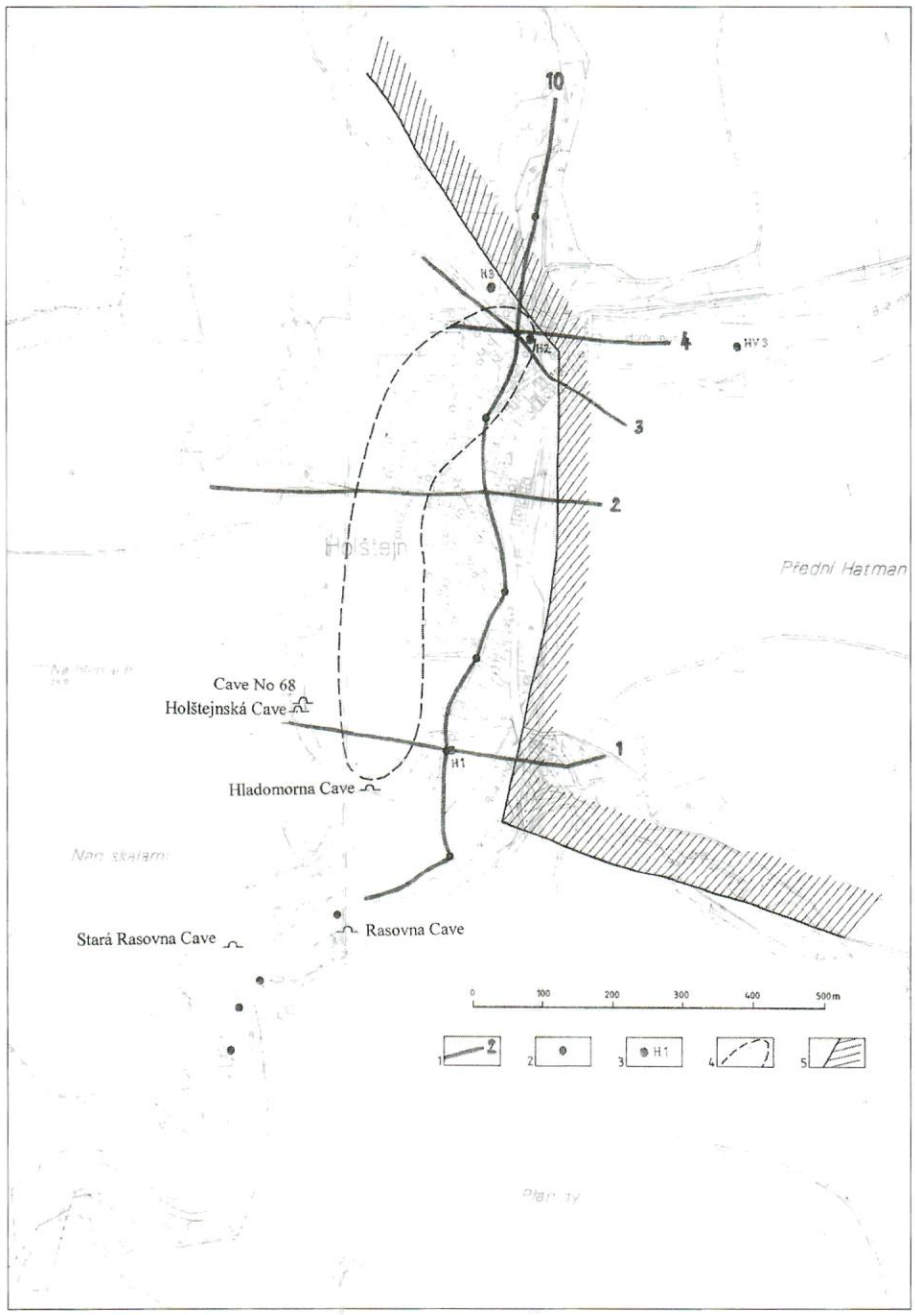

Fig. 23. Map of the Holštejnské Valley (published with permission of the Cadastral Office of the Town of Brno). 1 – gravimetric profiles; 2 – vertical electrical sounding points; 3 – locations of boreholes documented by DVOŘÁK (1961); 4 – contour of the deepest part of the valley; 5 – boundary of limestone and greywacke.

Obr. 23. Mapa Holštejnského údolí (publikováno se souhlasem Katastrálního úřadu města Brna). 1 – gravimetrické profily, 2 – lokalizace vertikálních elektrických sond, 3 – lokalizace vrtů (DVOŘÁK 1961), 4 – obrys nejhlubší části údolí, 5 – hranice vápence a droby.

dually passes south into the bottom of the narrow part of the valley, where the sediment thicknesses reach some 20 m. The present terminal wall of the southern part of the valley is formed by fluvial sediments (see also ŠTELCL, 1962a).

6.2. Morphology of the Sloupské Valley

Half-blind Sloupské Valley lies on the northern periphery of the Moravian Karst. The Sloupské Valley also consists of broad tract trending N–S, passing into narrow tract towards the Pustý žleb Canyon. The valley is drained by the Sloupský Creek, which sinks in the upper level of the Sloupsko-šošůvská Cave. The valley is filled with fluvial sediments up to the altitude of 468 m a. s. l.; these sediments were documented by four boreholes in 1959, which reached the limestone bottom (DVOŘÁK, 1961; see Fig. 25).

Five transverse gravimetric profiles were measured across the valley (intervals between measurement points of 25 m). A longitudinal gravimetric profile (intervals between measurement points of 50 m) started on the southern margin of the Sloup village, at the site of borehole S4, and ended on the northern margin of the Pustý žleb Canyon. Altogether 10 points of vertical electrical sounding were measured along the longitudinal axis (Fig. 25). Similarly to the Holštejnské Valley, the courses of the profiles were selected to cross borehole sites with known total sediment thicknesses. In some cases, the courses of the profiles were restricted by the extent of urban areas.

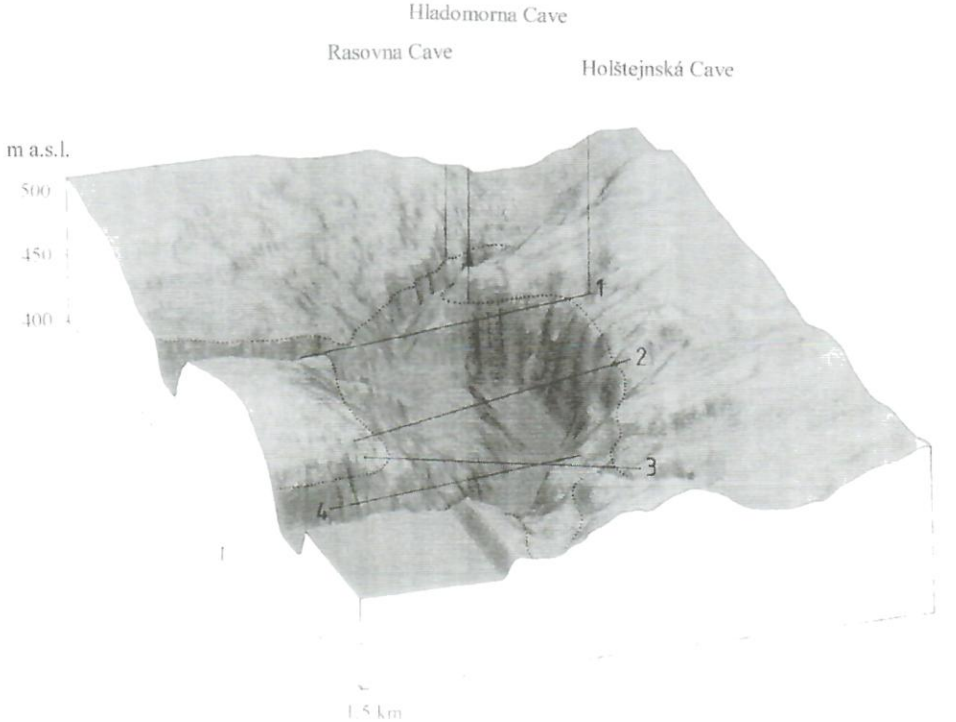

Fig. 24. 3-D image of the Holštejnské Valley without sedimentary fill; view from NE (KADLEC, 1996). Lines numbered 1 through 4 mark locations of transversal gravimetric profiles, the dotted line shows the level of the present surface (2.5 times exaggerated).

Obr. 24. 3-D diagram Holštejnského údolí bez sedimentární výplně, pohled od SV (KADLEC 1996). Linie označené 1–4 znázorňují pozici příčných gravimetrických profilů, tečkovaná linie znázorňuje povrch sedimentární výplně údolí (2,5× převýšeno).

