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GEOMORPHOLOGICAL EVOLUTION OF THE PODGORSKI KARST, SW SLOVENIA: CONTRIBUTION OF MAGNETO-STRATGRAPHIC RESEARCH OF THE ČRNOTIČE II SITE WITH *MARIFUGIA* SP.

GEOMORFOLOŠKI RAZVOJ PODGORSKEGA KRASA, JZ SLOVENIJA: PRISPEVEK K MAGNETOSTRATIGRAFSKIM RAZISKAVAM PROFILA ČRNOTIČE II Z *MARIFUGIO* SP.

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Abstract UDC: 551.44:550.38 (497.4 Črnotiče)

Pavel Bosák & Andrej Mihevc & Petr Pruner: Geomorphological evolution of the Podgorski Karst, SW Slovenia: contribution of magnetostratigraphic research of the Črnotiče II site with *Marifugia* sp.

The sequence of interior cave facies 9 m high is composed of cyclically arranged fluvial sediments (conglomerates, sands, silts, clays) in the lower part and by laminated to banded silts to clays in the upper part. Both parts are separated by pronounced unconformity associated with deep erosion of the lower part of the profile and tectonic tilting. The fill is covered by chaotic flowstone boulder breccia with red loamy matrix. One segment of the cavity wall was covered by tiny tubes of polychates worms comparable to recent fresh-water *Marifugia cavatica*. Both profiles show normal magnetozone with only one narrow reverse excursion in each. The correlation of the obtained magnetostratigraphy log can indicate the Gauss chron (ca 2.5 to 3.6 Ma) or the other long normal chron. Črnotiče II site was filled in a substantially short time. Gemorphological evolution of the Podgorski karst plateau (Classical Karst, Karst Edge) since Miocene underwent complicated development with distinct phases of repeating phreatic speleogenesis (horizontal caves), vadose evolution (drawdown shafts), filling, fossilisation, exhumation, block tilting and rotation, uplift and planation.
Key words: palaeomagnetism, geomorphology, speleogenesis, caves, cave fauna, *Marifugia cavatica*, Classical Karst.

Izvleček UDK: 551.44:550.38 (497.4 Črnotiče)

Pavel Bosák & Andrej Mihevc & Petr Pruner: Geomorfološki razvoj Podgorskega Krasa, JZ Slovenija: prispevek k magnetostratigrafskim raziskavam profila Črnotiče II z *Marifugio* sp.

Proučena je bil 9 m visoka sekvenca jamskih sedimentov Črnotiče II. V spodnjem delu grade profil ciklično urejene plasti fluvialnih sedimentov (konglomerati, peski, melji in gline), v zgornjem pa laminirane ali pasovite plasti melja in gline. Oba dela profila loči dobro izražena prekinitev, ki je povezana z močno erozijo v spodnjem delu profila in tektonskimi premiki . Fluvialna zapolnitev je prekrita s kaotično blokovno brečo z rdečim ilovnatim matriksom – porušenim stropom. Na enem delu sten votline so številne drobne cevke, ki pripadajo polihetnim črvom. Podobne so cevkam recentnega jamskega cevkarja *Marifugia cavatica*. Oba dela profila imata normalno polariteto, v vsakem pa je tudi kratka reverzna ekskurzija. Iz pridobljenih magnetostratigrafskih podatkov lahko sklepamo, da so se sedimenti odlagali v Gaussovi (2,5 do 3,6 Ma) ali kateri drugi dolgi dobi z normalno polariteto. Profil Črnotiče II je bil odložen v zelo kratkem času. Planota Podgorskega krasa je od miocena doživela komplicirano geomorfološko evolucijo, ki so jo povzročili tektonski dvig, nagibanje in rotacija ozemlja.Več obdobjem razvoja freatičnih in epifreatičnih jam je sledil nastanek vadoznih brezen, zapolnjevanje jam, denudacija in uravnavanje površja.
Ključne besede: paleomagnetizem, geomorfologija, speleogeneza, jama, jamska favna, *Marifugia cavatica*, Podgorski Kras, klasični Kras.

INTRODUCTION

Palaeomagnetic study 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, based on the agreement of both bodies. In 1998–1999 and in July 2001 to June 2003, the co-operation was included into intergovernmental agreements on scientific and technological co-operation between Czech Republic and Slovenia. The co-operation is roofed by the projects KONTAKT co-ordinated by the Czech Ministry of Education, Youth and Sports and Slovenian Ministry of Education, Sport and Science.

Research has covered several important sites of the Classical Karst, SW Slovenia, mostly uncovered by highway construction, yielding important results (location on Fig. 1). The results have been summarised both in unpublished reports and published papers (Bosák, Mihevc & Pruner, Eds. 1999; Bosák & Pruner, Eds. 1999; Bosák & Pruner 2001; Bosák, Pruner & Kadlec 2003; Bosák, Pruner & Mihevc 2002; Bosák, Pruner & Zupan Hajna 1998a-c, 1999; Bosák et al. 2000a-e, 2001, 2002a-b; Pruner & Bosák 1999, 2001a, b; Pruner, Bosák & Mihevc 1999, 2003; Pruner et al. 1998, 1999, 2000a-c, 2001, 2003).

In 2000 and 2001, another new site was studied – another part of palaeokarst cave in the Črnotiče Quarry near village of Črni Kal (Karst Edge, Classical Karst, SW Slovenia) – it was named Črnotiče II site. Sedimentary profile was described and sampled on June 30 to July 1, 2000 by Pavel Bosák, Andrej Mihevc and Petr Pruner with kind assistance of Mr. Jože Žumer. Fossils found on walls (Mihevc 2000) were supplementary sampled also during 2001.

GEOLOGICAL AND MORPHOLOGICAL BACKGROUND

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

The Kras belongs to Adriatic–Dinaric Carbonate Platform of the Outer Dinarids composed of shallow marine fossil-bearing Cretaceous and Paleogene carbonates. Eocene flysch encircled carbonate plateau. Complicated imbricated structure resulting in alternation of flysch and limestone thrust slices has been formed since Oligocene. Slices are elongated in the NW – SE direction due to strong pressures from NE to SW. Thrust planes dip northeastwards (cf. Placer 1981).

Karstification of the region is characterised by the presence of old caves dissected by younger shafts in places. Origin of shafts was connected with the drop of piezometric level, which lies now about 200 m below the surface. Shafts are both empty and filled with Pleistocene sediments (cf. e.g., Rakovec 1958; Brodar 1958).

Large valley systems on the surface of the Karst were believed to represent primary river valleys as they contain rests of fluvial sediments. Nevertheless, new evolution models indicate that such sediments represent fluvial fill of fossil caves (cf. Mihevc 1998, 1999a-c, 2001). The old cave fill appeared at surface and formed unroofed caves by erosion/chemical denudation of limestone roof. They are preserved as cave fluvial deposits and spelothems on the present surface, sometimes with traceable course of original cave passages. Such caves were described during the construction of highway network over the Classical Karst (e.g., Knez & Šebela 1994; Šebela & Mihevc 1995; Slabe 1996; Mihevc & Zupan Hajna 1996; Mihevc 1996; Mihevc, Slabe & Šebela 1998). About 70 unroofed caves have been discovered in last several years only along 40 km long construction strip of the highway. Some of them represent parts of the same cave palaeosystem(s) genetically linked to presently accessible caves as the older evolution stages. Unroofed caves represent common constituent of karst landscape in the whole Classical Karst (e.g., Mihevc 1996; Šušteršič 1998; Mihevc 1998 Geršl, Stepišnik & Šušteršič 1999). The shape and form of unroofed caves result from the morphology of present surface, original arrangement of fossil caves, intensity of younger karstification and degree of younger exhumation of the cave fill. They are often transformed by surface processes and represent an important element of the epikarst zone (Knez & Slabe 1999). In the field, they are expressed as narrow often meandering shallow trenches, shallow oblong depressions, doline-like forms and collapsed dolines. Mihevc (1999a) offered models of origin of unroofed caves. Unroofed caves are a typical example of palaeokarst – exhumed karst (sensu Bosák, Ford & Głazek 1989, 32) – partially incorporated into the present karst landscape and hydrological system.

The datation of sediments in some unroofed caves by palaeomagnetic method (Bosák, Pruner & Zupan Hajna 1998; Bosák et al. 1999, 2000b, e; Pruner & Bosák 2001b) indicated the substantial age of the cave fill, in most cases clearly older than 1.77 Ma.

Fig. 1: Location of studied sites in Slovenia. Legend: 1. Divača profile 2. Trhlovca cave, 3. Divaška jama cave, 4. Kozina profile, 5. Snežna jama cave, 6. Črnotiče I, 7. Črnotiče II quarry described in this paper.

SITE LOCATION AND CHARACTERISTIC

The Črnotiče Quarry is situated on the western margin of the Podgorski karst, a widely extended leveled plateau at foothills of the Slavnik Mt. (45° 33' 57'' N, 13° 52' 48'' E), ca 9 km from the Adriatic coast (Koper Bay). The altitude of the leveled surface is 440 m a.s.l. About 40 m deep quarry occupies an area of 300 by 300 m.

