ACTA CARSOLOGICA	29/2	1	15-33	LJUBLJANA 2000

COBISS: 1.08

PALAEOMAGNETIC RESEARCH OF A FOSSIL CAVE IN THE HIGHWAY CONSTRUCTION AT KOZINA, SW SLOVENIA

PALEOMAGNETNE RAZISKAVE STARE JAME BREZ STROPA NA GRADBIŠČU AVTOCESTE PRI KOZINI (JZ SLOVENIJA)

PAVEL BOSÁK[1] & MARTIN KNEZ[2] & DANA OTRUBOVÁ[1] &
PETR PRUNER[1] & TADEJ SLABE[2] & DANIELA VENHODOVÁ[1]

[1] Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-165 02 PRAHA, CZECH REPUBLIC, e-mail: inst@gli.cas.cz
[2] Karst Research Institute, ZRC SAZU, Titov trg 2, SI-6230 POSTOJNA, SLOVENIA, e-mail: izrk@zrc-sazu.si

Prejeto / received: 30. 6. 2000

Izvleček UDK: 56:550.38:551.44(497.4)

Pavel Bosák & Martin Knez & Dana Otrubová & Petr Pruner & Tadej Slabe & Daniela Venhodová: Paleomagnetne raziskave stare jame brez stropa na gradbišču avtoceste pri Kozini (JZ Slovenija)

Jama brez stropa je bila zapolnjena s peščenimi naplavinami dinamične strukture ter teksture svetlo rjave in oker barve. Na vrhu 5 m debelega prereza naplavin so bile rjava prst in skale. Pobranih je bilo 38 vzorcev naplavin. Posamezne magnetne cone nakazujejo, da je naplavina starejša od zgornjega Olduvaja (1,77 M); kot kozinski prerez se konča z reverzno polarizirano magnetno cono in ima dve normalni polarizirani coni. Prerez naplavin je podoben divaškemu. Predvidevamo, da je jama iz mesinskega obdobja in da so naplavine v njej posledica hitrega zvišanja gladine podzemeljske vode po ponovni zapolnitvi mediteranskega bazena z vodo, torej da so bile odložene pred 5,2 milijoni let.
Ključne besede: magnetostratigrafija, jama brez stropa, Kras, Slovenija.

Abstract UDC: 56:550.38:551.44(497.4)

Pavel Bosák & Martin Knez & Dana Otrubová & Petr Pruner & Tadej Slabe & Daniela Venhodová: Palaeomagnetic Research of a Fossil Cave in the Highway Construction at Kozina, SW Slovenia

A fossil channel was filled by sandy sediments of light brown to ochreous color with dynamic structures and textures (lower sequence) unconformably overlain by remains of collapsed roof with brown and ochreous matrix (upper sequence). The sedimentary profile was about 5 m high. In all 38 samples taken from the profile, only one was cemented. Samples were demagnetised by alternating field (AF) at 10 to 1,000 Oe. The cemented one was demagnetised by gradual thermal process from 80 to 560 °C in the MAVACS apparatus. Detected remanent magnetisation in a natural state varied between 95 and 36,470 pT, values of volume magnetic susceptibility are from 55 to 998 x 10^{-6} SI. Rocks showed low or medium magnetisation. Normal and inverse polarization was detected after demagnetisation. The primary component of magnetisation and resulting polarity could not be stated in samples with expressive viscose component (up to 90 %). According to arrangement of individual magnetozone, it can be stated that sediments are older than the top of Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina terminated by reverse polarised magnetozone and contains two normal polarised zones. The profile can be correlated with the Divača profile, not only from the palaeomagnetic point of view, but also from a lithological point of view. We suppose, as in Divača, that the cave is a result of the Messinian speleogenetic epoch and its fossilization was connected with rapid base level uplift after refilling of the Mediterranean basin by water. If this hypothesis is close to reality, the fossilization process can be dated from about 5.2 Ma up.
Key words: magnetostratigraphy, unroofed cave, Kras, Slovenia.

INTRODUCTION

Palaeomagnetic research of cave sediments in the Classical Karst has been carried out within the frame of the scientific co-operation between the Institute of Geology, Academy of Sciences of the Czech Republic and Institute of Karst Research of the Slovenian Academy of Sciences and Arts since autumn 1997. The research has covered several interesting sites of the Classical Karst, SW Slovenia, yielding important results. Places have been examined as follows: Divača profile at highway near village of Divača, Trhlovca Cave and Divaška Jama, Črnotiče near Črni Kal and unroofed cave system near Kozina.

Palaeomagnetic analyses were completed in the Laboratory of Palaeomagnetics of the Institute of Geology of the Academy of Sciences of the Czech Republic in Praha-Průhonice.

GEOLOGICAL AND MORPHOLOGICAL BACKGROUND

The Classical Karst is a low NW-SE trending longitudinal plateau along the Trieste embayment of the Adriatic Sea from the Vipava Valley in the NE to Friuli-Venezia Giulia lowlands and the Soča River in NW. Its length is about 40 km and width is 13 km. It covers totally about 440 km^2. The central part lies at 200 to 500 m a.s.l.

The Kras plateau belongs to Adriatic-Dinaric Carbonate Platform of the Outer Dinarids. It is composed of relatively shallow marine Cretaceous and Paleogene limestones rich in fauna and flora. Eocene flysch sediments encircle the carbonate plateau. Due to strong pressures in the NE→SW direction, a complicated imbricated structure was formed with an alternation of flysch and limestone zones (slices) elongated in the NW-SE direction. Thrust planes are dipping towards the northeast (*cf*. Placer 1981).

The karstification of the region is typical with the presence of old caves partly crossed by younger shafts. Shafts are connected with the drop of piezometric level, which lies now about 200 m below the surface. Shafts are both empty and filled with young (Pleistocene) sediments (*cf*. e.g., Rakovec 1958; Brodar 1958 in the Podgora Karst). Large valley systems on the surface of the Karst were believed to represent primary river valleys as they contain remains of fluvial sediments. Nevertheless, latest interpretations indicate that fluvial sediments represent rather the fill of fossil caves, than remains of surface fluvial systems (*cf*. Mihevc 1998, 1999a-c). The paleofill of caves appeared at the surface due to erosion and/or chemical denudation of the limestone surface. Such caves were called denuded, roofless or unroofed caves.

The unroofed caves represent old caves where overlying limestones were destroyed. They are preserved as fluvial deposits and spelothems on the present surface, sometimes with the traceable course of original passages. Such caves were originally described during the construction of highway network over the Classical Karst (Knez & Šebela 1994; Šebela & Mihevc 1995; Slabe 1996, 1997a, b, 1998; Mihevc & Zupan Hajna 1996; Mihevc 1996; Kogovšek, Slabe & Šebela 1997; Mihevc, Slabe & Šebela 1998; Šebela, Mihevc & Slabe 1999; Knez & Slabe 1999a, b; Šebela 1999). In all 250 caves have been discovered in last five years along an over 40 km long and about 25 m wide construction strip of the highway. Of them, 70 were unroofed. Some of them represented parts of the same cave paleosystem(s). Nevertheless it appeared that such caves are common over the whole Classical Karst (e.g., Šusteršič 1998; Mihevc 1998; Stepišnik & Šušteršič 1999;

Geršl, Stepišnik & Šušteršič 1999).

