Cenozoic History of the Moravian Karst Cave Systems, Czech Republic

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Abstract

The Moravian Karst (MK) is an example of a fluviokarst area, which is usually subdivided into three segments – each with a separate drainage pattern. Cave systems were formed by subsurface streams during the Cenozoic. These cave systems, the length of which exceeds 30 km, always consist of lower and upper cave levels. The lower levels are genetically linked with the bottom of the karst valley and were formed in the Early Miocene whereas large upper levels have been formed by subsurface rivers since the Late Miocene after blocking the springs of lower levels by sediments. The MK cave systems underwent several stages of cave sediment deposition and erosion. A reconstruction of hydrological processes during the Early, Middle and Late Pleistocene was based on radiometric and paleomagnetic datings of preserved cave deposits.

1. Introduction

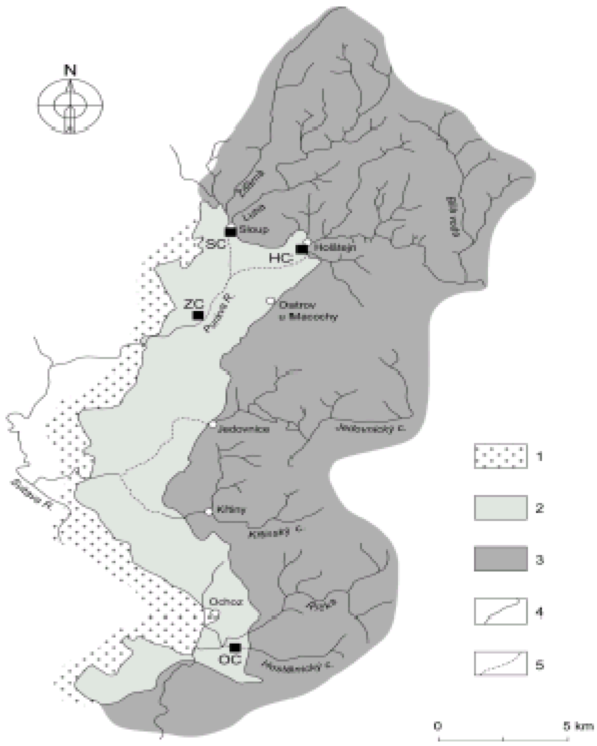
The MK is located in the eastern part of the Czech Republic.

Devonian limestones form a N-S-trending belt, 3–5 km wide and 25 km long. The karst area is surrounded by Lower Carboniferous nonkarstic sediments and Proterozoic granitoids (Fig. 1). The limestone surface is dissected by deep valleys, locally adopting the character of karst canyons dividing into the northern, central and southern segments. The streams flowing through cave systems spring N and E of the MK. Water passes through cave systems and re-appears on the surface at resurgences along the western margin of the karst area (see Fig.1). Each of the three segments of the MK is characterized by a separate drainage pattern. The 30 km long cave system is located in N segment of karst drained by the Punkva River. The large portion of this system is called the Amaterska Cave. The Rudicke propadani-Byci skala Cave with the length of 6 km was formed by the Jedovnicky Creek in the central segment. The Ochozska Cave is 1800 m long and was formed by the Hostenicky Creek in the S segment of the MK.All these large karst systems consist from lower active and upper flood cave levels. Flood passages are often filled with sequences of fluvial sediments intercalated by speleothem horizons.

2. Methods

The key sections in cave sediments were drawn at the scale 1:10.

Based on sedimentary structures the genesis of the individual sediment bodies was interpreted. The ages of the cave sediments were determined by several independent methods. Speleothems were dated using the 230Th/234U method (a-particle counting) in the Uranium-Series Laboratory of the Institute of Geological Sciences of the PAN in Warsaw and at the University of Bergen, Norway. In one case, the age of fluvial sediments was determined by measurement of 10Be and 26Al isotope contents in quartz pebbles. The dating was performed at 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 soft sediments and speleothems were performed in the paleomagnetic labs of the Institute of Geology AS CR in Praha, CZ and at Michigan Technological University, USA.