Palaeogene limestones and narrow zones of flysch in imbricated structure with dips of about 20 – 30° towards the NE compose the plateau. In the depth, the alternation of limestones and flysch is not completely impervious. Principal subsurface flows cross the structure draining an extensive karst area in the direction to springs at the coast. Water springs out from the Rižana and Osapska reka rivers (maximum discharge in several $m^3.s^{-1}$) under the plateau at altitudes of 50 – 100 m a.s.l. Totally 92 caves have been known on the plateau with the maximum depth up to 150 m.

Karst features in the Črnotiče and Črni Kal Quarries

Numerous caves have been opened during operations in the Črnotiče Quarry. Most of them were completely filled by sediments. About 80 m deep shaft was opened in 1991 in the northern part of

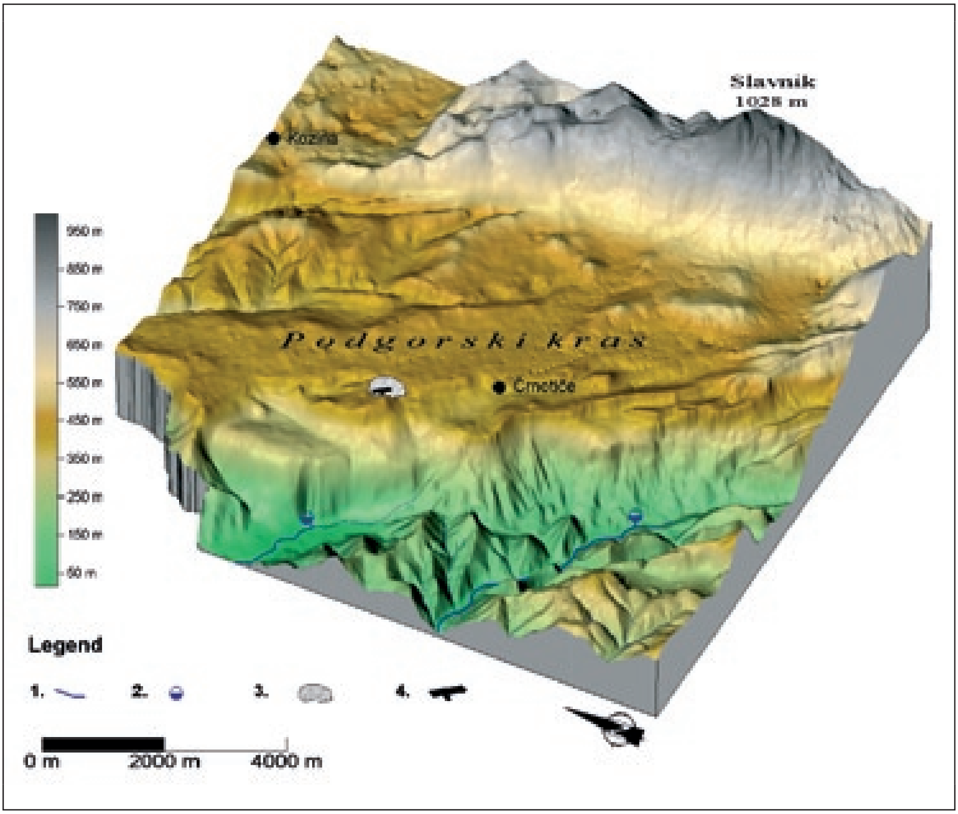


Fig. 2: Schematic cross section of the plateau edge, quarry and the cave studied. Legend: 1. stream, 2. Karst spring, 3. Črnotiče quarry, 4. outline of the cave excavated in the qaurry.

the quarry at the altitude of about 400 m a.s.l. The shaft with volume of several thousands of cubic meters remained unexplored.

Another shafts were opened on mining benches in the western part of the quarry. They were filled by gravel with matrix composed of terra rossa-derived clayey sediments. Stalagmites and stalactites covered the walls. Broken speleothems and numerous large mammal bones occurred in gravel. Bones have not been studied yet. Gravel was cemented in places. Calcitic cement was dated by Th/U method to 211± 45 ka by Andrej Mihevc in Speleothem Dating Laboratory, Department of Geology, Bergen University, Oslo, Norway.

Palaeokarst site of Črnotiče I (Bosák et al. 1999) represented a part of huge cave, which was gradually opened since 1990. About 1.75 m high profile of banded sandy stromatolitic carbonate rocks intercalated by red clays was deposited on corroded/eroded surface of older massive speleothems, which were strongly recrystallized. Palaeomagnetic analysis proved alternation of normal and reverse polarized magnetozones in arrangement indicating age over 1.77 Ma. The finds of problematic fish teeth have still been not determined. The profile occurred some 4 m below the surface of karst plateau (at about 435 m a.s.l.; cf. Fig. 2).

Črni kal Quarry at about 350 m a.s.l. opens about 1 km to the S of the Črnotiče Quarry. Both horizontal caves and vertical shafts have been uncovered. Horizontal cave with Palaeolithic tools and Pleistocene large mammal fauna was discovered in 1955 on the southern side of the quarry (Rakovec 1958; Brodar 1958). Other three sites yielded Middle and Late Pleistocene small mammals (Aguilar et al. 1998). Gravel and terra rossa-type clays filled shafts. Carbonate cement of gravels was dated by Th/U method to143 ± 13 ka.

Two types of caves can be observed in both quarries: (1) old horizontal caves with flysch-derived allogenic fluvial fill, and (2) vertical shafts filled only by autochthonous angular gravel, bone breccia, and terra rossa-type of soils.

Description of the cave

Extensive volumes of flowstones, sands and clays appeared in the western part of the quarry already before 1990 indicating the presence of large horizontal cave choked by sediments. Continuing quarry exploitation opened the cave entirely later. Some speleothems have remained in the southern quarry wall up to the present.

The cave was successively opened during several years by the progress of quarry front. It was not possible to contour the cave shape precisely owing to blasting technique applied. It was about 150 m long with the dip in the NW – SE direction. The opened cave represented a relic of a huge passage with the diameter of about 10 m. Sedimentary fill was 10 m thick at least. In the eastern part, the passage opened up to the present surface, but in the western part the ceiling has been still preserved.

The passage was entirely filled by the cave sediments deposited over the massive flowstones several meters thick. Calcitic speleothems 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. Poorly rounded pebbles, up to 4 cm large, were composed of Palaeocene limestone and flysch fragments. Laminated yellow brown clays were present on several places. Stalagmites and stalactites fragments were present within the sediment. Reddish clays composed the upper part of profile.

