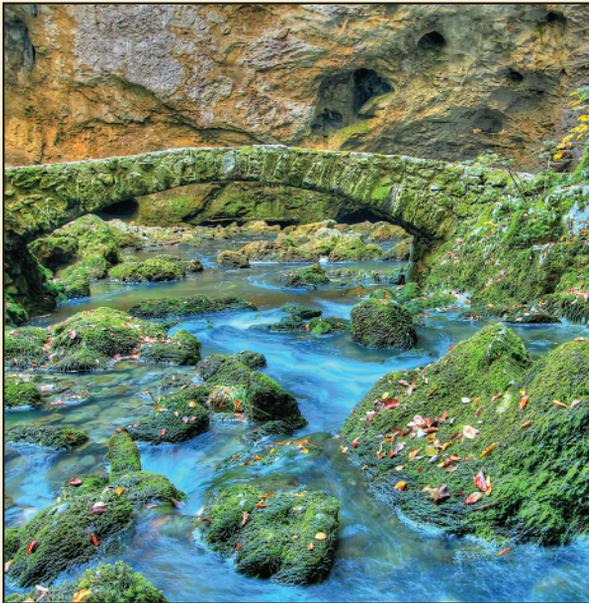


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59-1 • 2019

Contents

Maja KOCJANČIČ, Tomislav POPIT, Timotej VERBOVŠEK <i>Gravitational sliding of the carbonate megablocks in the Vipava Valley, SW Slovenia</i>	7
Małgorzata KIJOWSKA-STRUGAŁA, Anna BUCAŁA-HRABIA <i>Flood types in a mountain catchment: the Ochotnica River, Poland</i>	23
Irena MOCANU, Bianca MITRICĂ, Mihaela PERSU <i>Socio-economic impact of photovoltaic park: The Giurgiu county rural area, Romania</i>	37
Andrej GOSAR <i>The size of the area affected by earthquake induced rockfalls: Comparison of the 1998 Krn Mountains (NW Slovenia) earthquake (M_w 5.6) with worldwide data</i>	51
Matej GABROVEC, Peter KUMER <i>Land-use changes in Slovenia from the Franciscan Cadaster until today</i>	63
Mojca FOŠKI <i>Using the parcel shape index to determine arable land division types</i>	83
Mateja FERK, Matej LIPAR, Andrej ŠMUC, Russell N. DRYSDALE, Jian ZHAO <i>Chronology of heterogeneous deposits in the side entrance of Postojna Cave, Slovenia</i>	103

Special issue – Green creative environments

Jani KOZINA, Saša POLJAK ISTENIČ, Blaž KOMAC <i>Green creative environments: Contribution to sustainable urban and regional development</i>	119
Saša POLJAK ISTENIČ <i>Participatory urbanism: creative interventions for sustainable development</i>	127
Jani KOZINA, Nick CLIFTON <i>City-region or urban-rural framework: what matters more in understanding the residential location of the creative class?</i>	141
Matjaž URŠIČ, Kazushi TAMANO <i>The importance of green amenities for small creative actors in Tokyo: Comparing natural and sociocultural spatial attraction characteristics</i>	159

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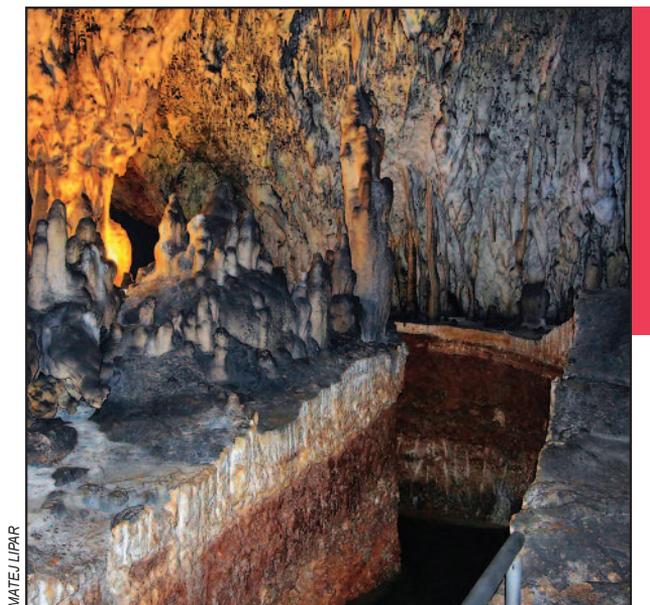
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Front cover photography: Stone bridge over the Rak River on the outskirts of the Rakov Škocjan polje, which is otherwise known for its beautiful natural bridges (photograph: Matej Lipar).

Fotografija na naslovnici: Kamniti most čez reko Rak na obrobju kraškega polja Rakov Škocjan, ki je sicer bolj znano po čudovitih naravnih mostovih (fotografija: Matej Lipar).

CHRONOLOGY OF HETEROGENEOUS DEPOSITS IN THE SIDE ENTRANCE OF POSTOJNA CAVE, SLOVENIA

Mateja Ferk, Matej Lipar, Andrej Šmuc, Russell N. Drysdale, Jian Zhao



MATEJ LIPAR

The trail cut into cave deposits.

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Chronology of heterogeneous deposits in the side entrance of Postojna Cave, Slovenia

ABSTRACT: The development of the tourist trail in the side passage Rov Novih Podpisov of Postojna Cave in 2002 exposed an over four metres thick sedimentary succession characterised by horizontal flowstone layers intercalated between fine-grained fluvial sediments, and gravel deposits that record past environmental changes. The time of the flowstone deposition was determined by radiocarbon and uranium-thorium dating techniques. The results yielded three distinctive age groups of flowstone facies of 33 ka BP, 103 ka BP and 153 ka BP. These results also indicate that flowstone deposition has not been limited solely to periods of warm climate, which suggests that environmental conditions during glacial periods in south-western Slovenia supported flowstone deposition.

