GEOLOGOS 5 (2000)

PL ISSN 1426-8981 • ISBN 83-86682-45-0

Magnetostratigraphy and unconformities in cave sediments: case study from the Classical Karst, SW Slovenia

PAVEL BOSÁK[1], PETER PRUNER[1], ANDREJ MIHEVC[2] & NADJA ZUPAN HAJNA[2]

[1] Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-165 02 Praha 6, Czech Republic

[2] Karst Research Institute, Slovenian Academy of Sciences and Arts, Titov trg 2, SLO-6230 Postojna, Slovenia

Abstract: Palaeomagnetic method (magnetostratigraphy) was applied to date four profiles of cave fill in the Classical Karst of Slovenia – Divaška jama, Trhlovca Cave, Divača profile at highway near village of Divača and Černotiče profile in a quarry near village of Črni Kal. The dynamic character of cave filling, and exhumation and fossilisation processes is expressed by numerous unconformities within profiles belonging to inner-cave facies. Brunhes/Matuyama boundary and Jaramillo subchron were interpreted in Trhlovca Cave and Divaška jama. Obtained magnetozones in Divača profile and Černotiče Quarry can be correlated with events within Matuyama up to Gilbert chrons. 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 as breaks in deposition can hidden a substantial part of the geological time. Without the help of other dating methods, especially biostratigraphy, and correlation of magnetostratigraphic results cannot be explicit.

Key words: cave sediments, palaeomagnetism, magnetostratigraphy, Tertiary/Quaternary, Classical Karst, Slovenia.

Introduction

The detailed palaeomagnetic study of cave sediments within the Classical Karst (*sensu* Kranjc 1997, 1998) in the SW Slovenia has started in 1997 (Bosák *et al.* 1998a, b, 1999, in press; Bosák & Pruner 1999). The study was provoked by the opening of several profiles of cave sediments during the construction of highway near villages of Divača and Kozina (*cf.* Mihevc 1996; Mihevc & Zupan Hajna 1996; Slabe 1996, 1997, 1998; Mihevc *et al.* 1998; Šebela 1999; Knez & Slabe 1999). Uncovered caves are often characterised by thinned roof or by completely missing roof. They were designed as denuded caves (Mihevc *et al.* 1998) or roofless/unroofed caves (Slabe 1997; Mihevc 1999a-c). Occurrences of such caves are not limited to some areas, but they are typical for the whole territory of the Classical Karst (e.g. Mihevc 1998, 1999a; Šusteršič 1998; Stepišnik & Šusteršič 1999).

Acknowledgement: We acknowledge especially contribution of Državna družba za ceste to covering costs of the first stage of this study (1997–1998). We are grateful to Mr. Mladen Grgurič from the management of the Černotiče Gradis Quarry for willing co-operation and permissions of our operations within the quarry (1998). Travel costs of Czech experts were covered from the program KONTAKT No. ME 251 of the Ministry of Education, Youth and Sports of the Czech Republic. Expenses of analytical procedures were covered from sources of the Program of Advancements in Scientific Research in Key Directions of the Academy of Sciences of the Czech Republic No. K1-042-603 and from the research project of the Czech government No. Z3 013 912.

Location

The Classical Karst is the carbonate plateau lying above the Trieste embayment at 200 to 500 m a.s.l. It has the typical NW-SE dinaric direction. The Plateau is built by Cretaceous and Tertiary limestones and dolomites. Eocene flysch encircles the region and forms imbricated zones within it.

The Divača Karst is situated in the SE edge of the Kras Plateau. There are known numerous caves but Škocjanske jame, Kačna jama, Divaška jama and Trhlovca Cave take special place. The Reka River sinks in the Škocjanske jame and flows into the active passages of the Kačna jama. Explored passages of the Divaška jama and Trhlovca Cave (Fig. 1) are situated some 200 m above the underground water course in this part of the Kras and they contain a lot of fluvial sediments. A fossil cave completely filled with sediments was uncovered during the highway construction between villages of Divača and Kozina, to the south of Divača (Fig. 1). The profile was named the Divača profile. Samples of the sediments from Divaška jama and Trhlovca Cave were originally taken only for the comparison.

The Podgora Karst is about 5 km wide karst plateau extended in the NW-SE direction. Its surface is located at 500 to 450 m a.s.l. The plateau surface is levelled and dismembered only by numerous dolines. The surface inclination is gentle, only some degrees. Only small allogenic surface streams of the first or second order exist on the plateau surface flowing from flysch zones. They sink at the carbonate/flysch contact (contact karst). The imbricated structure of alternating carbonates and flysch dips at an angle of about 20–30° towards the northeast. Profile in the Černotiče Quarry is situated at the southwestern edge of the plateau (so-called Karst Edge; Fig. 1).

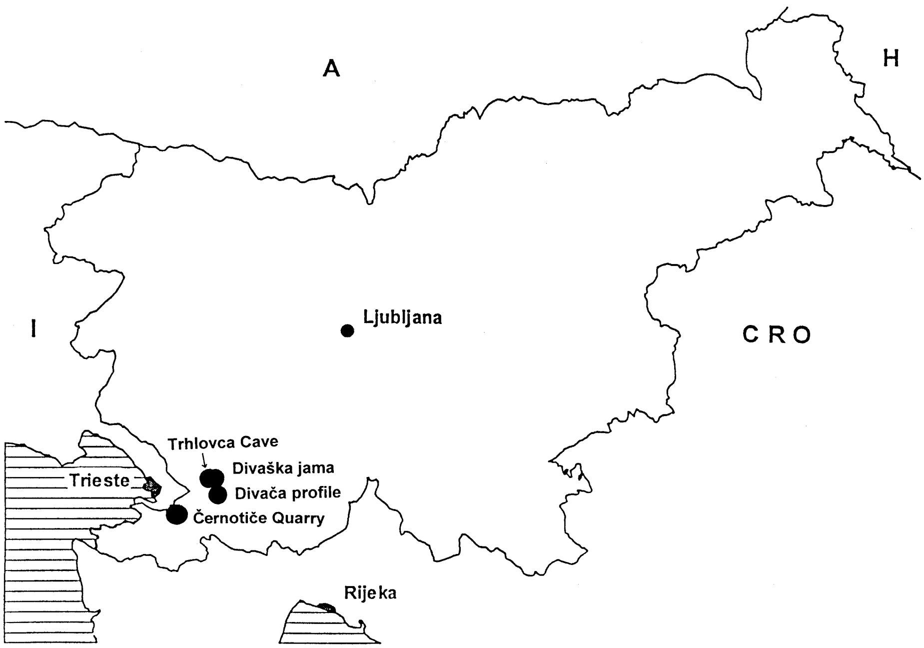

Fig. 1. Location of analysed samples.