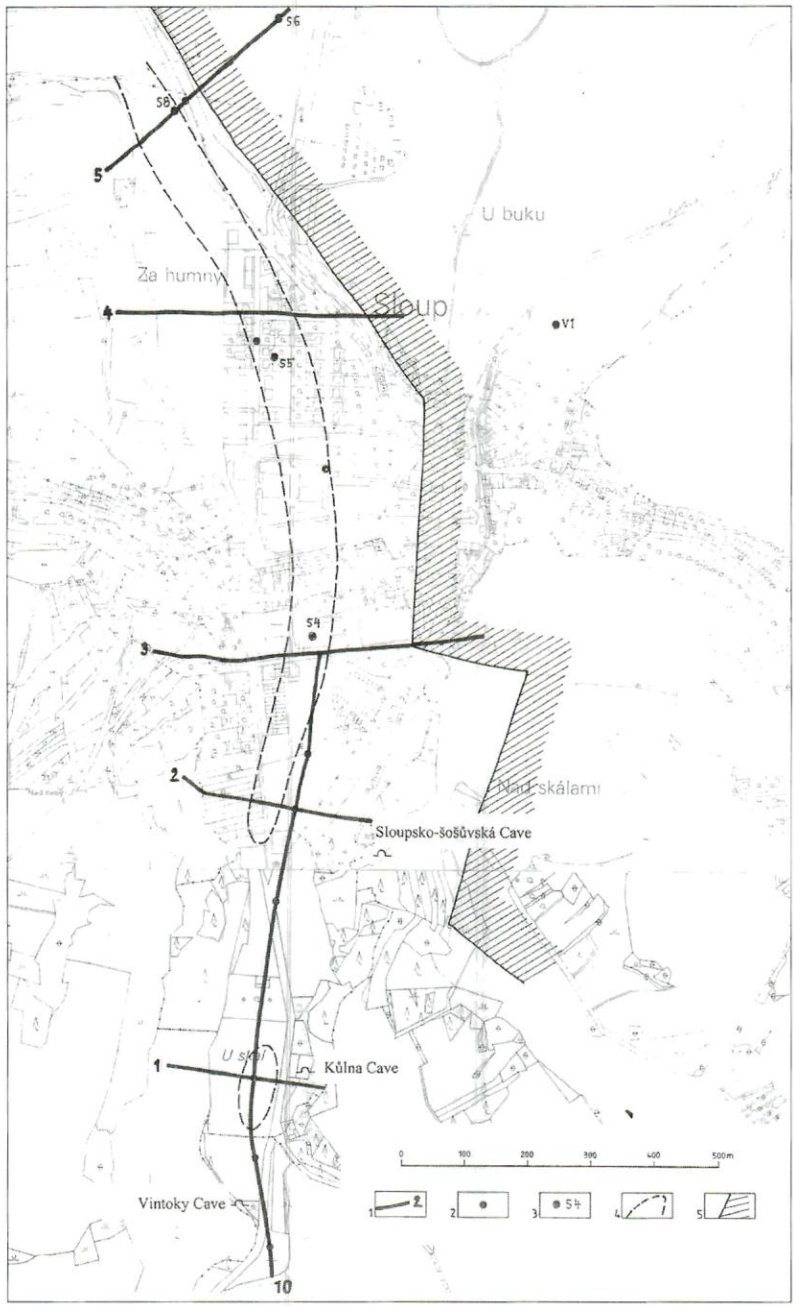

Fig. 25. Map of the Sloupské Valley (published with permission of the Cadastral Office of the Town of Brno). 1 – gravimetric profiles; 2 – vertical electrical sounding points; 3 – locations of boreholes documented by DVORÁK (1961); 4 – contour of the deepest part of the valley; 5 – boundary of limestone and greywacke.

Obr. 25. Mapa Sloupského údolí (publikováno se souhlasem Katastrálního úřadu města Brna). 1 – gravimetrické profily, 2 – lokalizace vertikálních elektrických sond, 3 – lokalizace vrtů (DVORÁK 1961), 4 – obrys nejhlubší části údolí, 5 – hranice vápence a droby.

Evaluation of geophysical data in a 3-D image without sedimentary fill (Fig. 26) shows that the valley reaches its highest depths in its western part. There, a relic of narrow canyon-like valley is present with its bottom lying at 410–430 m a.s.l., and the thickness of sedimentary fill reaches 50–60 m. The stream which created this half-blind canyon-like valley with an almost 70 m high terminal wall flowed from its bottom horizontally to the cave system. The eastern part of the valley is rimmed by ramp-like limestone plateau with surface at 440 m a. s. l. (20–30 m below the present surface of the sedimentary fill of the valley). Further south, the limestone plateau gradually passes into the bottom of narrow part of the Sloupské Valley.

6.3. Morphology of the Lažánecké Valley

The Lažánecké Valley runs across the Moravian Karst from Jedovnice village to the NW, across Lažánky village to Arnoštov village in the Punkevní Valley (Fig. 27). The Lažánecké Valley is filled with marine calcareous clays, with thickness is documented by borehole *L1* to 130 m (Schützneroová-Havelková, 1958).

Geophysical measurements in the Lažánecké Valley followed the gravity measurements conducted in the Jedovnické Valley by Dvořák and Sedlák (1991). Three gravimetric profiles were measured across the Lažánecké Valley. The easternmost one *G1*, crossed the narrowest part of the valley. The second one *G2*, crossed the site of *L1* bore-

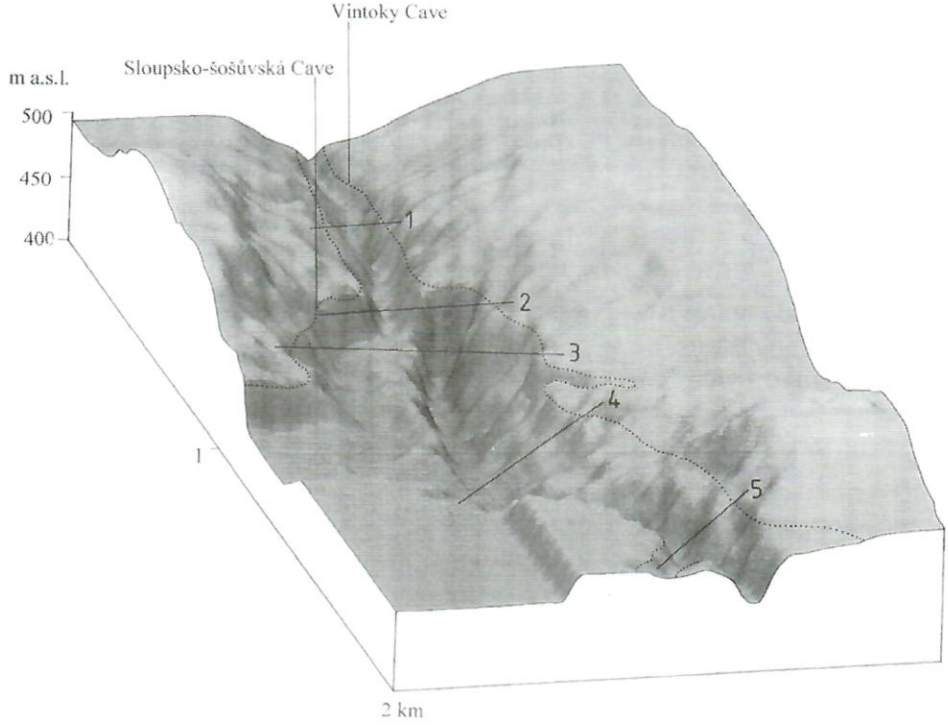

Fig. 26. 3-D image of the Sloupské Valley without sedimentary fill; view from NE (Kadlec, 1997a). Lines numbered 1 through 5 mark the locations of transversal gravimetric profiles, the dotted line shows the level of the present surface of the sedimentary fill in the valley (2.5 times exaggerated).

Obr. 26. 3-D diagram Sloupského údolí bez sedimentární výplně, pohled od SV (Kadlec 1997a). Linie označené 1–5 znázorňují pozici příčných gravimetrických profilů, tečkovaná linie znázorňuje povrch sedimentární výplně údolí (2,5× převýšeno).

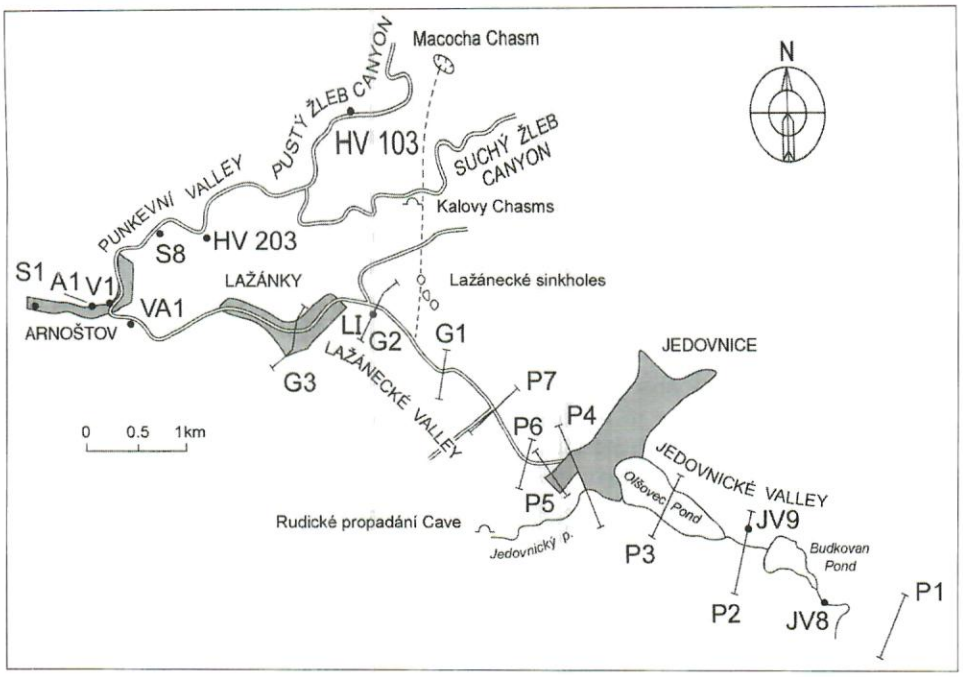

Fig. 27. Sketch-map of the geophysical survey in the Lažánecké Valley and its surroundings. P1–P7 – gravimetric profiles (Dvořák and Sedlák, 1991); G1–G3 – gravimetric profiles (Beneš, 1997); black points mark boreholes: S1 (Bouček, 1971), A1 (Schützenerová-Havelková, 1957), V1 (Ambrož, 1991), VA 1 (Vilšer, 1966), LI (Schützenerová-Havelková, 1958), JV 8, JV 9 (Vilšer, 1962), S8 (Prokop, 1988) HV 203 (Taraba, 1981) HV 103 (Taraba, 1976); dashed line marks the supposed pre-Badenian course of the subsurface Punkva River between the Macocha Chasm and resurgence in the Lažánecké Valley.

Obr. 27. Mapka geofyzikálních prací v Lažáneckém údolí a jeho okolí. P1–P7 – gravimetrické profily (Dvořák a Sedlák 1991), G1–G3 – gravimetrické profily (Beneš 1997), černé body znázorňují pozici vrtů: S1 (Bouček 1971), A1 (Schützenerová-Havelková 1957), V1 (Ambrož 1991), VA 1 (Vilšer 1966), LI (Schützenerová-Havelková 1958), JV 8, JV 9 (Vilšer 1962), S8 (Prokop 1988) HV 203 (Taraba 1981) HV 103 (Taraba 1976); čárkovaná linie znázorňuje průběh předpokládané předbadenské jeskynní chodby mezi Macochou a vývěrem v Lažáneckém údolí.