1 – Proterozoic granitoids; 2 – Devonian to Lower Carboniferous limestones; 3 – Lower Carboniferous shales, greywackes and conglomerates; 4 – surface reaches of streams; 5 – subsurface reaches of streams; caves with key sedimentary sections: SC – Sloupsko-sosuvska Cave; HC – Holstejnska Cave; ZC – Zazdena Cave; OC – Ochozska Cave

Fig. 1. Modern hydrography of the Moravian Karst

3. Key sedimentary sections in the cave systems of the Moravian Karst

3.1. Holstejnska Cave

The Holstejnska Cave is located near the N periphery of the MK, in a half-blind valley. This ponor cave is formed by a horizontal corridor, posing the upper level of a cave system. Its lower level is the Cave No. 68, lying 60 m deeper. The two levels are interconnected by vertical cavities filled with sediment. The Holstejnska Cave is a 40–50 m broad corridor filled with several sediment bodies of different ages. Local cavers excavated corridors in sediment fill of this cave more than 700 m long.

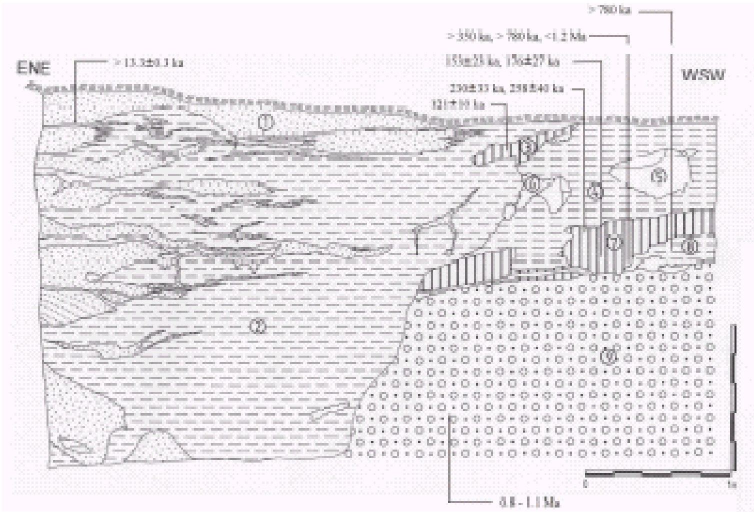
Key Section 1

Section is perpendicular to the flow direction of the subsurface stream and shows three sedimentary units (Fig. 2). The periods of fluvial activity were alternated by periods of speleothem deposition. Channels filled by youngest sediments (Unit C) are eroded into both older units.

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 10Be and 26Al isotopes measured in quartz pebbles from these deposits (KADLEC et al., 2000a). Fluvial sandy silts 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 (SROUBEK & DIEHL, 1995) and Th/U age exceeding the limits of this method, i.e. 350 ka (HERCMAN et al., 1997).

The 234U/ 238U 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 176 ±27 ka and 230 ±33 ka. Similar data were produced by older dating of flowstone from the upper part of this flowstone layer: 153 ±23 ka and 258 ±40 ka (Glazek et al., 1995). The above given results suggest that the hiatus in flowstone precipitation lasted ca. 500,000 years. The relic of a flowstone layer overlying Unit B was dated by the Th/U method at 121 ±10 ka. This means that fluvial clayey silt of Unit B was deposited in the penultimate glacial period between 153 ±23 and 121 ±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 in the S part of the Holstejnska Cave. The base of the stalagmite was formed at 13.3 ±0.3 ka, while its apex at 4.7 ±1.1 ka (KADLEC et al., 2000b). The youngest fluvial Unit C, lying below the stalagmite, was therefore deposited in the Last Glacial.



1 – medium- to coarse-grained sand, horizontally stratified, locally cross-bedded; 2 – clayey silt ;3 – relic of flowstone layer ;Unit B (fluvial sediments): 4 – clayey silt with no bedding, occasionally contains lenses of sandy gravel; 5 – limestone block; 6 – calcareous concretion ; 7 – relic of flowstone layer ;Unit A (fluvial sediments): 8 – sandy silt ;9 – sandy gravel with weathered greywacke pebbles and cobbles often cemented with carbonate, no bedding

Fig. 2. Section 1, the Holstejnska Cave Unit C (fluvial sediments)