Mihevc, Slabe & Šebela (1998), and Knez & Slabe (1999a, b) tried to typify the characteristic forms of unroofed caves. They are transformed by surface processes and represent an important element of the epikarst zone (Knez and Slabe 1999b). The shape and form of unroofed caves resulted from the morphology of the present surface, the original configuration of fossil caves, the intensity of younger karstification (speleogenesis) and a degree of younger exhumation of the cave fill. In the field, they are expressed as shallow oblong depressions, doline-like forms and collapsed dolines. Unroofed caves are a typical example of paleokarst - exhumed and/or rejuvenated karst (*sensu* Bosák, Ford & Głazek 1989, p. 32) - partially incorporated into the present karst landscape and hydrological system.

The dating of sediments in some unroofed caves by palaeomagnetic method (Bosák, Pruner & Zupan Hajna 1998a-c; Bosák, Mihevc & Pruner 1999; Pruner & Bosák 1999; Bosák et al. 1999, 2000) indicated the substantial age of the cave fill, clearly older than 1.77 Ma.

SITE LOCATION AND CHARACTERISTICS

The site was located to the NE of the village of Kozina close to the present main road from Ljubljana to Koper in a cut made during construction of the highway from Divača to Klanec (Fig. 1).

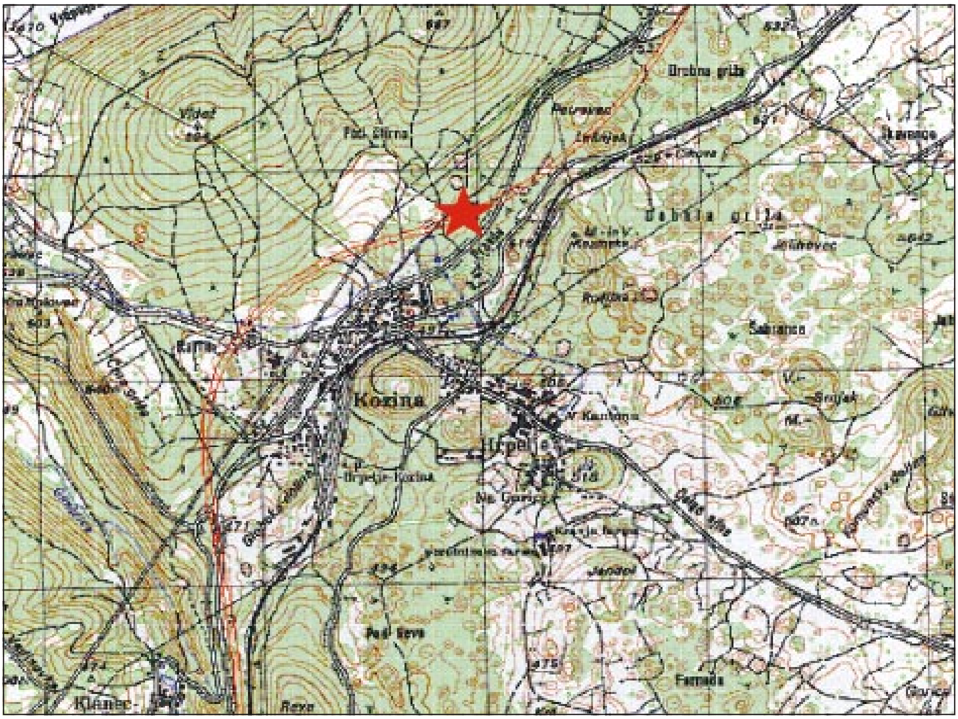

Fig. 1: Site location.

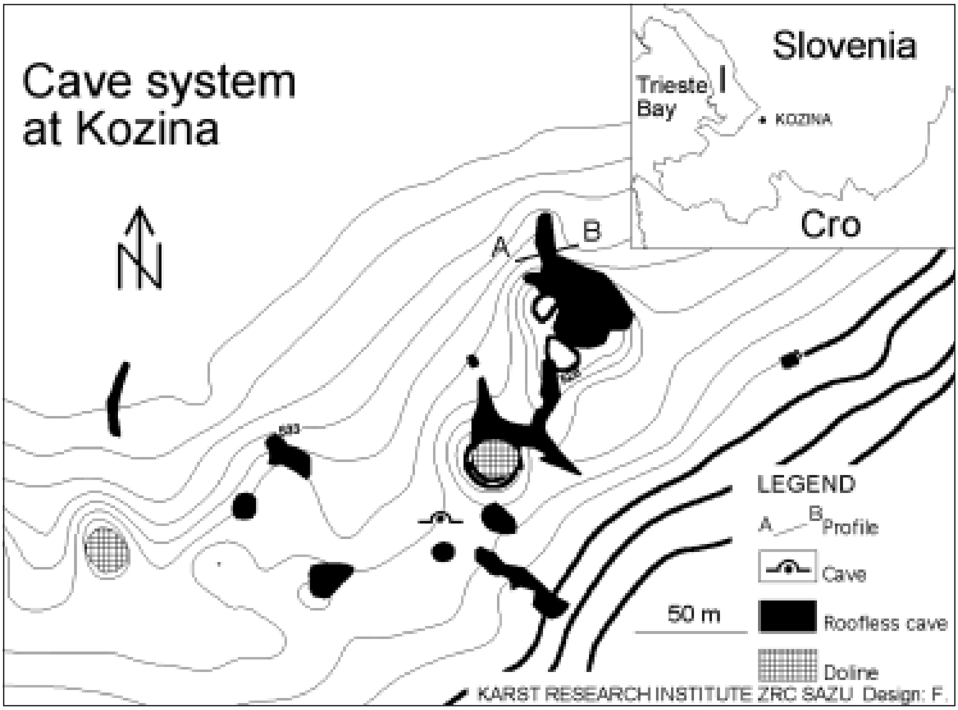

Fig. 2: Cave system at Kozina with caves, unroofed caves and dolines (after Knez & Slabe 1999, modified).

Knez & Slabe (1999b) described in detail the character of unroofed caves in the vicinity of Kozina. Caves were developed in Turonian to Thanetian shallow marine limestones. Tectonic contact with Eocene siliciclastics (flysch) was located near the construction site. The network of various karst forms (Fig. 2) resulting from unroofing of large and diversified cave system(s) occurs along the construction site. The largest cave system - 400 m long - was situated on the right side of construction near Kozina. The system appeared on the surface as more or less distinct oblong depressions forming the connection of doline-like depressions. Unroofed caves were morphologically more expressed near dolines, where erosion of cave fill down to dolines was more intense. Depressions were mostly small and shallow. Their bottoms were filled by brown and red soils to a thickness of several metres. There were traces of water inflow at the contact soil/limestone. At their bottoms, there were entrances to narrow and inaccessible shafts.