KEY WORDS: Geography, geoscience, geology, karst, stratigraphy, dating, ^{14}C , U/Th

Časovna interpretacija raznovrstnih sedimentov v stranskem vhodnem rovu Postojnske jame, Slovenija

POVZETEK: Pri modernizaciji turistične poti v Rovu novih podpisov, ki je stranski rov Postojnske jame, leta 2002 je bilo v več kot štiri metre globokem vkopu odkrito zaporedje menjajočih se plasti sige, fluvialnih sedimentov in grušča. Te plasti so pomemben pokazatelj preteklih okoljskih sprememb. Starost sige med plastmi je bila določena z radioogljikovo in uran-torijevo metodo. Siga se je odlagala v treh obdobjih, in sicer okoli 33 ka BP, 103 ka BP in 153 ka BP. Odlaganje sige ni bilo omejeno zgolj na topla obdobja, ampak se je siga odlagala tudi v hladnejših obdobjih. Rezultati kažejo, da je bilo na območju jugozahodne Slovenije vsaj v nekaterih hladnih obdobjih Pleistocena podnebje primerno za rast sige.

KLJUČNE BESEDE: Geografija, geoznanost, geologija, kras, stratigrafija, datiranje, ^{14}C , U/Th

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1 Introduction

Postojna Cave is a 24 km long system of underground passages with multiple entrances (Cave Register 2018, Figure 1). It is located in south-west Slovenia, which is famous for its high diversity (Perko, Hrvatin, and Ciglič 2015; Perko, Ciglič and Hrvatin 2017). Since 1819 the cave has been managed as a show cave (Shaw and Cuk 2015). During the last two centuries different parts of the cave were sequentially arranged and equipped for public access. It has a long tradition of cave exploration and scientific research (Valvasor 1689; Hohenwart 1830; Schmidl 1854; Perko 1910; Gams 1968; Gospodarič 1969; 1971; Ikeya, Miki and Gospodarič 1983; Šebela 1998; Šebela and Sasowsky 1999; Mihevc 2002; Stepišnik 2004; Šebela and Turk 2011; Ferk 2016; Domínguez-Villar et al. 2018; Pipan et al. 2018). It is a ponor cave of the Pivka River in the contact karst area where the surface streams (e.g., Lekinka River) from impermeable Eocene flysch rock sink into the karstified Upper Cretaceous limestone (Buser, Grad and Pleničar 1967; Šebela 1998; Pleničar, Ogorelec and Novak 2009; Stepišnik 2017).

The cave passages were formed at two main levels. The lower, several meters wide passages, are in the epiphreatic zone and periodically flooded on a yearly basis. The walls and ceiling contain solutional rock features (e.g. scallops), whilst the floor is mostly covered by fluvial sediments (i.e. flysch gravel) (Gospodarič and Habič 1966). Passages on the higher level have diameters mostly around 10 m and are hydrologically inactive. However, they preserve remnants of solution (e.g., scallops) and numerous interchanging fluvial and chemogenic sediments that were deposited in changing conditions, revealing a hydrologically dynamic evolution during their speleogenesis. Cave sediments indicate repeated fluvial deposition and successive erosion (Gams 1966; Gospodarič 1976). Palaeomagnetic analyses show that the oldest sediments are up to 2.15 Ma old, revealing that the cave system has evolved over a long period of time (Šebela and Sasowsky 1999; Zupan Hajna et al. 2008). The fluvial deposits and layers of flowstone close to the cave entrances are intersected by sequences of slope-derived gravel, remnants of Pleistocene large mammals and stone tools of Palaeolithic hunters (Rakovec 1954; Brodar 1966; 1969; Bavdek 2003).