3.2. Sloupsko-sosuvska Cave

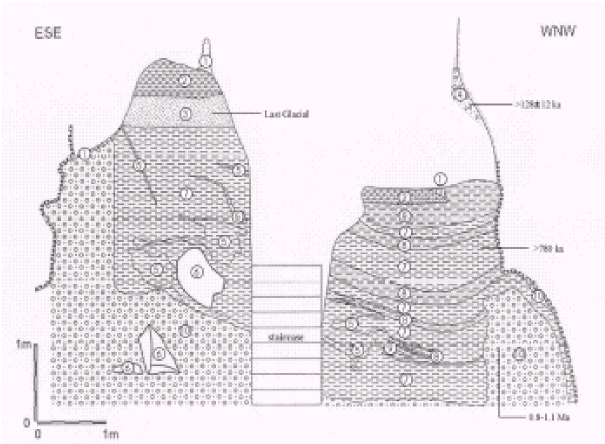
The Sloupsko-sosuvska Cave lies on the N periphery of the Moravian Karst, in a half-blind valley located 3 km W of the Holstejnska Cave (see Fig. 1). The cave system comprises the upper and the lower cave levels interconnected by several chasms up to 70 m deep. The length of the whole system exceeds 6 km. The modern stream disappears in the W part of the upper level, passes through vertical paths and re-appears at the lower level, then flows to the Amaterska Cave. Cave sediments of different ages are preserved at a number of locations at the upper level of the cave system.

Key Section 2

The section is oriented perpendicular to the flow direction of the subsurface stream. No speleothem are preserved in this section, instead stalagmite and thin crust at the top. In the oldest Unit A, the subsurface stream eroded a channel with steep banks filled with fine sediments of Unit B (Fig. 3).

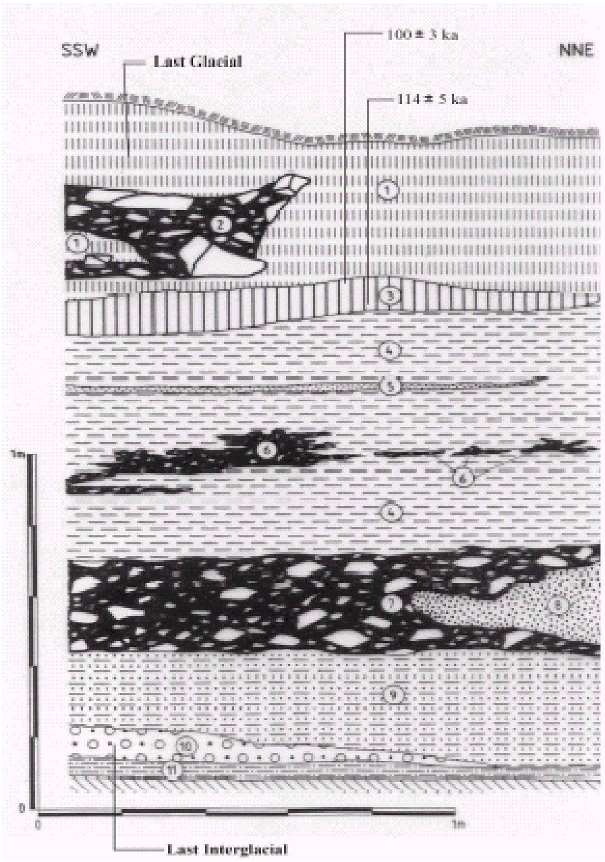
Age of sediments

Fine silt and sand (Unit B) filling the channel in gravel in Section 3 shows a reverse paleomagnetic polarity indicating the age older than 780 ka (SROUBEK & DIEHL, 1995). Lithology and intensity of weathering of pebbles in Unit A are comparable with those of the oldest fluvial sediments in the Holstejnska Cave (Unit A). Both units may therefore be of the same age, 0.8– 1.1 Ma. Their similar ages are also suggested by the equal rate of weathering of clay minerals at both localities (VÍT, 1996). The age of sandy gravel (Unit C) cemented to the cave walls above the section probably correspond with fillings exposed in the N part of the cave system, where 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. The youngest sandy gravel in Section 2 (Unit D) was then deposited in the Last Glacial and overgrown by stalagmites of probably Holocene age.



1 – stalagmite; Unit D (fluvial sediments): 2 – sandy gravel; 3 – sand; Unit C (fluvial sediments): 4 – relics of sandy gravel cemented to limestone walls in the neighbourhood of the section; Unit B (fluvial sediments): 5 – clayey to sandy silt cemented with cabronate; 6 – limestone blocks; 7 – clayey to sandy silt; 8 – laminae of clayey silt and fine-grained sand; 9 – sand; Unit A (fluvial sediments): 10 – sandy gravel with strongly weathered greywacke pebbles and cobbles

Fig. 3. Section 2, the Sloupsko-sosuvska Cave



1 – infiltration laminated silts; 2 – limestone scree; 3 – flowstone horizon; fluvial sediments: 4 – clayey silt; 5, 8 – medium sand; 9, 11 – sandy silt; 10 – sandy gravel; 6,7 - limestone scree

Fig. 4. Section 3, the Zazdena Cave

3.3. Zazdena Cave

The Zazdena Cave located near the Macocha Chasm provides one of the largest exposures of cave sediments in the Moravian Karst. The exposure dates to 1938–1940 when a tunnel 350 m long was excavated in sediments filling a horizontal cave corridor.