Cave passages were both free and choked, with very thin roofs, which are partly removed. Caves were filled dominantly by fine-grained fluvial sediments, sometimes with gravel beds derived from flysch sediments. In the SW, layers of flowstones and stalagmites formed intercalations with fluvial cave fill. Some sedimentary sections were covered by angluar blocks, boulders and debris derived from destroyed roof limestones. The debris are considered to be results of weathering/disintegration in a cold Pleistocene climate (Knez & Slabe 1999b).

PROFILE DESCRIPTION

The log of the sampled profile is presented in Figure 4. The whole profile consisted of more than 5 m of sediments. Its bottom was uncovered. The fill was composed of two principal sequences (Fig. 3 and Photo 1). The lower one was composed of ochreous sandy to clayey sediments with a thickness of about 3 m. Sediments of the lower sequence were sampled for palaeomagnetism. The lower sequence was overlain with sharp erosional surface by collapse breccia with limestone blocks to boulders (cm to m in size) and a matrix of brown loams with carbonate efflorescences on cracks (pseudomycelia). In the upper part of the collapse breccia, the matrix was rather ochreous

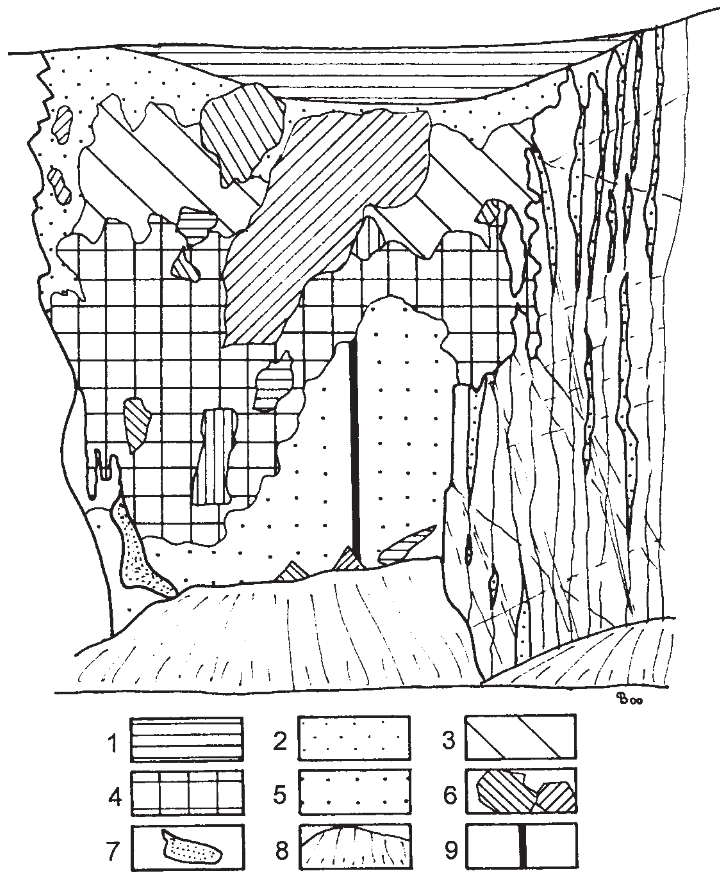

Fig. 3: Sketch of the profile in road cut near Kozina (cf. Photo 1). 1. debris from blasting, 2. terra rossa-like sediments, 3. collapsed material with matrix derived from sediments similar to lower sequence of profile, 4. collapsed material with brown matrix, 5. lower sequence, 6. blocks, 7. cave, 8. heap, 9. sampled profile (cf. Fig. 4).

with smaller rock fragments. The upper sequence was not sampled for palaeomagnetic analysis owing to the collapse character with possibility of postdepositional movement, slumping and sediment rotation.

Near the contact of sediments and limestone, a narrow inclined cave was developed in sediments of the lower sequence. The cave walls were covered by speleothems, which cemented surrounding sediment. The cave represents a younger waterway draining the fossil cave and shallow depression of the present surface.

Photo 1: The complete view of the profile in road cut near Kozina (Photo by P. Bosák).

Lower sequence

The lower sequence had a thickness of about 3 m. Palaeomagnetic samples are signed in cm from the base of the profile (□2-295). The following lithological units were distinguished:

1. sand, yellow, black-violet schlieren, very fine-grained, silty, indistinct lamination with higher clayey admixture, angular rock fragments.
2. clay, silty, variegated (ochreous, light brown with dark grey and violet schlieren and lamination), slightly finely sandy, more at the base, laminated (dynamic lamination), erosional base with secondary ferruginisation (□2-28).
3. clay, silty, ochreous to light brown, yellow and whitish yellow laminated, with laminae of fine-grained sand and fine sandy silt, thin ferruginized laminae, erosional base (□29-93).
4. clay, light brown, violet brown at the top, with thin white sand bend, erosional base (□98-109).
5. clay, silty, ochreous to light brown, yellow and whitish yellow laminated, with laminae of fine-grained sand and fine sandy silt, clasts of brown clays in the upper part, in places calcitized, erosional base, disconformably on layer No. 4 (some 10° lower inclination) (□116-212).

6. clay, silty, light brown, erosional base (□219-231).
7. clay, silty, ligh brown, slightly finely sandy in indistinct laminae, with coarse flakes of micas, with irregular clasts, erosional base.
8. breccia with light ochreous clayey matrix, erosional base.
9. clay, silty, brown, with Mn schlieren, erosional base (□290).
10. sand, yellow, fine-grained, with cross-bedding, erosional base (□295).

Five samples were taken from the profile for palynological analyses (Fig. 4), i.e., at 30, 30-45, 70-80, 130-150 and 180-200 cm from the profile base.

A sample from 70-80 cm yielded two highly corroded pollen grains belonging to herb vegetation (*Dipsacaceae* and *Apiceae* family). A sample from 130-150 cm yeilded one spore (fern).

No tree pollen was found. Pollen grains belong to herb vegetetion typical of dry, steppe-like region.