Metres	*Bed No.*	*Description*
0.00-0.20	1	Clay, slightly silty, light grey to whitish grey, slightly greenish
0.20-0.85	2	Sand, very fine-grained, clayey, ochreous, with laminae of grey clays, interlamination of clay and sand in places (bedding = 85/25)
0.85-1.45	3	Clay, locally with sandy laminae, locally silty, ochreous to brown, banded, with Fe and Mn impregnations, with Liesegang laminae (40 – 45° to lamination)
1.45-1.51	4	Sand, fine- locally medium-grained, clayey, greenish grey, with mm lamination
1.51-1.69	5	Clay, locally with sandy laminane, in places abundant, locally silty, ochreous to brown, locally variocoloured banded, with Fe and Mn impregnations, with Liesegang laminae (40-45° to lamination)
1.69-1.74	6	Microconglomerate, clayey-sandy matrix, brownish grey, with ovate flat clasts of ochreous to greyish white clays and silts (bedding = 350/5)
1.74-1.76	7	Silt, laminated, locally clayey, ochreous
1.76-1.92	8	Microconglomerate, clayey-sandy matrix, brownish grey, with ovate flat clasts (mm to 6 cm) of ochreous to greyish white clays and silts
1.92-2.00	9	Silt, laminated, locally clyey, ochreous
2.00-2.11	10	Microconglomerate, clayey-sandy, light brown, rounded clasts of clays to silts
2.11-2.15	11	Silt, clayey, laminated, ochreous
2.15-2.21	12	Microconglomerate, clayey-sandy, light brown, rounded clasts of clays to silts
2.21-2.24	12/1	Silt, clayey, laminated, ochreous
2.24-2.40	13	Microconglomerate, clayey-sandy, ochreous to light brown, rounded clasts of clays to silts
2.40-2.42	14	Silts, clayey, laminated, ochreous
2.42-2.67	15	Microconglomerate, clayey-sandy, dark ochreous to light brown, rounded clasts of clays to silts, upwards coarsening
2.67-2.72	16	Sand, quartzose, fine-grained, finely laminated, beige
2.72-2.74	17	Silt, clayey, laminated, ochreous
2.74-2.88	18	Microconglomerate, clayey-sandy, dark ochreous to ligh grey, rounded clasts of whitish clays to silts
2.88-2.98	19	Silt, clayey, laminated, dark ochreous
2.98-3.09	20	Conglomerate, clayey-sandy, dark ocgreous to light grey, rounded clasts of beige clays to silts, upwards fining, with cross bedding
3.09-3.11	20/1	Silt, beige, partly eroded
3.11-3.30	21	Conglomerate, clayey-sandy, variocoloured and dark brown to light brown, rounded clasts of beige clays to silts up to 2 cm, numerous small iron concretions, at the base microconglomerate, cross-bedded, stone at the base
3,30-3,45	22	Microconglomerate, dark ochreous with reddish brown, dark grey and blackish grey schlieren (Mn and Fe), to the left transition to sand with beds of gravel, fine-grained, silty, yellow
3.45-3.46	23	Silt, clayey, laminated, ochreous
3.46-3.66	24	Microconglomerate, dark ochreous with reddish brown, dark grey and blackish grey schlieren (Mn and Fe), to the left transition to sand with beds of gravel, fine-grained, silty, yellow
3.66-3.68	25	Silt, clayey, laminated, ochreous
3.68-3.95	26	Conglomerate, dark greenish and violet brown, with blackish violet stains, with rather big clasts of clays to silts, with pebbles and fragments of limestones cemented by hematite, with numerous small iron concretions
3.95-3.98	27	Silt, light ochreous, cemented (bedding = 0/0)
3.98-4.27	28	Conglomerate, brown, clasts of silts and clays, brown
4.27-4.32	29	Clay, silty, very fine-grained sandy, reddish ochreous, laminated
4.32-4.55	30	Sand, very fine-grained, beige, ochreous laminae, at base and top highly clayey and silty, laminated, pebbles of limestone up to 2 cm in places
4.55-4.65	31	Clay, silty in places, dark ochreous, locally with fine limestone fragments up to 3 mm
4.65-5.03	32	Conglomerate, brown, clasts of silts and clays
5.03-5.30	33	Silt, light grey to whitish grey, in lower part transition up to ochreous clays
5.30-5.60	34	Conglomerate, silty matrix, brown, clasts of clays and silts, rounded pebbles
5.60-5.70	34/1	Silt, very fine-grained sandy to silty sands, laminated, ochreous
5.70-5.76	35	Pebbles, brown
5.76-5.89	36	Clay, dark ochreous, laminated
5.89-5.90	37	Silt, beige
5.90-5.92	38	Silt, beige, cemented
5.92-5.95	39	Clay, dark ochreous, laminated
5.95-6.33	40	Conglomerate, silty matrix, brown, clasts of silts and clays, rounded pebbles (bedding = 155/10)
6.33-6.40	41	Silt, highly fine-grained sandy, ochreous, laminated
6.40-6.84	42	Conglometrate, silty matrix, brown, clasts of silts and clays, rounded pebbles, abundant flat pebbles, locally strongly cemented
5.84-7.06	43	Silt to clay, ochreous to beige, fine lamination
7.06-7.29	44	Loam, red
7.29-8.30	45	Blocks of limestones and speleothems with matrix of clayey loam of brownish red colour
8.30-8.50	46	Silt to clay, beige to ochreous, laminated
8.50-9.00	47	Blocks of limestones and speleothems with matrix of clayey loam of brownish red colour

Table 1: Detailed description of the profile – the main profile (from bottom to top).

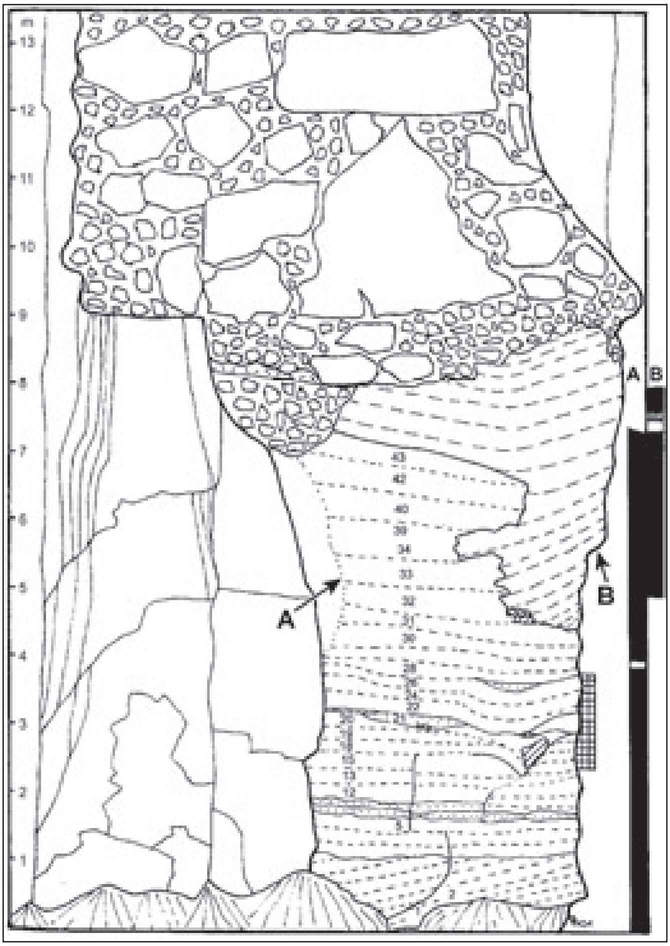


Fig. 3: Fossil cave passage, schematic sketch of the fill. A – the main profile, B – the right profile. Numbers in A – numbers of layers, for description see Table 1. Net – vertical extent of marifugia-like worm tubes on the wall. Columns on right: magnetostratigraphy; black – normal polarity, white – reverse polarity, vertical lines – unknown polarity.

DESCRIPTION OF PROFILE

The profile was more than 13 m high and from 4 to 7.5 m wide. The lower part was composed of cyclically arranged cave fill (0–9 m). The fill was divided by expressive erosional boundary into two parts. The upper part of the profile (above 9 m up to the surface) represented speleothems and blocks of broken speleothems and few limestone (Figs. 3 to 6).

Main profile

The main profile is composed of cyclically arranged sets of layers (Tab. 1; Fig. 3). The profile can be divided into two parts. The lower part, composed of layers Nos. 1 to 5, represents mostly variocoloured fine-grained laminated to banded sequence composed mostly of clays, silts and very fine-grained clayey sands interlaminated by clays and silts. There are abundant iron and manga-

Metres	*No. palaeomag sample*	*Description*
4.45-5.90	39-44	Silt, very fine-grained sandy with intercalations of sands, clayey, light ochreous
5.90-7.10	45-51	Sand, very fine-grained, silty, light ochreous to beige, in v 6,36-6,59 intercalation of redeposited rocks from the left part of the profile
7.10-8.80	52-54	Clay to silt, ochreous, locally light brown and chocolate brown, laminae and bands of very fine-grained sands
8.80-9.00		Blocks of limestones and speleothems with matrix of clayey loam of brownish red colour

Table 2: Detailed description of the profile – right part, above erosion (from bottom to top).

nese mineral impregnations, locally in a form of Liesegang concentric structures. Within the bed No. 3 there exists unconformity, which is indistinct from the lithological point of view, but rather expressive by differing layer inclination. The inclination of beds below the unconformity is about 25° and above it only about 5°.

The upper part of the main profile is composed of typical upwards fining fluvial cycles composed of microconglomerates to conglomerates, which sometimes pass to sands. Individual cycles are separated by thin interbeds of clays to silts (Fig. 3). The clastic material of gravels is formed of clasts of silts and clays, often well-rounded, sometimes flat. Some layers are cross-bedded, at least at the base. There are also abundant schlieren enriched in iron and manganese compounds. At the bases of some layers, there are clasts of limestones, causing bending of underlying beds, indicators of limited collapse of cave roof or fall of stones from cave walls. Probable prints of leaves and rests of highly decomposed bones were found in some layers. The top of profile (layer No. 44) is composed of redeposited terra rossa-type of soil.

Right profile

The main profile was deeply eroded before the deposition of the right upper part of the profile (Tab. 2; Fig. 3). The erosional boundary is highly uneven. At the base, there are several flat stones of limestone and intensive impregnation by iron and manganese compounds (thin crusts). The sequence is composed laminated to banded silts, clays and very fine-grained silty sands. The sequence is light coloured (ochreous dominates).

The sedimentary profile is covered by two generations of breccias separated by thin layer of silts, probably reworked deposits from the right part of the profile (Fig. 3). The first generation of breccias fills erosional channel. The clasts are comparably smaller then clasts in the main breccia body above. The matrix is composed of terra rossa-type clayey soil (loam). The main body of breccia contain abundant blocks and fragments of speleothems. Blocks are even more than 2 m in size.

PALAEOMAGNETIC AND PETROMAGNETIC MEASUREMENTS

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. Totally 54 oriented laboratory samples were studied in detail to detect their palaeomagnetic properties (for the list see Tab. 3). The magnetic susceptibility was measured in the field each 5 cm in both profiles by Kappameter KT-5 and totally 218 data were obtained (Tab. 7).

Laboratory procedures

Laboratory procedures was based on progressive demagnetisation by alternating field (AF) or thermal demagnetisation (TD) with the aim to detect components of remanent magnetic polarity in different intervals and to determine moduli and directions of remanent magnetisation.

