Palaeomagnetic and magnetostratigraphic research of cave sediments: theoretical approach, and examples from Slovenia and Slovakia

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Summary

The palaeomagnetic and magnetostratigraphic research represents the important tool for the deciphering of the age of cave infill process, when classical bio- and chronostratigraphic data are missing, which is a case of inner-cave facies, especially. Sedimentary fills of studied profiles were separated into individual sequences and cycles divided by numerous evidences of breaks in deposition (erosion features and/or precipitation features). Therefore, unconformities can hide a substantial geological time. The magnetostratigraphy of cave sediments brought surprisingly new data on age of the last cave filling, changing local theories for dating of speleogenetical processes: (a) Classical Karst (SLO): obtained magnetostratigraphic data older than Brunhes/Matuyama boundary clearly show the age of speleogenesis cannot be connected with Pleistocene climatic cycles. Fills of fossilised caves are clearly older than about 1.8 Ma. The speleogenesis was probably connected speleogenetical phase related to the Messinian crisis and the fossilization with post-Messinian sea-level rise in the Mediterranean region, and (b) speleogenesis of well-known Demänovská Cave System (Low Tatra Mts., SK) was much older than supposed earlier. Correlation of obtained magnetostratigraphic results, radiometric dating and river terraces of tributaries of the Váh River indicate definitively that there is no real correlation of cave levels and river terraces noted in numerous textbooks or river terraces of the Váh River are older than supposed earlier.

Introduction

The magnetostratigraphic research in caves both in Slovenia and Slovakia started in 1997-1998. It was provoked by the sterility of inner-cave facies and by limited use of absolute dating methods, like U-series and 14C. The age of speleogenesis in both regions have been connected traditionally with Pleistocene geomorphic cycles following the glacial/interglacial cycles. But preliminary data of HERCMAN et al. (1997) from Slovakia indicated substantially higher ages of the last cave fill than expected earlier. The palaeomagnetic and especially magnetostratigraphic method seemed to serve as useful tool to date processes in caves over the limits of common dating techniques. Here, we briefly summarise recent results and interpretations.

Laboratory procedures

Laboratory procedures were combined in a way that enabled the derivation of the respective magnetic remanence components in different temperature intervals, during progressive thermal demagnetisation (TD) and demagnetisation by alternating field (AF), the determination of moduli and directions of remanent magnetisation. Oriented hand samples were collected in the field from individual beds. Laboratory specimens in the form of small cubes 20x20x20 mm were prepared in the field or from the hand samples to be measured on the spinner magnetometers JR-4 and JR-5. Laboratory specimens in their natural state were subjected to progressive thermal demagnetisation using the MAVACS (Magnetic Vacuum Control System) apparatus securing generation of a high magnetic vacuum in a medium of thermally demagnetised specimens. All of specimens were also demagnetised by the alternating field procedures, up to the field of 1,000 Oe. The apparatus Schonstedt GSD-1 was employed for alternation field demagnetisation. This procedure was more effective than thermal demagnetisation; consequently, it was applied to the whole set of specimens. The Kirschvink multi-component analysis of was carried out to separate respective remanent magnetisation components. The Fischer statistics of were employed for calculation of mean directions of the pertinent remanence components derived by the multi-component analysis (for more detail see BOSÁK et al., 2000a).

Slovenia

The detailed palaeomagnetic study of cave sediments within the Classical Karst (*sensu* KRANJC 1997) in the SW Slovenia has started in 1997. The opening of several profiles of cave sediments during the construction of highway near villages of Divača and Kozina provoked the study. Uncovered caves are often characterised by thinned or by completely missing roof. Occurrences of such caves are not limited to some areas, but they are typical for the whole territory of the Classical Karst (*cf.* lit. in BOSÁK et al., 200a). Totally 165 oriented laboratory samples have been investigated for palaeomagnetic properties.