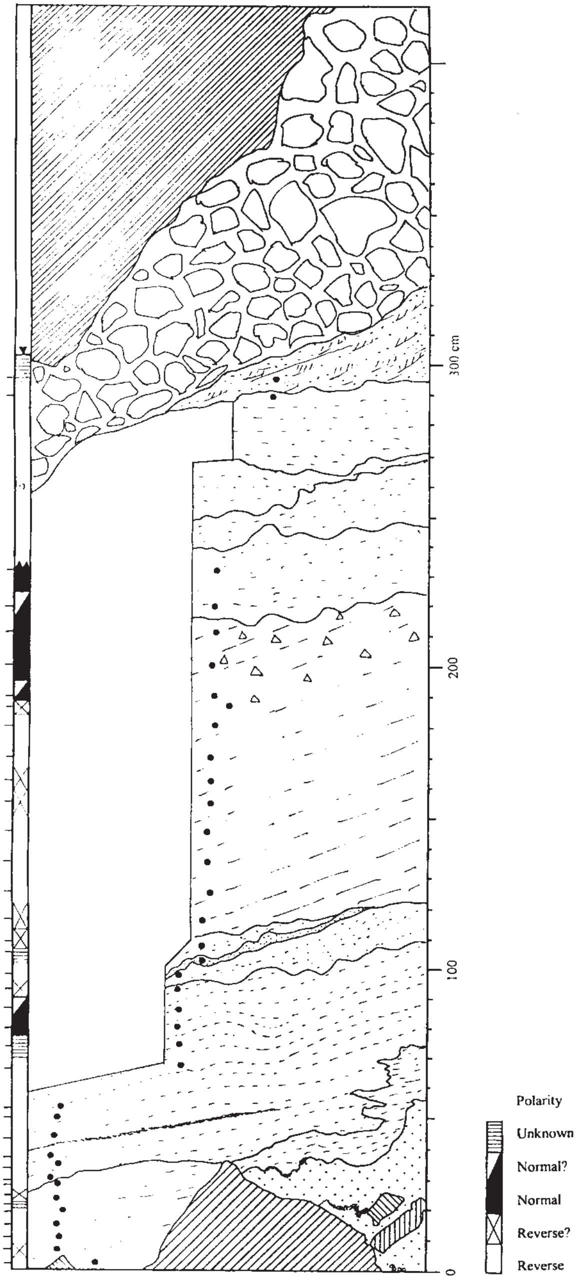

Fig. 4: Lithological log of the profile (cf. Fig. 3). Black dots - sampling points. Magnetic polarization: 1. unknown (?), 2. normal?, 3. normal, 4. reverse?, 5. reverse.

PALAEOMAGNETIC ANALYSES

In total, 38 oriented laboratory specimen of cave sediments were investigated for their palaeomagnetic properties.

Laboratory procedures

Laboratory procedures enabled (1) the derivation of components of respective magnetic remanence in different temperature intervals during progressive thermal demagnetisation (TD) and demagnetisation by alternating field (AF), and (2) 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. They were measured on the spinner magnetometers (JR-4 and JR-5; Jelínek 1966). Laboratory specimens of solid rocks in a natural state were subjected to progressive thermal demagnetisation on the MAVACS (Magnetic Vacuum Control System) generating high magnetic vacuum (Příhoda et al. 1989). All specimens were demagnetised by alternating field procedures (Schonstedt GSD-1), up to a field of 1,000 Oe (14 steps).

Remanent magnetisation of specimens in a 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. The directions of J_n and those of the remanent magnetisation of the thermally or AF demagnetised specimens in the course of progressive demagnetisation procedures are shown in stereographic projection.

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).

Separation of the respective remanent magnetisation components was carried out by multi-component Kirschvink analysis (Kirschvink 1980). 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 collected samples (total 38) were subjected to detailed AF demagnetisation; one sample was demagnetised thermally. Basic magnetic parameters are documented for the profile about 3 m high and total 38 samples in Table 1. The values of the moduli of J_n of rocks in natural state show a big scatter. Mean values of moduli of remanent magnetisation J_n and of magnetic susceptibility k_n in their natural state from 38 samples are $J_n = 7.005 \pm 8.391$ [nT], $k_n = 267 \pm 216 \times 10^{-6}$[SI]. Rocks show low or medium degree of magnetisation.

The directions of remanent magnetisation inferred by the above given procedures were tested using a multi-component analysis (Kirschvink 1980). Generally, the samples showed three remanence components: A, B and C. *A-components* are mostly of viscous or chemoremanent (weath-

Table 1: Basic magnetic parameters of samples from the Kozina profile.

Sample No.	J_n [nT]	k_n [10^{-6} SI]	Polarity
K 295	0.509	55	N
K 290	9.230	383	R
K 231	4.499	189	N
K 219	1.273	107	N
K 212	2.231	142	N
K 200	2.581	140	N
K 190	16.094	447	N
K 187	1.314	63	R
K 180	14.247	478	N
K 170	23.697	649	N
K 162	19.330	572	?
K 155	7.667	297	N
K 145	10.674	420	R
K 135	13.866	494	N
K 125	22.389	643	R
K 116	36.470	998	R?
K 109	17.493	529	R?
K 105	1.111	90	N
K 98	15.789	585	R
K 93	8.747	308	N?
K 87	8.382	264	N?
K 80	6.090	250	N
K 74	7.904	274	N?
K 66	1.570	132	R
K 53	2.712	148	R
K 50	1.746	135	R
K 43	1.972	129	R
K 37	0.723	108	R
K 34	0.349	87	R
K 29	0.144	70	R
K 28	0.095	107	R
K 25	0.178	104	N?
K 22	0.313	101	?
K 19	0.268	114	R
K 15	0.705	130	R?
K 11	1.390	155	R?
K 7	0.769	129	R?
K 2	1.682	137	R
Number of samples	38	38	-
Mean value	7.005	267	-
Mean deviation	8.391	216	-

ering) origin. They can be removed by alternating field with the intensity of 10 up to 30 Oe. Detected remanent magnetisation in a natural state varies between 95 and 36,470 pT, values of volume magnetic susceptibility are from 55 to 998 × 10^{-6} SI. Some samples showed expressive viscose component (up to 90 %); the primary component of magnetisation and resulted polarity cannot be therefore stated.

Normal and reverse *C-component* directions of the samples (Fig. 6) form two defined sets of samples with fisherian distribution. Mean directions of remanent magnetisation of the Kozina profile are documented in Table 2.

The top and lower part of the profile shows reverse magnetozone. There are two normal zones in the middle part of the profile.

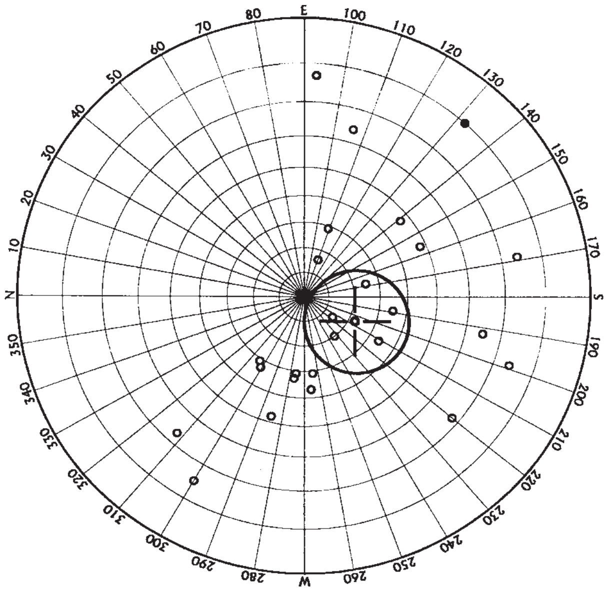

Fig. 5: Basic magnetic and magnetostratigraphic parameters of samples.