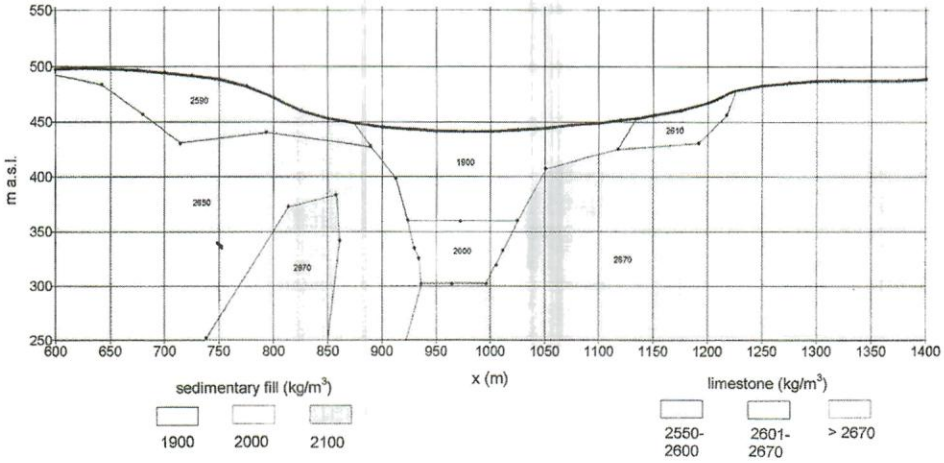

Fig. 28. Specific densities along transversal gravimetric profile G2.
Obr. 28. Měrné hmotnosti hornin podél gravimetrického profilu G2.

hole (location according to SCHÜTZNEROVÁ-HAVELKOVÁ; 1958). The last one *G3*, crossed the centre of the Lažánky village. Along profile *G1*, the Lažánecké Valley has the character of 164 m deep canyon, with bottom at ca. 310 m a. s. l. The width of the canyon at the bottom is ca. 20 m, similarly to the narrowest parts of the Suchý žleb Canyon. Along profile *G2*, the valley has the shape of a widely open letter V, with a flat bottom at 300 m a. s. l. In the NE part of the cross-section, relic of broad and shallow valley is preserved some 30 m below the present surface (Fig. 28). Shape of the Lažánecké Valley along gravimetric profile *G3* has again the character of widely open valley with bottom at 295 m a. s. l. Upper part of the valley is, much like in profile *G2*, significantly wider than the lower one. A common feature of all gravimetric profiles is the fact that limestone massif south of the Lažánecké Valley shows lower specific gravity than limestones north of the valley as a result of intensive karstification.

6.4. Morphology of the bottom of the Macocha Chasm

Bottom morphology of this 138 m deep chasm was characterized in detail by shallow seismics and vertical electrical sounding. Seismic profile, 50 m long, with 2-m or 5-m geophone spacings (marginal and central parts of the profile, respectively) was measured along the axis of talus cone, the surface of which is steeply inclined in the NW part of the chasm from the Písečná Cave (400 m a. s. l.) to the chasm bottom (350 m a. s. l.). Four points of vertical electrical sounding were measured along the cone axis and another three ones on the bottom (Fig. 30). The use of vertical electrical sounding is, however, complicated by the limited space available in the chasm with the width of ca. 40 m. Geoelectrical measurements were performed in two different electrode array. The first variant involved AB array of current electrodes (KAROUS, 1989). The maximum AB distance was 72 to 100 m depending on the space inside the chasm. The depth access of these soundings can be estimated at 18 to 25 m. In the second variant, electrode B was replaced by electrode C located in "infinity". This means that electrode C was grounded in a forest above the chasm at a distance of ca. 350 m. Cable leading to the electrode was dropped to the chasm bottom across the upper observation deck. The estimated depth access of the electrical sounding was thus extended to 35 m. Nevertheless, it must be taken into account that such electrode array introduces a higher inaccuracy into the interpretation of measured data.

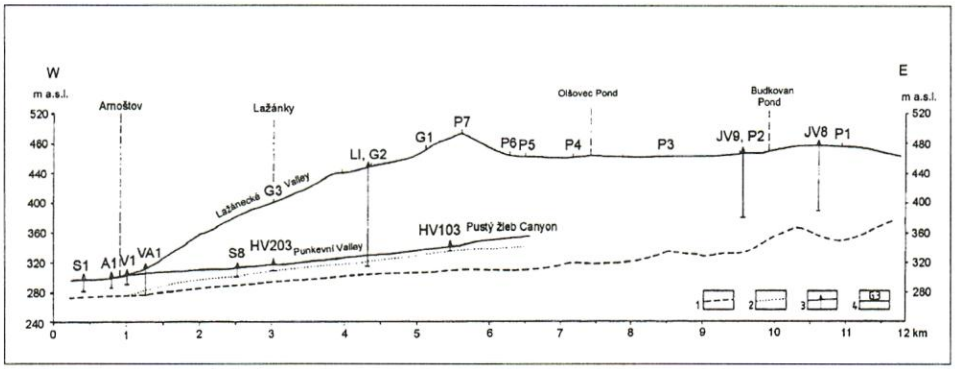

Fig. 29. Longitudinal section of the Lažánecké and Jedovnické valleys (KADLEC and OTAVA, 1999). 1 – bottom of the Lažánecké and Jedovnické valleys, 2 – bottom of the Punkevní Valley and Pustý žleb Canyon, 3 – boreholes, 4 – gravimetric profiles (for explanations see Fig. 27).

Obr. 29. Podélný profil Lažáneckým a Jedovnickým údolím (KADLEC a OTAVA 1999). 1 – vápencové dno Lažáneckého a Jedovnického údolí, 2 – vápencové dno Punkevního údolí a Pustého žlebu, 3 – vrty, 4 – gravimetrické profily (viz obr. 27).

As shown by the vertical electrical sounding, the bottom in the Macocha Chasm below the river bed between lakes is situated in the depth of 23 m (*V5*). Channel incised into the rocky bottom runs diagonally across the chasm (Fig. 31).

Sediment accumulation forming the cone in the NW part of the chasm consists of two layers with different physical characteristics. Most of the cone volume is formed by sedi-

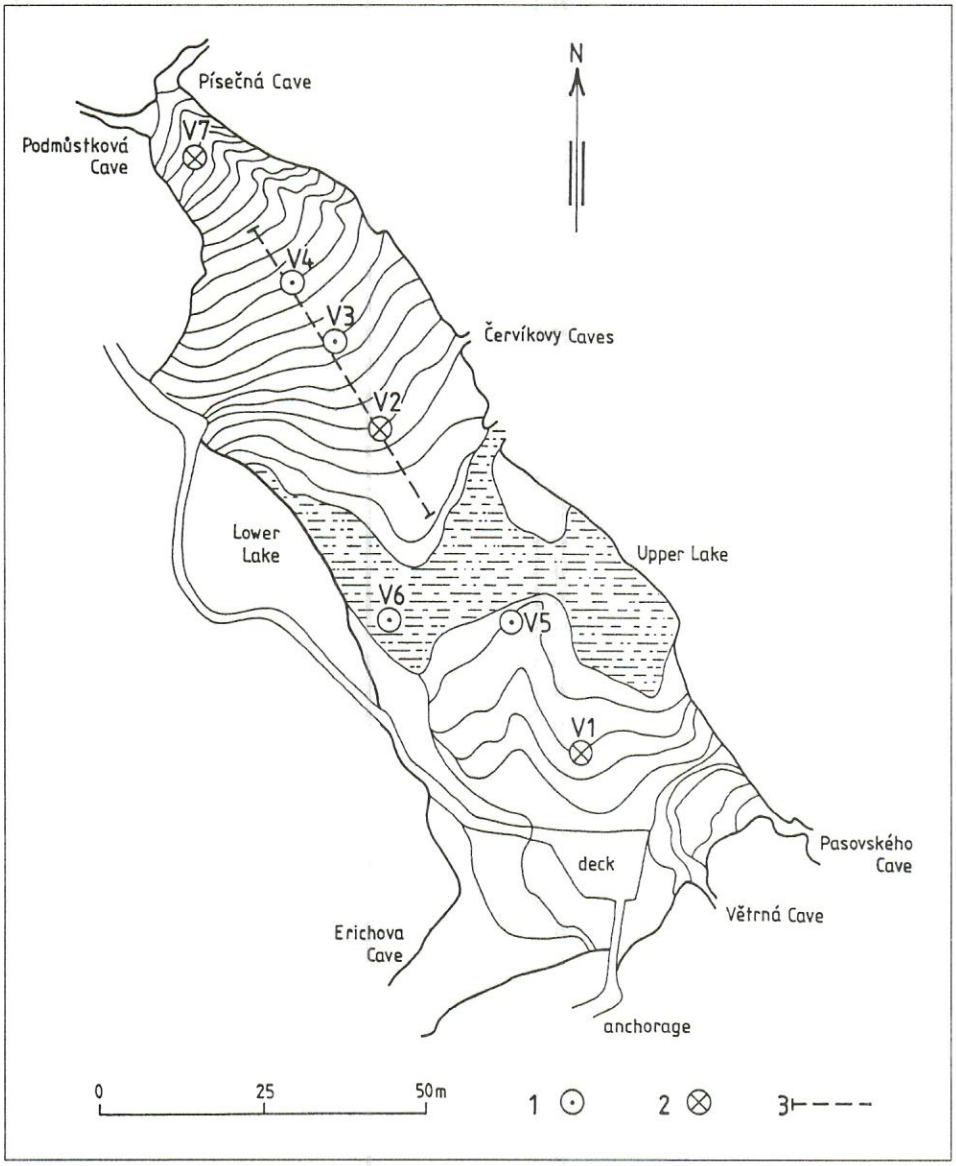

Fig. 30. Sketch-map of the bottom of the Macocha Chasm (modified after Absolon, 1970a). 1 – vertical electrical sounding points (AB array); 2 – vertical electrical sounding points (AC array); 3 – seismic profile.

Obr. 30. Mapka dna propasti Macocha (upraveno podle Absolona 1970a). 1 – pozice vertikálních elektrických sond (uspořádání AB), 2 – pozice vertikálních elektrických sond (uspořádání AC), 3 – seismický profil.