Profiles of cave sediments

Divaška jama

The entrance to the cave is situated in two collapsed dolines. The accessible channels are about 700 long and they are lying transversally to bedding. They follow faults having more or less the N-S direction. The Divaška jama is filled by lithologically variable sediments and speleothem of different generations in the thickness at least of 30 m. About 2 m deep profile was excavated at the end of the cave in the Žibernova Dvorana Hall (*x* 5 059 260, *y* 5 418 340, *z* 370 m).

Four sequences can be distinguished in this profile (Fig. 2). The lower sequence is composed of brownish clays to silty clays with upward increased admixture of sandy fraction (samples 1–14, 44–34). Sediments are finely laminated (varvite-like clays). Above the erosion contact, the sequence No. II starts with light-coloured sands, only several centimetres thick. Sands are overlain by "collapsed" clay with numerous small-scale fissures and slides (samples 15, 33–30). Next layer is built of sand (sample 16). The whole sequence is terminated by clays (sample 17). Sequence No. III is composed of flowstone with stalagmite. Speleothem is covered by laminated brownish clays of cave lacustrine facies (sequence No. IV; samples 22–19).

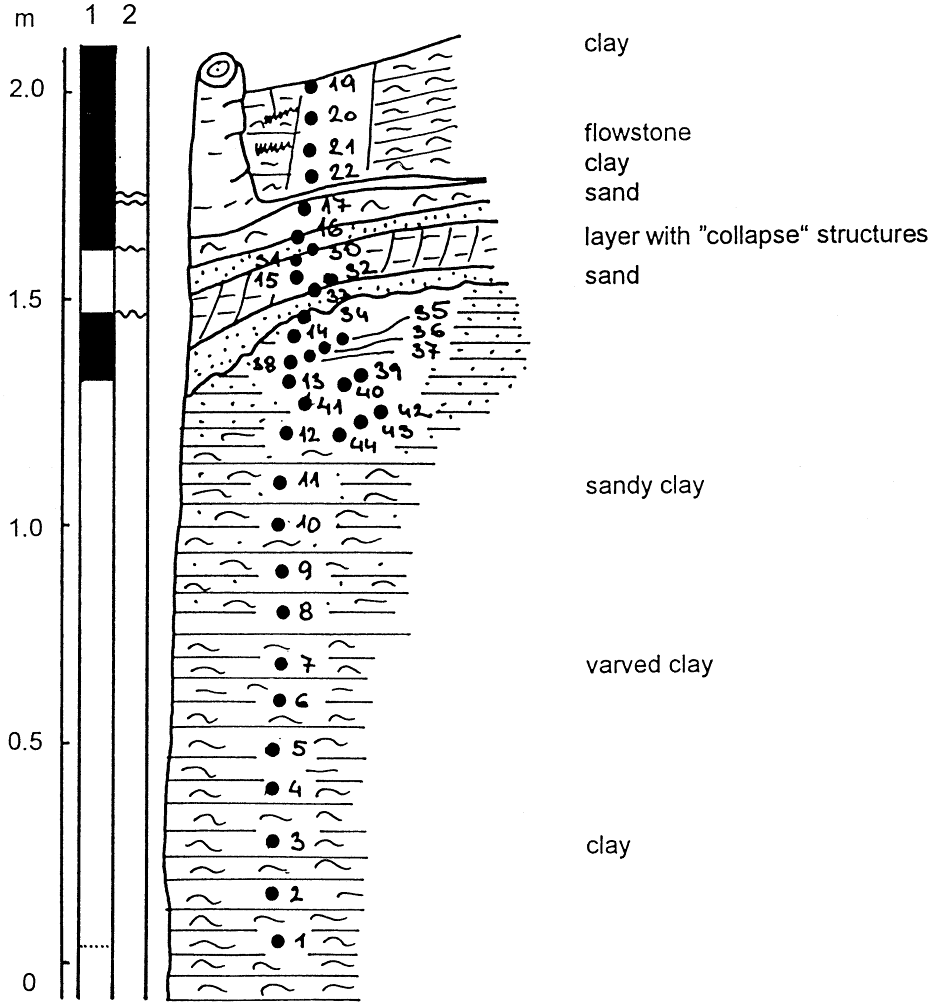

Fig. 2. Lithological log of the profile in the Divaška jama (after N. Zupan Hajna in Bosák *et al.* 1998a, completed in new samples).

Black dots with numbers – palaeomagnetic samples. **1** – palaeomagnetic chart (black – normal polarised zone, white – reverse polarised zone), **2** – erosion surfaces.

Trhlovca Cave

The Trhlovca Cave represents the continuation of the Divaška jama. Its channel is located at different altitude and it contains different sediments. Both caves are separate by collapsed doline. The entrance to the Trhlovca Cave is situated in the collapsed doline under its W wall. About 60 m long main channel follows the N-S direction. About 3 m high profile in fluvial sediments was sampled at the end of the cave (*x* 5 059 230, *y* 5 418 265, *z* 410 m).