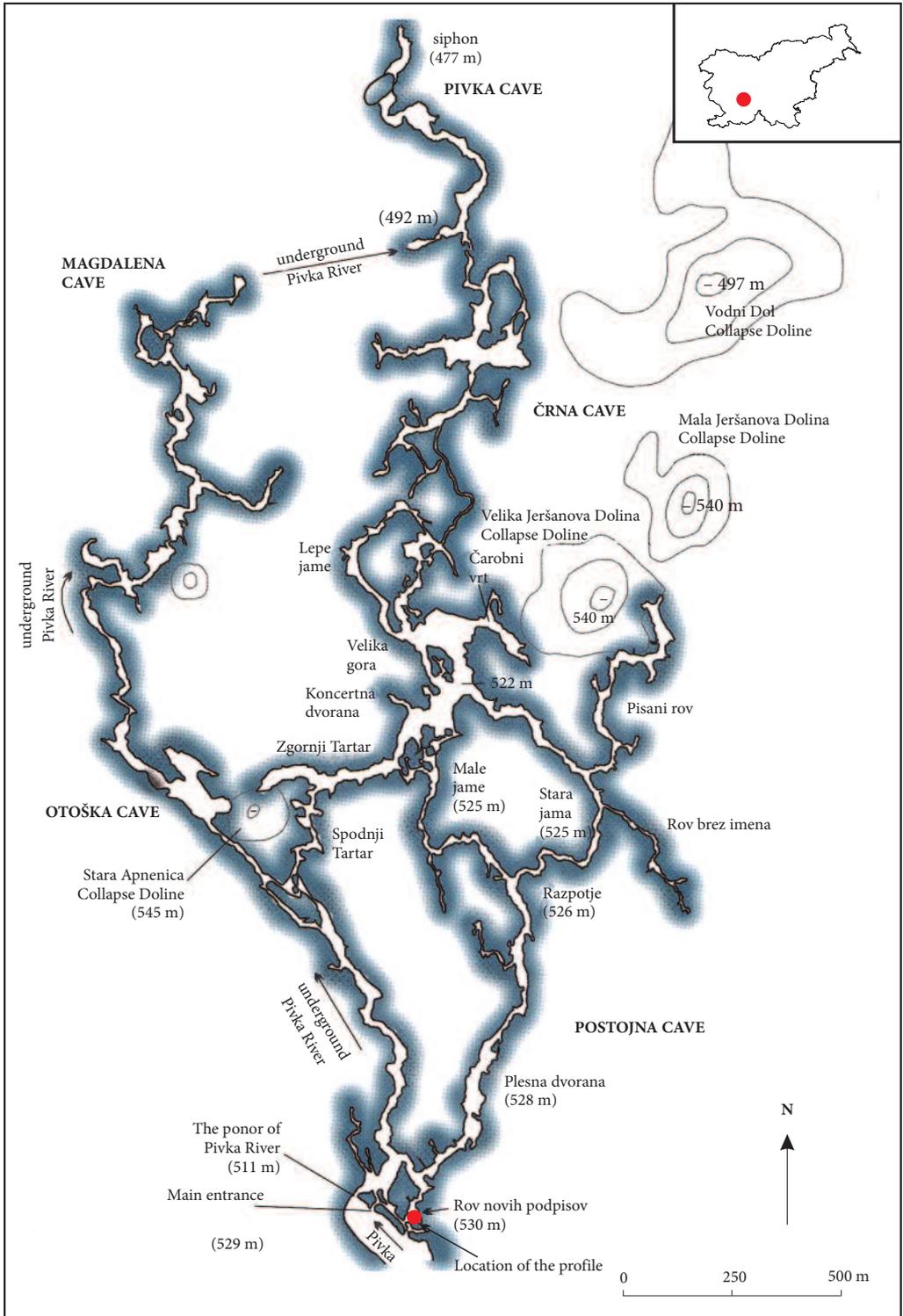
About 50 m east of the main entrance to Postojna Cave is the entrance to one of its side passages called *Rov Novih Podpisov* that joins the main channel *Stare Jame* after about 150 m. The passage belongs to the higher and hydrologically inactive level. The passage floor at the entrance is on the elevation of 530 m a.s.l. which is from 10 to 19 m above the present ponor of Pivka River (from 511 to 520 m a.s.l.) depending on the water level. The shallow cave passage, from 2 to 4 m high and in average 10 m wide, was equipped as a biospeleological laboratory in 1931. At present it operates as the Vivarium with a research facility and an exhibition section where basic concepts of karstology and speleobiology are presented to the visitors. Recent slope-derived gravel covering the entrance was removed during construction works in the 1930s. In 2002 the entrance part was modified to ease access to the Vivarium for tourists. An over four metres deep trench was cut into the floor exposing a flowstone covered sedimentary succession composed of various cave sediments.

Palaeomagnetic research on the exposed sediments showed only N polarized magnetisation corresponding to the Brunhes Chron indicating the sediment was deposited within the last 780 ka (Zupan Hajna et al. 2008). Despite lacking any data of numerical dating the profile was interpreted as «very young» (Zupan Hajna et al. 2008, 176). Based on Mousterian artefacts found in a nearby cave channel also filled with various sediments (Brodar 1966; Bavdek 2003), the middle and upper part of the profile was interpreted to be less than 40 ka old and the flowstone layer covering the profile to be of Holocene age (Mihevc and Zupan Hajna 2004; Gabrovšek and Mihevc 2009; Mihevc and Gabrovšek 2012). However, results of the first numerical dating of the uppermost flowstone revealed it was deposited 36 ka BP (Ferk 2016) strongly implying the previous chronological interpretations of the profile were inaccurate.

The aim of the paper is to present results of two different dating techniques coupled with additional mineralogical and grain size analyses to provide the robust chronological timeline of the exposed heterogeneous deposits, which will be beneficial for further palaeoenvironmental studies.

2 Methods

The 4.16 m thick profile was recorded in resolution bed-to bed using standard sedimentological log in 1:10 scale. Six stratigraphic levels were identified (Figure 2). From the succession five flowstone samples were



acquired for age and geochemical analysis and one fine-grained clastic sediment sample was collected for mineralogical and grain size analyses.

2.1 Laboratory analyses for chemically precipitated sediment layers (flowstone)

Two stratigraphically older samples of flowstone were dated by the uranium-thorium (U/Th) method at the University of Queensland (Brisbane, Australia). To assure that samples have enough U/Th for dating, they were first sampled to provide ICP-MS trace element data. Ages were corrected for non-radiogenic ^{230}Th incorporated at the time of deposition. Full details of the method are provided in Hellstrom (2003; 2006). Age errors are reported as 2σ uncertainties.

In addition, the flowstone samples were analysed for both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopes at the stable isotope laboratory at the University of Melbourne (Australia), alongside with four samples of present-forming flowstone to compare the results for basic interpretation of climatic differences between the times of older flowstone deposition and present. Analyses were performed on CO_2 produced by reaction of the sample with 100% H_3PO_4 at 70 °C using continuous-flow isotope ratio mass spectrometry (CF-IRMS), following the method previously described in Drysdale et al. (2009) and employing an AP2003 instrument. Results are reported using the standard δ notation (‰) relative to the VPDB scale. Based on the following working standards, the uncertainty was 0.05‰ for $\delta^{13}\text{C}$ and 0.07‰ for $\delta^{18}\text{O}$ based on the NEW 1 standard.

Three stratigraphically higher deposited samples of flowstone were dated by the radiocarbon technique at the Beta Analytic Laboratory in Miami, USA. All samples provided enough carbon for accurate measurements. The ages are reported as RCYBP (radiocarbon years before present (AD 1950)). The modern reference standard was 95% the ^{14}C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby ^{14}C half-life (5568 years). The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the $\delta^{13}\text{C}$ relative to the Vienna Peedee Belemnite (VPDB) scale. The Calendar Calibrated results are calculated from the Conventional Radiocarbon Age and listed as 2σ calibrated results.