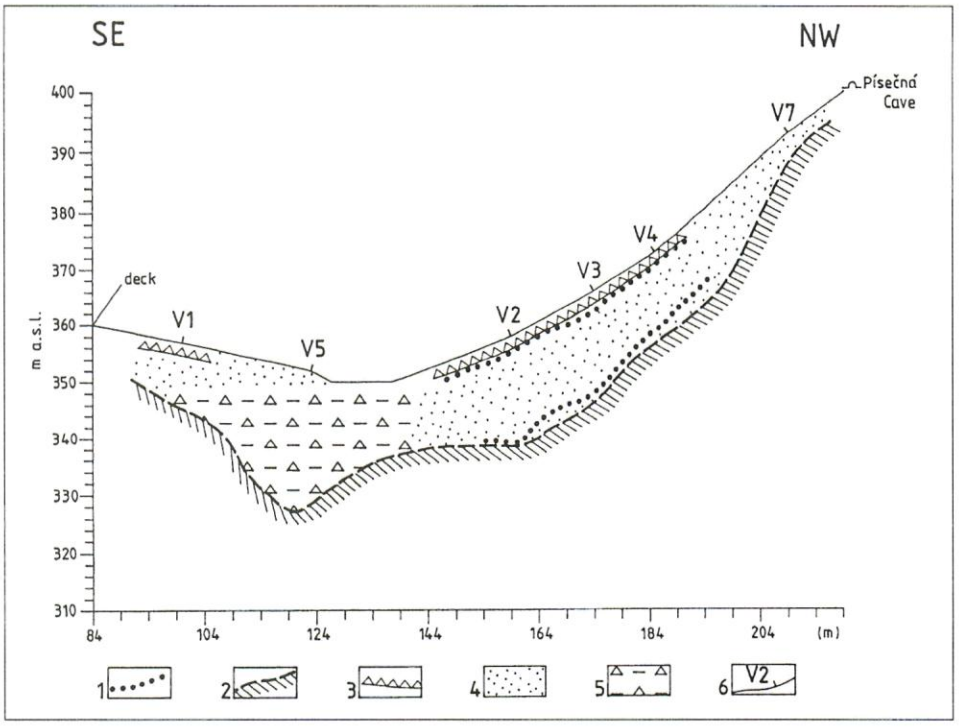

Fig. 31. Longitudinal section of the bottom of the Macocha Chasm. 1 – physical boundaries in sedimentary fill indicated by seismic measurement; 2 – limestone bottom of the chasm; 3 – limestone talus; 4 – fluvial sand or sandy gravel; 5 – limestone talus below the water level; 6 – vertical electrical sounding points.
Obr. 31. Podélný profil dnem propasti Macocha. 1 – fyzikální rozhraní v sedimentární výplni detekované seismickým měřením, 2 – vápencové dno propasti, 3 – vápencová suť, 4 – fluviální písek nebo písčitý štěrk, 5 – vápencová suť pod hladinou vody, 6 – pozice vertikálních elektrických sond.

ments with specific resistivity on the order of hundreds of m corresponding to sand and sandy gravel. Values of specific resistivity decrease downwards. This means that the sediments become finer or more water-saturated. Sand and sandy gravel are coated by layer 1 to 2 m thick, with resistivity values on the order of thousands of m. The layer, identified also by seismics, corresponds to coarse limestone talus deposited on the surface of the cone. The overall thickness of sediments detected in the axial part of the cone ranges between 3.5 m (*V7*) and 19 m (*V2*). As illustrated in Fig. 31, the bedrock in the NW part of the chasm inclines towards the bottom of the Macocha Chasm.

7. Origin and history of cave systems in the northern segment of the Moravian Karst: Discussion

7.1. Paleogene

In the Paleogene, the Moravian Karst was covered by Cretaceous sediments of a substantial thickness. They were subjected to erosion of such extent that in the late Paleogene surface streams started to form shallow valleys in the limestones. Valleys functioned as a local base level, associated with the formation of the first horizontal cave systems (Panoš, 1963; Štelcl, 1964; Hypr, 1980), e.g., the Holštejnská Cave and the upper level of the Sloupsko-šošůvská Cave. No Paleogene sediments were preserved in these caves.

A different situation occurs in the Macocha Chasm. The genesis of this vertical cavity can be dated back to the Lower Cretaceous (buried karst of PANOŠ, 1961). Similar depressions filled with detrital sediments are common in the central segment of the Moravian Karst (e.g., BOSÁK, 1977). Cave corridors lie at several altitude levels in the Macocha Chasm. One of them is the Erichova Cave, with the prominent entrance in the SW part of the chasm at 368 m a.s.l. The horizontal corridor of the cave is filled with quartz sand. Heavy mineral assemblage is dominated by zircon, staurolite and disthene, and less frequent epidote-group minerals, garnet, tourmaline and rutile (VÍT, 1996). The assemblage differs from assemblages of modern fluvial sediments, suggesting that sand in the Erichova Cave is partly derived from Cretaceous sediments (cf. KRYSTEK, 1959). The very high age of these cave sediments is also evidenced by the completely weathered clay minerals to kaolinite. Weathering of clay minerals of such intensity has not been recorded in any other cave in the N segment of the Moravian Karst (VÍT, 1996). Quartz sand could be transported into the Erichova Cave during the Paleogene, when stream flowing along the western margin of the Moravian Karst was sinking in the Macocha Chasm (KADLEC and BENEŠ, 1996).

7.2. Lower Miocene

Nappe formation and folding of Paleogene flysch sediments was taking place during the Savian phase of the Alpine Orogeny in the Carpathian Foredeep (SE of the Moravian Karst), at the Oligocene/Miocene boundary. Northwesterly nappe advance resulted in uplift of the Drahanská Highland including the Moravian Karst area (KETTNER, 1960; PANOŠ, 1964; DVOŘÁK, 1995). This uplift induced changes in stream gradients and hydrographic conditions of the whole area. In the late Lower Miocene, the Svitava River was deeply incised in the limestone plateau as evidenced by relics of Lower Badenian marine sediments preserved 10–15 m above the present level of the Svitava River (HYPR, 1975). Karst streams draining the individual segments of the Moravian Karst towards the west, to the Svitava River, deepened shallow Paleogene valleys into karst canyons. In the N segment of the Moravian Karst, both phases of valley formation are documented by the morphologies of the Pustý žleb and Suchý žleb valleys (PANOŠ, 1963; KREJČÍ, 1960). The Lažánecké Valley also underwent both stages of evolution. Morphological evidence is, however, hidden beneath Lower Badenian marine sediments (Fig. 28). The Lažánecké Valley was incised to a greater depth than the Pustý žleb and Suchý žleb canyons. As supposed by PANOŠ (1961, 1963), smaller caves were formed in the slopes of canyons as the karst valleys deepened. Erosion by surface streams was the dominant agent at that time, and continuous cave systems draining individual segments of the Moravian Karst were not developed yet.

The end of the Lower Miocene (Karpatian) was characterized by docking of nappes in the Carpathian Foredeep (BRZOBOHATÝ, 1996). Movements and gradient changes of bottoms of surface valleys may have occurred at the tectonic contact between limestones and non-karstic sediments on the N and E margin of the Moravian Karst. With the tendency to reach graded profiles again, streams created cave systems with ponors on the N and E margins of karst. These systems were guiding water through the limestones to the SW, towards the base level formed by the Svitava River. The altitude level of such underground drainage was controlled by bottoms of canyon-like karst valleys, on which subsurface streams were resurging to the surface. In the N segment of the Moravian Karst, a cave system was established comprising ponors along the N and E contacts of the limestones with Lower Carboniferous sediments, and resurgence near the bottom of the Lažánecké Valley. This valley was the deepest one and functioned as a local base

level (PANOŠ, 1963). The graded profile of the subsurface stream with a gradient of 11 gradually passes from lower cave level in the ponor area across the active level of the Amatérská Cave and the rocky bottom of the Macocha Chasm to the bottom of the Lažánecké Valley (KADLECOVÁ and KADLEC, 1996).

The longitudinal profile in Fig. 29 indicates that rocky bottom of the Lažánecké Valley is inclined westwards (to the Svitava River) with a gradient of 11 ‰, lying 25 m deeper than the bottom of the Punkevní Valley. The increase in the altitude difference between valley bottoms can be partly explained by the shift from the surface drainage pattern to the underground drainage pattern in the N segment of the Moravian Karst, with practically all water resurging in the Lažánecké Valley. Canyons of Pustý žleb and Suchý žleb as well as the Punkevní Valley became dry and were not deepened down to the level of the Lažánecké Valley. Anyway, the Punkevní Valley merged as a hanging valley into the Lažánecké Valley, and not vice versa, as suggested by HYPR (1980).

Besides other caves, the pre-Badenian cave level includes Cave No. 68 in the Holštejnské Valley and the whole active part of the Amatérská Cave. In the area south of the Macocha Chasm, this system included the Skleněné dómy Halls in the Punkevní Cave. Further course of the pre-Badenian cave level from the Macocha Chasm to the south is marked by the Kalovy Chasms, the bottom of which lies 35 m below the bottom of the Suchý žleb Canyon, and the N-S-trending line of the Lažánecké sinkholes between the Suchý žleb Canyon and the Lažánecké Valley (see Fig. 27; KADLEC and OTAVA, 1999).

In the Holštejnské and Sloupské valleys, deep half-blind valleys were formed by headward erosion. Waters flowed horizontally into the cave system. The Holštejnská Cave and the upper level of the Sloupsko-šošůvská Cave became located 50–60 m above the bottom of a half-blind valley and therefore hosted no streams (see Figs. 24 and 26). Parallel situation occurred in the central segment of the Moravian Karst. The Jedovnický Creek created deep half-blind valley, then flowing horizontally into the cave system of the Rudické propadání Cave (DVOŘÁK, 1994).

7.3. Middle Miocene (Lower Badenian)

In the earliest Middle Miocene, the eastern margin of the Bohemian Massif was transgressed by the sea. The Drahanská Highland and the Moravian Karst were covered by marine calcareous clays (e.g., DVOŘÁK et al., 1993). This marine transgression lasted 1 m.y. (MALKOVSKÝ, 1979) and interrupted all karstification processes. It was a major event, dividing the Cenozoic history of the Moravian Karst into two periods (PANOŠ, 1964; BOSÁK et al., 1989).