The sedimentary profile has very complicated internal structure (Fig. 3). It

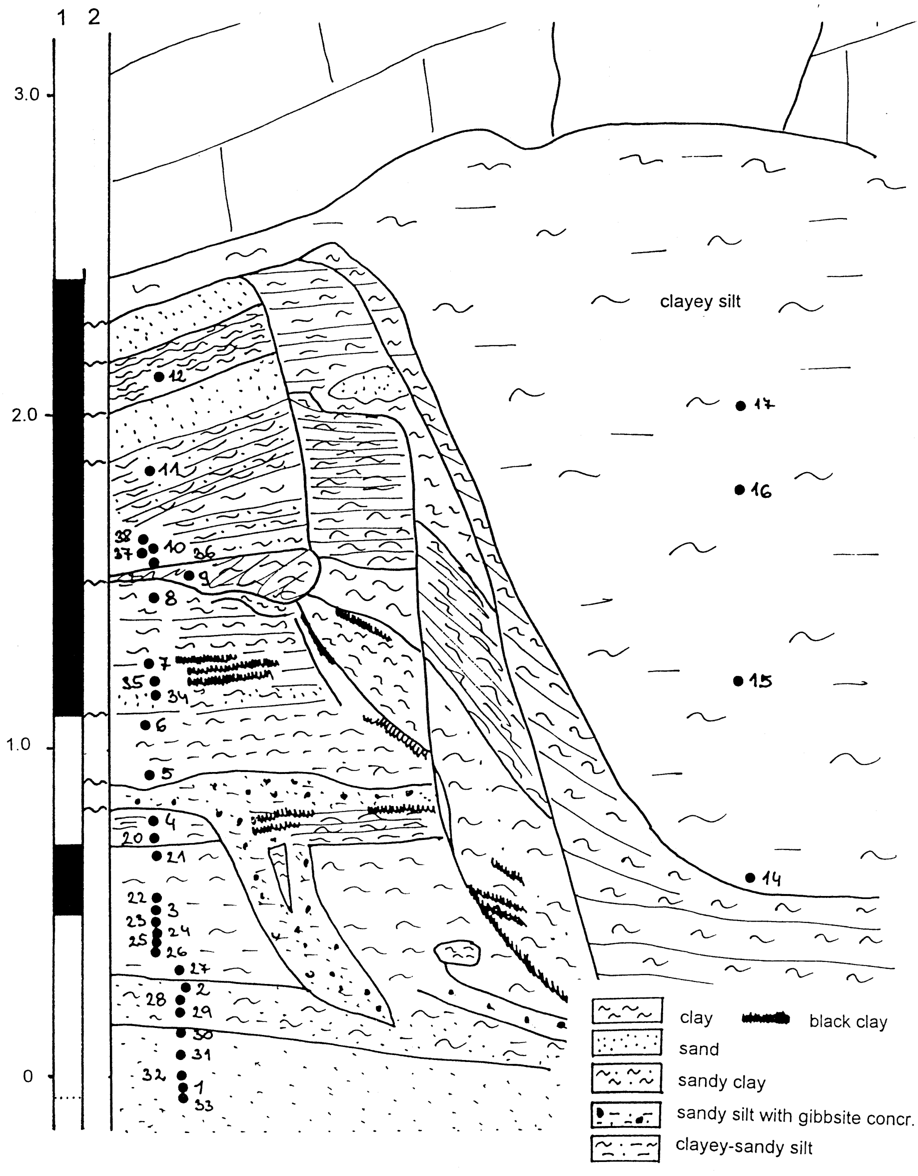

Fig. 3. Lithological log of the profile in the Trhlovca Cave (after N. Zupan Hajna in Bosák *et al.* 1998a, completed in new samples).

Black dots with numbers – palaeomagnetic samples. **1** – palaeomagnetic chart (black – normal polarised zone, white – reverse polarised zone), **2** – erosion surfaces.

consists of blocks separated by fissures. Blocks are moved. The disturbation of the profile is caused by the collapse of the right side of the profile. Sampling was performed in left part of the profile close to the limestone wall in a uniform sedimentary sequence and in the central part of the profile in sequence lying above original sediments and deposited only after the collapse. The profile in the left side is composed of variegated cave sediments with complicated lithology and internal structure (samples 1–12, 20–38). Clayey layers alternate with sandy beds. Black clay intercalations are very distinct feature here. Younger fill is composed of silty clays (samples 14–17).

Divača profile

The profile is situated to the south of Divača, on the E border of a new motorway at the profile No. 30, on the S slope of larger doline (Fig. 1). The profile is about 6 m high and represents the cross-section of a fossil cave completely filled by fluvial sediments (*x* 5 058 400, *y* 5 420 100, *z* 453 m). The site is now completely reclaimed.

Four sedimentary sequences were distinguished in the profile (Fig. 4). They are separated by breaks. The lower sequence No. I (sample 1) is composed of variegated clays and silty clays with some sandy admixture. It is separated from above lying sediments by thicker ferruginised zone with limonite crust. The sequence No. II (samples 2–5) is built of variegated clayey silts to clays, with rare sandy admixture. It terminates by thin ferrugineous crust which makes more distinct the erosion base of the sequence No. III. The sequence No. III (samples 6–15) is characterised by typical fluvial cycles from 4 to 40 cm thick consisting of whitish beige, beige and ochreous sands, with light-coloured clayey and silty terminations of individual cycles. Sands are dominantly fine-grained, cross-bedded. Lutites are often laminated. The profile terminated by about 30 cm thick layer of redeposited soils of the terra rossa type (sequence No. IV). Red soil was covered by partly decomposed cave roof formed by dark grey Paleogene limestones.

Strong secondary ferruginisation is typical for the whole sedimentary section, Sediments of the cave fill are slightly indurated by contact type of carbonate cementation and some parts are highly indurated by poikilitic calcite cement composed of crystals up to several centimetres large. The profile was strongly tectonised as the consequence of collapse of the right side of the cave fill (probably caused by rejuvenated karstification). Network of parallel fissures developed. They are sometimes characterised by several mm up to 10–15 cm thick “crushed” zones with carbonate cement and infiltration of terracotta-coloured clay.

Črni Kal-Černotiče

The profile was situated in the western wall of the Černotiče Quarry (45° 33’ 57’’ N, 13° 52’ 48’’ E). The quarry lies 9 km from the Adriatic coast in the Koper Bay. About 150 m long cave with the dip in the NW-SE direction was