Key Section 3

Layers of fluvial sandy gravel, sand and silt were deposited in the cave corridor. These deposits are covered by a flowstone horizon up to 20 cm thick. The infiltration laminated silts transported by meteoric waters, coming vertically through the cracks and karst chimneys, filled cave passage up to the ceiling.

Both fluvial and infiltration deposits are intercalated by the horizons of limestone scree transported from near karst chimney.

Age of sediments

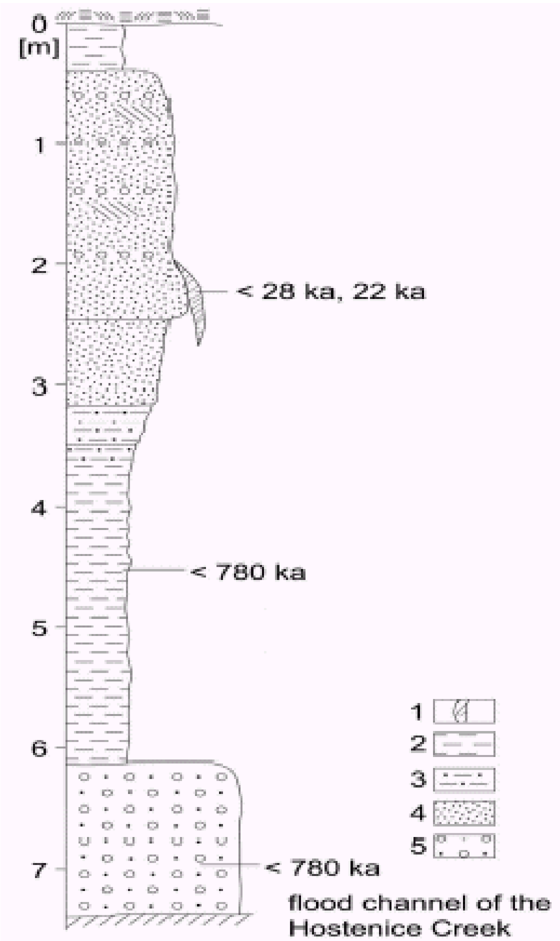
The Th/U dating has revealed that flowstone horizon was deposited at the beginning of the Last Glacial between 114 ±5 ka and 100 ±3 ka. Underlying fluvial sediments were deposited probably in the Last Interglacial. Laminated clayey silts underlying by flowstone were deposited during the Last Glacial.

3.4. Ochozska Cave

The section is located in a large flood corridor, which was originally filled with fluvial sediments up to the ceiling. The upper portion of 7 m thick sequence is exposed due to later erosion of subsurface stream. The lower portion of the sedimentary body was exposed by recently excavated 4 m deep test-pit.

Key Section 4

Lower portion of the section is formed by a gravel bar deposited on the limestone bottom of cave corridor. Due to collapse of cave mouth the corridor was filled by silts and sands deposited from stagnant or slowly flowing water (Fig. 5). Later the subsurface stream eroded a flood channel in this sedimentary sequence. Flowstone crusts were precipitated on the slopes of this channel.



Fluvial sediments: 1 – clayey silt; 2 – sandy silt; 3 – sand; 4 – sandy gravel

Fig. 5. Section 4 (the upper portion), the Ochozska Cave

Age of sediments

The paleomagnetic record was measured in 30 samples colected from clayey silts. All these samples reveal normal paleomagnetic orientation which mean that the age of deposits is most probably lower than 780 ka. The samples from the flowstone crust were dated by Th/U method. However, the carbonate is highly contaminated by detrital Th. Therefore, the results of datings have only approximative value. The flowstone is younger then 28 or 22 ka, respectively.

4. Discussion on History of the Moravian Karst Cave Systems

The early history of the MK cave systems is proposed on the basis of morphology of cave systems and half-blind valleys investigated by gravity and vertical electrical sounding survey (DVORAK, 1994; KADLEC 1996, 1997) because Tertiary cave deposits were excavated from cave passages and only Quaternary sequences are preserved.

In the **Paleogene**, surface streams in the Moravian Karst area formed shallow valleys. First horizontal cave systems originated at the levels of the bottoms of these oldest valleys.

