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STRUCTURAL GEOLOGY OF THE ŠKOCJAN CAVES (SLOVENIJA)

STRUKTURNA GEOLOGIJA ŠKOCJANSKIH JAM (SLOVENIJA)

Stanka ŠEBELA[1]

Abstract UDC 911.2:551.44(497.4 Škocjan)

Stanka Šebela: Structural geology of the Škocjan Caves

The Škocjan Caves are developed inside 300 m thick column of Cretaceous and Paleocene limestones. Most of the underground Reka River flows within the 130 m thick Lipica Formation (K_2^{4-5}). Data from field structural geological mapping (1:500) performed in 1991-1992 (Hankejev Kanal) and in 1997-2007 (Tiha and Šumeča Jama) are analysed and presented on a new structural geological map. The Reka River follows bedding-plane strike and dip direction in Šumeča Jama and Hankejev Kanal. From the western part of Hankejev Kanal to the ponor in Martelova Dvorana the Reka River flows perpendicular to strike direction of bedding-planes with dip direction of the bedding contrary to river flow. Bedding-planes with interbedded slips were especially favourable for the development of initial passages. The bend of the Reka River in Hankejev Kanal is developed at the intersection of multiple fault zones. Cross-Dinaric oriented faults in Podorna Dvorana and at northern edge of Martelova Dvorana can potentially be neotectonically active.

Keywords: structural geology, Škocjan Caves, Slovenia.

Izvleček UDK 911.2:551.44(497.4 Škocjan)

Stanka Šebela: Strukturna geologija Škocjanskih jam

Škocjanske jame so razvite znotraj 300 m debelega litološkega stolpca krednih in paleocenskih apnencev. Večina podzemeljske Reke teče znotraj 130 m debele lipiške formacije (K_2^{4-5}). Podatki terenskega strukturno-geološkega kartiranja (1:500) opravljeni v letih 1991-1992 (Hankejev kanal) in med leti 1997-2007 (Tiha in Šumeča jama) so analizirani in predstavljeni na strukturno-geološki karti. Podzemeljska Reka sledi slemenitvi in vpadu plasti v Šumeči jami in Hankejevem kanalu. Od zahodnega dela Hankejevega kanala do ponora v Martelovi dvorani teče podzemeljska Reka pravokotno na slemenitev plasti in v obratni smeri od smeri vpada plasti. Plasti z medplastnimi zdrsi so bile še posebno ugodne za razvoj inicialnih rovov. Koleno, ki ga naredi podzemeljska Reka v Hankejevem kanalu, je razvito tam, kjer se seka več prelomnih con. Prečno dinarsko usmerjeni prelomi v Podorni dvorani in na severnem robu Martelove dvorane so lahko potencialno ugodni za neotektonsko aktivnost.

Ključne besede: strukturna geologija, Škocjanske jame, Slovenija.

INTRODUCTION

The Škocjan Caves (Fig. 1) have always been of a great interest for various researchers. Due to the spacious canyon-like underground channel it has been a challenge for geologists to make a geological map of the cave. Gospodarič was the first who in 1965 described the geology and morphology, and in 1983 published a geologic map of Škocjan Caves Karst. It was a lithologic and structural geologic map of the surface, with a ground plan of the cave and a longitudinal cross section (Gospodarič 1983). Next year the same author (Gospodarič 1984) published a geological map of the cave but without Hankejev Kanal. Detailed structural geological mapping of Hankejev Kanal was performed by Šebela in 1991-1992 and published in Kranjc *et al.* (1992) and of Tiha and Šumeča Jama by the same author in 1997-2007 and presented in Mihevc *et al.* (1998).

[1] Karst Research Institute ZRC SAZU, Titov trg 2, 6230 Postojna, Slovenia, e-mail: sebela@zrc-sazu.si

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Interpretation of aerial photographs (1:5,000 scale) of the overlying topography (Šebela 1994) showed that the most common direction of the underground passages of Reka River corresponds to the most frequent direction of the tectonically broken zones on the surface. The Dinaric trend 285-315° represents 27.16% of detected geological lineaments (Šebela 1994).