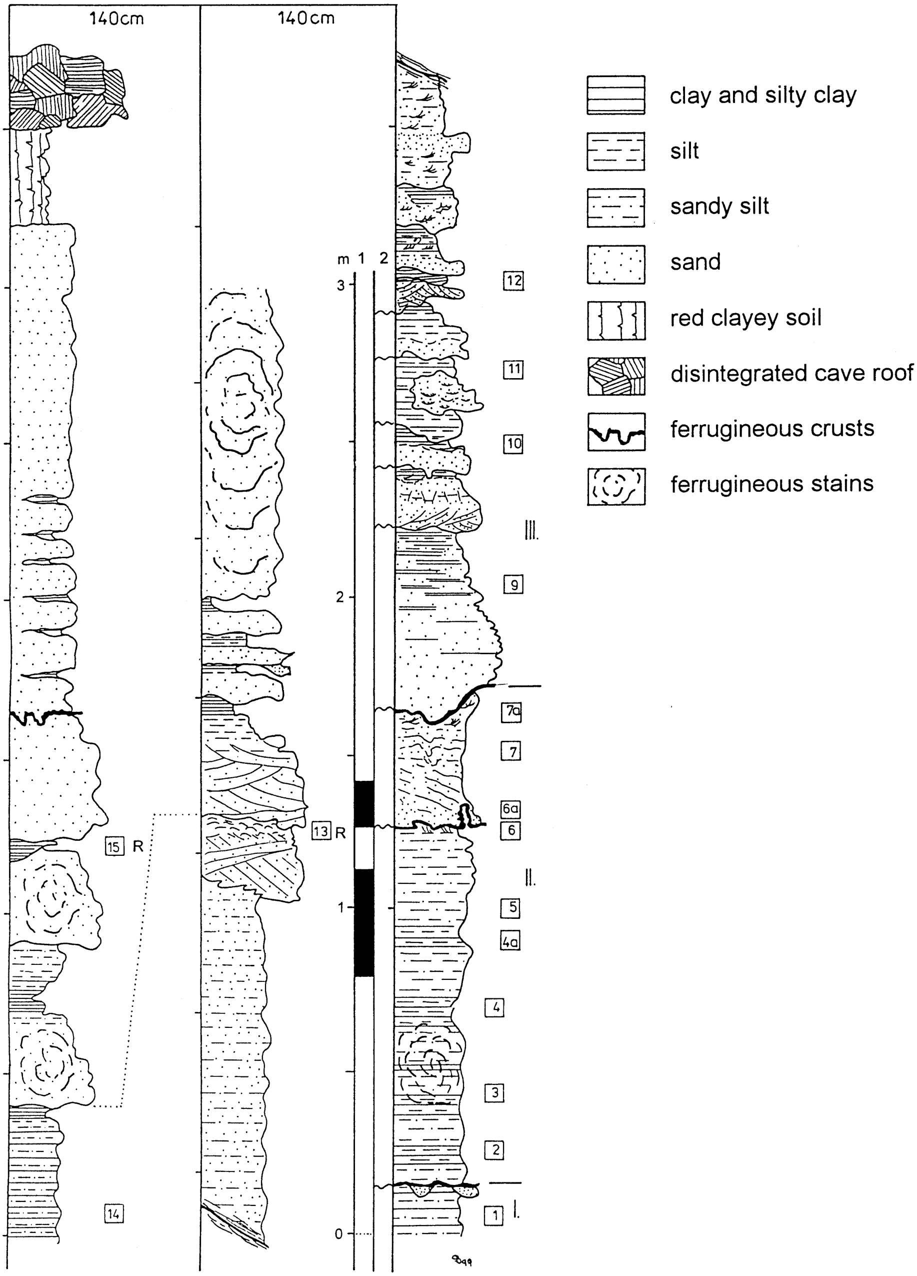

Fig. 4. Lithological log of the Divača profile (modified after P. Bosák in Bosák *et al.* 1998a).

Number in squares – palaeomagnetic samples. **1** – palaeomagnetic chart (black – normal polarised zone, white + R – reverse polarised zone), **2** – erosion surfaces.

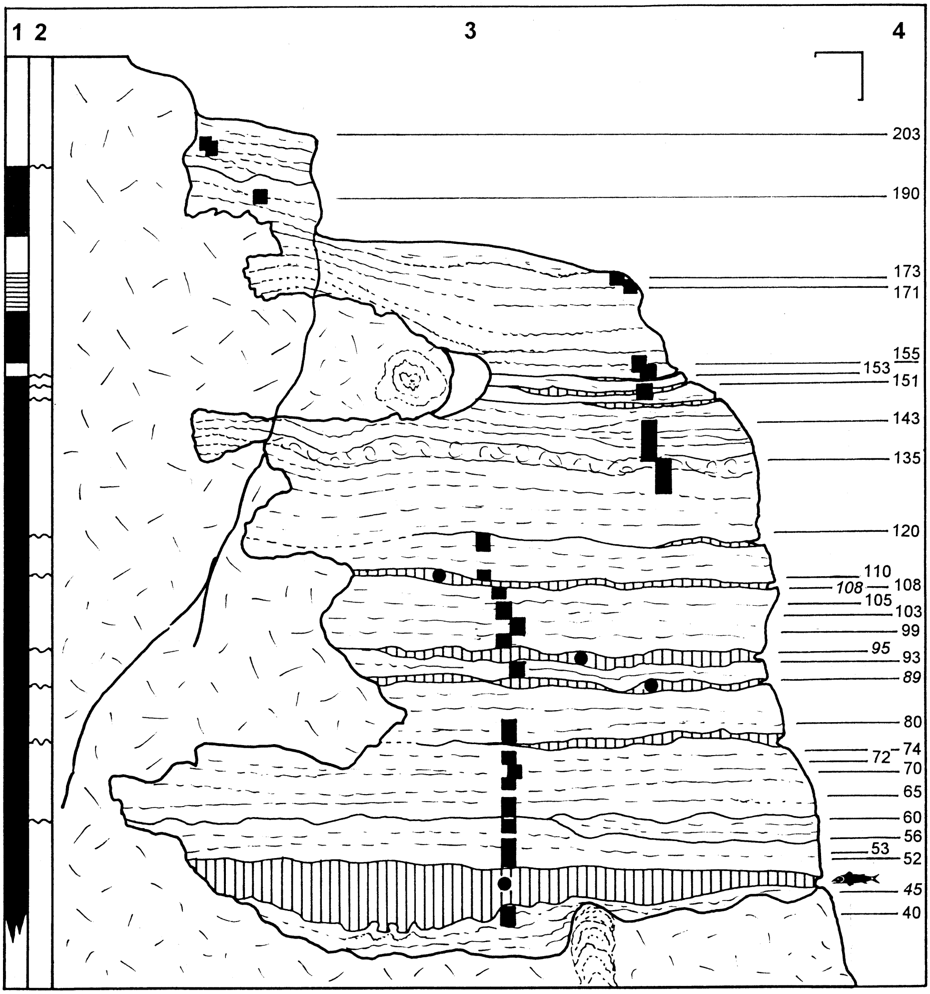

Fig. 5. Speleothem sequence in the Černotiče Quarry (after Bosák *et al.* in press).
Black squares – palaeomagnetic samples, black dots – clay samples. **1** – palaeomagnetic chart (black – normal polarised zone, white – reverse polarised zone, shaded – unknown polarity), **2** – erosion surfaces, **3** – lithological log, **4** – numbers of samples, symbol – find of fossils.

opened by quarry operations in 1990 to 1998. The cave represented a relict of a huge passage with the diameter of about 10 m. The passage was entirely filled by the cave sediments deposited over massive flowstones several meters thick. Calcareous sediments were extended up to the present surface where they were strongly disintegrated. Gravel and conglomerates were preserved and mixed up with sand and clay on several places. The cave roof was situated about 4 m below the surface of the Podgora karst plateau at about 440 m a.s.l.

The studied profile consisted of two parts (Fig. 5): (1) older sequence of coarsely recrystallised speleothems, and (2) younger sequence of laminated to banded carbonate rocks with intercalations or red clays. The fill was situated just below the levelled surface of the karst plateau and it consisted of several large blocks little displaced by blasting in a quarry.