If any of the cave systems were filled with marine sediments during the transgression, these deposits were completely eroded by subsurface streams later. Lower Badenian marine sediments have not been found *in situ* in any cave of the N segment of the Moravian Karst.

7.4. Middle Miocene (Middle Badenian) to Pliocene

In the period between the marine regression and the end of the Miocene, the Moravian Karst was under the influence of erosion, slowly removing marine sediments from the surface. Surface streams also gradually eroded sediment fill of karst canyons of the Pustý žleb and Suchý žleb. Renewed formation of smaller caves in canyon slopes during the erosion of marine sediments was supposed by PANOŠ (1963). The different situation occurred in the Lažánecké Valley. The Jedovnický Creek opened a completely new path into the pre-Badenian cave system draining the central segment of the Moravian Karst. As a result of this hydrographic change, no major surface stream was flowing through

the Lažánecké Valley to remove marine clays. Therefore, clay fill of the Lažánecké Valley pose a barrier within limestones of the Moravian Karst, which has been preventing the drainage of waters from the N segment of the Moravian Karst till present. This barrier reaches to the depth of 280–300 m a. s. l. (i.e., some 200 m below the surface of karst plateau). The former resurgence of the Punkva River near the bottom of the Lažánecké Valley remained permanently sealed beneath marine clays at a depth of almost 140 m below the present surface. The barrier of the Lažánecké Valley caused the rise of the groundwater table north of it. Blockage of the resurgence led to the filling of the pre-Badenian cave system with water: streams were flowing on the surface through karst canyons, eroding marine clays.

As soon as the erosion of the marine clays in the Pustý žleb Canyon near the Macocha Chasm reached the level of 390 m a. s. l., the subsurface stream of Punkva created a new resurgence – the uppermost level of the Punkevní Cave (the so-called Crystal Passage). With ongoing erosion of marine sediments from the Pustý žleb Canyon, the levels of resurgence corridors dropped down up to the Punkevní Cave (360 m a.s.l.) and finally the present resurgence at 350 m a. s. l. After the Punkva River produced a new resurgence in the Punkevní Cave, a horizontal cave corridor started to form N of the Macocha Chasm due to intensive flow at the level of the risen groundwater table (cf. Ford, 1987) – the present flood level of the Amatérská Cave. The huge corridors of upper level of the Amatérská Cave were formed by subsurface stream during the Pliocene and Lower Pleistocene. This means that the upper flood level is younger than the lower, active corridor. This explanation markedly differs from the older views on the origin of the Amatérská Cave: their authors assumed a progressive formation of corridors depending on the lowering base level. Hypr (1980) and Bosák et al. (1989) suggested that the lower, active level was formed in the Quaternary as the valley deepened. Nevertheless, the rocky bottom of the Pustý žleb Canyon near the Punkevní Cave lies 20 m higher than the active corridor of the Amatérská Cave. Vít (2000) also explained the formation of the two levels of the Amatérská Cave as due to progressive base-level drop but believed that both levels are pre-Badenian in age.

In the area of the Macocha Chasm, the groundwater table is risen by 20–25 m above the level of the pre-Badenian cave system, to reach the altitude of 350 m. This is also the level at which the subsurface Punkva River resurges to the surface. Older cave systems between the Macocha Chasm and the Lažánecké Valley are lying now permanently below the risen groundwater table. During severe floods, this groundwater table rises by a few more metres, opening karst springs near the bottom of the Suchý žleb Canyon.

Marine clays were eroded from the Holštejnské and Sloupské valleys in the Middle and Late Miocene. Surface streams started to flow horizontally through cave systems into the Amatérská Cave again, much like before the Lower Badenian transgression. Both these valleys propagated to the east probably in the Pliocene. This process was associated with the formation of plateaus on eastern sides of the valleys, visible in Figs. 24 and 26. Streams, which generated these erosive landforms, were shifting further east in both cases. In the Sloupské Valley, the stream created a lower cave level on the eastern side of the valley and used it on its way to the Amatérská Cave.

More prominent erosion of the eastern slopes in N-S-trending parts of valley is also visible in the Pustý žleb Canyon, in valleys in non-karstic rocks N and NW of the Moravian Karst. Such unusual, intensive lateral corrosion of eastern slopes was described by Panoš (1961) on a Recent example from the Sloupské Valley. This feature could be explained by a subtle tilt to the east due to uplifting of the area, which resulted from the waning Alpine Orogeny.

7.5. Lower Pleistocene

Alternation of glacial and interglacial climate resulted in changes in the behaviour of stream systems. In colder periods, the streams were characterized by higher discharge and also higher amounts of load (see VANDENBERGHE, 1993, a.o.). Large volumes of fluvial sediments might be responsible for blocking of caves draining ponor valleys. Water started to flow on the surface through karst canyons, and ponor valleys of Holštejnské and Sloupské were gradually filled with fluvial sediments. Streams, which started to flow into the Holštejnská Cave and the upper level of the Sloupsko-šošůvská Cave, opened vertical connections between the upper and lower levels in both systems, directing water to the Amatérská Cave. At the end of the Lower Pleistocene (0.8–1.1 Ma), however, this path was closed, possibly as a result of an inhibition of flow of the subterranean stream in the Amatérská Cave due to, e.g., catastrophic choke. In such case, Holštejnská and Sloupsko-šošůvská ponor caves became filled with fluvial sandy gravel (Unit A) transported from the area N of the Moravian Karst (OTAVA and VÍT, 1992).

7.6. Middle Pleistocene

In Middle Pleistocene, streams re-entered the Holštejnská Cave and the Sloupsko-šošůvská Cave, partly eroding fluvial sediments deposited in the Early Pleistocene. After closure of this path for the subterranean stream in the latest Middle Pleistocene, the Holštejnská Cave and the Sloupsko-šošůvská Cave were filled with fluvial sediments (Unit B and Unit C, respectively). The end of detrital sedimentation in both caves is marked by a flowstone layer deposited in the last interglacial period. Massive detrital sedimentation could be caused by the roof collapse of the Macocha Chasm, which blocked the flow of the Punkva River on the bottom of the chasm (KADLEC and BENEŠ, 1996).

Narrow tracts of the Holštejnské and Sloupské valleys trending south, to the karst canyons, were probably formed in the Middle Pleistocene. It was the time when cave systems were blocked by sediments and streams were flowing on the surface. In an attempt to reach a lower-positioned underground path, water created new connections to the lower drainage level along karstified faults and fissures. Such connection was found in the Stará Rasovna Cave area in the Holštejnské Valley, while in the Sloupské Valley the stream was sinking in the Vintoky Cave (see Figs. 23 and 25). Narrow tracts of the ponor valleys originated by the effect of headward erosion as a response to changes of stream gradient. Both narrow valleys were later filled with fluvial sediments covered by loess loams deposited in the last glacial (SMOLÍKOVÁ and KADLEC, 1993).

7.7. Upper Pleistocene

The last episode of fluvial erosion and accumulation took place in the ponor caves. Subterranean streams produced channels in older fluvial accumulations, through which they flowed into chasms connecting upper and lower levels again. After repeated blockage of this path, channels and the whole cave corridors were partly or completely filled with the youngest fluvial sediments. During the last interglacial period, a surface stream penetrated to the Kůlna Cave, from where it was sinking to the lower cave level. Surface of sediment fill of the valley in front of this cave have to be lying a few metres higher than today, to allow water to enter the cave. After filling of this vertical path with fluvial and colluvial sediments, limestone talus with silty-sandy matrix and sand- and silt-dominated flood sediments were deposited in the S part of the Kůlna Cave during the last glacial period.

The youngest fill of the Holštejnské and Sloupské valleys is composed of fluvial sandy gravel and loess loam.

In the last interglacial period, the Zazděná Cave was filled with fluvial sediments at the anomalous situation after the rise of the subterranean stream level due to the collapse of the near Macocha Chasm. The same deposits of a subterranean stream are present in the Amatérská Cave and in the Písečná Cave in the Macocha Chasm at 400 m a. s. l. – i.e., 50 m above the bottom of the chasm. The end of fluvial sedimentation in the Zazděná Cave is marked by a flowstone layer deposited on the surface of fluvial sediments at the beginning of the last glacial period. Still in the last glacial period, the Zazděná Cave horizontal corridor was filled with laminated infiltration sediments up to the ceiling.

A subterranean stream was flowing through the Písečná Cave to the Macocha Chasm probably during the whole last glacial period. This is indicated by the absence of loess relics on the bottom of the chasm: loess was commonly deposited on the surface of the karst plateau around the chasm. The collapse of the roof of the chasm and closure of drainage paths pushed the Punkva River to higher level in the Punkevní Caves as documented by fluvial sandy gravel preserved in relics in this level.

At the time of the roof collapse, the Macocha chasm had a character of vertical cavity, some 40 m in diameter. The chasm was elongated in northwesterly direction by the effect of headward erosion in response to the steep gradient of the subterranean stream flowing into the chasm from the Písečná Cave. During this process, a slope was developed on the limestone, steeply inclined from the Písečná Cave to the bottom of the chasm. The slope was covered with fluvial sand and sandy gravel transported from the Písečná Cave. The surface of the sediments in overlain by a bed of coarse limestone talus fallen from the adjacent vertical walls of the chasm. Older papers dealing with the origin of the Macocha Chasm usually stated that the steep slope below the Písečná Cave is formed by coarse limestone talus formed during the collapse of the chasm roof (Kříž, 1864; Absolon, 1904, 1912, 1970a; Panoš, 1961).

7.8. Holocene

In the Holocene, the active cave systems as well as the ponor valleys were dominated by stream erosion. Older fluvial sediments were eroded by rainwater flowing to the corridor of the Holštejnská Cave through a karst chimney, and the space thus created was filled with fine laminated sediments only several centuries old.

Limestone talus accumulated on the bottoms of karst canyons and below limestone walls during the Holocene, burying many cave entrances. Stratigraphy of these sediments was studied by Ložek (1979) and Ložek and Cílek (1995) using molluscan assemblages.