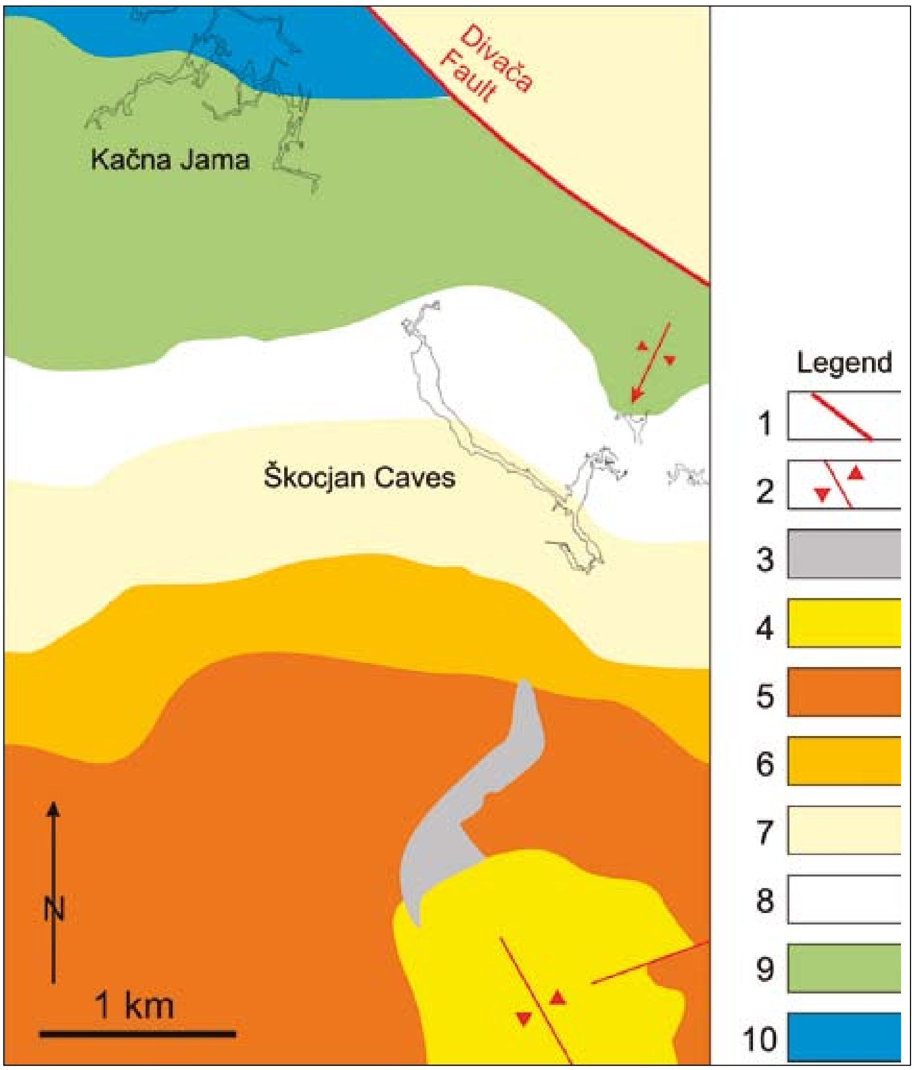


Fig. 1: Stratigraphic map of the area above Škocjan Caves and southern part of Kačna Jama. 1- fault, 2- syncline, 3- alluvium, 4- Eocene flysch, 5- Eocene alveolinid-nummulitid limestone, 6- Slivje limestone (bedded, mainly miliolid limestone) within the Liburnian Formation (Pc), 7- Liburnian Formation (K-Pc), 8- Lipica Formation, bedded and massive limestone with rudist biostromes and bioherms (K_2^{4-5}), 9- Sežana Formation (K_2^{2-4}), 10- Repen Formation ($K_2^{1,2}$). Compiled by S. Šebela after Jurkovšek et al. 1996.

In 1996 and 1998 Knez published results on the bedding-plane impact on development of initial channels in the example of Velika Dolina collapse doline. Cave passages or their fragments and other traces of the underground karstification do not appear scattered at random on the walls but they are obviously gathered along only 3 formative bedding-planes (Knez 1996). The inception occurred along interbedded slips that pushed the beds aside leaving an interval (Knez 1996).

The structural-lithological data from geological map of the surface above the cave (Gospodarič 1983) and the data from the cave (Gospodarič 1984) were used for schematic geological sketch of the surroundings of Škocjan Caves that was completed by Knez (Knez & Slabe 1999; Knez & Šebela 2004).