Older sequence. The sequence consisted of nearly white, very coarse-grained, recrystallised speleothem mass with distinct stalagmites completely surrounded by crystalline calcite. This sequence clearly continued to speleothems covering rest of walls of host cave. The wall rests were nearly completely covered by sinter crusts with draperies and similar forms of speleothems. The rocks of older sequence were not sampled for palaeomagnetic analyses, because it is generally known that such very pure monomineral rocks lack carriers of remanent magnetisation (impurities of magnetic minerals).

Younger sequence. Carbonate rocks of the younger sequence filled a corrosion niche with a complex morphology carved in the older sequence. Speleothems were laminated to banded with an alternation of bands of different texture, structure and colour. Individual bands were often separated by disconformities developed either as a single erosion/corrosion surfaces or as intercalations of red clays. The total preserved thickness of this sequence was about 175 cm. Carbonate rock are expected to be the product of deposition from organic-rich films (algal or diatom mats) on which fine carbonate grains were trapped or crystallised (Bosák *et al.*, in press).

Palaeomagnetic analyses

Totally 127 oriented laboratory samples (Divaška jama – 36, Trhlovca Cave – 35, Divača profile – 29 and Černotiče Quarry – 27) have been investigated for their palaeomagnetic properties.

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 20 × 20 × 20 mm were prepared in the field or from the hand samples to be measured on the spinner magnetometers JR-4 and JR-5 (Jelínek 1966).

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 (Příhoda *et al.* 1989). 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 AF demagnetisation. This procedure was more effective than thermal demagnetisation; consequently, it was applied to the whole set of specimens.

The remanent magnetisation of specimens in their natural state (NRM) is identified by the symbol J_n, the corresponding remanent magnetic moment by the symbol M. Graphs of normalised values of $M/M_o = F(t)$ were constructed for each analysed specimen.

Phase or mineralogical changes of magnetically active (mostly Fe-oxides) minerals frequently occur during the laboratory thermal tests, especially at low temperature intervals. These changes can be derived from the graphs of normalised values of $k_t/k_n = f(t)$, where k_n designates the volume magnetic susceptibility of specimens in natural state and k_t the susceptibility of specimens demagnetised at temperature t °C. The k_t and k_n values were measured on a kappa-bridge KLY-2 (Jelínek 1973).

Using the multi-component analysis of Kirschvink (1980) carried out separation of the respective remanent magnetisation components. The statistics of Fisher (1953) were employed for calculation of mean directions of the pertinent remanence components derived by the multi-component analysis.

Palaeomagnetic results

All the samples collected were subjected to a detailed demagnetisation by the alternating field and/or thermal method.

Divaška jama

The moduli of J_n values of the studied rocks in their natural state show big scatter. All of specimens were demagnetised by the AF procedures, up to the field of 1,000 Oe (14 steps). The selected samples were progressively isothermally magnetised by a direct field of intensities of 1, 2, 4 up to 900 mT (19 steps). The values of saturated remanent magnetisation (J_s – IRM) reached high values – several thousands of [nT]. One sample was also demagnetised by the AF after saturate magnetisation. Samples showed also three remanence components in general: A, B and C. The A-components are mostly of viscous or chemoremanent (weathering) origin. An alternating field can remove them with the intensity of 10 to 30 Oe. The normal and reverse C-component directions of the samples form two defined sets of samples with fisherian distribution (Tab. 1).

Table 1. Mean palaeomagnetic directions for investigated localities.

	Polarity	Mean palaeomagnetic directions		α_{95}	*k*	*n*
		D [°]	I [°]			
DIVAČA	N	341.8	35.1	27,2	21,5	3
PROFILE	R	180.8	–54.2	11,9	13,1	13
DIVAŠKA	N	341.3	46.5	17,4	9,7	9
JAMA	R	188.8	–38.2	9,4	10,2	26
TRHLOVCA	N	5.6	55.8	12,6	9,6	16
CAVE	R	210.2	–50.8	16,1	6,2	16
ČERNOTIČE	N	10.6	55.0	15,8	5,0	21
	R	173.0	–31.1	93,9	2,0	3

Polarity – N: normal, R: reverse; D, I – declination and inclination of the remanent magnetisation after dip correction; α_{95} – semi-vertical angle of the cone of confidence calculated according to Fischer (1953) at the 95% probability level; *k* – precision parameter; *n* – number of analysed samples (107 samples from the total number of 127 are listed in the Table, i.e. those yielding reliable data of C-component of the remanent magnetisation).

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 (Fig. 2).

Trhlovca Cave

The moduli of J_n values of the studied rocks in their natural state show also big dispersion. The values of volume magnetic susceptibility are low but show a smaller dispersion than J_n values. All of specimens were demagnetised by the AF procedures, up to the field of 1,000 Oe (14 steps). The selected samples were progressively isothermally magnetised by a direct field of intensities of 1, 2, 4 up to 900 mT (19 steps). The values of saturated remanent magnetisation (J_s) reached values – several hundreds to about thousand of [nT]. Samples showed again three remanence components identical to those from the Divaška jama (Tab. 1).

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 (Fig. 3).

Divača profile

Values of the J_n moduli of studied sediments in their natural state are exceptionally low, highly depending on the origin of the magnetisation. Values of volume magnetic susceptibility are also low but show smaller scatter than J_n values. Selected samples were progressively isothermally magnetised by a direct field with intensities of 1, 2, 4 up to 900 mT (19 steps). The values of saturated remanent magnetisation (J_s) reached high values – several hundreds of [nT]. All specimen were demagnetised by the AF (alternating field) procedures, up to the field of 1,000 Oe (14 steps). Several specimens were also experimentally subjected to thermal demagnetisation (TD) up to 500 ºC, but generally less effective than by the AF demagnetisation. Three remanence components were detected again. The A-component is mostly of viscous or chemoremanent (weathering) origin. An alternating field can remove them with the intensity up to 30 Oe. Normal and reverse C-component directions of samples form two defined sets of samples with fisherian distribution. The number of normal components is only three, which means bigger value of α_{95} for the mean direction calculated after Fisher (1953) for the 95% probability level (Tab. 1).

Two narrow normal magnetozones were detected in the lower part of reverse palaeomagnetic directions. The remanence components were not defined for two samples (samples 2 and 3) and two specimen were disintegrated (samples 12 and 14; *cf.* Fig. 4).