8. Conclusions

In the Paleogene, the first valleys and the earliest horizontal cave systems were formed in the Moravian Karst, now preserved in relics only, especially in the ponor area on the N periphery. The Lower Miocene was dominated by surface stream erosion producing deep canyon-like valleys. As indicated by the morphologies and gradients of these valleys, extensive cave systems draining the individual segments of the Moravian Karst appeared for the first time during the latest Early Miocene, prior to the transgression of the Lower Badenian sea. In the N segment of the Moravian Karst, a single continuous level of subsurface drainage developed, with ponors on the N and E margins of the karst area and resurgence near the bottom of the Lažánecké Valley. Changes in hydrographic conditions due to marine transgression resulted in the formation – probably during the Pliocene – of two levels of subsurface drainage including the flood level of the Amatérská Cave. In the Pliocene and Quaternary, streams were repeatedly opening new paths to reach the pre-Badenian drainage level. The repeated presence of subterranean streams in cave systems throughout late Cenozoic history resulted in re-shaping of cave

corridors and in complete erosion of the existing sedimentary fill. As a result, only fluvial sediments of Quaternary age are preserved in a majority of caves in the N segment of the Moravian Karst. Periods of activity of subterranean streams alternated with periods of quiescence when speleothems were deposited in caves. In the latter periods, streams were flowing on the surface through karst canyons. The evolution of the Kateřinská Cave was isolated, with no evidence for being a part of the extensive, yet unexplored cave system, as suggested by K. Absolon.

The oldest Quaternary deposits of subterranean streams in the N segment of the Moravian Karst were preserved in ponor caves in the proximity of the boundary of limestones and non-karstic rocks. They include fluvial sediments deposited in the Holštejnská Cave and the Sloupsko-šošůvská Cave in the latest Early Pleistocene (at 0.8 to 1.1 Ma). This depositional phase is evidenced by the filling of the Holštejnské and Sloupské valleys with fluvial sediments up to the level of the mouths of the two above mentioned caves. Another major period of fluvial deposition in caves can be dated to the latest Middle Pleistocene (ca. 170–121 ka), when the Holštejnská Cave as well as large portions of the Sloupsko-šošůvská Cave were filled. It could have been triggered by the collapse of the roof of the Macocha Chasm and the subsequent blocking of the drainage path leading to the resurgence in the Pustý žleb Canyon. After the collapse, the level of the subterranean stream rose and new path into the Macocha Chasm was created using the Písečná Cave. At this anomalous hydrological situation, episodic deposition of fluvial sediments in the lower-positioned horizontal corridor of the Zazděná Cave occurred as the subterranean stream flowed from the Amatérská Cave to the Písečná Cave in the last interglacial period. Termination of fluvial processes in the Zazděná Cave is documented by flowstone deposition at the beginning of the last glacial period (115–99 ka).

In the Late Pleistocene (ca. 120–14.5 ka), cave systems were subjected to the last episode of fluvial erosion and accumulation. In the Holocene, cave systems are dominated by erosion of older fluvial deposits.

The deposition of fluvial sediments and the filling of cave corridors of the N segment of the Moravian Karst were usually controlled by local interruptions in the subterranean stream flow within the cave systems. Therefore, periods of accumulation caves of the Moravian Karst cannot be correlated with fluvial terraces of surface streams, the formation of which was controlled by climatic oscillations during the Pleistocene.

Acknowledgments

The study of cave sediments of Moravian Karst was financed from the following grant projects: grant projects of the Grant Agency of the Czech Republic No. 205/93/0276 and No. 205/95/0841, grant project within the U.S.-Czech Science and Technology Program No. 95 051 and grant projects within the National Science Foundation No. INT-950737 and No. EAR-9705718. This study falls within the research plan No. CEZ: Z3-013-912 of the Institute of Geology, Academy of Sciences of the Czech Republic.

The authors wish to thank P. Bosák and J. Hladil for their critical reviewing the manuscript. We are very grateful to the management of the Administration of the Moravian Karst Protected Landscape Area and the Administration of the Moravian Karst Caves for their permission to access the caves. We also thank E. Janoušek for photographic documentation of cave sediments and Z. Zícha for his help in generating a computer image of ponor valleys in the Moravian Karst. We thank E. Kulíková of the Czech Geological Survey and J. Rajlichová of the Institute of Geology AS CR for technically accurate drawing of figures included in this paper.

SOUHRN

Moravský kras je příkladem fluviokrasu s rozsáhlými jeskynními systémy vytvořenými podzemními toky. V jeskyních jsou na mnoha místech zachovány klastické sedimenty podzemních toků i chemogenní jeskynní karbonáty (speleotémy). Klíčové profily v jeskynních sedimentech byly detailně graficky dokumentovány. Studium sedimentárních textur umožnilo genetické zařazení jednotlivých sedimentárních akumulací. Stáří jeskynních sedimentů bylo stanoveno pomocí různých metod. Speleotémy (sintrové horizonty a stalagmity) datovala metoda $^{230}Th/^{234}U$ (α-particle counting), zatímco uhlíky a kosti byly datovány radiokarbonovou metodou. Stáří fluviálních sedimentů bylo v jednom případě stanoveno pomocí izotopů ^{10}Be a ^{26}Al v křemenných valounech. Paleomagnetický záznam měřený v klastických i chemogenních jeskynních uloženinách umožnil orientačního určení stáří sedimentů. Geofyzikálním měřením se podařilo získat informace o morfologii i stavbě sedimentárních těles vyplňujících jeskynní dutiny a krasová údolí. Vždy byly aplikovány dvě metody – gravimetrie a vertikální elektrické sondování nebo mělká seismika a vertikální elektrické sondování.

V ponorových Sloupsko-šošůvských jeskyních a v Holštejnské jeskyni je v reliktech zachováno několik různě starých akumulací fluviálních sedimentů. Nejstarší říční sedimenty jsou starší než paleomagnetická hranice Brunhes/Matuyama. Uložily se před 0,8–1,1 mil. let. Druhá akumulace fluviálních sedimentů se ukládala v období před 153 +24/–21 až 121 +10/–10 tis. lety. Nejmladší říční sedimenty se uložily během posledního glaciálu v rozmezí 121 +10/–10 až 13,3 +0,3/–0,3 tis. let. V Amatérské jeskyni jsou zachovány fluviální sedimenty pravděpodobně z posledního glaciálu. Na povrchu těchto sedimentů vyrostl stalagmit, jehož spodní část je stará 9,42 ±0,75 tis. let. Rozsáhlý profil v horizontální chodbě Zazděné jeskyně tvoří fluviální sedimenty podzemního toku, který proudil jeskyní v posledním interglaciálu. Na povrchu sedimentů se uložila vrstva sintru před 114,37 +5,05/–4,85 až 99,85 +3,30/–3,21 tis. lety. Nadložní infiltrační sedimenty se ukládaly v průběhu posledního glaciálu. Rytmicky zvrstvené infiltrační sedimenty vyplňující zadní vertikální část Zazděné jeskyně jsou starší než 780 tis. let, jak dokládá reverzní paleomagnetická orientace naměřená v horní části profilu. V Kateřinské jeskyni bylo datováno ukončení tvorby vápencových sutí (12,7 ±4,3 tis. let BP) transportovaných komíny do Ledové chodby. O stáří reliktu fluviálních sedimentů zachovaných v horní části Medvědího komína nejsou v současné době žádné bližší informace.

Na základě stáří jeskynních sedimentů a morfologie Holštejnského, Sloupského a Lažáneckého údolí, zjištěné pomocí geofyzikálního měření, je možné rekonstruovat posloupnost procesů, které ovlivnily vývoj jeskynních systémů v s. části Moravského krasu. V paleogénu vznikla v krasové oblasti první údolí a nejstarší horizontální jeskynní systémy, zachované v reliktech hlavně v ponorové oblasti na s. okraji krasu. Ve spodním miocénu převládala povrchová eroze vodních toků, která vytvořila hluboká kaňonovitá údolí. Morfologie a spádové poměry těchto údolí naznačují, že rozsáhlé jeskynní systémy odvodňující jednotlivé části Moravského krasu existovaly již na konci spodního miocénu před transgresí spodnobadenského moře. V s. části Moravského krasu to byla souvislá úroveň podzemního odvodňování s ponory na s. a v. okraji vápencového území a vývěrem u dna Lažáneckého údolí. V důsledku hydrografických změn způsobeným mořskou transgresí došlo pravděpodobně v pliocénu ke zdvojení úrovně podzemního odvodňování a vzniku vyšší povodňové chodby Amatérské jeskyně. V průběhu pliocénu a kvartéru vodní toky vytvářely cesty směřující k předbadenské úrovni podzemního odvodňování. Jeskynní systémy byly opakovaně protékány podzemními toky, které přemodelovaly jeskynní chodby a erodovaly starší sedimentární výplně. Proto jsou ve většině jeskyní Moravského krasu zachovány pouze fluviální sedimenty kvartérního stáří. Období aktivity podzemních toků se střídala s periodami klidu, kdy se v jeskyních ukládaly chemogenní sedimenty. V té době proudily vodní toky po povrchu krasovými kaňony.

V s. části Moravského krasu jsou nejstarší sedimenty zachovány v ponorových jeskyních v blízkosti hranice vápenců a nekrasových hornin. Jedná se o fluviální sedimenty uložené koncem spodního pleistocénu v Holštejnské jeskyni a v horní úrovni Sloupsko-šošůvských jeskyní. Tato sedimentační fáze dokládá vyplnění Holštejnského i Sloupského údolí fluviálními sedimenty do výše ústí obou jeskyní. Další období fluviální sedimentace v jeskyních se odehrálo koncem středního pleistocénu, kdy byla vyplněna jak Holštejnská jeskyně, tak rozsáhlé části Sloupsko-šošůvských jeskyní. Příčinou mohl být kolaps stropu propasti Macochy, který podzemnímu toku zablokoval cestu k vývěru v Pustém žlebu. Po kolapsu stropu propasti se hladina podzemního toku vzdula a voda vytvořila novou cestu z Amatérské jeskyně do Písečné jeskyně v Macoše. Během této anomální hydrologické situace došlo k periodickým průnikům vodního toku s fluviálními sedimenty do níže položené horizontální chodby v Zazděné jeskyni. Ukončení říční sedimentace v Zazděné jeskyni dokládá sintrová vrstva uložená na povrchu fluviálních sedimentů počátkem posledního glaciálu. V průběhu svrchního pleistocénu proběhlo v Holštejnské, Sloupsko-šošůvských a v Amatérské jeskyni poslední období fluviální eroze a akumulace. V holocénu a v současnosti převažuje eroze starších říčních uloženin.