2.2 Laboratory analyses for clastic sediment sample

The qualitative and quantitative mineral composition of the stratigraphically highest and youngest loamy sediment (facies B, see chapter 3) was determined by X-ray powder diffraction (XRD) analysis, which, in turn, indicates the source of the sediment (Haldorsen et al. 1989; Stanley, Nil and Galili 1998). We used the Faculty of Natural Sciences and Engineering, University of Ljubljana (Slovenia) Philips PW3710 diffractometer equipped with a Cu K α radiation and a graphite monochromator, operating at 40kV and 30mA in continual scan mode with a speed of 0.5 °/min from 2° to 70° 2 Θ . The Rietveld Method was used for semiquantitative mineralogical analysis.

To determine the deposition dynamics of the same sediment the grain size analysis using a Malvern Mastersizer 2000 particle analyser at La Trobe University (Melbourne, Australia) was carried out; full details of the latter analytical procedure are provided in Sperazza, Moore and Hendrix (2004).

3 Results and discussion

The maximum thickness of the exposed profile is 416 cm. We divided it into six stratigraphic levels of various horizontal facies (Figure 2). From bottom to top, these are:

- 416 to 370 cm, subangular gravel mixed with fine-grained sediment (facies F);
- 370 to 210 cm, very angular gravel mixed with fine-grained sediment and partly cemented with calcite (facies E);
- 210 to 190 cm, white flowstone layers intercalated by two up to 1 cm thick black layers (facies D);
- 190 to 90 cm, angular gravel mixed with fine-grained sediment containing bones in the lower part (facies C);
- 90 to 45 cm, fine-grained sediment with indistinctive horizontal parallel lamination (facies B);
- 45 to 0 cm, white flowstone layers intercalated by millimetre thin layers of fine-grained sediment towards the lowest part (facies A).

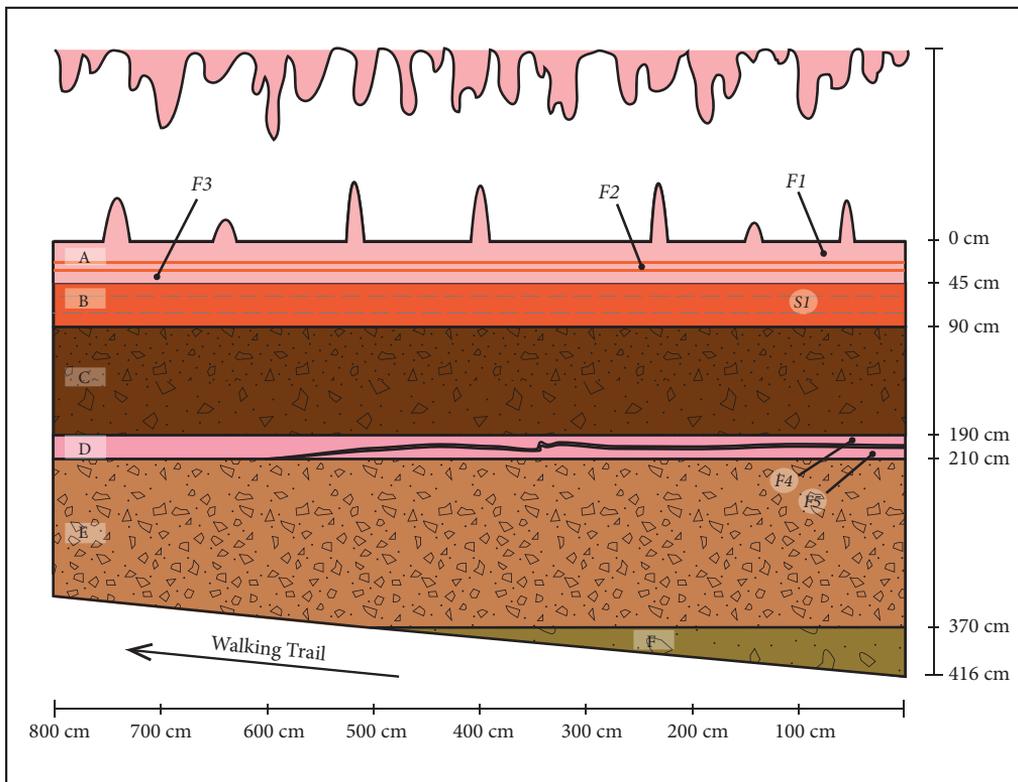


Figure 2: Stratigraphic levels of horizontal facies identified in the analysed sediment profile in the side passage *Rov Novih Podpisov* of Postojna Cave.

3.1 Facies F

Facies F is the oldest recognised facies in the succession (Figure 2). The total thickness cannot be determined due to the limited exposure but is at least 46 cm thick. The facies consists of subangular limestone gravel with clast size mostly around 5–10 cm and some larger pieces with diameters up to 20 cm. The gravel is poorly sorted and mixed with grey to yellow fine-grained sediments presumably originating from the flysch rocks in the Pivka Basin (Zupan Hajna et al. 2008). Mihevc and Zupan Hajna (2004) describe the facies F as the oldest sediment deposited in the cave by the Pivka River which was partly eroded away in the upper part.

3.2 Facies E

The facies E is 160 cm thick and is the thickest facies in the succession (Figure 2). It consists of very angular well sorted limestone gravel with clast size around 5 cm. The gravel originates from the local limestone which builds cave walls and ceiling. It is partly cemented with calcite in the upper part. The amount of calcite cement decreases towards the lower part of the facies. The gravel is mixed with light brown fine-grained sediment.