Črni Kal-Černotiče

Samples are characterised by intermediate up to high magnetic values of $J_n = 104.79 \pm 69.61$ [nT] and $k_n = 1{,}778 \pm 1{,}204.10^{-6}$ [SI] which is caused by the proved presence of relatively high amount of Fe-minerals (hematite, goethite). Mean palaeomagnetic directions for the group of normal palaeomagnetic polarity are equal to D = 10.6º; I = 55.0º, and for the group of reverse polarity are D = 173.0º; I = –31.3º. Three-component remanent magnetisation was detected. The A-component is undoubtedly of viscous (weathering) origin and can be demagnetised in a temperature range of 20 to (60) 120 ºC. The B-component also has a secondary origin but shows harder magnetic properties which can be demagnetised in a temperature range of about 120 to 360 ºC. The C-component is the most stable, with demagnetisation in a temperature range of about 400 to 560 ºC. The fisherian distribution forms two defined sets of samples with normal and reverse polarities (Tab. 1).

Magnetostratigraphic investigations defined normal and reverse polarity magnetozones. Magnetostratigraphic results indicate also one unknown polarity. 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 (Fig. 5).

Discussion

The knowledge of unroofed caves contributed substantially to the concepts of speleogenesis in the Classical Karst. There existed a general concept about genesis of karst: Eocene flysch covered Cretaceous and Palaeocene limestones. Flysch was later removed and fluvial forms developed in limestones, which were not karstified at that time. Rivers started to sink during Miocene or Pliocene. Therefore, large-scale geomorphology of the whole Classical Karst was focused on the search of fluvial elements of the surface morphology. Large elongated depressions were explained as dry valleys (Melik 1951). Gravel found on karst surface was supposed to be evidence of rivers (Radinja 1967, 1985; D'Ambrosi & Legnani 1965). Habič (1984) explained general morphology, cave levels and collapses by structural differences and neotectonic movements, but within any time scale of the succession of processes.

Detailed study of unroofed caves proved that gravels on the surface belong to cave fill. They occur even on the top of hills of the Kras Plateau. There is no evidence of preserved previous surface fluvial sediments or forms on the recent relief (Mihevc & Zupan Hajna 1996). With the help of estimated rates of the chemical denudation, the age of different unroofed caves was estimated to about 750–1,500 ka (Mihevc 1996); sediments in them showed, that there were deposited by different, now no more existing sinking rivers.

Gospodarič (1984, 1985, 1988) expected, that somewhat blocked karstification during cold Pleistocene periods encouraged gravel production, fill of ponors and caves and partial reconstruction of surface drainage pattern. Large gravel transport also helps to develop large canyon of the Reka in Škocjanske jame and main large collapses during cold Pleistocene events because of the frost action (Gospodarič 1984). Postojna Cave System, Škocjanske jame and some other caves were supposedly formed during Quaternary and the oldest sedimentary/speleothem fill was correlated with Mindel (Elster) or Günz (Gospodarič 1981, 1984, 1988). Laminated sediments from the Divaška jama were attributed to Mindel and those from the **Trhlovca Cave** to Günz, but sediments were expected to be younger than Jaramillo normal polarity event within the Matuyma reverse epoch (Gospodarič 1985, Table 1 on p. 35). Preliminary results of palaeomagnetic research (Bosák *et al.* 1998a, b) showed substantially older age of sediments in both caves. Interpretation of data from the Divača profile indicated fossilisation of caves during Pliocene or even Miocene age with assumed start of speleogenesis connected with the Messinian crisis.

The application of the magnetostratigraphy of cave sediments of the Classical Karst seemed to be ideal tool for dating. It is generally known here that fossils can be found only in the upper parts of sedimentary fill (especially large mammals max. 200–250 ka old). The time range of numerical dating methods applicable in karst is too short (ca 350 ka). Nevertheless, the magnetostratigraphy approach is facing numerous real problems. The examples of studied profiles of