Oriented hand samples were collected from individual horizons. Sediments were sampled to small plastic cubes 20 x 20 x 20 mm. In the laboratory, they were measured on the JR-5 spinner magnetometer (Jelínek 1966). Fifty specimens were demagnetised by the alternating field procedures, up to the field of 1,000 Oe in 14 steps on the LDA apparatus. Four specimens were thermaly demagnetised on the MAVACS (Magnetic Vacuum Control System) apparatus generating high magnetic vacuum (Příhoda et al. 1989).

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

The volume magnetic susceptibility (MS) kn were measured on the KLY-2 kappa-bridge (Jelínek 1973). Separation of the respective remanent magnetisation components was carried out by Kirchshvink multi-component analysis (Kirschvink 1980). The statistics of Fisher (1953) was applied for calculation of mean directions of pertinent remanence components derived by multi-component analysis.

Fig. 4: Section of fossil cave passage on quarry wall. Altitudes in m a.s.l. are given. Asterisk locates the find of Marifugia cf. Cavatica (see Fig. 7). Photo by A. Mihevc before excavation of lowermost part of cave fill.

Metres (cm)	***Number***	***Bed No.***
007	1	1
016	2	1
029	3	2
041	4	2
052	5	2
060	6	2
067	7	2
074	8	2
082	9	2
086	10	3
094	11	3
107	12	3
116	13	3
127	14	3
137	15	3
144	16	3
152	17	5
158	18	5
163	19	5
169	20	5
178	21	7
195	22	9
213	23	11
223	24	12/1
241	25	14
270	26	16
294	27	19
310	28	20/1
331	29	22
346	30	23
366	31	25
395	32	27
427	33	29
455	34	31
567	35	34
590	36	37/38
703	37	43
Right profile		
505	39	-
517	40	-
528	41	-
545	42	-
562	43	-
585	44	-
598	45	-
607	46	-
636	47	-
659	48	-
672	49	-
686	50	-
705	51	-
731	52	-
764	53	-

Table 3: Palaeomagnetic samples.

Palaeomagnetic and petromagnetic results

Principal petromagnetic and palaeomagnetic parameters are documented in Table 4 and Figures 8 and 9. Values of the NRM (Jn) and MS (kn) moduli in natural state of rocks show small scatter. Mean values of Jn and kn moduli are documented in Table 5. Mean values of the NMR and MS moduli from 38 samples of the main profile (0.07–7.03 m) are characterised by low Jn and kn. The mean values of moduli of Jn and of kn from 16 samples of the right profile (5.05–7.70 m) are characterised by low or very low Jn and kn.

The MS values measured in the field are documented in Table 6 and Figure 10. The MS mean values of different intervals are presented in Figure 11.

Remanent magnetisation directions were tested by the multi-component analysis. A-components of remanence have mostly viscous or chemoremanent (weathering) origin; they can be removed by alternating field with the intensity of 10 up to 30 Oe. Normal and reverse C-component directions are documented in Table 4 and Figures 8 and 9. The fisherian distribution forms two defined sets of samples with normal and reverse polarities. Stereographic projections of directions of normal and reverse palaeomagnetic C-component of samples are shown in Figure 12. Mean palaeomagnetic direction is documented in Table 7, the calculated value of α_{95} (semi-vertical angle of the cone of confidence) is not possible calculate for group of reverse polarisation due to small number os samples.

Fig. 5: Cave fill before the sampling for palaleomagnetism (photo by P. Bosák).

Palaeomagnetic and magnetostratigraphic investigations carried out on 54 oriented laboratory specimens provided data concerning principal magnetic properties and identification of palaeomagnetic directions. Magnetostratigraphic results show normal and reverse polarity magnetozones. Both profiles are dominated by normal polarised magnetozone. One narrow reverse polarity subzone (excursion) is situated in the middle part (3.95–3.99 m) of the main profile and one narrow reverse polarity subzone (excursion) – documented on one sample only – is situated in the upper part (7.64 m) of the right profile.

FOSSILS

Calcareous tubes were attached to the wall in the lower part of the passage between 426 and 427 m a.s.l. (Figs. 3, 4 and 7). They were placed separately or in groups of up to several hundred individuals. The end parts of tubes, which were perpendicular to the wall, were often broken off. Fossils were compared with the recent serpulid tubes of *Marifugia cavatica* (Mihevc 2000; Mihevc et al. 2001a, b, 2002a, b).

Calcareous tube of *Marifugia* sp. is curved, max. 30 mm long. Sometimes flattened tube is attached to substratum in its initial centimetres. Cylindrical detached part is more or less perpendicularly erected to wall and straight. The tube diameter is from 0.2 to 0.85 mm, max. 1.5 mm. The maximum width of the collar-like pleats varies among specimens and populations. Tubes may be very densely packed or very distantly set. Stable isotope analysis (Mihevc et al. 2002b) of fossil tubes from Črnotiče II site is comparable with stable isotope compositions of recent fresh-water species and highly differs from those of marine serpulids.

Fig. 6: Cave fill after the sampling for palaeomagntism (sampling points located by paper card with numbers; photo by P. Bosák).

Marifugia cavatica Absolon et Hrabe, 1930 is recently the only fresh-water species of the Serpulidae family (Annelida: Polychaeta) and the only known tube worm inhabiting continental caves (Kratochvil 1939). It was never found even in brackish waters (cf. Sket 1986). It is filter feeder with free-swimming larvae (Matjašič & Sket 1966). It can be very sparsely settled in clear and fast flowing streams where it may construct dense colonies. Nevertheless, thick masses of many layers of tubes (as described by Absolon & Hrabe 1930) represent unique exception. Recently, it is widely, although not continuously, distributed within the Dinaric Karst (Sket 1970b), biogeographically belonging to holo-Dinaric elements (sensu Sket 1994). Although it was originally considered as marine element colonising fresh cave waters directly from the sea (Absolon & Hrabe 1930), it is supposed recently that it has colonised cave waters

	No.	Thickness	Jn	kn	DP	IP	Polarity
		[m]	[mA/m]	x10-6[SI]	[°]	[°]	
MAIN PROFILE	CR 1	0.07	0.377	92	64	45	N?
	CR 2	0.16	0.341	83	29	46	N?
	CR2.5	0.25	0.385	81	323	48	N
	CR 3	0.29	0.307	91	337	77	N
	CR 4	0.41	3.078	182	6	53	N
	CR 5	0.52	0.273	69	7	58	N
	CR 6	0.60	0.376	73	325	40	N
	CR 7	0.67	0.311	101	306	67	N
	CR 8	0.74	0.587	65	342	77	N
	CR 9	0.82	0.375	82	328	49	N
	CR10	0.86	1.402	108	333	48	N
	CR11	0.94	0.486	86	335	49	N
	CR12	1.07	0.418	88	330	54	N
	CR13	1.16	0.308	106	357	66	N
	CR14	1.27	0.586	87	12	57	N
	CR15	1.37	0.383	61	357	57	N
	CR16	1.44	0.494	89	358	43	N
	CR17	1.52	0.254	108	322	67	N
	CR18	1.58	0.913	91	355	45	N
	CR19	1.63	0.361	90	304	66	N
	CR20	1.69	3.333	263	29	34	N
	CR21	1.78	2.916	228	328	53	N
	CR22	1.95	0.376	85	16	47	N
	CR23	2.13	0.593	107	55	77	N
	CR24	2.23	0.443	111	319	56	N
	CR25	2.41	0.388	126	-	-	?
	CR26	2.70	0.142	23	51	52	N
	CR27	2.94	0.183	104	342	53	N
	CR28A	3.10	0.123	55	11	44	N
	CR28B	3.12	0.183	58	22	2	N?
	CR31	3.66	1.908	130	276	57	N?
	CR32/1	3.95	3.452	109	276	-25	R?
	CR32/3	3.99	3.690	110	193	-5	R
	CR33	4.27	0.279	93	316	37	N
	CR34	4.55	0.195	82	10	61	N
	CR35	5.67	2.005	137	21	75	N
	CR36	5.90	0.108	17	-	-	?
	CR37	7.03	0.441	88	343	55	N

Table 4/1: Principal magnetic and palaeomagnetic parameters of samples from the main profile.

from fresh-water lakes since Pliocene or Pleistocene, like other stygobionts with comparable distribution (Sket 1997).

DISCUSSION

Palaeomagnetic analysis

Palaeomagnetic analysis detected dominant normal polarisation of remanent magnetisation in both parts of sedimentary fill in Črnotiče II site. One narrow reverse polarised subzone (excursion) occurs in middle part of the main profile and another one in upper part of the right profile. Declination and inclination mean values for normal palaeomagnetic polarity in the main profile are D = 348.0°; I = 58.0°. Declination and inclination mean values for normal palaeomagnetic polarity in the right profile are D = 339.1°; I = 57.2° (Tab. 5). Nevertheless, differences in declination and inclination in both part of profile are within the precision parameter (α_{95}). The correlation of obtained arrangements of normal magnetozones and reverse polarised excursion can indicate the Gauss chron (2.581 to 3.58 Ma) or the other long normal chron. The age of the right section should be estimated to at least 1.77 Ma matching our results with geomagnetic polarity timescales (GPTS; Cande & Kent 1995). The main profile should be therefore older. Palaeomagnetic dating of both parts of sedimentary fill gave the minimum possible age only because of uncorformities in them.