Mihevc and Zupan Hajna (2004) assumed the layer was deposited at the beginning of the last glacial period (Würm glaciation; Marine Isotope Stage (MIS) 5-2) in climate similar to the present one (Mihevc and Gabrovšek 2012) although no numerical datations were published. Results of the current study revealed an older age of the deposits, since the deposition of the facies E ended more than 150 ka BP (see chapter 3.3).

3.3 Facies D

The facies F is covered by a 30 cm thick layer of white flowstone (facies D; Figure 2). The flowstone includes two up to 1 cm thick black layers that resemble charcoal. Two samples of flowstone from facies D were analysed; sample F4 was taken from the upper part of the facies, from above the black layer, and sample F5 was taken from the lower part of the facies, from beneath the black layer.

The results of the ICP-MS trace element data (Table 1) revealed that both samples have U/Th levels high enough for dating. The U/Th dating results yielded an age of 103.2 ka (MIS 5c) for the stratigraphically younger flowstone (F4) and 153.1 ka (MIS 6) for the older flowstone (F5) (Table 2).

Table 1: ICP-MS trace element data for the flowstone of facies D. Concentration results in ppb or ng/g. Note: ^6He (i.e. enriched ^6Li), ^{61}Ni , ^{103}Rh , ^{115}In , ^{187}Re and ^{235}Np (i.e. enriched ^{235}U) are internal standards added to the sample solutions.

Sample	F4	F5	F4	F5	F4	F5		
^6He	0	0	^{86}Sr	24994	30598	^{165}Ho	2.8	2.8
^7Li	72.2	27.7	^{89}Y	106.7	108.8	^{166}Er	7.7	7.8
^9Be	28.2	12.8	^{90}Zr	96.2	70.4	^{169}Tm	1.1	1.1
^{25}Mg	102191	104147	^{93}Nb	9	4.8	^{172}Yb	6.5	6.7
^{31}P	341172	162150	^{98}Mo	4.3	2.1	^{175}Lu	0.9	0.9
^{43}Ca	427280107	411705358	^{103}Rh	0	0	^{178}Hf	1.6	1.2
^{45}Sc	112.9	111.8	^{111}Cd	35	47.8	^{181}Ta	-0.4	-0.5
^{49}Ti	1702.1	1291.9	^{115}In	0	0	^{184}W	4.7	4
^{51}V	326.8	236.1	^{120}Sn	2.3	-3.9	^{187}Re	0	0
^{53}Cr	265.1	340.9	^{121}Sb	2.2	2.2	^{202}Hg	46	45.7
^{55}Mn	1097.7	1525.3	^{133}Cs	17	9.3	^{205}Tl	12.5	12.7
^{57}Fe	807828	776202	^{137}Ba	2569.5	12116	^{206}Pb	83.8	69.3
^{59}Co	256.4	312.3	^{139}La	84.2	79.5	^{207}Pb	76.1	62.6
^{60}Ni	42550	3658	^{140}Ce	167.5	134.8	^{208}Pb	79.1	64
^{61}Ni	0	0	^{141}Pr	22.3	19.9	^{209}Bi	2.3	1.4
^{65}Cu	687.3	411.9	^{146}Nd	84.7	82.1	^{220}Bkg	0	0
^{66}Zn	1170.7	550	^{149}Sm	18.7	17.8	^{232}Th	13	9.7
^{69}Ga	15.2	-57.8	^{151}Eu	4.1	4.2	^{235}Np	0	0
^{71}Ga	26.4	14.8	^{159}Tb	2.8	2.4	^{238}U	362.4	215.3
^{74}Ge	1.6	0.2	^{160}Gd	17.8	16.5	U/Th	28.0	22.2
^{85}Rb	187.5	100.2	^{161}Dy	14.8	12.8			

Table 2: U-Th isotope data for the flowstone of facies D. Two laboratory standards included: YB-1 is an ANU speleothem standard with an age of 30.2 ± 0.6 ka. SRM-960 U is a metal standard manufactured during the World War II (~1936).

Sample	F4	F5	SRM-960 standard	YB-1 speleothem std
Sample wt. (g)	0.103	0.103	0.1057	0.10214
U (ppm)	0.35038	0.23732	5.53963	0.12525
$\pm 2\sigma$	0.00015	0.00010	0.0046	0.00004
^{232}Th (ppb)	51.442	46.151	0.008	0.486
$\pm 2\sigma$	0.083	0.062	0.000	0.001
$(^{230}\text{Th}/^{232}\text{Th})$	13.091	12.044	1484.971	339.829
$\pm 2\sigma$	0.039	0.034	28.251	1.229
$(^{230}\text{Th}/^{238}\text{U})$	0.6334	0.7719	0.0007	0.4343
$\pm 2\sigma$	0.0016	0.0020	0.00001	0.0015
$(^{234}\text{U}/^{238}\text{U})$	1.0095	1.0055	0.9636	1.7492
$\pm 2\sigma$	0.0011	0.0009	0.0007	0.0013
Uncorr. Age (ka)	107.59	159.0	0.0805	30.53
$\pm 2\sigma$	0.51	1.0	0.0009	0.12
Corr. Age (ka)	103.2	153.1	0.0805	30.46
$\pm 2\sigma$	2.3	3.1	0.0009	0.12
Corr. Initial ($^{234}\text{U}/^{238}\text{U}$)	1.0132	1.0090	0.9636	1.8174
$\pm 2\sigma$	0.0015	0.0015	0.0007	0.0014

The up to 1 cm thick black layers resembling charcoal deposits in the middle part of the flowstone has not been examined. According to the presence of a Palaeolithic site in the close vicinity where artefacts of Mousterian stone tools were discovered (Brodar 1966) it is likely the layer is a cultural deposit. Based on the measured ages of the flowstone underlying and covering the black layer it should be attributed to the presence of Neanderthals, which is in accordance with the Mousterian stone tools found nearby (Brodar 1966; Bavdek 2003).