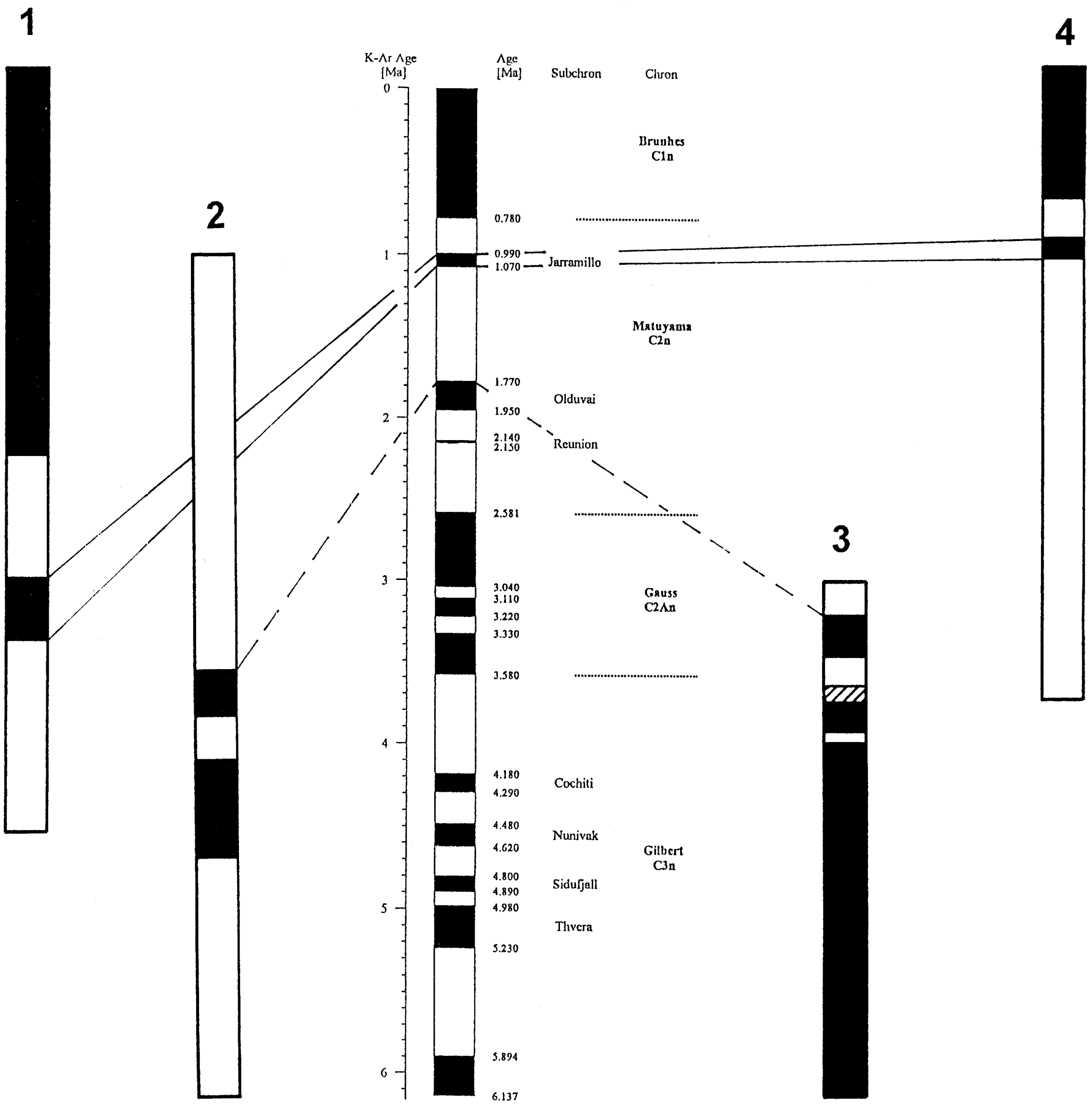

Fig. 6. Correlation of obtained magnetostratigraphic results with standard palaeomagnetic scales (after Cande & Kent 1995, in the centre).

1 – Trhlovca Cave, **2** – Divača profile, **3** – Černotiče Quarry, **4** – Divaška jama. Profiles of studied cave sediments are at the same scale. Correlation of profiles 2 and 3 with the standard scale represents the youngest possibility. Black – normal polarised zone, white – reverse polarised zone, shaded – unknown polarity.

cave sediments belonging to inner-cave facies from different positions of the Classical Karst of the SW Slovenia can serve as good case study.

Sedimentary fills of all studied profiles were separated into individual sequences and cycles divided by numerous evidences of breaks in deposition. Some breaks were expressed by erosion features (cut down of channels – e.g. Divača profile and Trhlovca Cave, intercalations of clays in speleothem sequences – e.g. Černotiče Quarry) and/or precipitation features (ferrugineous crusts – e.g. Divača profile). Some of magnetostratigraphic zones start (samples 153 or 203 of Černotiče Quarry) or finish (sample 4 of Trhlovca Cave, sample 14 of Divaška jama) on such manifestations of unconformities (*cf.* Fig. 2–5). Such features prove enormously complicated deposition dynamics with numerous breaks in deposition and erosions caused that parts of original profiles can be missing; whole caves and cave systems can be even several times completely filled and exhausted (*cf.* Panoš 1962–1963). 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.

Palaeontological finds are usually rare. The nature of cave sediments, especially of the inner-cave facies, does not favour the preservation of fossil remains, which could contribute to dating of cave sediments or to the correlation of magnetozones with standard scales. Most of fossils in such cave facies could be redeposited by erosion of older sediments or derived from collapsed near-surface (epikarst) fills of substantially older age (*cf.* e.g. Horáček & Kordos 1989). Divača profile, Divaška jama and Trhlovca Cave, although examined for palynology, did not yield any results, which is generally not surprising (Bosák *et al.* 1998a, b). Although some fish remains were found in the Černotiče profile (*cf.* Fig. 5, column 4), they have been under the examinations yet and their age has been still unknown (Bosák *et al.* 1999, in press).

The abundance of detailed internal division and scarcity of fossils make the correlation of obtained magnetostratigraphic picture with standard palaeomagnetic scales problematic. The correlation of profile in the **Trhlovca Cave** was relatively easy. No substantial erosion is marked at boundaries of magnetozones with normal and reverse polarity, except of the top of layer with sample 4 (Fig. 3). Short reverse polarised zone below the boundary of normal and reverse polarised zones can be correlated with the Jaramillo subchron in Matuyama reverse chron. Sediments are thus older than expected by Gospodarič (1985, 1988)

Similar picture was obtained also for the **Divaška jama.** Nevertheless, the break in deposition marked by the precipitation of flowstone with stalagmite (dated by the U-series method as older than 350 ka, *cf.* Bosák *et al.* 1998a, b; *cf.* Fig. 2) represents a substantial time-span in which some changes could be hidden. Therefore, the correlation cannot be assumed as completely final. Sediments are again substantially older than expected by Gospodarič (1985, 1988).

Correlation of sediments from the Divača profile and Černotiče Quarry with the standard scale was problematic. The tool for the correlation of the **Divača profile** was the dominant normal polarity in the upper part of the profile and prevailing reverse polarity zone in the lower part. Nevertheless the correlation is not explicit, as reverse polarised magnetozones can belong to Matuyama, Gauss or Gilbert chrons, i.e. from about 1.77 to nearly 5.23 Ma (Bosák *et al.* 1998a, b; Bosák & Pruner 1999).

The arrangement of the distribution of normal and reverse polarity magnetozones within the **Črnotiče log** depends on numerous unconformities within the profile. We can estimate neither the duration of the deposition of freshwater banded carbonate body nor the duration of individual breaks in the deposition of carbonates. Two magnetozones are limited by such erosion surfaces, i.e. reverse polarised magnetozone of sample 153 at its base and normal polarised magnetozone of sample 190 at its top (Fig. 5). It cannot be excluded that both magnetozones were in reality longer. Similarly, eight erosion surfaces detected within lower normal polarised magnetozone (some breaks are represented by relatively thick layers of red clays) could hidden eventual changes in the orientation of the magnetic field (polarisation changes). Therefore, correlations are difficult. We can assume only, that the top of the highest normal polarised magnetozone could be compared with the top of the Olduvai subchron (1.77 Ma) as the youngest possibility, and the rest of profile should be older (Bosák *et al.* 1999, in press).

Conclusions

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 from the Classical Karst 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. Breaks in deposition can hide a substantial part of the geological time. 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 finely exemplified on all examined logs from the Classical Karst, especially on sediments from the Divača profile and Černotiče Quarry. The preliminary correlation of obtained magnetostratigraphic data with standard scales indicate substantially older age of cave filling processes than expected earlier, shifting the possible start of the speleogenesis within the Classical Karst deeply below the Tertiary/Quaternary boundary.

References

BOSÁK P., MIHEVC A. & PRUNER P., 1999: Cave fill in the Černotiče Quarry, SW Slovenia: palaeomagnetic, mineralogical and geochemical study (Preliminary Report). MS, unpubl. rep., Institute of Geology, Academy of Sciences of the Czech Republic & Karst Research Institute Slovenian Academy of Sciences and Arts: 1–108. Praha–Ljubljana.

BOSÁK P., MIHEVC A., PRUNER P., MELKA K., VENHODOVÁ D. & LANGROVÁ A., in press: Cave fill in the Černotiče Quarry, SW Slovenia: palaeomagnetic, mineralogical and geochemical study. *Acta Carsologica*, 28. Ljubljana.