Mean palaeomagnetic directions of studied profile differ from Črnotiče I site. Declination and inclination mean values for Črnotiče I site are as follows: for group of normal palaeomagnetic polarity D = 4.4°; I = 53.8°, and for group of reverse polarity D = 173.0°; I = -31.3°. Declination and inclination mean values for Črnotiče II site are as follows: for group of normal palaeomagnetic polarity D = 345.4°, I = 58.1°, and for group of reverse polarity D = 229.9°, I = -58.0° (Tab. 5). Nevertheless, data concerning the reverse polarities of both sites cannot be taken into account owing to low number of analysed samples. Declination data from normal polarities indicate difference in 19° anticlockwise rotation. Inclination data differ within the 5% error bar of the statistical method. According to differences in declination values, Črnotiče I and Črnotiče II sites differ in age of deposition. Detected anticlockwise rotation is in general agreement with Cenozoic tectonic evolution of the Adriatic microplate (cf. Fodor et al. 1998). The matching magnetostratigraphic data of both sites with the GPTS (Cande & Kande 1995) can indicate time difference of about 1 Ma between infilling processes on both sites, i.e. time-span available for rotation of the respective tectonic block.

	No.	*Thickness*	J_n	k_n	D_p	I_p	*Polarity*
		[m]	*[mA/m]*	$x10^{-6}$*[SI]*	*[°]*	*[°]*	
RIGHT PROFILE	CR39	5.05	0.412	92	321	70	N
	CR40	5.17	0.652	84	318	66	N
	CR41	5.28	0.333	55	347	56	N
	CR42	5.45	0.542	88	360	54	N
	CR43	5.62	0.732	68	347	71	N
	CR44	5.85	1.194	94	338	43	N
	CR45	5.93	1.009	94	312	53	N
	CR46	6.07	0.763	63	333	40	N
	CR47	6.36	0.271	42	18	51	N
	CR48	6.59	0.407	94	331	24	N
	CR49	6.72	0.310	47	345	68	N
	CR50	6.86	0.342	62	17	70	N
	CR51	7.05	0.353	72	316	55	N
	CR52	7.31	0.135	32	282	47	N?
	CR53	7.64	0.413	68	55	-52	R?
	CR54	7.70	0.792	157	201	35	N?

Table 4/2: Principal magnetic and palaeomagnetic parameters of samples from the right profile.

	J_n *[mA.m*$^{-1}$*]*	$k_n x10^{-6}$*[SI]*	
Mean value	0,862	99	Interval [m]
Standard deviation	1.036	45	0.07 – 7.03
Number of samples	38	38	
Mean value	0.541	76	Interval [m]
Standard deviation	0.281	28	5.05 – 7.64
Number of samples	16	16	

Table 5: Mean value and standard deviation of natural remanent magnetisation and volume magnetic susceptibility.

Geomorphology and speleogenesis

We suppose, similarly as in Divača and Kozina profiles, and Črnotiče I site (Bosák, Pruner & Zupan Hajna 1998; Bosák et al. 1999, 2000b, e; Pruner & Bosák 2001b), that the cave resulted from the Messinian karst cycle (sensu Perna 1996), especially if normal polarised magnetozones can be correlated with normal Gauss epoch. The karst cycle started with evaporation-driven Mediterranean sealevel drop, as a consequence of regional climate change. This change influenced also the general conditions of karstogenesis in the foreland of the Mediterranean basin, including the Classical Karst. The cycle finished by base-level uplift, climate change and a sequence of speleogenetic/fossilisation/exhumation/rejuvenation processes.

Deep entrenchment of valleys in regions surrounding the Mediterranean Basin (Khumakov 1967, 1971; Clauzon 1973, 1980; Clauzon, Puig & Guendon 1997) were connected with Mediterranean sealevel drop down to the level of -1,500 m (Hsü 1973; Hsü, Cita & Ryan 1973; Hsü et al. 1977). Deep karst with the depths of 1 to 3 km developed in the whole Mediterranean region (Perna 1996) as a result of piezometric-level drop and underground karst drainage directed into the Mediterranean Basin from its foreland (Głazek 1993). Sinking rivers introduced high-energy input to karst system and could provoke extensive speleogenesis. The start of the speleogenesis in the whole Classical Karst can be linked with this process.

The substatial change in speleogentic processes was connected with base level-uplift after opening of Gibraltar strait, which is dated back to about 5.2–5.3 Ma (Hsü 1973; Cita & Corselli 1993) and indicated by the extreme thickness of Pliocene–Quaternary fill in some river valleys (e.g., of Rhône River, southern France, Clauzon 1973, 1980; Clauzon, Puig & Guendon 1997). Subsequent fossilisation/exhumation/rejuvenation processes were associated with changes in regional base level and hydrological situation as a consequence of Cenozoic relief/neotectonic evolution resulted from block rotation and tilting due to the collison of the African (Adriatic) and Eurasian lithospheric plates (cf. Fodor et al. 1998), and sea-level and climatic changes within the Mediterranean Basin.

Presented age estimates of the start of speleogenesis are in accordance with geomorphological observations: karst denudation rate in the area was estimated to about 60 $m.Ma^{-1}$ (Gams 1974). At least 100 m of rock were removed by karst denudation above the cave. Therefore, according

Fig. 7: Cave wall with tubes of Marifugia cf. cavatica. For location see Figs. 4 (asterisk) and 3 (net); (photo by A. Mihevc).

to minimum age of studied sediments, we may suppose that well-developed karst with large water caves populated by animals adapted to cave life existed in the Podgorski kras Plateau even during Pliocene.

cm	*k_n 10^{-3} SI*	*cm*	*k_n 10^{-3} SI*	*cm*	*k_n 10^{-3} SI*	*cm*	*k_n 10^{-3} SI*
000	-	185	0.07	370	0.79	555	1,63
005	-	190	0.11	375	0.84	560	1.06
010	0.02	195	0.05	380	0.56	565	0.72
015	-	200	0.11	385	0.62	570	0.56
020	0.08	205	0.12	390	1.05	575	0.57
025	0.04	210	0.12	395	0.59	580	1.02
030	0.06	215	0.15	400	0.96	585	0.70
035	0.04	220	0.13	405	0.72	590	0.50
040	0.04	225	0.15	410	2.12	595	0.67
045	0.08	230	0.21	415	1.50	600	1.22
050	0.10	235	0.13	420	1.48	605	0.54
055	0.14	240	0.05	425	1.09	610	0.63
060	0.08	245	0.07	430	0.43	615	0.56
065	0.12	250	0.15	435	0.13	620	1.50
070	0.08	255	0.22	440	0.43	625	3.53
075	0.05	260	0.08	445	0.45	630	0.46
080	0.07	265	0.08	450	0.13	635	0.85
085	0.08	270	0.06	455	0.46	640	0.45
090	0.09	275	0.11	460	0.22	645	0.96
095	0.09	280	0.14	465	0.27	650	0.47
100	0.05	285	0.17	470	0.65	655	0.62
105	0.05	290	0.16	475	0.53	660	0.67
110	0.08	295	0.13	480	0.80	665	0.45
115	0.10	300	0.12	485	0.65	670	0.38
120	0.06	305	0.18	490	1.03	675	0.27
125	0.08	310	0.17	495	0.88	680	0.40
130	0.03	315	0.26	500	0.60	685	0.56
135	0.07	320	1.46	505	0.52	690	0.34
140	0.07	325	4.07	510	0.53	695	0.11
145	0.10	330	1.09	515	0.91	700	0.17
150	0.23	335	1.78	520	0.45	705	0.17
155	0.15	340	1.14	525	0.74	710	0.23
160	0.10	345	3.00	530	0.84	715	0.11
165	0.12	350	1.22	535	0.98	720	0.29
170	0.19	355	1.55	540	0.96	725	0.22
175	0.44	360	0.63	545	1.37	730	0.14
180	0.80	365	0.74	550	1.34		

Table 6/1: Value of magnetic susceptibility measured by Kappameter KT-5 from the main profile.

Cm	k_n 10^{-3} SI	cm	k_n 10^{-3} SI
445	0.00	625	0.51
450	0.00	630	0.04
455	0.00	635	0.58
460	0.00	640	0.04
465	0.00	645	0.12
470	0.00	650	0.09
475	0.00	655	0.07
480	0.00	660	0.85
485	0.13	665	0.25
490	0.00	670	0.07
495	0.01	675	0.09
500	0.06	680	0.11
505	0.13	685	0.09
510	0.08	690	0.10
515	0.11	695	0.07
520	0.08	700	0.07
525	0.08	705	0.09
530	0.11	710	0.06
535	0.07	715	0.05
540	0.09	720	0.10
545	0.08	725	0.06
550	0.10	730	0.09
555	0.08	735	0.01
560	0.16	740	0.11
565	0.07	745	0.10
570	0.16	750	0.07
575	0.14	755	0.07
580	0.16	760	0.08
585	0.17	765	0.08
590	0.21	770	0.06
595	0.21	775	0.06
600	0.06	780	0.06
605	0.14	785	0.09
610	0.05	790	0.08
615	0.12	795	0.10
620	0.11		

Table 6/2: Value of magnetic susceptibility measured by Kappameter KT-5 from the right profile.