Gospodarič's (1983) geological map and the new survey of Hankejev Kanal and Martelova Dvorana, accomplished in 1998, were presented by Mihevc (1998, 2001). The same author (Mihevc 2001) determined the predecessor of the present Škocjan Caves as the roofless cave Brezstropa Jama in Lipove Doline lying above the caves. Škocjan Caves are in the massive limestone with sporadic tectonised bedding-planes. Along them in phreatic conditions initial passages formed being connected by phreatic shafts and developed in fractured zones (Mihevc 2001).

Mihevc (1998, 2001) correlated tectonised bedding-planes (marked with numbers 300-700) with the formation of different cave passages. In the stratigraphic column the bedding-plane marked by number 300 is the highest. Within bedding-plane 300 the upper elliptical part of the Hankejev Kanal is developed. The lower bedding-plane numbered 400 influenced the formation of phreatic passage Tunel. The ponor entrance of Reka River in Velika Dolina is developed in bedding-plane 500. Tominčeva Jama follows bedding-plane number 600.

In 2007 (Gabrovšek *et al.*) structural geology of Brihta Jama was accomplished.

Detailed structural mapping was presented in 2008 (Rijavec) to recognise major tectonic structures, which influenced the development of the cave system Škocjan Caves-Kačna Jama.

Some characteristics of development of Škocjan Caves can be visible from calculated denudation rates in karst (Gabrovšek 2007) and from the age of karst relief in W Slovenia reported by Mihevc (2007).

For this article data from field geological mapping performed by S. Šebela in 1991-1992 (Hankejev Kanal) and in 1997-2007 (Tiha and Šumeča Jama) are analysed and presented on Fig. 2. The principal method was detailed structural-geological mapping (field mapping at scale 1:500) introduced by Čar (1982) and verified in more caves in Slovenia, as for example in Predjama (Šebela & Čar 1991) and Postojna Cave (Šebela 1998, 2008).

GEOLOGICAL CHARACTERISTICS

LITHOSTRATIGRAPHY

The oldest rocks in the surrounding area of Škocjan Caves (Fig. 1) are Turonian limestones of Repen Formation ($K_2^{1,2}$), representing Pelagic limestone (bedded, mainly micritic limestone with pelagic microfossils) and massive partly recrystallized limestone with displaced rudist shells (Repen; Jurkovšek *et al.* 1996).

Above this in the stratigraphy is Turonian-Senonian Sežana Formation (K_2^{2-4}), which holds the NE part of the cave (Schmidlova Dvorana, Tominčeva Jama, Mahorčičeva and Mariničeva Jama; Fig. 2). Gospodarič (1984) described this unit as thick-bedded Turonian limestone. The Sežana Formation (Jurkovšek *et al.* 1996) represents bedded limestone with rare rudist biostromes. Šumeča Jama and Hankejev Kanal are (Figs. 1 and 2), according to Gospodarič (1984) developed in massive Senonian limestone. This is the Lipica Formation (Jurkovšek *et al.* 1996), representing bedded and massive limestone with rudist biostromes and bioherms (K_2^{4-5}). Gospodarič (1984) determined that the thin-bedded limestone from Maastrichtian and Danian age (K_2^4+Pc_1) are the youngest in Škocjan Caves (southern part of Velika Dvorana). Jurkovšek *et al.* (1996) described this unit as the Liburnian Formation (K-Pc) with bedded and platy limestone, marly limestone and limestone breccia.

On the surface south of the underground passages of Škocjan Caves (Fig. 1) the next outcrop in the stratigraphic column is the Slivje limestone (bedded, mainly miliolid limestone) within the Liburnian Formation. This Eocene alveolinid-nummulitid limestone is mostly bedded with local limestone with chert and limestone with lithothamnians, corals and hydrozoans. The last two units are Eocene flysch (alternation of marls, sandstone, breccia and conglomerate) and alluvium (Jurkovšek *et al.* 1996).

Regarding Fig. 1 we need to emphasize that limestone bedding-planes on the surface above the Škocjan Caves generally dip towards the SW. The syncline (oriented NE-SW) south from Divača Fault was identified on the surface by Jurkovšek *et al.* (1996) and its axis is reported to end north from Tominčeva Jama. According to strike and dip data of bedding-planes in the cave, gently folded bedding-planes (Fig. 2) south of Müllerjeva Dvorana can represent frictional folds connected with folding deformations.

