RELICT FLOWSTONE AT MACHNÍN (THE JEŠTĚD RIDGE, NORTH BOHEMIA, CZECH REPUBLIC) AND ITS IMPORTANCE FOR RELIEF EVOLUTION

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Nikola Jurková, Pavel Bosák, Maryna Komar, Petr Pruner: Relict flowstone at Machnín (the Ještěd Ridge, North Bohemia, Czech Republic) and its importance for relief evolution. Geomorphologia Slovaca et Bohemica, 7, 2007, 2, 3 Figs., 27 Refs.

Unroofed caves represent special features of superficial karst morphology. They developed due to the transformation of underground cavities caused by a range of geomorphic processes especially by relief lowering by chemical denudation. Unroofed caves can be identified on the karst surface due to their shape or due to occurrence of cave sediments and speleothems. The rest of flowstone crust represents the first indication of unroofed cave in the Czech Republic, although typical features of unroofed caves are missing (depression-like form, cave walls) and also geomorphic position on top of limestone ridge is unique. It represents highly evolved example of unroofing process. The flowstone overlying calcite-cemented breccia was discovered in position *in situ* in one small karst area of the Ještěd Ridge. Upper Pliocene to Lower Pleistocene (about 3.6 to 0.7 Ma) age has been obtained by palynological and paleomagnetic analyses. Comparison of age and relative altitude position indicates the valley incision rate from 28 to 143 mm.ka^{-1}.

Key words: relict of cave, cave sediments, palynology, paleomagnetism, tectonics, Ještěd Ridge

1 INTRODUCTION

Karst represents terrain with distinctive hydrology and landforms. They arise from a combination of high rock solubility (in comparison with other rock types) and well-developed secondary porosity. The result is the specific type of relief, differing from other types of landscape, and well-developed subsurface, mostly conduit drainage. One of the most important relief-forming processes is the chemical denudation actively influencing the lowering of the karst surface in time together with other erosion/denudation processes (weathering, erosion, collapsing, etc.). The process is controlled by rock structure and texture, type of cover, climate, etc. (cf. FORD and WILLIAMS 2007, p. 1-5). Karstlands function as traps or preservers of the geologic and environmental past, especially of terrestrial (continental) history where correlative sediments are mostly missing, but they carry also marine records (HORÁČEK and BOSÁK 1989, BOSÁK 2002).

Relicts of caves expressed as depression-like forms in relief without roof were originally described by ŠEBELA and MIHEVC (1995) from the highway construction at Povir village in the Karst (SW Slovenia). The term of unroofed cave was used by MIHEVC (1996) for the first time. The use of this term was stabilized only at the beginning of the 21st Century, as before such forms were described as roofless caves or denuded caves. From the terminological point of view the term *unroofed* seems as the only correct as it integrates also