Cave fauna

Above-mentioned presumption agrees with a fact that the origin of principal part of Dinaric cave fauna has been estimated to Pliocene (Sket 1970a). However, recent studies indicate that some important members of cave fauna could retard in colonisation of cave environment even to postglacial times (Sket 1997). Since also a polytopic and polychronous immigration of surface species underground has been supposed, both hypotheses are not necessarily in contradiction (Mihevc et al. 2001b).

The comparison of fossilised calcareous tubes from the fossil cave in Črnotiče II site with tubes of the recent *Marifugia cavatica* from its western localities reveals no differences. They widely match in their shape and dimensions. The fossil tubes do not surpass any measures of the recent ones. Even the wall thickness is nearly equal which elimi-

Locality	Polarity	Mean palaeomagnetic directions		α_{95}	k	n
		D [°]	I [°]			
Črnotiče I	N	4.4	53.8	9.9	14.8	16
	R	473.0	-31.3	-	1.2	3
Črnotiče II Summary	N	345.4	58.1	5.1	19.2	43
	R	229.9	-58.0	-	1.4	3
Črnotiče II Main profile	N	348.0	58.0	6.3	18.5	30
	R	-	-	-	-	2
Črnotiče II Right profile	N	339.1	57.2	9.4	20.3	13
	R	-	-	-	-	1

Explanations: D, I – declination, inclination of the remanent magnetization after dip correction, α_{95} – semi-vertical angle of the cone of confidence calculated according to Fisher (1953) at the 95% probability level, k – precission parametr, n – number of analysed samples. Anomalous samples excluded.

Table 7: Mean palaeomagnetic directions of samples from Črnotiče I and Črnotiče II sites.

nates a possibility of corrosion in the clayey sediments. The fossil locality is located also within the general distribution area of *Marifugia cavatica*. Some recent sites (Rižana and Osapska reka rivers, near Movraž, and underground Reka system) occur only 3 – 10 km far from Črnotiče. Since *Marifugia cavatica* is also the only known builder of such tube type in fresh waters and there is no indication that fossilised cave could have ever been flooded by sea, the identity or close relation of fossil cave tube worm with the living one is the only solution (Mihevc et al. 2001b). The new finding represents support of high age of the Dinaric cave fauna, nevertheless numerical dating of fossil tubes is necessary.

EVOLUTION OF THE PODGORSKI KARST

Ma	*Age*	*Process*	*Profile*	*Note*	*Fossils*
	Late Pleistocene	Uplift			
0.143 ±0.013 **0.211** ±0.043	Late Pleistocene Middle Pleistocene	Shaft fossilisation (several phases), Planation		Removal of weathering material from surface to caves, autochthonous material	Mammalian bones
	Middle Pleistocene	Uplift, planation		Roof collapse of horizontal caves	
		Vadose speleogenesis*		Drawdown vadose shafts	
		Uplift, planation		Drop of piezometric level, final fossilisation of horizontal caves	
		Deposition*	Črnotiče II, lower breccia	Authochthonous material	
	Upper Pliocene	Uplift, erosion		Fossilisation of horizontal caves	
2.5	Upper Pliocene	Deposition	Črnotiče II, right profile	Fine-grained siliciclastics, allogenic	
		Block tilting, erosion		Roof collapse, ferricretes	
		Deposition	Črnotiče II, main profile upper part	Fluvial cycles, allogenic	Destructed leafs and bones?
		Erosion			
3.6	Middle Pliocene	Deposition	Črnotiče II, main profile lower part	Fine-grained siliciclastics, allogenic	*Marifugia cf. cavatica*
	Middle to Lower Pliocene	Block tilting and rotation 19° anticlockwise			
4.2	Lower Pliocene	Speleothem growth	Črnotiče I	Stromatolitic limestones with intercalation of red clays	Fish teeths?
		Erosion	Črnotiče I		
5.4	Topmost Miocene	Speleothem growth	Črnotiče I	Coarse-recrystallised speleothems	
	Miocene	Speleogenesis		Phreatic	

*Note: Pliocene to Miocene ages in Ma are only illustrative, resulting from rough matching of magnetostratigraphic results with the GPTS; * processes can be simultaneous resulting from continuous uplift and planation!*

Table 8: Evolution scheme of the Podgorski karst.

The cave developed (Črnotiče II site) along large subterranean river as indicated by dimensions of cave profile, scallops on walls, and sedimentary fill. Forms of scallops are characteristic rather for slow water flow. The paragenetic evolution of the cave cannot be excluded. Sessile serpulid tubes were probably buried step by step when the passage was partly filled with fine sediment. Fine-grained sediments of the lower part of left (main) profile were later eroded and replaced by fluvial cyclic fill. In that part of the cave wall no serpulid tubes were found. Cyclically arranged fill was later deeply eroded. The hiatus could be prolonged as indicated by roof collapse, iron-rich crusts on eroded surface and palaeomagnetic data. The erosional surface was overlain by fine-grained laminated siliciclastics. Deposition of both parts of the profile has to be quite rapid, as indicated by dominant normal polarised magnetozones. After next erosion, autochthonous angular gravel with red clay matrix deposited. This fill can be genetical equivalent of breccias in vertical shafts, i.e. removed products of surface planation. Finally, the prolonged karst denudation removed rock above the cave, and ceiling and a part of walls collapsed. Coarse-grained breccia with matrix of terra rossa-type of soils was formed. Collapse breccia containing massive speleothems indicates that the cave in a final stage was not completely filled up to the roof, enabling the growth of rich speleothems. Finally, the prolonged karst denudation removed rock above the cave. Coarse-grained breccia containing predominantly speleothems and mixed with terra-rossa type of soils was formed.

The obtained data from the Podgorski karst plateau and its cave enable to reconstruct the geomorphic evolution of that respective block (Tab. 8). There are developed two principal types of caves: old horizontal caves with flysch-derived allogenic fluvial fill, and vertical shafts filled only by

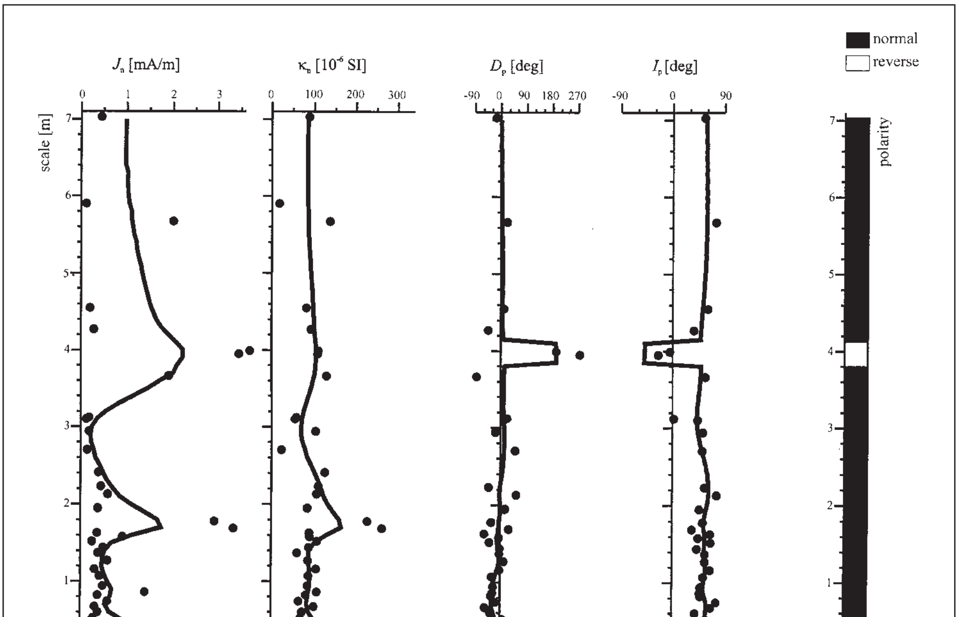


Fig. 8: Basic magnetic and magnetostratigraphic parameters of samples from the main profile.