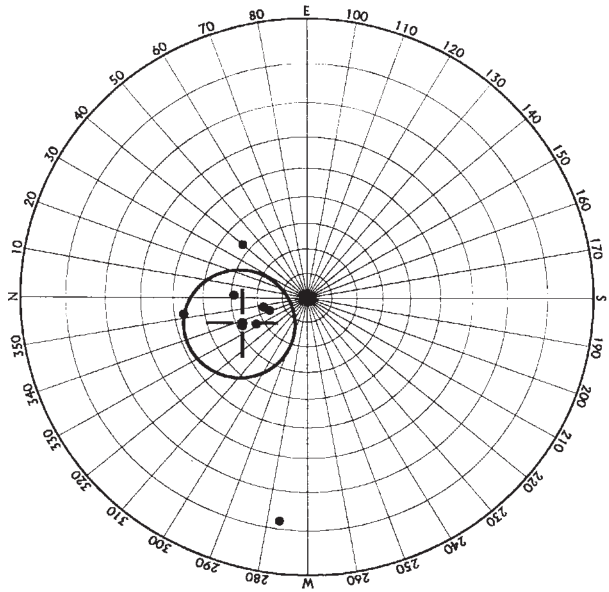

Fig. 6: Samples with normal palaeomagnetic polarity (A) and samples with reverse palaeomagnetic polarity (B). Stereographic projection, full (open) circles represent projection onto lower (upper) hemisphere. The mean direction calculated according to Fisher (1953) is denoted by a crossed circle, the confidence circle at the 95 % probability level is circumscribed about the mean direction.

Table 2: Mean palaeomagnetic directions for investigated locality.

Locality	Polarity	Mean directions of the remanent magnetisation		α_{95}	k	N
		D[°]	I[°]			
KOZINA	N	338.2	62.3	20.7	8.1	8
	R	206.0	-67.6	20.1	3.1	25

Magnetostratigraphic results

Palaeomagnetic and magnetostratigraphic investigations yielded data on basic magnetic properties and identification of palaeomagnetic directions:

(i) Magnetostratigraphic investigations obtained for the Kozina profile defined normal and reverse polarity magnetozones.

(ii) Magnetostratigraphic results of samples from Kozina profile and Divača profile show the close correlation between both profiles:
- two normal subzones in reverse magnetozone were interpreted for both profiles;
- good correlation of moduli values of remanent magnetisation (J_n).

DISCUSSION

The lithology of profile clearly shows two-phase depositional history. The lower sequence, was eroded after its deposition. The erosional channel was more deeply developed at left side of the passage. The free space in the cave was later filled during collapse processes by block to boulder debris mixed with brown karst sediments. Ochreous intercallations in the upper part of the upper sequence can indicate the presence of eroded sediments comparable with the lower sequence. Thinning of cave roofs by erosion and karst denudation induced their collapses.

Lithological composition of the lower sequence is comparable with the Divača profile in a fossil cave near village of Divača (Bosák, Pruner & Zupan Hajna 1998a-c), especially with its sequences Nos. I and II. Layer No. 10 of the Kozina profile could be correlated with the base of sequence No. III of the Divača profile. It seems that sediments were derived from a similar source rocks, most probably from weathered Eocene flysch.

Important erosional boundaries of main lithological units within the lower sequence are located between samples Nos. 28/29, 93/98, 109/116, 212/219, 290/295. Contrary to other studied profiles (Bosák et al. 2000) erosional boundaries are not situated at boundaries of normal and reverse polarized zones, but within them. This fact can indicate also that breaks in deposition did not take a substantial time-span.

The magnetostratigraphic picture obtained in the Kozina profile is fully comparable with magnetozones detected in the Divača profile (Bosák, Pruner & Zupan Hajna 1998a-c; Bosák et al. 2000), both in occurrence of the normal and reverse polarised magnetozones (Fig. 8) and in the character of the moduli of remanent magnetisation (J_n; Fig. 7). The dominant part of both profiles is represented by reversed magnetozones. There are two relatively narrow normal polarised zones. Unfortunately, there is a gap in sampling between Kozina samples No. 213 and 290, owing to rock petrography unfavourable for sampling. Some difference in the arrangement of normal polarised magnetozones in both profiles can result also from different rates of deposition during fossilization of both channels.

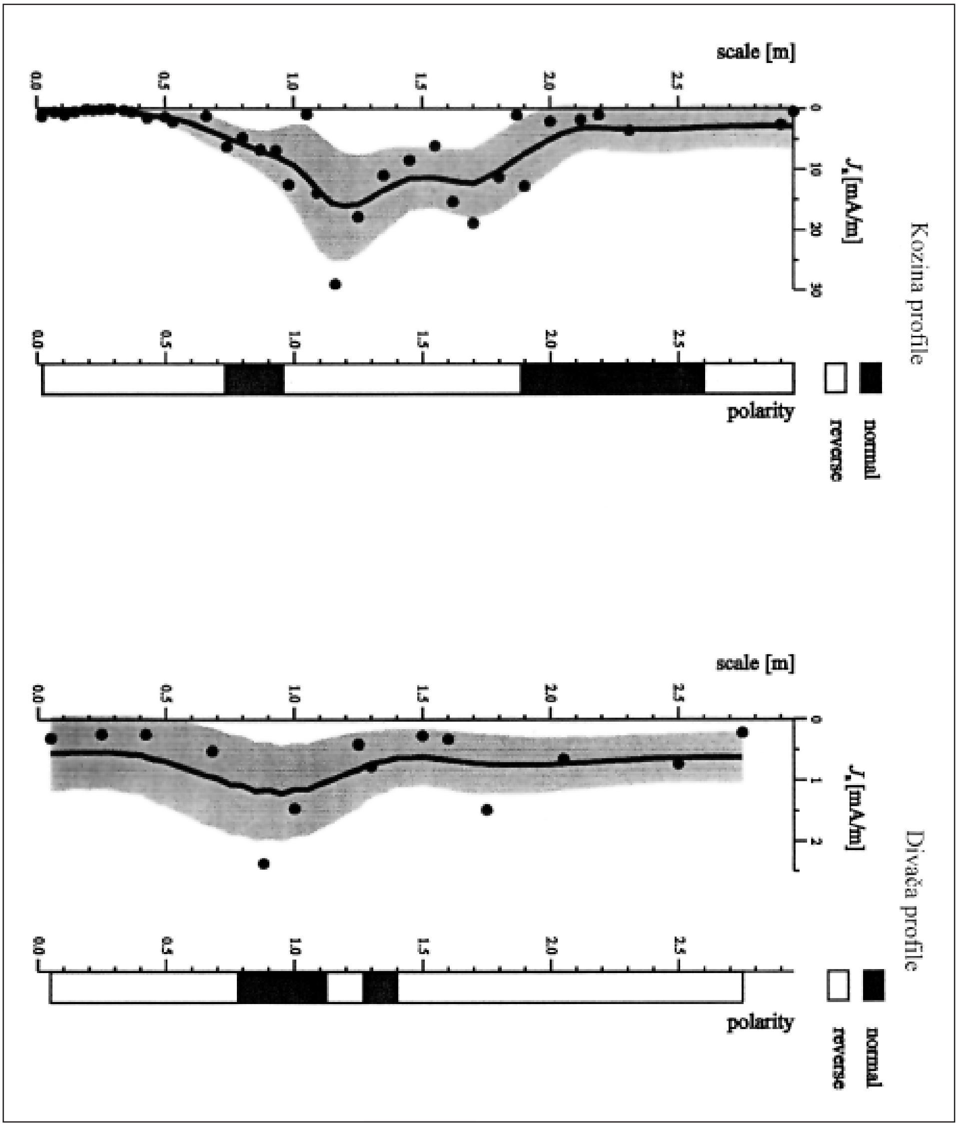

Fig. 7: Comparison of basic magnetic and magnetostratigraphic parameters of Divača profile (after Bosák, Pruner & Zupan Hajna 1998c) and Kozina profile.