Studied sites

The accessible channels of the *Divaška jama* are situated between two collapsed dolines. The studied profile consisted of laminated clays and silty clays covered by flowstone layer and clays. The top of the profile shows normal magnetozone. The narrow normal subzone is in the long reverse magnetozone in the upper part of the cross-section. The middle and lower part of the profile show reverse palaeomagnetic directions. The *Trhlovca Cave* represents the continuation of the Divaška jama. The sedimentary profile has very complicated internal structure consisting of blocks separated by fissures. Sediments are especially clays and silty clays. The long normal magnetozone was interpreted from the top across middle part of the 4 m high cross-section. The lower part of the profile shows reverse magnetozone and narrow normal subzone. The *Divača profile*, discovered during highway construction, was 6 m high alternation of sands and clays in typical fluvial cycles. The lower part of the profiles was composed of laminated clays and silty clays. Two narrow normal magnetozones were detected in the lower part of reverse palaeomagnetic directions. The *Kozina profile*, discovered during highway construction, was 5 m high, 3 m were composed of clays, the upper part consists of collapsed roof. The top and lower part of the profile shows reverse magnetozone. There are two normal zones in the middle part of the profile. The *Črni Kal-Črnotiče profile* was situated in active quarry in a part of a huge passage with the diameter of about 10 m. The part of profile was composed of laminated silty-sandy (?)algal limestones intercalated by red clays of the terra rossa type. The long normal magnetozone was interpreted in the lower half of the log. The top part of the profile shows reverse palaeomagnetic direction interrupted by two normal polarised zones. No fossil remains were detected in all studied profiles, except some damaged pollen grains without stratigraphic importance in Kozina site (BOSÁK et al., 2000a, b).

Discussion

The comparison of obtained magnetostratigraphic results with the standard scales (CANDE & KENT 1995) indicate, that sediments of the Divaška Jama and Trhlovca Caves include Brunhes/Matuyama boundary and Jaramillo chron, i.e., they are substantially older than expected by GOSPODARIČ (1988). The age of the youngest sedimentary fill in both accessible caves is from at least 1.1 Ma to more than 350 ka old (spelothem dating in the Divaška Jama Cave;, cf. in BOSÁK et al., 1998)

Correlation of sediments from the Divača and Kozina profiles, which are nearly identical and Črnotiče Quarry with the standard scale was problematic as reverse polarised magnetozones can belong to Matuyama, Gauss or Gilbert chrons, i.e., from about 1.77 down to more than 5.23 Ma (BOSÁK et al., 2000a, b). If the age of the youngest fill is so old, therefore the speleogenesis itself has to be connected with the Messinian speleogenetical epoch (*sensu* PERNA, 1996) and the fossilization was than connected with rapid base level uplift after refilling of the Mediterranean basin by water (BOSÁK et al., 2000a, b).

Slovakia

The research started in 1998 to help to decipher the ages of fill of some caves, especially those open to public. Caves are developed in Mesozoic carbonate sequences belonging to different nappe levels of the West Carpathians in the Low Tatra Mts., High Tatra Mts., Slovenské rudohorie Mts. and Slovak Karst. Inner-cave facies were studied. Totally 95 oriented laboratory samples have been investigated for palaeomagnetic properties (PRUNER et al., 1999).

Studied sites

The *Belianská Cave* (High Tatra Mts.) contains limited sedimentary profiles. The studied ones were about 1.5 m high composed of silts with rare intercalations of flowstones. Upper part was reverse polarised, the lower one showed normal polarization with one reversed sample. Five profiles of fluvial cave sediments (1 to 3 m thick) were studied in the 4th and 5th levels of the *Demänovská Cave of Freedom* (Low Tatra Mts.). Profiles were mostly composed of gravels, sands and silts/clays with some flowstone interlayers. Profiles at the 4th level showed normal polarisation, while profiles at the 5th level were reverse polarised. Two profiles in the *Demänovská Cave of Peace* were composed of sands and silts (about 0.5 m thick). All samples were normal polarised. The *Domica Cave* (Slovak Karst) was studied in two separate areas. Profiles, 0.5 to 1.5 m thick were composed of silts, sometimes slightly cemented, with some inter-layers of flowstones. All samples were normal polarised, except the single sample. The *Ochtinská Aragonite Cave* (Slovenské Rudohorie Mts.) yielded data only from one 0.7 m thick profile of clays with asbolane layers, covered by flowstone. The upper part of the profile showed normal polarisation, the rest reverse polarisation (PRUNER et al., 1999).