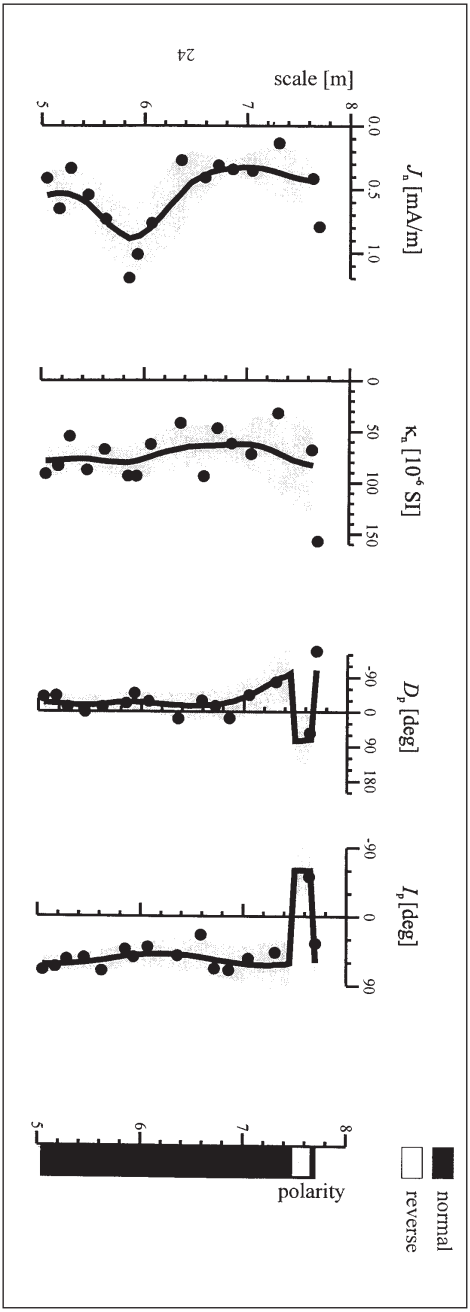


Fig. 9: Basic magnetic and magnetostratigraphic parameters of samples from the right profile.

autochthonous angular gravel, bone breccia, and terra rossa-type of soils. Fill of fossil horizontal unroofed caves can be roughly estimated back to 4.2–5.2 Ma (Črnotiče I stromatolitic limestones) and 2.5–3.6 Ma (Črnotiče II site). The age difference is indicated by mean palaeomagnetic parameters detected for both sites. The hiatus must be long enough to enable the anticlockwise rotation of the Podgorski plateau as the constituent of the Adriatic microplate in about 19°.

The old horizontal caves represented subterranean drainage routes of allogenic water streams directed from flysch regions into limestones. Caves developed deeply below the surface, at least in a depth comparable to recent river caves of the area (more than 100 m; e.g., Škocjanske jame Caves). The evolution of vertical drawdown shafts with dominance of later autochthonous fill resulted from vadose speleogenesis due to the drop of piezometric level related to tectonic uplift. Drawdown shafts connected the surface with active zone of phreatic speleogenesis in the depth. The uplift detached horizontal caves from the hydrological system causing their fossilization. Intensive planation processes took part on the surface during later evolution; in glacial periods with accelerated intensity. Planation led to the formation of leveled surface of the Podgorski karst plateau and to collapse of roofs of horizontal caves. Fossilisation of shafts by surface-derived angular gravel mixed with terra rossa-derived matrix took part during Middle to Late Pleistocene interglacials. This is proved by finds of mammals and Th/U data of carbonate cement of gravel (211 ± 43 and 211 ± 13 ka). Precipitation of the cement was connected with formation of speleothems in favourable climatic conditions. Those ages indicate also the cessation of main vertical speleogenesis in the vadose zone, which was connected with continuous uplift and shift of active phreatic speleogenesis to lower levels.

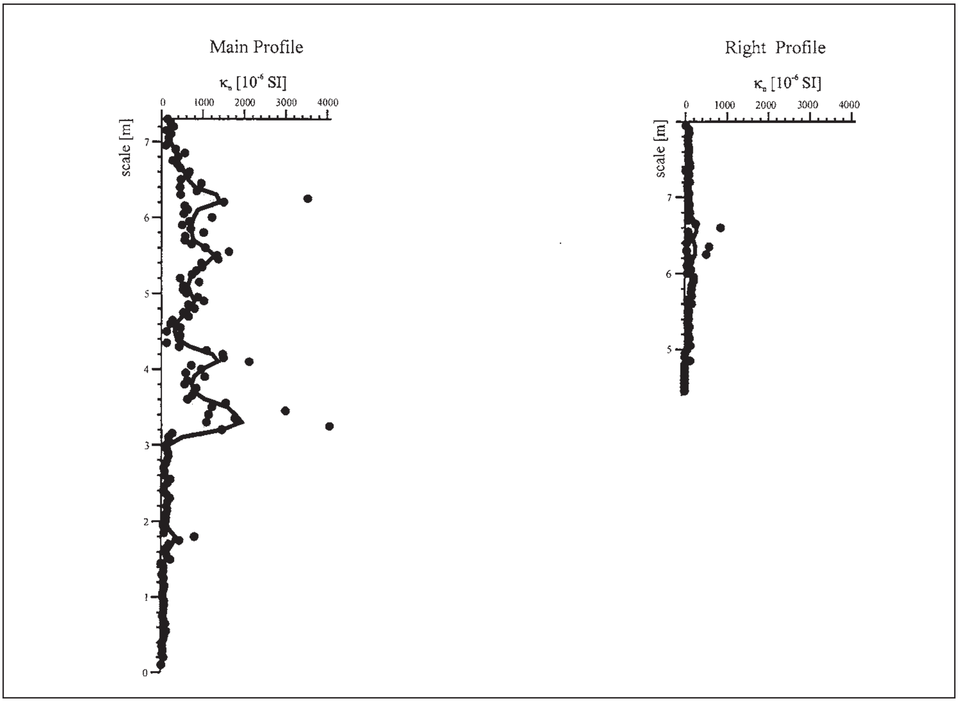
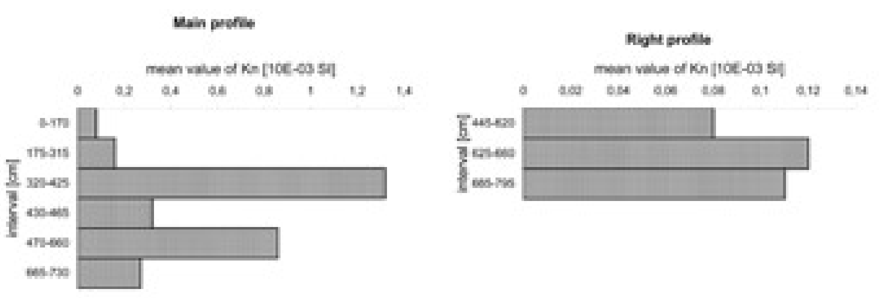


Fig. 10: Magnetic susceptibility data measured by Kappameter KT-5 from the main and the right profile.



Interval [cm]	Mean k_v [10E-03 SI]	St dev	N
0-170	0,08	0,08	35
175-315	0,16	0,14	29
320-425	1,32	0,84	22
430-465	0,32	0,13	8
470-660	0,86	0,53	39
665-730	0,27	0,13	14

Interval [cm]	Mean k_v [10E-03 SI]	St dev	N
445-620	0,08	0,06	36
625-660	0,12	0,29	8
665-795	0,11	0,16	27

Fig. 11: Mean value of magnetic susceptibility data measured by Kappameter KT-5 from the main and the right profile.

CONCLUSIONS

Črnotiče II profile is about 9 m high section of interior cave facies. The sequence is composed of cyclic fluvial sediments (conglometares, sands, silts, clays) in the lower part (so-called main profile) and by laminated to banded silts to clays in the upper part (so-called right profile). Both parts are separated by pronounced unconformity associated with deep erosion of the lower part of the profile and tectonic tilting. Sediments were palaeontologically sterile. Rare fossil finds (leafs?, bones?) were poorly preserved. One segment of the cavity wall was covered by tiny tubes of polychates worms comparable to recent fresh-water *Marifugia cavatica*. The fill is covered by chaotic boulder breccia with red loamy matrix. The cave developed along large subterranean river with rather slow water flow. The paragenetic evolution of the cave cannot be excluded.

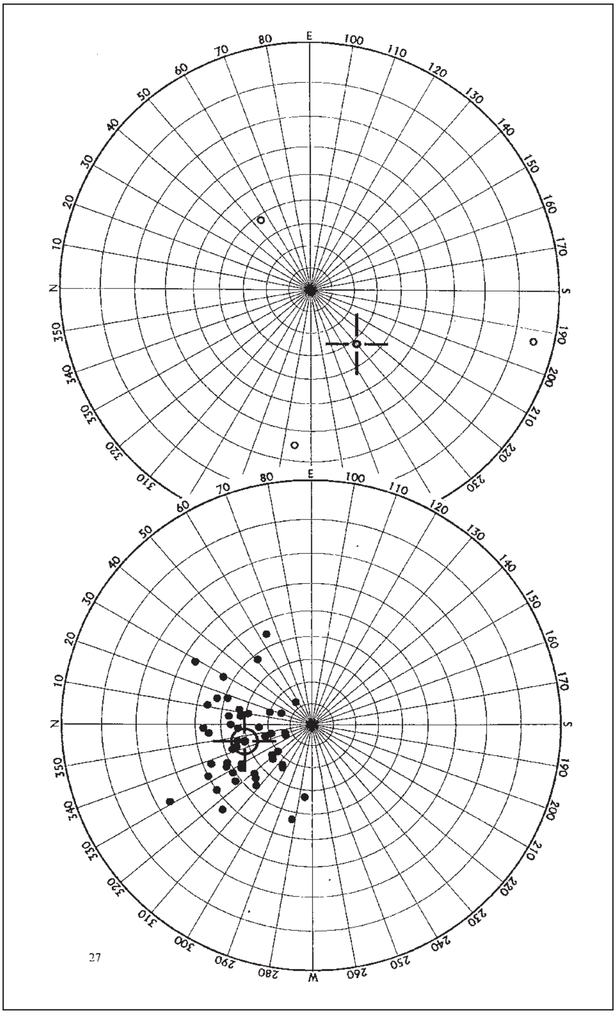


Fig. 12: Samples with normal (left side) and reverse (right side) of palaeomagnetic polarity.