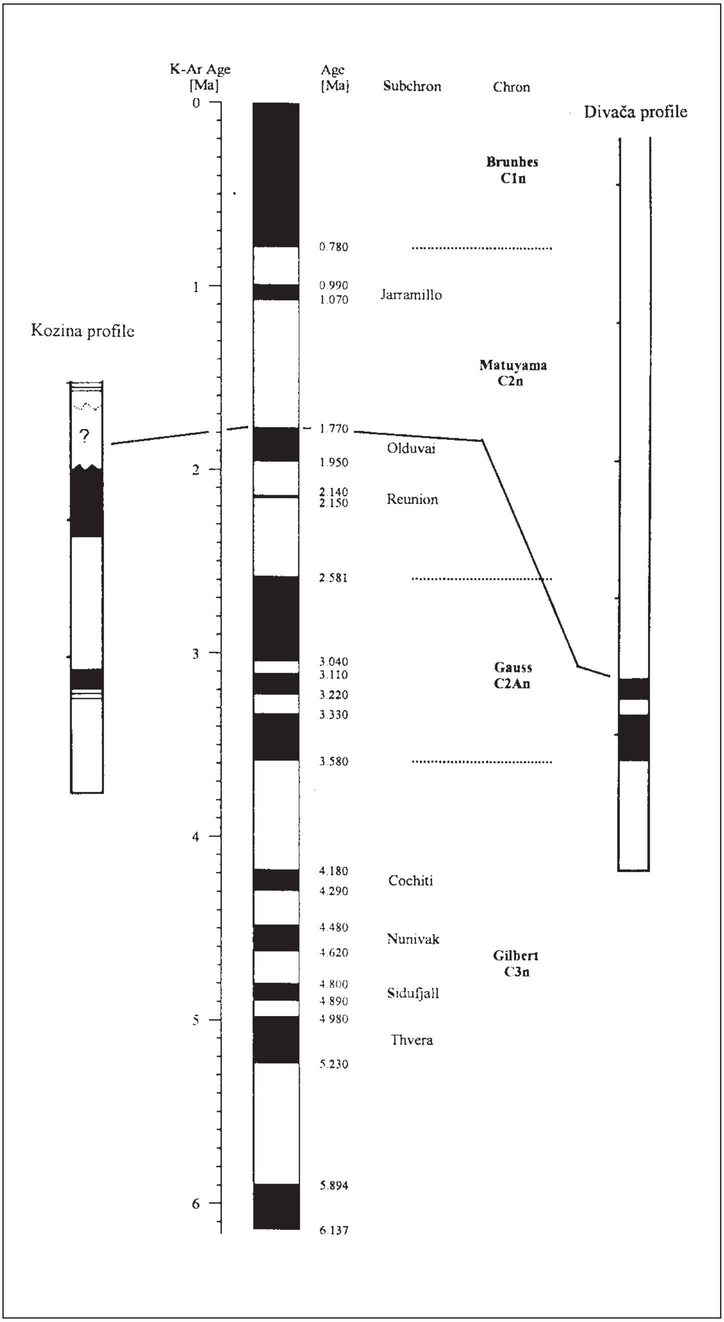

Fig. 8: Correlation of obtained magnetostratigraphic results with standard palaeomagnetic scales (after Cande & Kent 1995, in the centre).

The age of the profile at Kozina is older than the Bruhnes/Matuyama boundary (0.78 Ma). According to arrangement of individual magnetozones, it could be stated that sediments are older than the top of Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina terminates by reverse polarised magnetozone and contains two normal polarised zones (Fig. 8). Closely comparable character of moduli values of remanent magnetisation (J_n; Fig. 7) highly supports the age correlation of both profiles from fossil caves at Divača and Kozina.

We suppose, as in Divača profile, that the cave is a result of the Messinian speleogenetic epoch (especially if normal polarized magnetozones could be correlated with those within the reverse Gilbert epoch; Fig. 8). The Mediterranean sea-level rapidly fell at that time (Hsü 1973; Hsü, Cita

& Ryan 1973; Hsü et al. 1977), which was connected with deep entrenchment of valleys in regions surrounding the Mediterranean Basin (e.g., valleys of Ebro, Durance, Var, Po or Orontes Rivers, valley of Rhône River in southern France with extreme thickness of Pliocene-Quaternary fill - Clauzon 1973, 1980; Clauzon, Puig & Guendon 1997, Nile Valley in Egypt - Khumakov 1967, 1971, valleys in carbonate plateau of Cyrenaika in Libya or in carbonate-flysh region of Istria in Croatia. Deep karst with the depths of 1 to 3 km developed in the whole Mediterranean region (Perna 1996) as a result of underground karst drainage directed into the Mediterranean Basin from its foreland (Głazek 1993). Perna (1996, p. 12) designed the resulted karst forms as Messinian karst cycle. Now submerged parts of such systems are often expressed by large submarine springs (vrulja on the Adriatic coast, Cyrenaica, Apulia, southern France, etc.) and other features (Sardinia). Very probably, the Divača and Kozina fossil caves represent the result of this phase.

The fossilization of cave systems was connected with rapid base level uplift after refilling of the Mediterranean basin by water after opening of Gibraltar strait, which is dated to about 5.2-5.3 Ma; Hsü 1973; Cita & Corselli 1993). Further fossilisation resulted from changes in regional base level and hydrological situation due to gradual relief/neotectonic evolution of this part of the Karst and sea level changes in the Mediterranean Basin.

CONCLUSIONS

The construction of highway from Divača to Klanec (SW Slovenia, Classical Karst) uncovered a number of fossil caves and unroofed caves. One of them was situated near village of Kozina. The fossil channel was unroofed with remains of collapsed roof only in the upper part. It formed a mild depression in the field. The sedimentary profile in the cave was about 5 m high. It was composed mostly of sandy sediments of light brown to ochreous color with clayey and silty intercalations. Sediments contained dynamic structures and textures (lamination, cross-lamination, etc.). Erosional surfaces divided the profile into individual sequences.