According to the general palaeoclimatic curve for that time frame (Friedrich et al. 2016), the flowstone was deposited during the MIS 6 glacial period with generally colder temperatures and the MIS 5c interstadial with generally warmer temperatures. In addition, the flowstone layers have heavier oxygen isotopic values (-6.45‰ (F4) and -6.20‰ (F5)) than the present-forming flowstone (~ -6.83), which may reflect a reduced plant activity and thus lower levels of soil CO_2 production, or a higher proportion of plants adapted to the climate with less effective rainfall during the time of flowstone deposition (103.2 ka and 153.1 ka BP; Figure 3). This could be especially valid for the MIS 6 glacial period (and the heaviest value of the F5 sample) when global water circulation was reduced due to lower evaporation.

3.4 Facies C

Facies C is a 1 m thick layer of moderately sorted gravel composed of angular limestone clasts. In the lowermost part the clasts are up to 10 cm large and animal bones are present between them, while the clasts are smaller (up to 5 cm) in the middle and upper part of the facies. The gravel is mixed with brown fine-grained sediment. The clasts are composed of the same rock as the cave walls and ceiling. Mihevc and Gabrovšek (2012) interpreted the gravel slid from the entrance deeper into the cave by cryoturbation. Based on archaeological findings of Mousterian stone tools at the nearby Palaeolithic site, few tens of metres away (Brodar 1966), Mihevc and Zupan Hajna (2004) assumed the facies C was deposited between 40 and 20 ka BP and during the Last Glacial Maximum. However, results of the numerical dating methods show the time of gravel deposition in the cave is constrained by the lower lying 103.2 ka old horizontal layer of flowstone (facies D) and the 36.8 ka old flowstone topping the profile (facies A). Therefore, the facies C is older than previously believed and was deposited between MIS 5c and MIS 3. The gravel production may have intensified at the transition between MIS 5a and the glacial maximum during MIS 4 when the general average temperatures were lower than the present one (Friedrich et al. 2016).

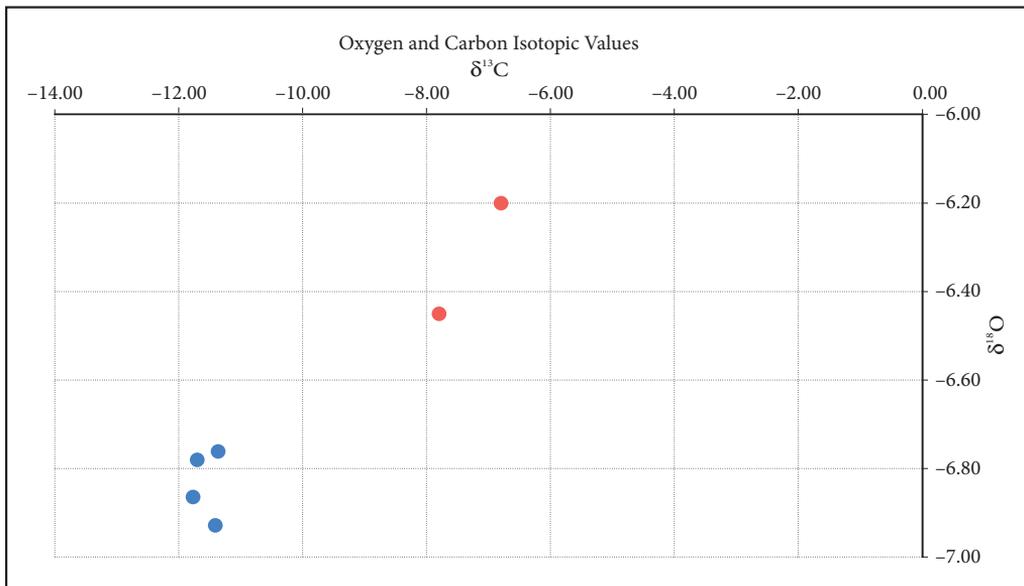


Figure 3: Diagram of oxygen and carbon isotope values of the flowstone (facies D). Orange colour: flowstone samples F4 and F5; blue colour: present-day samples of flowstone.

3.5 Facies B

Facies B is a 45 cm thick layer of homogenous red fine-grained sediment with partially preserved horizontal and parallel lamination which was sampled for mineral and grain size analyses. The X-ray powder diffraction (XRD) analysis showed that the sediment consists of quartz (47%), muscovite/illite (24%), chlorite (18%), K-Na feldspar (7%) and kaolinite (4%) (Ferk 2016). Based on the mineral composition the provenance of this sediments are flysch rocks (Orehek 1970) present in the Pivka River catchment (Buser, Grad and Pleničar 1976; Pleničar, Ogorelec and Novak 2009). The grain size analysis showed the sediment is silt loam according to the Soil Bulk Density Calculator (Wentworth 1922; Plaster 1992), consisting of 68.61% silt, 21.9% clay, and 9.49% sand (Table 3; Figure 4).

Table 3: Grain size characteristics of the facies B sediment (sample S1).