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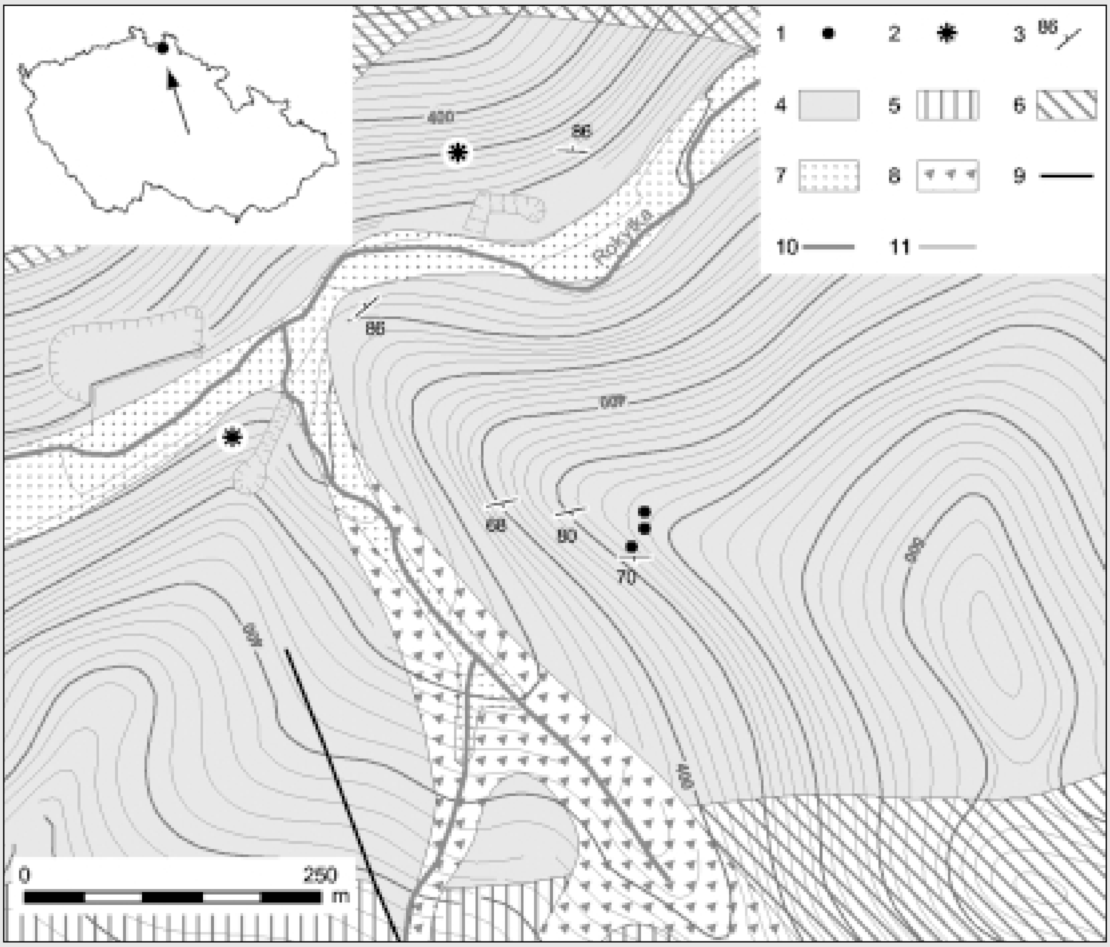

Fig. 1 Site location and geology of the study area (geology according to KACHLÍK 2002, modified by N. Jurková).
1 – outcrops of flowstone, 2 – cave entrances, 3 - direction and inclination of foliation, 4 – crystalline limestone, 5 – crystalline schists, 6 – other metamorphic rocks, 7 – fluvial sediments, 8 – deluvial sediments, 9 – fault, 10 – stream, 11 – contour (interval 5 m)

the process of the evolution. The term *denuded* can be misinterpreted as cave once existing but recently completely missing in the surface morphology. The term *roofless* is descriptive (non genetical) and simply means the cave without the ceiling/roof. KNEZ and SLABE (2001) designed the process as *unroofing* for the first time.

Unroofed caves originate during the gradual transformation of underground form to surface landform due to the denudation of rock overburden (for summary on chemical denudation and its rates see e.g., GAMS 1981, FORD and WILLIAMS 2007). The expression of unroofed caves in the relief depends on original shape and dimensions of the cave, cave fills and relations to surface (MIHEVC et al. 1998). Unroofed caves form mostly slightly meandering, elongated, oblong or doline-like shallow depressions, series of dolines, etc. Relicts of vertical to subvertical cave walls are often transformed by subaerial geomorphic processes; in the developed stage they can even disappear. The position of unroofed cave is than detectable only by the occurrence of cave fills (sediments, flowstones, etc.) often holding different vegetation cover due to higher soil moisture (e.g., KNEZ and SLABE 1999 and 2002). This feature enables the detection of unroofed caves on aerial photographs (ŠEBELA 1999; MIHEVC 2001). Appearing on the surface, unroofed caves became under the control of subaerical processes and transformation (weathering, pedogenesis, etc.). Therefore relicts of clastic cave fills occurring on the surface of the Kras (SW Slovenia) were originally interpreted as surface fluvial deposits (MIHEVC 2001). Therefore, unroofed caves represent one of very special examples of karst traps. They mostly represent the relict type of paleokarst (*sensu* BOSÁK et al. 1989).

After the discovery of unroofed caves in Slovenia, when expected to represent only a rarity, such features have been reported from number of countries. MAIS

(1999) and KLIMCHOUK et al. (2006) described unroofed caves resulting from glacial erosion in high-mountainous relief in the Northern Calcareous Alps (Austria) and Central Taurus (Turkey). The origin of giant collapse dolines in tropical cone and tower karst in China was connected with the unroofing of large-scale river caves by KLIMCHOUK (2006). He concluded that the collapse of reduced cave roofs enhanced by chemical denudation plays an important role in this process. At the present, unroofed caves are considered as the integral and important part of the surface karst morphology and evidence of prolonged history of the evolution of karst relief.