Totally 54 samples were studied by alternating field and thermal demagnetisation methods. Magnetostratigraphic results show dominace of normal polarity magnetozones. One narrow reverse polarity subzone (excursion) is situated in middle part of the main profile. Another narrow reverse polarity subzone (excursion), documented on one sample only is situated in the upper part of the right profile. The correlation of the obtained arrangements of normal magnetozones and very narrow reverse polarised subzones (excursion) of both profiles can indicate the Gauss chron (ca 2.6 to 3.6 Ma) or the other long normal chron. The age of the section should be estimated to at least 1.77 Ma matching obtained results with geomagnetic polarity timescales. According to mean palaleomagnetic parameters it can be stated that both profiles in the Črnotiče Quarry, i.e Črnotiče fresh-water carbonates (I) and Črnotiče II differ in age of the deposition. The deposition is separated by period of anticlockwise rotation (about 19˚) during a period of about 1 Ma.

Gemorphological evolution of the Podgorski karst plateau since Miocene underwent complicated devepoment with distinct phases of repeating phreatic speleogenesis, vadose evolution, filling, fosslisation, exhumation, block tilting and rotation, uplift and planation. The evolution is summarized in Table 8. Two principal types of caves are in the Podgorski karst plateau: old horizontal caves with allogenig fill, and vertical shafts with fill derived from autochthonous sources. Fill of fossil horizontal unroofed caves can be roughly dated back to 4.2–5.2 Ma (Črnotiče I stromatolitic limestones) and 2.5–3.6 Ma (Črnotiče II site). The anticlockwise rotation of the Podgorski plateau in about 19° took part between both depositional phases. Old horizontal caves represented deep subterranean drainage routes of allogenic water streams directed from flysch regions into limestones. The evolution of vertical drawdown shafts with dominance of later autochthonous fill resulted from vadose speleogenesis connecting surface with phreatic zone. Later uplift detached horizontal caves from the hydrological system and fossilized them. Intensive planation processes took part on the surface during later evolution, in glacial periods with accelerated intensity, causing the origin of leveled surface and disintegration of cave roofs. Fill of shafts by surface-derived angular gravel mixed with terra rossa-derived matrix took part during Middle to Late Pleistocene interglacials. U-series ages from carbonate cement (211 ± 43 and 211 ± 13 ka) date the cessation of vertical vadose speleogenesi as the consequence of continuous uplift.

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GEOMORFOLOŠKI RAZVOJ PODGORSKEGA KRASA, JZ SLOVENIJA: PRISPEVEK K MAGNETOSTRATIGRAFSKIM RAZISKAVAM PROFILA ČRNOTIČE II Z *MARIFUGIO* SP.

POVZETEK

Kamnolom Črnotiče leži na zahodnem robu Podgorskega krasa, obsežni uravnani planoti ob vznožju Slavnika (45° 33' 57'' S, 13° 52' 48'' V). Višina uravnanega površja je okrog 440 m. Plato grade paleogenski apnenci in ozke luske fliša ki upadajo pod kotom 20-30° proti SV. Profil Črnotiče II predstavlja okrog 9 m visok prerez jamskih sedimentov. Sekvenca sedimentov je sestavljena iz v spodnjem delu ciklično urejenih plasti fluvialnih sedimentov (konglomeratov, peskov, meljev in glin), v zgornjem (v tekstu ga imenujemo desni profil) pa iz laminirane pasovite plasti melja in gline. Oba dela profila loči dobro izražena prekinitev, ki je povezana z močno erozijo v spodnjem delu profila. Fluvialna zapolnitev je prekrita s kaotično blokovno brečo z rdečim ilovnatim matriksom – porušenim stropom. Jamo je oblikovala velika podzemna reka s počasnim tokom. Morda se je rov oblikoval tudi v paragenetskih pogojih. Sedimenti v profilu so bili brez paleontoloških ostankov. Slabo ohranjeni fosilni ostanki (listi in kosti?) so bili preslabo ohranjeni za določitev. Na enem delu votline pa so se ohranile številne, na steno pritrjene drobne cevke, ki pripadajo polihetnim črvom. Podobne so cevkam recentnega sladkovodnega črva *Marifugia cavatica*.

V profilu je bilo vzetih 54 vzorcev, ki so bili nato proučeni z izmeničnim magnetnim poljem ter termično demagnetizacijo. Vrednosti modulov naravne remanentne magnetnosti Jn magnetne susceptibilnosti kn vzorcev kamnine v naravnem stanju kažejo majhno razpršenost. Srednje vrednosti modulov Jn in kn iz 38 vzorcev glavnega profila (0.07–7.03 m) imajo vrednosti Jn = 0.862 ± 1.036 [mA.m-1]in kn = 99 ± 45 x 10-6[SI]. To skupino vzorcev označujejo nizke vrednosti Jn in kn . Srednje vrednosti Jn in kn modulov iz 16 vzorcev iz desnega profila (5.05–7.70 m) so Jn = 0.541 ± 0.281[mA.m-1]in kn = 76 ± 28 x 10-6[SI]. Tudi za vzorce iz desnega profila so značilne nizke vrednosti Jn in kn.

Magnetostratigraski rezultati kažejo, da prevladujejo v profilu vzorci z normalno magnetno orientacijo. Ena ozka reverzna polaritetna podcona (ekurzija) je v srednjem delu glavnega profila (od 3.95 to 3.99 m). Druga ozka reverzna magnetna subcona (eksurzija), določena le pri enem vzorcu, leži sredi zgornjega dela (7.64 m) desnega profila. Razporeditve normalne magnetocone in obeh ozkih reverznih subcon (ekskurzij) kaže, da so se sedimenti odložili v Gaussovi normalni (cca 2.6 to 3.6 Ma) ali v kateri drugi dolgi normalni magnetoconi. Starost sedimentov je najmanj 1.77 Ma če upoštevamo rezultate dobljene na osnovi geomagnetne polaritetne časovne skale.

Starosti sedimentov v črnotiškem kamnolomu, določene na osnovi srednjih paleomagnetnih parametrov kažejo razliko v starosti sladkovodnih karbonatov iz profila Črnotiče I in opisanega profila Črnotiče II. Obdobje sedimentacije obeh loči čas rotacije ozemlja v nasprotni smeri urinega kazalca (za 19°) v času okrog 1 Ma.

Geomorfološka evolucija podgorskega krasa je od Miocena doživela zapleten razvoj z obdobji ponavljajoče se freatične speleogeneze, vadoznega razvoja, zapolnjevanja, fosilizacije, denudacije, nagibanja in rotacije tektonskih enot, tektonskega dvigovanja in uravnavanja. Razvoj je sumarno prikazan na Tabeli 8. Na Podgorskem krasu sta dva glavna tipa jam: stare, horizontalne jame z alogenimi zapolnitvami in navpična brezna z zapolnitvami, ki so nastale iz lokalnega gradiva. Zapolnitve horizontalnih brezstropih jam lahko grobo datiramo na 4.2–5.2 Ma (Črnotiče I stromatolitski apnenec) in na 2.5–3.6 Ma (Črnotiče II). V času med nastankom obeh zapolnitev je prišlo do rotacije celotnega Podgorskega krasa v nasprotni smeri urinega kazalca za okrog 19°. Stare horizontalne jame so prevajale

alogene reke, ki so pritekale s fliša na apnenec. Razvoj vertikalnih vadoznih brezen z dominantnimi kasnejšimi avtohtonimi zapolnitvami je posledica vadozne speleogeneze oziroma pretakanjem vode med površjem in gladino freatične cone. Kasnejši dvig je ločil vodoravne jame od njihovega hidrološkega zaledja in povzročil njihovo fosilizacijo. Sledilo je denudacijsko zniževanje in uravnavanje površja, ki je bilo zlasti intenzivno glacialnih obdobjih. Tako je nastalo obsežno uravnano površje z brezstropimi in porušenimi jamami.

Brezna so zapolnili s površja izvirajoči ostrorobi grušči. Grušči so pomešani z ilovicami, ki so nastale iz terra rosse v toplejših interglacialnih obdobjih v poznem pleistocenu. Datacije karbonatnega cementa gruščev iz zapolnjenih brezen s pomočjo U izotopov (211 ± 43 in 211 ± 13 ka) opredeljujejo čas zapolnitev tega dela vadoznih brezen. Brezna so obenem tudi pokazatelj speleogeneze, ki sledi dvigovanju reliefa.