Grain size (mm)	Classification		Percentage (%)	
	Major	Minor		
2-1	Sand	Very coarse sand	0.59	9.49
1-0.5		Coarse sand	2.21	
0.5-0.25		Medium sand	2.18	
0.25-0.125		Fine sand	1.27	
0.125-0.062		Very fine sand	3.24	
0.062-0.031	Silt	Very coarse silt	10.15	68.61
0.031-0.016		Coarse silt	18.43	
0.016-0.008		Fine silt	21.07	
0.008-0.004		Very fine silt	18.96	
< 0.004	Clay	Clay	21.9	21.9

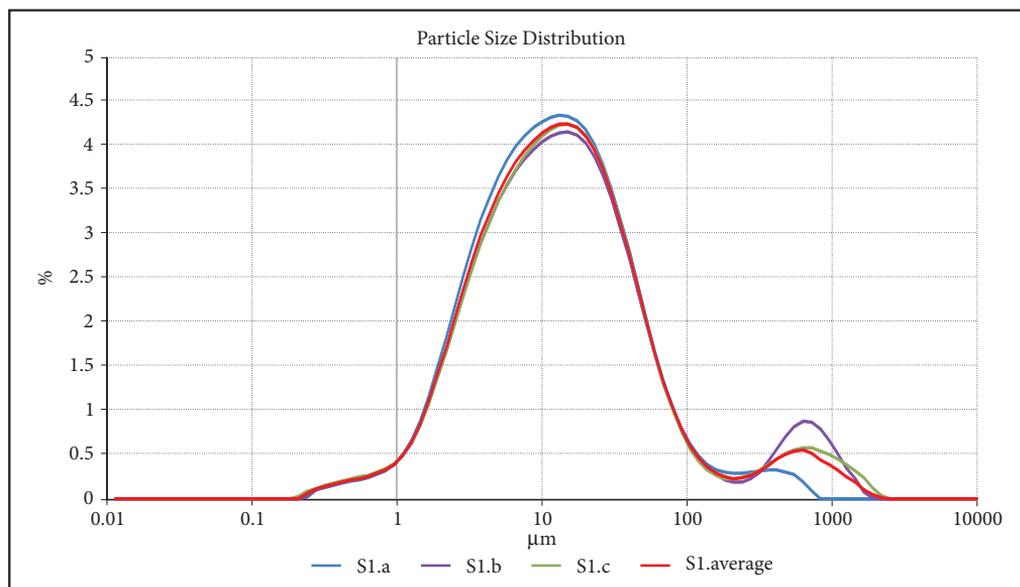


Figure 4: Grain size characteristics of the facies B sediment (sample S1).

Supposedly, these sediments were washed into the cave from the Pivka Basin during episodic flooding and sedimentation from suspension in a standing or slow-moving water as suggested by parallel horizontal lamination and silt loam texture of the sediment (cf. Farrant and Smart 2011; Ferk 2016). Considering that the laminas are less than 1 mm thick, the 45 cm thickness of the sediment would suggest a long time-scale of periodical flooding and not a single extreme event. However, laminated silt loam deposits can derive from aeolian material redeposited by overland flow (Mücher and De Ploey 1984) which is in accordance with Zupan Hajna et al. (2008) who suggested that the sediment of facies B was washed into the cave from the surface. Nevertheless, the age of the flowstone (facies A) above the silt loam sediment shows that the sedimentation of facies B ceased around 36.8 ka BP.

3.6 Facies A

The top layer of the profile, facies A, is a 45 cm thick white flowstone. In the lower half the flowstone is intercalated with thin layers of red fine-grained sediment. Three flowstone samples from facies A were dated using radiocarbon technique (Table 4). The micro location of the samples within the flowstone was chosen based on their stratigraphic location (Figure 2): sample F1 was taken from the top of the facies A, sample F2 was taken from the middle of the facies A underlying an up to 5 cm thick layer of fine-grained sediment, and sample F3 was taken from the lowest part of the facies underlying an up to 1 cm thick layer of intercalated fine-grained sediment. The calibrated radiocarbon ages of flowstone F1, F2 and F3 yielded ages of 33.2 ka, 34.9 ka and 36.8 ka BP, respectively. Their accordance with the stratigraphical position strengthens the reliability of the results and suggests the deposition of the facies A between 33.2 and 36.8 ka (Ferk 2016). The age of the facies A is older than previously thought when it was linked to the Holocene (Mihevc and Zupan Hajna 2004; Zupan Hajna et al. 2008).

The deposition of flowstone occurred during MIS 3 which is characterised by high variation of average temperature amplitudes, although the stage in general is part of the last glacial period (Lisiecki and Raymo 2005). During the MIS 3 the temperatures were globally slightly higher than during the MIS 2 and MIS 4 periods. The cave entrance at that time must have been blocked as flowstone deposition requires absence of frost weathering. This is strongly indicated also by the absence of broken speleothems or frost weathering affected speleothems during the Last Glacial Maximum (e.g. MIS 2). The end of flowstone deposition towards the final stage of MIS 3 marks the beginning of a still ongoing hiatus in deposition at the location of the analysed profile.