Unroofed caves have not been described yet from the territory of the Czech Republic. Some karst landforms south of Sloup village in the northern part of the Moravian Karst can represent such forms, but their recognition is difficult due to thick Quaternary cover on limestone surface.

2 Flowstone relict on the Ještěd Ridge

The trace of original cave in a high degree of transformation on the Ještěd Ridge was represented by relicts of flowstone and underlying calcite-cemented breccia at village of Machnín (JURKOVÁ 2007). Any rest of cave walls was not found (**Fig. 1** to **3**).

Karst of the Ještěd Ridge is developed in the WSW-ENE-trending and fault limited stripes of metamorphosed Devonian limestones (CHLUPÁČ 1998, KACHLÍK 2002; **Fig. 1**). The Ještěd Ridge represents the NW-SE-trending horst limited on the SW by the Lusatian Thrust (thrusted over Bohemian Cretaceous Basin) and on the NE by the Šimonovice-Machnín Fault (contact with Krkonoše-Jizera granites and the Liberec Basin; e.g., CHALOUPSKÝ et al. 1989). Crystalline complexes of Upper Proterozoic to Upper Paleozoic ages belong to the Ještěd segment of the Krkonoše-Jizera Crystalline Unit.

The region belongs to the West Sudetes Unit and constitutes the geomorphological unit of the Ještěd-Kozákov Ridge (DEMEK et al. 1987, DEMEK, MACKOVČIN et al.2006). From the morphostructural point of view, the Ještěd Ridge represents horst range of mountainous relief with the complicated internal structure and still active tectonic movements (KACHLÍK and KOZDRÓJ in KOZDRÓJ et al. 2001). The evolution of the relief is connected with so-called Saxonian movements, the response of the Alpine Orogeny in the foreland of the Bohemian Massif. Movements are of post-Cretaceous, mostly Cainozoic age and the vertical movement on the Lusatian Thrust was estimated to over 1,000 m (MALKOVSKÝ 1979). Relicts of Miocene coal-bearing deposits and not dated multicolored weathering crusts were detected in the Liberec Basin. The relief is characterized also by deeply entrenched valleys with steep slopes (inclination often >40°) as a result of backward erosion due to the tectonic uplift.

Crystalline limestones of the studied site were highly tectonically disturbed and in some places also silicified (veinlets of quartz). Their contact with metamorphic schists was tectonic. This part of karstological subunit No. 162-45 (*sensu* BÍLKOVÁ et al. 1995) contains 17 short and fracture-guided caves. They are filled with variety of speleothems, autochthonous and allochthonous clastic sediments (D. HORÁČEK in HROMAS, in prep.). Superficial karst forms are rare. Some karst spring occur also, some of them deposit the travertine.

The relict of former cave at Machnín village is situated on morphologically expressive ridge of crystalline limestone at about 440 m a.s.l., i.e. about 100 m above the riverbed of the Rokytka River (**Fig. 1**). The position

Fig. 2 In situ outcrop of flowstone. Photo by N. Jurková

Fig. 3 Detail of flowstone and breccia. Photo by N. Jurková

of the cave was identified by finds of *in situ* flowstone outcrops in more or less horizontal position over the area of several tens of square meters (**Fig. 2**). Flowstone is up to about 20 cm thick, white, recrystallized and composed of columnar calcite crystals with still visible horizontal lamination to banding. Irregular layer of up to 15 cm thick yellowish brown calcite-cemented breccia is developed at the flowstone base (**Fig. 3**). Breccia is composed of angular fragments of vein quartz and decomposed (weathered) crystalline schists with the size up to 5 cm. Rests of silty matrix is cemented by calcite. Breccia fragments can be also found displaced downslope by gravitation processes.

3 Dating

Sample of flowstone was studied for the content of plant pollen and spores. About 200 grams of the sample was dissolved in hydrochloric acid and the residuum was treated by the common procedure of preparation of palynological samples (M. Komar). The following genera were detected: *Pinus* s/g *Haploxylon* < *Pinus* s/g *Diploxylon, Picea, Betula, Alnus, Pterocarya, Ulmus, Fagus, Quercus, Corylus* and *Salix*. The assemblage can be preliminarily interpreted as Upper Pliocene to Lower Pleistocene.