Příčinou ukládání fluviálních sedimentů a vyplňování jeskynních chodeb bylo ve většině případů lokální přerušení proudění podzemního toku v jeskynním systému. Nelze proto srovnávat akumulační období v jeskyních Moravského krasu s tvorbou říčních teras povrchových toků, jejichž vznik je ovlivněn převážně klimatickými oscilacemi, k nimž docházelo v průběhu pleistocénu.

REFERENCES

ABSOLON, K., 1904: Propasť Macocha na Moravě. – Klub Čes. Tur., 83p.

ABSOLON, K., 1905–11: Kras Moravský a jeho podzemní svět. – Wiesner, 218p.

ABSOLON, K., 1912: Průvodce Moravským krasem zejména jeho krápníkovými jeskyněmi. – Barvič a Novotný, 221p.

ABSOLON, K., 1922: Macocha a krápníkové jeskyně Punkvina a Kateřinská, vodní jeskyně Punkvy. – Barvič a Novotný, 74p.

ABSOLON, K., 1970a: Moravský kras 1. – Academia, 416p.

ABSOLON, K., 1970b: Moravský kras 2. – Academia, 345p.

AMBROŽ, J., 1991: Silnice II/379, Blansko – most (Starohraběcí). Zpráva o inženýrsko-geologickém průzkumu pro zakládání mostu. – MS, Geofond, Praha, 16p.

BENEŠ, V., 1994: Geofyzikální měření v Holštejnském a Sloupském údolí v Moravském krasu. – MS, Čes. geol. Úst., 29p.

BENEŠ, V., 1997: Moravský kras-Lažánecké údolí. Zpráva o geofyzikálním měření. – MS, archiv Čes. geol. Úst., 13p.

BEZVODOVÁ, B., DEMEK, J., ZEMAN, A., 1985: Metody kvartérně geologického a geomorfologického výzkumu. – UJEP (Brno), 207p.

BOSÁK, P., 1977: Spodnokřídový fosilní kras v Evropě. – Čes. Kras (Beroun), 2:59–64.

BOSÁK, P., 1978: Rudická plošina v Moravském krasu – část III. Petrografie a diageneze karbonátů a silicitů reliktu jury u Olomučan. – Čas. Morav. Muz. (Brno), Vědy přír., 58: 7–28.

BOSÁK, P., HORÁČEK, I., PANOŠ, V., 1989: Paleokarst of Czechoslovakia. – in Paleokarst: a systematic and regional review (P. Bosák, D. C. Ford, J. Glazek, I. Horáček, eds.), Academia, 107–135.

BOUČEK, M., 1971: Zpráva o inženýrské-geologickém průzkumu v prostoru dostavby strojírny 1 v závodě ČKD Blansko. – MS, Geofond, Praha.

BRZOBOHATÝ, R., 1996: Neogenní sedimenty v okolí Mokré. – MS, MU, Brno, 22p.

BULL, P. A., 1981: Some fine-grained sedimentation phenomena in caves. – Earth Surf. Proc. and Land., Vol. 6:11–22.

DOBKINS, J. E., FOLK, R. L., 1970: Shape development on Tahiti-Nui: J Sed. Petrol., Vol. 40, No. 4, 1167–1203.

DVOŘÁK, J., 1961: Výsledky vrtného průzkumu v severní části Moravského krasu. – Symposion o problémech pleistocénu, Anthropos (Brno), 14:93–95.

DVOŘÁK, J., 1994: Neogenní výplň údolí u Jedovnic a otázka stáří hlavních jeskynních úrovní v severní části Moravského krasu. – J. Czech. geol. Soc., 39(2):1–7.

DVOŘÁK, J., 1995: Tektonický a morfologický vývoj jv. okraje Českého masívu při podsouvání pod Karpaty. – Knih. Zem. Plyn Nafta, 16:15–24.

DVOŘÁK, J., FRIÁKOVÁ, O., MITRENGA, P., REIL, L., 1984: Vliv stavby východní části brněnského masívu na vývoj nadložních sedimentárních formací. – Věst. Ústř. Úst. geol., 59:21–28.

DVOŘÁK, J., PTÁK, J., 1963: Geologická vývoj a tektonika devonu a spodního karbonu Moravského krasu. – Sbor. geol. Věd, Geol., 49–84.

DVOŘÁK, J., SEDLÁK, J., 1991: Jedovnice na Drahanské vrchovině – gravimetrický a geologický výzkum neogénem vyplněných depresí. – MS, Čes. geol. Úst., 20p.

DVOŘÁK, J., ŠTELCL, O., DEMEK, J., MUSIL, R., 1993: Geologie a geomorfologie Moravského krasu. – in Moravský kras – labyrinty poznání (R. Musil, ed.), GEO program, 32–76.

FORD, D. C., 1987: Characteristics of dissolutional cave systems in carbonate rocks. – in Paleokarst (N. P. James, P.W. Choquette eds.), Springer-Verlag, 25–57.

GLAZEK, J., HERCMAN, H., VÍT, J., 1995: Předběžné výsledky datování sintrů metodou $^{230}Th/^{234}U$ z Holštejnské jeskyně. – in Svět v podzemí (V. Cílek ed.), Knih. Čes. speleol. Spol., 25:24–29.

HANZLÍKOVÁ, E., BOSÁK, P., 1978: Misrofossils and microfacies of the Jurassic relict near Olomučany (Blansko district). – Věst. Ústř. Úst. geol., 52:73–79.

HARMON, R. S., THOMPSON, P., SCHWARZ, H. P., FORD, D. C., 1975: Uranium-series dating of speleothems. – Natl. Speleol. Coc. Bull., 37:21–33.

HERCMAN, H., LAURITZEN, S. E., GLAZEK, J., VÍT, J., 1997: Uranium-series dating of speleothems from Amaterska and Holstejnska Caves, Moravian Karst, Czech Republic. – Proc. 12th Int. Cong. Speleol., Basel, 45–47.

HLADIL, J., 1983: The biofacies sedimentation of Devonian Limestones in the central part of the Moravian Karst. – Sbor. geol. Věd, Ř G, 38:71–94.

HLADIL, J., MELICHAR, R., OTAVA J., GALLE, A., KRS, M., MAN, O., PRUNER, P., CEJCHAN, P., OREL, P., 1999: The Devonian in the Easternmost Variscides, Moravia: A holistic analysis directed towards comprehension of the original context. – Abh. Geol. B.-A., 54:27–47.

HYPR, D., 1975: Miocenní sedimenty v oblasti Moravského krasu a okolí. – MS, Dipl. Thesis, UJEP, Brno: 56s.

HYPR, D., 1980: Jeskynní úrovně v severní a střední části Moravského krasu. – Sbor. Okr. Mus. v Blansku, 12:65–79.

KADLEC, J., 1994: Význam poloh ostrohranných klastů v sedimentech vnitrojeskynní facie Zazděné jeskyně, Moravský kras. – Geol. Výzk. na Mor. a Slez. v Roce 1993, 9–10.

KADLEC, J., 1996: Holštejnské údolí v Moravském krasu. – in Speleologie na Holštejnsku. Výzkumy v letech 1966–1996 (R. Zatloukal ed.), Knih. Čes. speleol. Spol., 28:7–12.

KADLEC, J., 1997a: Reconstruction of the development of semiblind ponor valleys in Moravian Karst based on geophysical surveying, Czech Republic. – Proc. 12th Int. Cong. Speleol., Basel, 387–390.

KADLEC, J., 1997b: Reconstruction of the sedimentary processes in the Moravian Karst (northern segment) cave systems during the Cenozoic. – MS, Ph.D. Thesis, UK Praha, 149p.

KADLEC, J., 1997c: Shape of fluvial pebbles in surface and subsurface karst streams from Moravian Karst, Czech Republic. – Proc. 12th Int. Cong. Speleol., Basel, 13–16.

KADLEC, J., BENEŠ, V., 1996: Jak vznikla Macocha? – Speleo (Praha), 23:5–17.

KADLEC, J., HERCMAN, H., NOWICKI, T., GLAZEK, J., VÍT, J., ŠROUBEK, P., DIEHL, J. F., GRANGER, D., 2000: Dating of the Holštejnská Cave deposits and their role in the reconstruction of semiblind Holštejn Valley Cenozoic history (Czech Republic). – Geologos, Univ. A. Mickiewicza (Poznań), 5(2000): 57–65.

KADLEC, J., OTAVA, J., 1999: Genesis of cave systems of Moravian Karst as a function of the Jedovnice and Lažánky valleys development. – Abst. 2nd Natl. Speleol. Conf., Czech. Speleol. Soc., 18–20.

KADLECOVÁ, R., KADLEC, J., 1995: Vznik a stáří Amatérské jeskyně. – Speleo (Praha), 20:16–22.

KAROUS, M., 1989: Geoelektické matody průzkumu. – SNTL (Praha), 423p.

KETTNER, R., 1960: Morfologický vývoj Moravského krasu a jeho okolí. – Čs. Kras, 12:47–84.

KNIES, J., 1895: Příspěvky ku poznání diluviální fauny moravských jeskyň. – Věst. Čes. Akad. Vědy Slovesn. Umění, 4:218–231.

KREJČÍ, J., 1960: K otázce existence krasového cyklu. – Sbor. Čs. Spol. zem., 65:315–325.

KRYSTEK, I., 1959: Příspěvek k otázce geneze a stáří rudických vrstev. – Kras v Českoslov., 1:22–23.

KRÍŽ, M., 1864: O jeskyních moravských. – Živa, roč. 12:234–249.

KRÍŽ, M., 1891: Kůlna a Kostelík. Dvě jeskyně v útvaru devonského vápence na Moravě. Bádání a rozjímání o pravěkém člověku. – Brno, 474p.

KRÍŽ, M., 1900: O jeskynních Sloupských. – Čas. Vlast. muz. Spolku v Olomouci, 17:46–64, 102–115.

KUKLA, J., LOŽEK, V., 1958: K problematice výzkumu jeskynních výplní. – Čs. Kras, 11:19–41.

KVÍTKOVÁ, L., 1999: Vliv klimatu na mineralogické a petrografické složení sedimentů jeskyně Kůlna, Moravský kras. – MS, Dipl. Thesis, MU Brno, 44p.