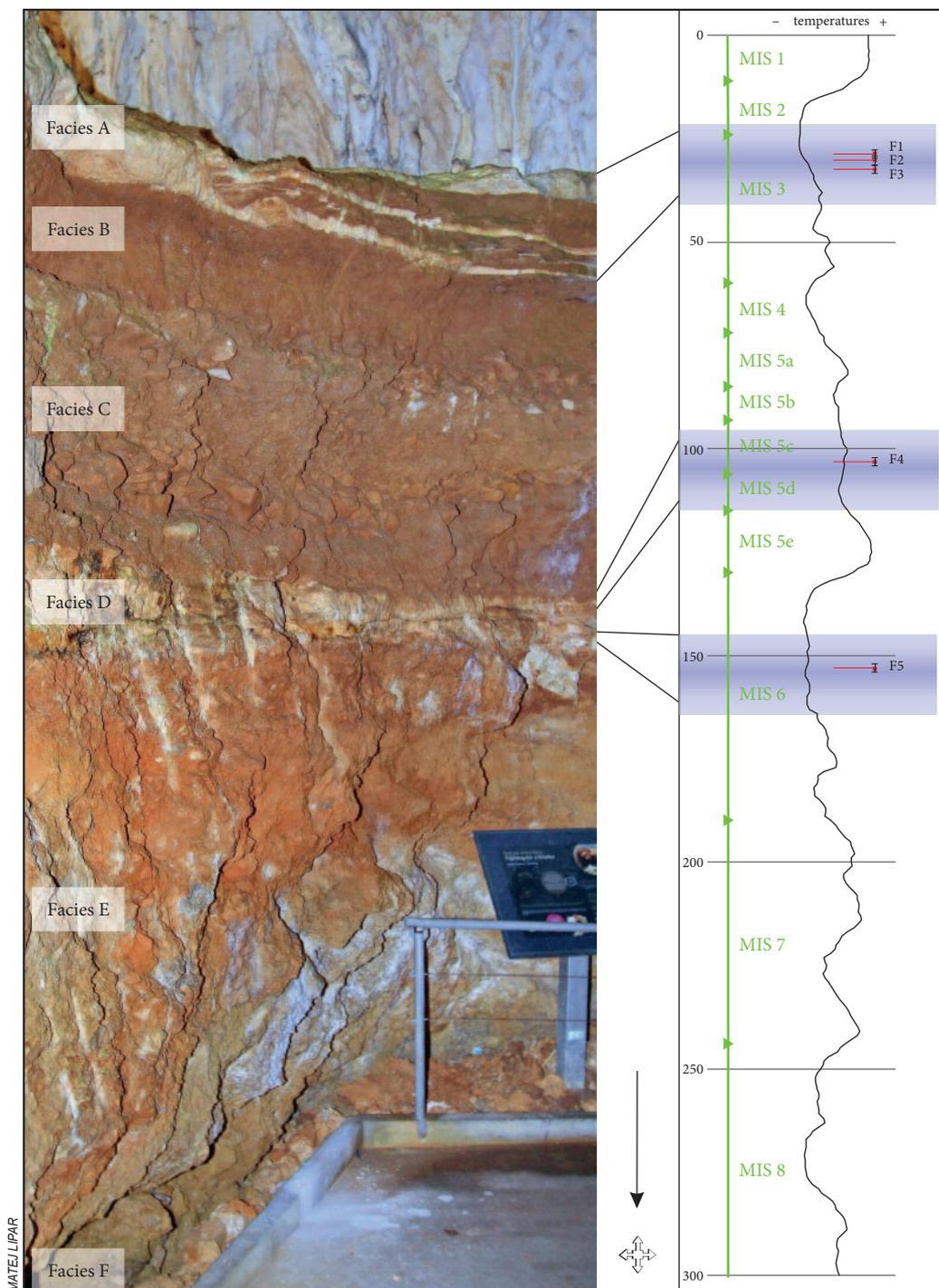
The carbon isotopic values of the flowstone are heavier than the present values (see Section 3.3) and suggest a reduced plant activity compared to a modern vegetation above the cave or a higher proportion of plants more adapted to drought (Gillies 2011), which could be a result of colder climate with less effective precipitation.

Table 4: Results of radiocarbon dating of the topmost flowstone (facies A).

Sample	Measured Radiocarbon Age (BP)	±1RSD	Conventional Radiocarbon Age (BP)	±1RSD	δ13C (‰ PDB)	Calibrated Radiocarbon Age (BP)	±2σ
F1	28410	140	28720	140	-5.9	33165	275
F2	30060	160	30330	160	-8.4	34860	180
F3	32080	180	32360	180	-7.8	36800	240

4 Conclusion

Construction works for touristic purposes in the Postojna Cave led to the exposure of an over 4 metres deep sedimentary succession composed of various cave sediments in the side passage *Rov Novih Podpisov of the Postojna Cave*. Six horizontal stratigraphic levels of depositional facies were identified (bottom to top); subangular gravel (facies F), very angular gravel (facies E), flowstone (facies D), angular gravel (facies C), red silt loam (facies B), and flowstone (facies A).



MATEJ LIPAR

Figure 5: The profile of deposits at the side entrance of the Postojna Cave with the timeline of sediment deposition. The temperature curve is based on data by Friedrich et al. (2016).

Flowstone from two stratigraphic levels (facies A and D) was collected for radiocarbon (3 samples) and uranium-thorium (2 samples) dating, respectively. The dating results show the deposits are older than previously thought. The stratigraphically higher and younger flowstone was deposited in the second half of MIS 3 (33,2–36,8 ka BP), and the stratigraphically lower flowstone was deposited in the second half of MIS 6 (153,1 ka BP) and in MIS 5c (103,2 ka BP). The numerical dates of the flowstone age show its deposition during periods of low average temperatures. Consequently, we argue that despite lower temperatures in these periods the amount of precipitation was probably lower, but still sufficient to allow flowstone deposition.

During MIS 6 and MIS 5c the flowstone deposition was probably occasionally interrupted which is indicated by two distinctive up to 1 cm thick black layers resembling charcoal, stretching throughout the side passage. The black layers could be a cultural deposit attributed to the Neanderthal activities and related to the nearby Palaeolithic site where Mousterian stone tools were found.

The dated facies of flowstone are separated by a 1 m thick layer of gravel (facies C) and a 45 cm thick layer of red silt loam (facies B). The silt loam was sampled for mineral and grain size analyses, proving the sediments origin in flysch rocks from where it was transported into the cave and deposited whether from calm water during floods or overland flow redeposition of aeolian sediment. Both facies between the flowstone layers were deposited between MIS 5c and MIS 3.

Based on the flowstone age, the stratigraphically lowermost layers of gravel (facies F and E) were deposited earlier than 153.1 ka BP. Especially the lowermost subangular gravel (facies F) could reach a significant age, since the upper boundary of the facies shows traces of an erosion phase during which at least some of the gravel was removed before the next depositional phase of gravel deposition begun (facies E).

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