The upper level of the Sloupsko-sosuvska and Holstejnska caves and many other care relics date back to this time (e.g., PANOS, 1963; HYPR, 1980). During the **Lower Miocene** Karpatian nappes were docked in the Carpathian Foredeep (SE of the MK).

Northwesterly nappe advance resulted in uplift of large areas at the E margin of the Bohemian Massif including the MK. The shallow valleys of Paleogene age were deepened due to river gradient changes. Tectonics movements and gradient changes of bottoms of surface valleys may have occurred at the contact between limestones and non-karstic sediments. With the tendency to reach graded profiles again, streams created in each segment of the MK cave system with ponors on the N or E periphery of karst. The lower levels of the Sloupsko-sosuvska and Holstejnska caves and lower active passages of the Amaterska, Rudicke propadani-Byci skala and Ochozska caves were formed. These systems were guiding water through the limestones to the SW, towards the base level formed by the local larger rivers. The resurgences of this cave systems were located at the bottoms of deep karst valleys formed during the Lower Miocene period of tectonic instability. In the early **Middle**

Miocene (during Lower Badenian), sea transgressed over the Moravian Karst and other areas on the E margin of the Bohemian Massif. The surface of the karst area was covered by marine sands and clays and all karst processes were interrupted.

It was a major event, dividing the Cenozoic history of the MK into two periods. In the period between the marine regression and the **end of the Miocene**, the MK was under the influence of erosion, slowly removing marine sediments from the surface. The marine transgression induced hydrographic changes, which influenced further development of cave systems during the Late Cenozoic. The former resurgence of the Punkva River near the bottom of the pre-Badenian valley remained permanently sealed beneath marine clays at a depth of almost 140 m below the present surface. The blockage of this resurgence from the Amaterska Cave caused the rise of the groundwater table.

Intensive flow at the level of the risen groundwater table caused the origin of a horizontal cave passage. The subsurface stream formed the large corridors of upper flood level of the Amateska Cave during the **Pliocene** and Early Pleistocene. The large flood passage in Ochozska Cave was formed in the same time period.

The Jedovnický Creek opened a completely new path into the pre-Badenian cave system draining the central segment of the MK. Newly formed passages in the Rudicke propadani-Byci skala cave have the character of high meandering corridors indicating rapid incision of subsurface stream, which tended to join the lower, pre-Badenian cave level.

Alternation of glacial and interglacial climate started in the **Early Pleistocene** 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. 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 were gradually filled with fluvial sediments. Streams, which started to flow into the Holstejnska Cave and the upper level of the Sloupskososuvska Cave, opened vertical connections between the upper and lower levels in both systems, directing water to the Amaterska Cave. At the end of the Early 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 Amaterska Cave due to, e.g., catastrophic choke. In such case, Holstejnska and Sloupsko-sosuvska ponor caves became filled with fluvial sandy gravel (Unit A). In the **Middle Pleistocene**, streams reentered the Holstejnska Cave and the Sloupsko-sosuvska 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 Holstejnska Cave and the Sloupsko-sosuvska 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. 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 & BENES, 1996). The fluvial deposition in the Zazdena Cave was also induced by roof collapse in the near Macocha Chasm (KADLEC, 1994). Also the Ochozska Cave was filled with fluvial sediments deposited after the cave mouth collapse, which blocked the resurgence the Hostenicky Creek. 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. The last episode of fluvial erosion and accumulation took place in the caves during the **Late Pleistocene**. Subterranean streams produced channels in older fluvial accumulations, through which they flowed into chasms connecting upper and lower levels in ponor caves in the N segment of the MK. After repeated blockage of this path, channels and the whole cave corridors were partly or completely filled with the youngest fluvial sediments. The Zazdena Cave corridor was filled with laminated infiltration sediments up to the ceiling. In the Ochozska Cave the erosion of older fluvial sediments prevailed during the Last Glacial. In the **Holocene**, the active cave systems were dominated by stream erosion.

Abundant speleothem decorations were deposited in flood passages during the Holocene.

5. Conclusions

1. Subsurface rivers formed the MK cave systems with ponors on the N or E periphery and resurgences along the W periphery of karst area in the late Early Miocene, before the Badenian marine transgression.

2. Large flood corridors were formed during the Pliocene as a consequence of hydrographic change caused by transgression and marine sediment deposition.

3. Several periods of fluvial aggradation and erosion can be distinguished during the Pleistocene: in the late Early, late Mid and Late Pleistocene. Periods of fluvial deposition alternated with periods of speleothem deposition.

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

Acknowledgements

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