The karst of Škocjan Caves is developed in limestones of a WNW-ESE oriented monocline, with fault systems mainly having NW-SE and NNE-SSW directions (Gospodarič 1983).

The monocline dips towards the S-SW under Eocene flysch near Dane, about 2 km south from Škocjan Caves. The bedding-planes inside the monocline are rather uniformly oriented from NNW towards SSE, dipping 20-35° towards the SSW (Gospodarič 1983).

TECTONICS

Regarding its geotectonic position, the area of Škocjan Caves belongs to the External Dinarides (Poljak 2000), for which folding and overthrusting towards the south and SW is typical. According to Placer (1981) the area of Škocjan Caves is part of the parautochthon of the Komen thrust sheet, that includes Trieste-Komen anticlinorium. The last one consists of larger and smaller folds (Jurkovšek *et al.* 1996).

The most important regional faults in the area are the Dinaric oriented (NW-SE), Raša and Divača Faults (Fig. 3). The Raša Fault has a multiphase kinematic development. During the first phase it was a reverse fault with the overthrusting tendency towards the SW. During relaxation of regional pressures individual parts of the fault acquired gravitational character, and in the last phase it evolved into the strike-slip fault (Jurkovšek *et al.* 1996).

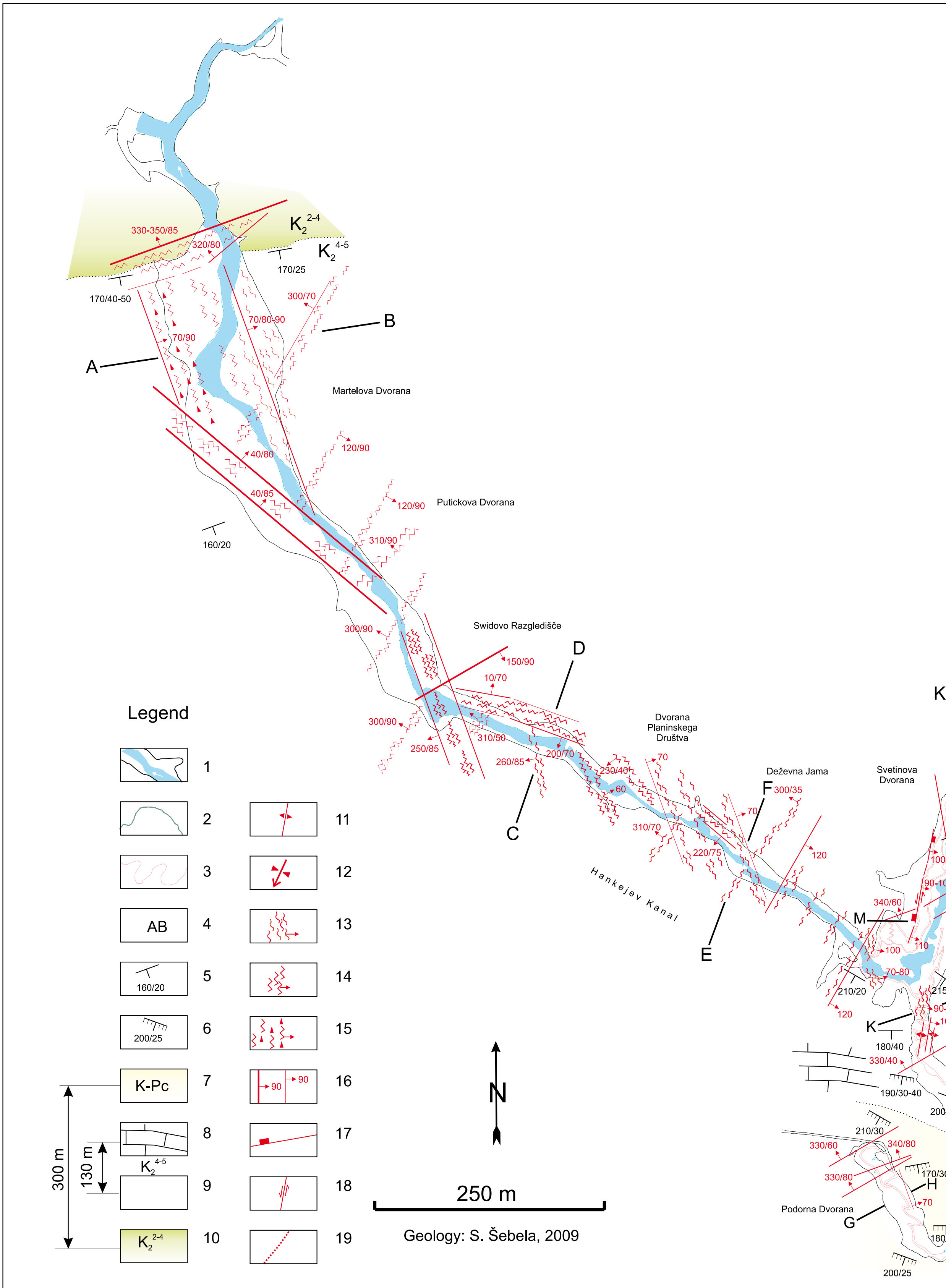
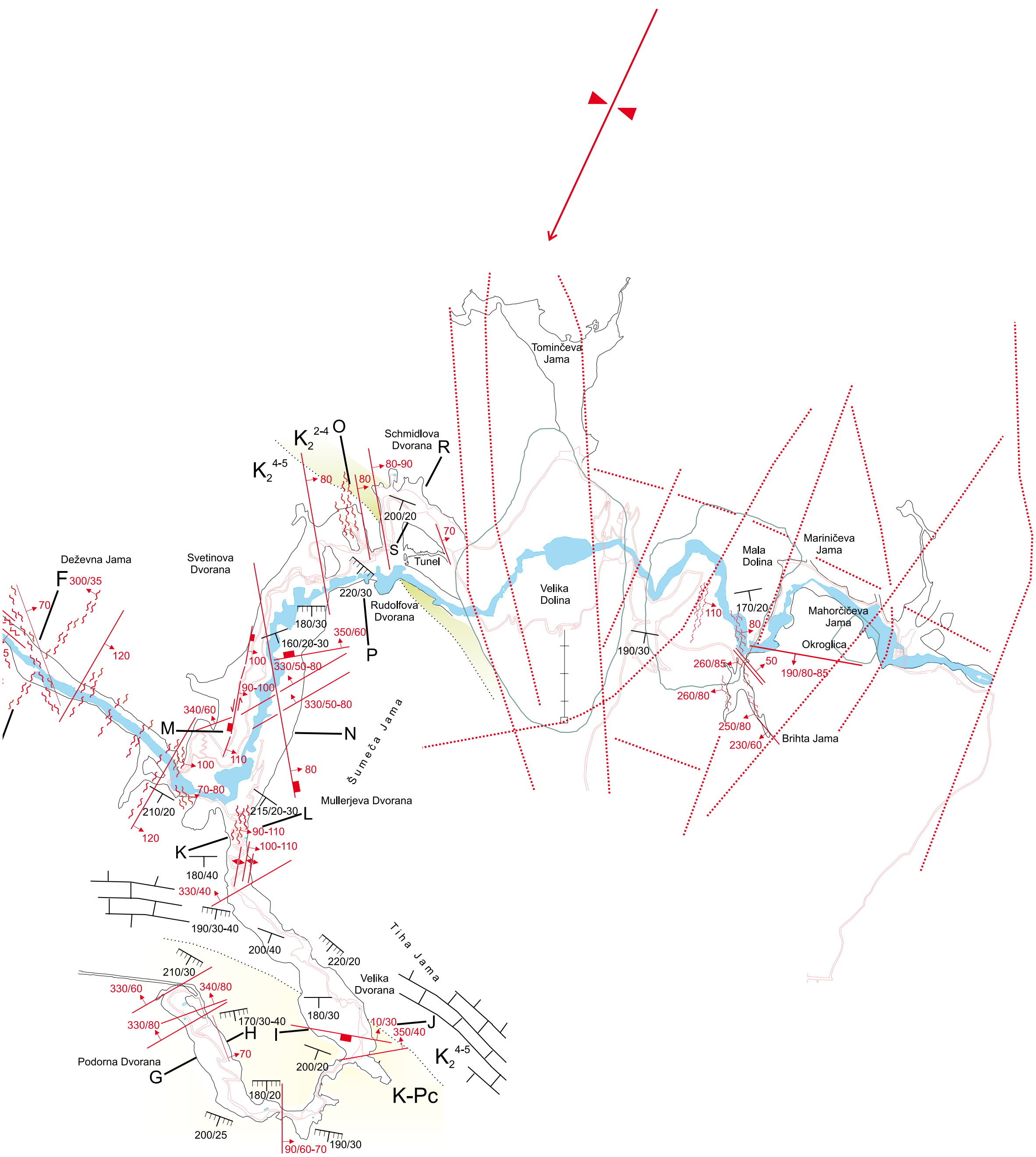