Non-oriented hand specimen of flowstone was studied for its paleomagnetic properties (P. Pruner). It was cut in the laboratory to cubes 2x2x2 cm. The preliminary interpretation of paleomagnetic data obtained from 2 demagnetized samples showed that the sample is normal polarized (Superconducting Rock Magnetometer SRM Type 755 4 K). Normal polarization can indicate several possibility of ages: (1) it is younger than Brunhes/Matuyama boundary (0,78 Ma) or (2) it is older representing (a) some of normal polarized subchrons within the Matuyama Chron (Jaramillo 0.99-1.07 Ma, Olduvai 1.77-1.95 Ma, Reunion 2.14-2.15 Ma) or (b) normal polarized Gauss Chron (2.581-3.580 Ma; CANDE and KENT 1995).

4 Discussion

The relict of flowstone and breccia found on the top of limestone ridge represents *in situ* preserved evidence of the former cave in highly evolved stage of unroofing. Its original character, direction or size cannot be identified due to completely missing cave walls and rocky relief forms (speleogens). The layer of flowstone with underlying breccia indicates the development in vadose conditions. Clastic material under the flowstone was derived from local sources – vein quartz from limestones and shists and weathered clasts from surrounding crystalline rocks.

The genesis of the former cave should be closely connected with the relief evolution of this part of the Ještěd Ridge, i.e. with its post-Cretaceous and mostly Cainozoic history, tectonic activity and changes of surface and subsurface hydrological conditions. The unroofing of the original cave could be connected with intensive backward erosion reflecting the tectonic uplift and with periglacial processes in the foreland of Middle Pleistocene continental glacier(s). Rocks in surroundings of limestones were highly tectonically disturbed. Therefore they were less resistant to weathering and erosion in the comparison with indurated (silicified) crystalline limestones. Original limestone landforms were gradually transformed to relatively sharp ridges. Original caves were nearly completely denuded.

The understanding of origin and evolution of the former cave can contribute not only to the study of the development of karst phenomena and landforms, but also to the determination of intensity of land-forming processes (like valley entrenchment). It can indirectly contribute data concerning the dynamics of neotectonic movements reflected in the contemporary morphology. The rate of valley entrenchment, i.e. stream backward erosion, can be derived from dating of the cave fill compared with the altitudinal position of studied site above the local base level. Both flowstone and underlying breccia were deposited in vadose conditions in altitude very close to the position of the former base level (karst spring). Its vertical distance from the present base level (the Rokytka River) is about 100 m. Palynological and paleomagnetic dating of flowstone sample indicates the maximum time span for the erosion incision from about 0.7 up to about 3.6 Ma (Lower Pleistocene to Upper Pliocene). The minimum rate of the Rokytka Valley incision can be thus estimated from 143 to 28 $mm.ka^{-1}$. Those dates are only approximate, as the further research is needed in the region, including more detailed geomorphic mapping and application of broader spectra of dating methods (palynology, magnetostratigraphy, Th/U method, etc.).

5 Conclusions

Unroofed caves uncover former subsurface interiors with underground cavities. Gradual denudation processes transform them to surface landforms as special features of the epikarst zone. Dating of the former cave fill (clastic and chemical sediments) can help in the understanding of the relief evolution and intensity of land-forming processes.

Relict of former cave at Machnín village represents the first find of unroofed cave in highly evolved stage from the Czech Republic. The former cave was recognized from *in situ* outcrops of flowstone and calcite-cemented breccia in altitude of about 100 m above the local base level (the Rokytka River). Original walls completely disappeared by erosion. Cave evolution was closely connected with post-Cretaceous, mostly Cainozoic morphotectonic development of this geomorphic unit. The flowstone was dated by palynology and paleomagnetic method to Upper Pliocene to Lower Pleistocene (about 3.6 to 0.7 Ma). The combination of dating and altitudinal site position indicates the valley incision rate from 28 to 143 $mm.ka^{-1}$.

Acknowledgement

Authors appreciate the help of Mr. Daniel Horáček and Mr. Jiří Malík, cavers from the Liberec city, for location of the site and the help during the field work. Anonymous reviewer contributed by number of notes and ideas. Palynological analyses were performed within the frame of agreement between the Institute of Geology AS CR, v.v.i., Praha and Institute of Geological Sciences, NASU, Kiev. Paleomagnetic research was supported by the Grant Agency of the Academy of Sciences of the Czech Republic, Grant No. IAA300130701 (Paleomagnetic research of karst sediments: paleotectonic and geomorphological implications).

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