LOWE, D. R., 1975: Water escape structures in coarse-grained sediments. – Sedimentology, 22:157–204.

LOŽEK, V., 1963: K otázce tvorby svahových sutí v Českém krasu. – Čs. Kras, 14:7–16.

LOŽEK, V., 1973: Příroda ve čtvrtohorách. – Academia, 372p.

LOŽEK, V., 1979: Zpráva o biostratigrafických výzkumech v jeskyních Řečiště, Srnčí a Holštejnské v Moravském krasu. – Čs. Kras, 31:114–115.

LOŽEK, V., CÍLEK, V., 1995: Late Weichselian-Holocene sediments and soils in mid-European calcareous areas. – Sbor. geol. Věd, Anthropozoikum, 22:87–112.

MALKOVSKÝ, M., 1979: Tektogeneze platformního pokryvu Českého masívu. – Knih. Ústř. Úst. geol., 53, 176p.

MOTYČKA, Z., POLÁK, P., SIROTEK, J., VÍT, J., eds., 2000: Amatérská jeskyně: 30 let od objevu největšího jeskynního systému České republiky. – Čes. speleol. Spol. (Brno), 232p.

MUSIL, R., (ed.), 1974: Die Amatérská jeskyně – Hhle. Die bedeutendste entdeckung der letzten zeit in Moravský kras (Mhrischen Karstes). – Stud. geogr. (Brno), 27, 136p.

NISHIIZUMI, K., LAL, D., KLEIN, J., MIDDLETON, R., ARNOLD, J. R., 1986: Production of ^{10}Be and ^{26}Al by cosmic rays in terrestrial quartz in situ and implications for erosion rates. – Nature (Lond.), 319:134–136.

OSBORNE, R. A. L., 1984: Lateral facies changes, unconformites and stratigraphic reversals: their significance for cave sediment stratigraphy. – Cave Sci., 11(3):175–184.

OTAVA, J., VÍT, J., 1992: Paleohydrography of the northern tributaries of the Punkva River reconstructed from the analysis of cave sediments (Moravian Karst, Drahany Upland). – Scripta Univ. Purkyn. brun., Geol., 22:141–156.

PANOŠ, V., 1961: Sloupské údolí a Pustý žleb v Moravském krasu, jejich postavení v krasovém cyklu. – MS, Cand. Thesis, Nár. knih. Praha, 357p.

PANOŠ, V., 1963: K otázce původu a stáří sečných povrchů v Moravském krasu. – Čs. Kras, 14:29–41.

PANOŠ, V., 1964: Der Urkarst in Ostflügel der Bohmischen Masse. – Z. Geomorphol., N. F., 8(2):105–162.

PELÍŠEK, J., 1940: Prozkum nánosů v jeskyni „Zazděná" v Moravském krasu. – Příroda a škola, 33(9):265–273.

PELÍŠEK, J., 1948: Jeskynní sedimenty Moravského krasu. – Čs. Kras, 1:7–11.

PELÍŠEK, J., 1974: Sedimente des Höhlensystems Amatérská, nrdlich Ostrov im Gebiet des Mährischen Karstes. – in: Die Amatérská jeskyně – Höhle. Die bedeutendste entdeckung der letzten zeit in Moravský kras (Mährischen Karstes) (R. Musil, ed.), Stud. geogr. (Brno), 27:61–67.

PELÍŠEK, J., 1975: Sedimenty jeskyně „Zazděná" ve střední části Moravského krasu. – Speleol. Věst. (Brno), 6:7–17.

PELÍŠEK, J., 1980: Rytmicky tence vrstevnaté sedimenty v jeskyních Moravy. – Čs. Kras, 31:69–73.

PROKOP, R., 1988: Zpráva o inženýrsko-geologickém průzkumu pro studii rekonstrukce jezu na Jakubově jezeře ČKD Blansko. – MS, Geofond, Praha.

PŘIBYL, J., 1966: Paleohydrografická situace Sloupských jeskyní v severní části Moravského krasu na základě studia morfologie a přednostní orientace valounů ve štěrcích. – Čas. Morav. Muz. (Brno), Vědy přír., 51:73–84.

PŘIBYL, J., 1972a: Geologie jeskynních sedimentů Moravského krasu. – MS, Rigor. Thesis, MU Brno, 66p.

PŘIBYL, J., 1972b: Příspěvek k sedimentologickým poměrům jeskyně „Zazděná" v Pustém žlebu (Moravský kras). – Speleol. Věst. (Brno), 1:34–39.

PŘIBYL, J., 1973: Paleohydrography of the caves in the Moravian Karst (Moravský kras). – Stud. geogr. (Brno), 28:1–64.

PŘIBYL, J., 1988: Paleohydrografický vývoj a morfotektonika severní části Moravského krasu a Amatérské jeskyně. – Rozpr. Čs. Akad. Věd, Ř. mat. přír. Věd, 98(1):1–82.

PŘIBYL, J., RAJMAN, P., 1980: Punkva a její jeskynní systém v Amatérské jeskyni. – Stud. Geogr. (Brno), 68:141p.

RINK, W. J., SCHWARCZ, H. P, VALOCH, K, SEITL, L., STRINGER, C. B., 1996: Dating of Micoquian industry and Neanderthal remains at Kůlna Cave, Czech Republic. – J. Archaeol. Sci., 23:889–901.

SCHMID, E., 1958: Höhlenforschung und sedimentenanalyse. – Schrift. Inst. Ur-und Frgesch. Schweiz, 13:185p.

SCHÜTZNEROVÁ-HAVELKOVÁ, E., 1957: Nový nález tortonských sedimentů v dolním údolí Punkvy. – Čs. Kras, 10:86–88.

SCHÜTZNEROVÁ-HAVELKOVÁ, E., 1958: Mocnost tortonských sedimentů v Lažáneckém údolí v Moravském krasu. – Čs. Kras, 11:180–182.

SEITL, L., 1998: Paleontologické výzkumy ve Sloupských jeskyních (severní část moravského krasu). – Acta Mus. Moraviae, Sci. geol., 83:123–145.

SMOLÍKOVÁ, L., KADLEC, J., 1993: Interglaciál v holštejnském údolí v Moravském krasu. – Věst. Čes. geol. Úst., 68(4):63–64.

ŠLECHTA, M., RYŠAVÝ, P., 1974: Objev Amatérské jeskyně ve vztahu k podzemní Punkvě. – in Die Amatérská jeskyně – Höhle. Die bedeutendste entdeckung der letzten zeit in Moravský kras (Mährischen Karstes) (R. Musil, ed.), Stud. geogr. (Brno), 27:37–41.

ŠROUBEK, P., DIEHL, J. F., 1995: Paleomagnetické/environmentálně magnetické studium jeskynních sedimentů Moravského krasu. – in: Svět v podzemí (V. Cílek, ed.), Knih. Čes. speleol. Spol., 25:29–30.

ŠROUBEK, P., DIEHL, J. F., KADLEC, J., VALOCH, K., in press: A Late Pleistocene paleoclimatic reconstruction based on mineral magnetic properties of the entrance facies sediments of Kulna Cave, Czech Republic. – Geoph. J. Int.

ŠTELCL, O., 1962a: Geomorfologické poměry Holštýnského poloslepého údolí v Moravském krasu. – Čs. Kras, 13:31–51.

ŠTELCL, O., 1962b: K otázce stáří Lažáneckého žlebu v Moravském krasu. – Čs. Kras, 13:57–66.

ŠTELCL, O., 1963: Jeskynní úrovně severní části Moravského krasu. – Čs. Kras, 14:17–27.

ŠTELCL, O., 1964: Geomorfologické poměry jihozápadní části Drahanské vrchoviny. – Sbor. Čs. Spol. zem., 69:21–45.

TARABA, J., 1976: Moravský kras. Dílčí zpráva za II. etapu regionálního hydrogeologického průzkumu. – MS, Geofond, Praha.

TARABA, J., 1981: Zpráva o podrobném hydrogeologickém průzkumu. Blansko – ČKD. – MS, Geofond, Praha.

VALOCH, K., 1988: Die Erforschung der Kůlna Höhle 1961–1976. – Anthropos (Brno), 24, 204p.

VALOCH, K., 1989: Osídlení a klimatické změny v poslední době ledové na Moravě. – Čas. Morav. Muz. (Brno), Vědy přír., 74:7–27.

VANDENBERGHE, J., 1993: Changing fluvial processes under changing periglacial conditions. – Z. Geomorph. N.F., 88:17–28.

VILŠER, M., 1962: Zpráva o dalším nálezu miocenních sedimentů západně od Lažánek a jihovýchodně od Jedovnic. – Zpr. geol. Výzk. v Roce 1961:213–214.

VILŠER, M., 1966: Zpráva o hydrogeologickém posouzení vlivu staveb Výzkumného ústavu vodních strojů ČKD Blansko na hydrogeologický vrt VA 1 na katastrálním území obce Lažánky. – MS, Geofond, Praha, 6p.

VÍT, J., 1990: Asociace těžkých minerálů v sedimentech jeskyní Moravského krasu. – MS, Dipl. Thesis, MU Brno, 75p.

VÍT, J., 1996: Fluviální sedimenty severní části Moravského krasu. – MS, Ph.D. Thesis, MU Brno, 110p.

VÍT, J., 2000: Sedimentologie. – in: Amatérská jeskyně: 30 let od objevu největšího jeskynního systému České republiky (Z. Motyčka, P. Polák, J. Sirotek, J. Vít, eds.), Čes. speleol. Spol. (Brno), 121–131.

WANKEL, J., 1868: Dei Slouper Höhle und ihre Vorzeit. – Denkschrift d. math. natur. Sec. d. Kais. Acad. d. Wissensch., 28:95–130.

WANKEL, J., 1882: Bilder aus der Mhrischen Schweiz und ihrer Vergangenheit. – Wien, 422p.

ZATLOUKAL, R., VÍT, J., MRAVEC, P., 1996: Jeskyně Holštejnská (č. 518) – Nezaměstnaných (č. 517). – in Speleologie na Holštejnsku. Výzkumy v letech1966–1996 (R. Zatloukal, ed.), Knih. Čes. speleol. Spol. (Praha), 28, 14–20.