Legend
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
AB
160/20
200/25
K-Pc
300 m
130 m
250 m
Geology: S. Šebela, 2009
N
Martelova Dvorana
Putickova Dvorana
Swidovo Razgledišče
Dvorana Planinskega Društva
Deževna Jama
Svetinova Dvorana
Podorna Dvorana
Hankejev Kanal
A
B
C
D
E
F
G
H
K
M
330-350/85
320/80
170/25
170/40-50
300/70
70/80-90
70/90
40/80
40/85
120/90
310/90
300/90
150/90
10/70
250/85
310/50
260/85
200/70
230/40
220/75
300/35
340/60
210/20
180/40
330/40
190/30-40
210/30
330/60
340/80
330/80

Fig. 2: Structural geology of Škocjan Caves. 1- cave passage with water flow direction, 2- collapse doline, 3- trail, tourist path, 4- cross section, 5- strike and dip direction of bedding-plane, 6- strike and dip direction of interbedded slip, 7- Liburnian Formation, thin bedded limestone (K-Pc), 8- Lipica Formation, bedded limestone (K_2^{4-5}), 9- Lipica Formation, thick bedded and massive limestone (K_2^{4-5}) 10- Sežana Formation, bedded limestone (K_2^{2-4}), 11-anticline, 12- syncline, 13- fissured zone, 14- broken zone, 15- crushed zone, 16- well expressed fault with dip direction/less expressed fault with dip direction, 17- fault with vertical movement, subsidence of northern block, 18- fault with horizontal sinistral movement, 19- faults determined from aerial photography (Šebela 1994). Geology by S. Šebela, cave map by F. Drole (1997).