BOSÁK P. & PRUNER P. eds., 1999: Palaeomagnetic research of cave sediments in Divaška jama and Trhlovca Caves, SW Slovenia. MS, unpubl. rep., Institute of Geology, Academy of Sciences of the Czech Republic & Karst Research Institute Slovenian Academy of Sciences and Arts: 1–59. Praha–Postojna.

BOSÁK P., PRUNER P. & ZUPAN HAJNA N., 1998a: Palaeomagnetic research of cave sediments in SW Slovenia. MS, unpubl. Institute of Geology, Academy of Sciences of the Czech Republic & Karst Research Institute Slovenian Academy of Sciences and Arts: 1–144. Praha–Postojna.

– 1998b: Palaeomagnetic research of cave sediments in SW Slovenia. *Acta Carsologica*, 27/2, 3: 151–179. Ljubljana.

CANDE S. C. & KENT D. V., 1995: Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, 100, B4: 6093–6095.

D'AMBROSI C. & LEGNANI F., 1965: Sul problema delle sabbie silicee del carso di Trieste. *Bolletin della Societa Adriatica di Scienze*, LIII, 3. Trieste.

FISHER R., 1953: Dispersion on a sphere. *Proceedings of the Royal Society*, A 217: 295–305. London.

GOSPODARIČ R., 1981: Generacije sig v Klasičnem Krasu Slovenije. *Acta Carsologica*, 9(1980): 90–110. Ljubljana

– 1984: Jamski sedimenti in speleogeneza Škocjanskih Jam. *Acta Carsologica*, 12(1983): 27–48. Ljubljana.

– 1985: O speleogenezi Divaške jame in Trhlovce. *Acta Carsologica*, 13(1984): 5–34. Ljubljana.

– 1988: Paleoclimatic record of cave sediments from Postojna karst. *Annales de la Société Géologique de Belgique*, T. 111: 91–95. Liège.

HABIČ P., 1984: Reliefne enote in strukturnice matičnega Krasa. *Acta Carsologica*, 12(1983): 5–26. Ljubljana.

HORÁČEK I. & KORDOS L., 1989: Biostratigraphic investigations in paleokarst. [In:] P. BOSÁK, D. C. FORD, J. GLAZEK & I. HORÁČEK (eds.): Paleokarst. A systematic and regional review, 599–612. Academia-Elsevier. Praha–Amsterdam.

JELÍNEK V., 1966: A high sensitivity spinner magnetometer. *Studia Geophysica et Geodetica*, 10: 58–78. Praha.

JELÍNEK V., 1973: Precision A. C. bridge set for measuring magnetic susceptibility and its anisotropy. *Studia Geophysica et Geodetica*, 17: 36–48. Praha.

KIRSCHVINK J. L., 1980: The least-squares line and plane and the analysis of palaeomagnetic data. *Geophysical Journal of the Royal Astronomical Society*, 62: 699–718. Oxford.

KNEZ M. & SLABE T., 1999: Unroofed caves met during the motorway construction near Kozina and their recognition on karst surface. 7th International Karstological School. Classical Karst – Roofless Caves. Abstracts: 30–31. Postojna.

KRANJC A., 1997: Introduction. [In:] A. KRANJC *et al.*: Kras. Slovene Classical Karst. 11–17. Znanstvenoraziskovni center SAZU, Inštitut za raziskovanje krasa. Ljubljana.

– 1998: Kras (the Classical Karst) and the development of karst science. *Acta Carsologica*, 27/1: 151–164. Ljubljana.

MELIK A., 1951: Pliocenska Pivka. *Geografski Vestnik*, 13: 17–39. Ljubljana.

MIHEVC A., 1996: Brezstropa jama pri Povirju. *Naše Jame*, 38: 92–101. Ljubljana.

– 1998: Speleogeneza matičnego krasa. MS, doktorska dis.: 1–150, Univerza v Ljubljani, Filozofska fakulteta, Oddelek za geografio. Ljubljana.

– 1999a: The caves and the karst surface-case study from Kras, Slovenia. Etudes de géographie physique, suppl. XXVIII, Colloque européen-Karst 99: 141–144.

– 1999b: Roofless caves. 7th International Karstological School Classical Karst – Roofless Caves. Guide-booklet for the excursions: 2–25. Postojna.

– 1999c: Unroofed caves as geomorphic and speleologic features. 7th International Karstological School. Classical Karst – Roofless Caves. Abstracts: 33–34. Postojna.

MIHEVC A., SLABE T. & ŠEBELA S., 1998: Denuded caves – an inherited element in the karst morphology; the case from Kras. *Acta Carsologica*, 27/1: 165–174. Ljubljana.

MIHEVC A. & ZUPAN HAJNA N., 1996: Clastic sediments from dolines and caves found during the construction of the motorway bear Divača, on the Classical Karst. *Acta Carsologica*, 25: 169–191. Ljubljana.

PANOŠ V., 1962–1963: The question of origin and age of planation surfaces in the Moravian Karst. *Československý Kras*, 14: 29–41. Praha.

PŘÍHODA K., KRS M., PEŠINA B. & BLÁHA J., 1989: MAVACS – a new system of creating a non-magnetic environment for palaeomagnetic studies. *Cuadernos de Geologica Ibérica*, 12: 223–250. Madrid.

RADINJA D., 1967: Vremska dolina in Divaški kras. Problematika kraške morfogeneze. *Geografski zbornik SAZU*, 10: 157–256. Ljubljana.

– 1985: Kras v luči fosilne fluvialne akumulacije. *Acta Carsologica*, 14–15: 99–108. Ljubljana.

ŠEBELA S., 1999: Morphological and geological characteristics of two denuded caves in SW Slovenia. 7th International Karstological School. Classical Karst – Roofless Caves. Abstracts: 36–37. Postojna.

SLABE T., 1996: Karst features in the motorway section between Čebulovica and Dane. *Acta Carsologica*, 25: 221–240. Postojna.

– 1997: The caves in the motorway Dane-Fernetiči. *Acta Carsologica*, 26/2: 361–372. Ljubljana.

– 1998: Karst features discovered during motorway construction between Divača and Kozina. *Acta Carsologica*, 27/2: 105–113. Ljubljana.

STEPIŠNIK U. & ŠUSTERŠIČ S., 1999: The "unroofed cave" near the Bunker (Laški Ravnik). 7th International Karstological School. Classical Karst – Roofless Caves. Abstracts: 35–36. Postojna.

ŠUSTERŠIČ F., 1998: Interaction between cave systems and the lowering karst surface: case study: Laški Ravnik. *Acta Carsologica*, 27/2: 115–138. Ljubljana.