Discussion

Palaeomagnetic and magnetostratigraphic results from the Domica Cave, Ochtinská Aragonite Cave and Demänovská Cave of Peace brought no surprising data, because some of speleothems (flowstones) were already dated by the U-series method (cf. in PRUNER et al., 1999). Reverse polarised sample in the Domica Cave does not represent the Blake event, as data from cover flowstone are ca 131 ka. Boundary Brunhes/Matuyama was interpreted in the Ochtinská Aragonite Cave, because cover speleothem is ca 164 ka old. Nevertheless, the magnetostratigraphic data allow reconstruction of the evolution scheme of the cave more precisely.

Data from the Belianská Cave were surprising. The comparison with the standard scales (CANDE & KENT 1995) indicates, that the profile is older than 1.77 Ma. Sediments can be correlated possibly with the Matuyama/Gauss boundary at 2.58 Ma, or even with the older boundaries (e.g., at 6.15 Ma). The data allowed the definitoin of a new working hypothesis on the evolution of the cave, being formed by ascending warmer waters in connection with the uplift of High Tatra Mts. (study in preparation for the print).

Data from the Demänovská Cave System indicate the uncertainty in correlation of cave levels with river terraces of the Váh River (e.g., DROPPA 1966). Magnetostratigraphic interpretation of profiles proved the data of U-series dating of speleothems at the 4th level of the system. From the combination of data resulted, that the 4th cave level was dry already at about 700 ka (base of speleothem is ca 685 ka; e.g., HERCMAN et al., 1997), although previous correlation with river terraces assumed the age of speleogenesis to Mindel 2, i.e. to ca 330-500 ka (DROPPA, 1972). Data indicate that the speleogenetic process was substantially older than supposed earlier, which correlate well with data from Polish Tatra Mts. (GŁAZEK, 1989).

Theoretical Approach and Conclusions

The application of the magnetostratigraphy of cave sediments seemed to be an ideal tool for dating. It is generally known here that fossils can be found only in the upper parts of sedimentary fill, and the time range of numerical dating methods applicable in karst is short (ca 350 ka). Nevertheless, the magnetostratigraphy approach is facing numerous real problems, as exemplified especially on Slovenian sites. Sedimentary fills of profiles were separated into individual sequences and cycles divided by numerous evidences of breaks in deposition. Some of breaks were expressed by erosion and/or precipitation features. Some of magnetostratigraphic zones start on such unconformities. This proves that the whole cave systems could be several times completely filled and exhausted. Therefore, unconformities within sedimentary profiles can hide a substantial geological time. The velocity of deposition cannot be calculated in such profiles. The time duration of individual magnetozones cannot be calculated and the geometric character of obtained magnetostratigraphic picture cannot be compared with standard scales (BOSÁK et al., 2000b).

Therefore, the dating of cave sediments by the application of palaeomagnetic methods - magnetostratigraphy - represents a highly difficult and sometimes risky task, as the method is comparative in its principles and does not provide numerical outputs. Case studies indicate, that without the help of other dating methods, especially biostratigraphy, any correlation of obtained results cannot be explicit. Dynamic character of cave filling, exhumation and fossilisation is expressed by numerous unconformities within preserved sedimentary profiles. Therefore, the correlation of obtained arrangements of normal and reverse polarised magnetozones with standard palaeomagnetic scales can be finish only with difficulties and with a high degree of uncertainty. Such reality can be exemplified on examined logs both from the Classical Karst and from Slovakia, especially on profiles with complex magnetostratigraphic arrangements (Divača, Kozina, Črni Kal, Belianská Cave).

The obtained magnetostratigraphic data indicate substantially older age of cave filling processes than expected earlier: (1) shifting the possible start of the speleogenesis within the Classical Karst deeply below the Tertiary/Quaternary boundary, presumably to the Messinian speleogenetical epoch, and (2) changing the view on speleogenesis of some of Slovak caves and the state-of-the-art in the correlation of cave levels with river terraces; river terraces have to be older than earlier supposed.

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Figure 1 Measured magnetostratigraphic profiles in some of Slovenian (A) and Slovak caves (B) and their correlation with the magnetostratigraphic chart (after CANDE & KENT 1995)

A. Slovenia: 1 Črni Kal-Černotiče, 2 Kozina profile, 3 Divača profile, 4 Divaška Jama, 5 Trhlovca Cave; B. Slovakia 1-2 Belianská Cave, 3-7 Demänovská jaskyňa Slobody, 8-9 Demänovská jaskyňa Mieru, 10-13 Domica Cave, 14 Ochtinská Aragonite Cave