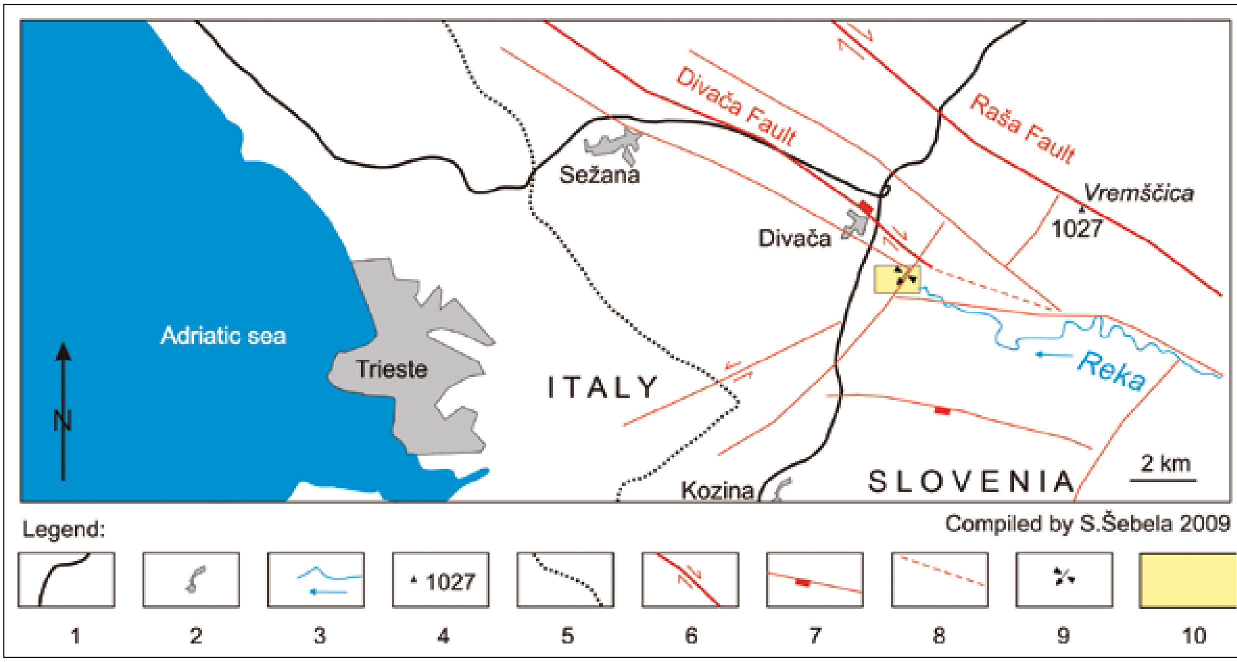


Fig. 3: Structural geological map of the wider area of Škocjan Caves, SW Slovenia. 1- highway, 2- town, 3- river with flow direction, 4- mountain with altitude in metres, 5- border line between Italy and Slovenia, 6- fault zone with horizontal movement, 7- fault zone with vertical movement, 8- supposed fault zone, 9- syncline axis, 10- area of Škocjan Caves (Fig. 2). Compiled by S. Šebela after Jurkovšek et al. 1996; Placer 1981, 2007; Poljak 2000.

In 2004 a TM 71 extensometer was installed at the SE foot of Vremščica to monitor the Raša Fault. The average reverse uplift of the hanging wall (SW) block is 0.24 mm/year, with a left-lateral displacement of 0.16 mm/year (Gosar 2007).

The position of Divača Fault NW from Divača (Fig. 3) is clear, but its SE continuation has different interpretations. Placer (1981) evaluated the principal tectonic zone running 1-2 km north from Škocjan Caves and the Reka River. Close to Gornja Košana the Divača Fault unites with the Raša Fault (Placer 1981). Poljak's (2000) structural-tectonic map shows three principal fault lines of the Divača Fault zone. The northern one joins the fault that runs parallel with the Reka River and unites with Raša Fault about 1.5 km SE from Ribnica village.

According to Jurkovšek *et al.* (1996) the Divača Fault runs about 1 km north from Tominčeva Jama of Škocjan Caves. The flanks of Divača Fault indicate a shear slide. Evidence of overthrusting, normal subsidence and horizontal movements are present (Jurkovšek *et al.* 1996).

Rijavec (2008) detected a NNW-SSE oriented fault zone situated about 200 m east of the ponor of Reka River that cuts several faults of Divača Fault zone and displaces them (with dextral horizontal movement) for 250-500 m.

Within the studied area two basic groups of tectonic structures are presented. The first were formed during the Cretaceous-Paleogene compression in the NE-SW direction and represent Dinaric structures as regional folds of NW-SE direction and reverse faults of the same orientation. During relaxation phases some reverse faults acquired normal faulting. During that time also cross-Dinaric normal faults were formed. The second deformations resulted from regional compression in the general N-S direction during the Neogene and Quaternary, which is expressed as strike-slip faults in a NW-SE orientation (Jurkovšek *et al.* 1996).

STRUCTURAL GEOLOGICAL MAPPING OF THE ŠKOCJAN CAVES

For detailed structural geological mapping, cave maps at the scale 1:500 (Karst Research Institute ZRC SAZU) were used. The field geological data of Hankejev Kanal and Martelova Dvorana were collected from 11 September 1991 to 5 February 1992 and for the rest of the cave from 1997 to 2007.

The challenges to detailed structural geological mapping of Škocjan Caves cannot be compared to any other cave. Martelova Dvorana for example has a volume of 2.100,000 m^3 and is the largest underground chamber of the Classical Karst. It is 308 m long and up to 123 m wide, having an average width of 89 m. On average, the chamber roof is 106 m high. The highest point of the chamber is 146 m. Its lowest point is at 214 m above sea level (Mihevc 1995). Geological mapping was done mostly along the trails. Some geological elements were estimated on the distance from the ceiling of the passages. We need to take into account that some geological structures are curved in the vertical as well as the horizontal sense. In such cases average strike and dip directions were used.