In total 38 samples taken from the profile, only one from them was cemented. Samples were demagnetised by alternating field (AC) at 10 to 1,000 Oe. The cemented one was demagnetised by gradual thermal process from 80 to 560 °C in the MAVACS apparatus. Individual components of remanent magnetisation after the demagnetisation by alternating or thermal field were detected by multi-component analysis by the Kirschvink method. Detected remanent magnetisation in a natural state varied between 95 and 36,470 pT, values of volume magnetic susceptibility are from 55 to 998.10^{-6} SI. Rocks show low or medium magnetisation. Normal and inverse polarization was detected after demagnetisation. Some samples showed expressive viscose component (up to 90 %); the primary component of magnetisation and resulted polarity could not be stated.

The profile contains inverse and normal polarity magnetozones. The character of distribution of magnetozones is similar to the previous locality of Divača profile (fossil cave in road cut at Divača). The age of the profile at Kozina is older than the Bruhnes/Matuyama boundary (0.78 Ma). According to arrangement of individual magnetozones, it could be stated that sediments are older than the top of Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina terminates by reverse polarised magnetozone and contains two normal polarised zones.

The profile can be correlated with the Divača profile, not only from the palaeomagnetic point of view, but also from lithological point of view. We suppose, as in Divača, that the cave is a result of Messinian speleogenetic epoch and its fossilization was connected with rapid base level uplift after refilling of the Mediterranean basin by water. If this hypothesis is close to reality, the fossilization process can be dated from about 5.2 Ma up.

ACKNOWLEDGEMENT

We are grateful especially to DARS (Motorway administration) who financed karstological control and gave permisson for access to the construction site. The company covered also expenses of analytical procedures. We are also grateful to the Institute of Protection of Natural and Cultural Heritage, Nova Gorica by which karstological control was organised. We acknowledge field assistance of Nadja Zupan Hajna and the technical staff of Karst Research Institute, ZRC SAZU, Postojna, Slovenia, during sampling. Palynological analyses were kindly carried out by Dr. Metka Culiberg from Institute of Biology, ZRC SAZU, in Ljubljana, Slovenia. Software for evaluation of palaeomagnetic measurements was prepared by Dr.Ota Man (Institute of Geology AS CR, Praha). Some figures were drawn by Mrs. Věra Havlíková (Institute of Geology AS CR, Praha) and Mr. F. Drole (Karst Research Institute ZRC SAZU, Postojna). Travel costs were covered within the frame of the program KONTAKT No. ME.251 of the Czech Ministry of Education, Youth and Sports and Slovenian Ministry of Science and Technology. Expenses of analytical procedures were partly 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. The study is a result of Research Plan of the Institute of Geology AS CR No. CEZ: A09/98:Z3-013-912.

REFERENCES

Bosák P., Ford D.C. & Głazek J., 1989. Terminology. - In: P. Bosák, D.C. Ford, J. Głazek & I. Horáček (Eds.): Paleokarst. A Systematic and Regional Review: 25-32. Elsevier-Academia. Amsterdam-Praha.

Bosák P., Mihevc A. & Pruner P., Eds., 1999. Cave fill in the Črnotiče Quarry, SW Slovenia: palaeomagnetic, mineralogical and geochemical study (Preliminary Report). - MS, MS, Geol. úst. AV ČR and Karst Res. Inst. SAZU: 1-108. Praha-Postojna.

Bosák P., Mihevc A., Pruner P., Melka K., Venhodová D. & Langrová A., 1999. Cave fill in the Črnotiče Quarry, SW Slovenia: Palaeomagnetic, mineralogical and geochemical study. - Acta Carsologica, 28/2, 2: 15-39. Ljubljana.

Bosák P., Pruner P., Mihevc A. & Zupan Hajna N., 2000. Magnetostratigraphy and unconformities in cave sediments: case study from the Classical Karst, SW Slovenia. - Geologos, 5: 13-30. Poznań.

Bosák P., Pruner P. & Zupan Hajna N., 1998a. Palaeomagnetic research of cave sediments in SW Slovenia. - MS, Geol. úst. Akad. Věd Čes. rep. and Karst Res. Inst. Slovenian Acad. Sci. Arts: 1-144. Praha-Postojna.

Bosák P., Pruner P. & Zupan Hajna N., 1998b. Palaeomagnetic research of cave sediments in SW Slovenia. - 6th Int. Karstol. School.: Classical Karst-Alpine Caves, Guide-Booklet for the Excursions and Abstracts of Papers: 35-37. Speleol. Assoc. Slovenia and Karst Res. Inst.

SAZU. Postojna.
Bosák P., Pruner P. & Zupan Hajna N., 1998c. Paleomagnetic research of cave sediments in SW Slovenia. - Acta Carsologica, XXVII/2, 3: 151-179. Ljubljana.
Brodar S., 1958. Črni kal, nova paleolitska postaja v Slovenskem Primorju. - Razprave, IV: 269-364. 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.
Cita M.B. & Corselli C., 1993. Messiniano: vent´anni dopo. - Mem. Soc. Geol. It., 49: 145-164. Roma.
Clauzon G., 1973. The eustatic hypothesis and pre-Pliocene cutting of the Rhone valley. - Init. Rep. Deep Sea Drilling Proj., 13: 1251-1256.
Clauzon G., 1980. Le canyon Messinien de la Durance (Provence, France): une preuve paleogeographique de bassin profond de dessication. - Palaeogeogr. Palaeoclimatol. Palaeoecol., 29, 1/2: 15-40.
Clauzon G., Puig J.M. & Guendon J.L., 1997. Géomorphologie quantitative et paléogéomorphologie dans les karsts du domaine Méditerranéen. - Livret-Guide de l´Excursion „Manifestations karstiques induites par le creusement messinien: exemples rhodano-duranciens“. CNRS (URA 903)-Université de Provence. Aix-Marseille.
Fisher R., 1953. Dispersion on a sphere. - Proc. Roy. Soc., A 217: 295-305. London.
Geršl M., Stepišnik U. & Šušteršič F., 1999. The “unroofed cave” near the Bunker (Laški Ravnik). - Acta Carsologica, 28/2: 77-90. Ljubljana.
Głazek J., 1993. Krysys messyński (wyschnięciwe Morza Śródziemskiego w górnym miocenie) i jego rola w paleogeografii Europy. - Streszczenia referatów wygłoszonych na posiedzeniach Oddziału Poznańskiego (1991-1992): 13-15. Pol. Tow. Geol., Inst. Geol. UAM. Poznań.
Hsü K.J., 1973. Quando il Mediterraneo si disseco. - Le Scienze, 56: 19-29. Milano.
Hsü K.J., Cita M.B. & Ryan W.B.F., 1973. Origin of Mediterranean evaporites. - Init. Rep. Deep Sea Drilling Proj., 13: 1203-1231.
Hsü K.J., Montadert L., Bernoulli D., Cita M.B., Erickson A., Garrison R.E., Kidd R.B., Mrlierws F. & Wright R., 1977. History of the Mediterranean salinity crisis. - Nature, 267, 5610: 399-403.
Jelínek V., 1966. A high sensitivity spinner magnetometer. - Stud. geoph. geod., 10: 58 - 78.
Jelínek V., 1973. Precision A.C. bridge set for measuring magnetic susceptibility and its anisotropy. - Stud. geoph. geod., 17: 36 - 48.
Khumakov I.S., 1967. Pliocenovye i pleistocennovye otlozhenia doliny Nila v Nubii i verchnem Egipte. - Trudy Geol. Inst. AN SSSR, 170: 1-115. Moskva.
Khumakov I.S., 1971. Nekotorye voprosy geologicheskoy istorii Sredizemnomorskogo basseyna v konce miocena-nachala pliocena po novym dannym. - Sov. Geol., 14, 10: 3-14. Moskva.
Kirschvink J. L., 1980. The least-squares line and plane and the analysis of palaeomagnetic data. - Geophys. J. Royal Astronom. Soc., 62: 699 - 718. Oxford.
Knez M. & Šebela S., 1994. Novo odkriti kraški pojavi na trasi avtomobilske ceste pri Divači. - Naše jame, 36: 102. Ljubljana.
Knez M. & Slabe T., 1999a. 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.

Knez M. & Slabe T. 1999b. Unroofed caves and recognising them in karst relief (Discovered during motorway construction at Kozina, South Slovenia). - Acta carsologica, 28/2, 103-112. Ljubljana.

Kogovšek J., Slabe T. & Šebela S., 1997. Motorways in Karst (Slovenia) - Proc. and Fieldtrip excursion guide, 48th Motorway Geol. Sympos.: 49-55.

Mihevc A., 1996. Brezstropa jama pri Povirju. - Naše jame, 38: 92-101. Ljubljana.

Mihevc A., 1998. Speleogeneza matičnega krasa. - MS, doktorska dis.: 1-150, Univerza v Ljubljani, Filozofska fakulteta, Oddelek za geografijo. Ljubljana.

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

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

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

Mihevc A. & Zupan Hajna N., 1996. Clastic sediments from dolines and caves found during the construction of the motorway near Divača, on the Classical Karst. - Acta Carsologica, 25: 169-191. Ljubljana.

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.

Perna G., 1996. Il carsismo Messiniano nell´area del Mediterraneo. - Speleologia, XVII, 34: 5-12. Milano.

Placer L., 1981. Geološka zgradba jugozahodne Slovenije. - Geologija, 24/1: 27-60. Ljubljana.

Příhoda K., Krs M., Pešina B. & Bláha J., 1989. MAVACS - a new system of creating a non-magnetic environment for palaeomagnetic studies. - Cuad. Geol. Ibérica, 12: 223-250. Madrid.

Pruner P. & Bosák P., 1999. Zpráva k projektu KONTAKT ME 251..(1998) Česko-slovinská spolupráce, Research of karst sediments on the example of the Classical Karst, Slovenia. - MS, Geol. úst. AV ČR: 1-78. Praha.

Rakovec I., 1958. Pleistocenski sesalci iz jame pri Črnem kalu. - Razprave, IV: 365-434. Ljubljana.

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

Slabe T., 1997a, b. The caves in the motorway Dane-Fernetiči. - Acta Carsologica, 26/2: 361-372. Ljubljana.

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

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

Šebela S. & Mihevc A., 1995. The problems of construction on karst-the examples from Slovenia. - In: B.F. Beck & F.M. Pearson (Eds.): Karst geohazards, engineering and environmental problems in karst terrains. Proc. Fifth Multidisciplinary Conference on Dolines and Engineering and Environmental Impacts on Karst: 475-479. A.A. Balkema, Rotterdam.

Šebela S., Mihevc A. & Slabe T., 1999. The vulnerability map of karst along highways in Slovenia. In: B.F. Beck, A.J. Pettit & J.G. Herring (Eds.): Hydrogeology and engineering geology of dolines and karst. Proc. Seventh Multidisciplinary Conference on Dolines and Engineering and Environmental Impacts on Karst: 419-422. A.A. Balkema, Rotterdam.

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.

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

PALEOMAGNETNE RAZISKAVE STARE JAME BREZ STROPA NA GRADBIŠČU AVTOCESTE PRI KOZINI (JZ SLOVENIJA)

Povzetek

Gradnja avtoceste med Divačo in Klancem (JZ Slovenija, Kras) je razkrila številne stare jame in jame brez stropa. Ena od njih je ležala v bližini kraja Kozina. Fosilni rov je bil v zgornjem delu brez stropa. Na površini je kazal blago vdrtino. Sedimentni profil v jami je bil visok okrog 5 metrov. Sestavljen je bil pretežno iz peščenega sedimenta rahlo rjave do okraste barve z glinenimi in muljastimi vložki. Sedimenti so vsebovali različne teksture in strukture (laminacija, navzkrižna plastovitost, itd). Erozijske površine so profil razdelile v posamezne sekvence.

Iz profila je bilo skupno vzetih 38 vzorcev, eden od njih je bil cementiran. Vzorci so bili demagnetizirani z izmeničnim poljem (AC) pri 10 do 10.000 Oe. Cementirani vzorec je bil demagnetiziran z postopnim termalnim procesom od 80 do 560°C v MAVACS napravi. Posamezne komponente remanentnega magnetizma po demagnetizaciji z izmeničnim ali termalnim poljem so bile ugotovljene z multikomponentno analizo Kirschvink-ove metode. Ugotovljeni remanentni magnetizem je v naravnem stanju variiral med 95 in 36.470 pT, vrednosti magnetne občutljivosti so bile med 55 in 998 10^{-6} SI. Kamnina kaže nizko do srednjo magnetizacijo. Normalna in inverzna polarizacija je bila ugotovljena po demagnetizaciji. Nekateri vzorci so kazali izrazito viskozno komponento (do 90 %); primarna komponenta magnetizacije in posledična polarnost nista bili ugotovljeni.

Profil vsebuje normalne in inverzne magnetne cone. Lastnost porazdelitve magnetocon je podobna prejšnji lokaciji profila Divača (fosilna jama v cestnem useku pri Divači). Starost profila pri Kozini je starejša od Bruhnes/Matuyama (0,78 Ma). Glede na razporeditev posameznih magnetocon lahko zaključimo, da so sedimenti starejši kot vrh Olduvai (1,77 Ma), saj se magnetostratigrafski profil pri Kozini konča z reverzno polarizacijsko magnetocono in vsebuje dve normalni polarizirani coni.

Profil lahko vzporejamo s profilom Divača ne samo z vidika paleomagnetizma, temveč tudi z vidika litologije. Predpostavljamo, podobno kot v Divači, da je jama rezultat mesinske speleogenetske dobe in je bila njena fosilizacija povezana s hitrim dvigom terena in ponovno zapolnitvijo Sredozemlja z vodo. Če je ta hipoteza blizu resničnosti, je lahko starost fosilizacijskih procesov večja od okrog 5,2 Ma.