Nine cross sections with geological data are presented (Fig. 4) to better understand the size and position of different cave passages. All cross sections are referenced at the same altitude, 270 m, which represents the ponor of the Reka River at the western part of Velika Dolina. The top of cross section AB running through Martelova Dvorana (Fig. 4) is situated 60-70 m below the land surface, and the top of EF is about 100 m below the surface.

Cave passages are developed within a 300 m thick package of limestones (Fig. 2) that are generally dipping SW, with local dips towards south and SE. The bulk of cave passages are related to the underground Reka River flow that runs through 130 m thick Lipica Formation.

In Velika and Mala Dolina and in Šumeča Jama most of the bedding-planes dip towards the SW at 20-30°. In southern part of the cave in Tiha Jama bedding-planes are dipping towards the SW or south at 20-40°. Hankejev Kanal is developed in massive limestone (lower part of the Lipica Formation). In Martelova Dvorana some measurements of bedding-planes were possible showing that the thick-bedded limestone dips towards the SE at 20-50°.

Jurkovšek *et al.* (1996) indicated a SW plunging syncline (Figs. 1 and 3). The syncline starts south Divača Fault and ends before entering Tominčeva Jama. Regarding the synclinal axis orientation, it originates from Neogene and Quaternary (Jurkovšek *et al.* 1996). As for strike and dip of bedding planes in the cave (Fig. 2) a gentle synclinal axis can be determined NW from Šumeča Jama, which is about 200 m west of the position of the syncline on the map of Jurkovšek *et al.* (1996).

In Tiha Jama, just south from Müllerjeva Dvorana (Fig. 2) two gentle anticlinal (Fig. 5) axes with orientations of 10-20° east from north were determined. They represent local deformations, small-scale frictional folds probably that may correspond to the SE end of the wider deformation zone of the synclinal axis. We can speak about gently folded bedding-planes.

Gospodarič (1983) described that the Škocjan Caves are developed within the monocline.

The monocline and syncline are probably Neogene and Quaternary in age. The monocline, syncline and small frictional folds are all evidences of folding and thrusting deformations.

Another important evidence of folding is interbedded slips (Fig. 6). Gospodarič (1983) wrote about numerous bedding-planes transformed into tectonic mirrors and faults. Knez (1996, 1998) introduced the so called formative bedding-planes with interbedded slips in the example of Velika Dolina. Mihevc (2001) connected five tectonised bedding-planes with the initial formation of different cave passages. Detailed structural geological mapping of cave passages (Fig. 2) established that most of interbedded slips occur in Tiha Jama and some in Šumeča Jama with 20-40° of dip direction mostly towards SW.

Beside folds and bedding-planes especially those tectonised, faults and fissures are also important for the formation of cave passages. On the surface above Škocjan Caves the carbonate rocks are broken and trending NW-SE and NNE-SSW. Fault planes are very steep and undulated, and of mostly wrench-fault character (Gospodarič 1983).

Prominent tectonic lineaments determined by aerial photography (Šebela 1994) run over the collapse dolines, such as Mala and Velika Dolina, and have a general N-S, or NNE-SSW trend. A second general trend is tectonic deformations in the Dinaric orientation NW-SE.

In Podorna Dvorana and Tiha Jama (Fig. 2) prevailing joints have cross-Dinaric orientation (Fig. 7). A well-expressed N-S oriented fault (Fig. 8) is situated between Podorna and Velika Dvorana. In the southern part of Velika Dvorana a reverse fault (10/30°) was identified. In Šumeča Jama prevailing faults and fissures are NNW-SSE and cross-Dinaric oriented. Along some faults it was possible to detect vertical and normal faulting. On a N-S oriented fault (90-100°) at least three different movements were detected. On the southern end of the fault there are traces of vertical movement (subsidence of NW block); in the middle there was horizontal sinistral-lateral movement and at northern end of the fault there was vertical movement (subsidence of SE block). In the chamber of massive gours (north from Rudolfova Dvorana) fissured zone with dip direction of 80° was detected. The same joint direction can be followed in the direction towards Velika Dolina.

In Velika and Mala Dolina structural geological lineaments were determined by analysis of aerial photography (Šebela 1994). Through Velika Dolina the direction of almost N-S prevailes, and through Mala Dolina the direction of N25 °E is the most frequent (Fig. 2). Some

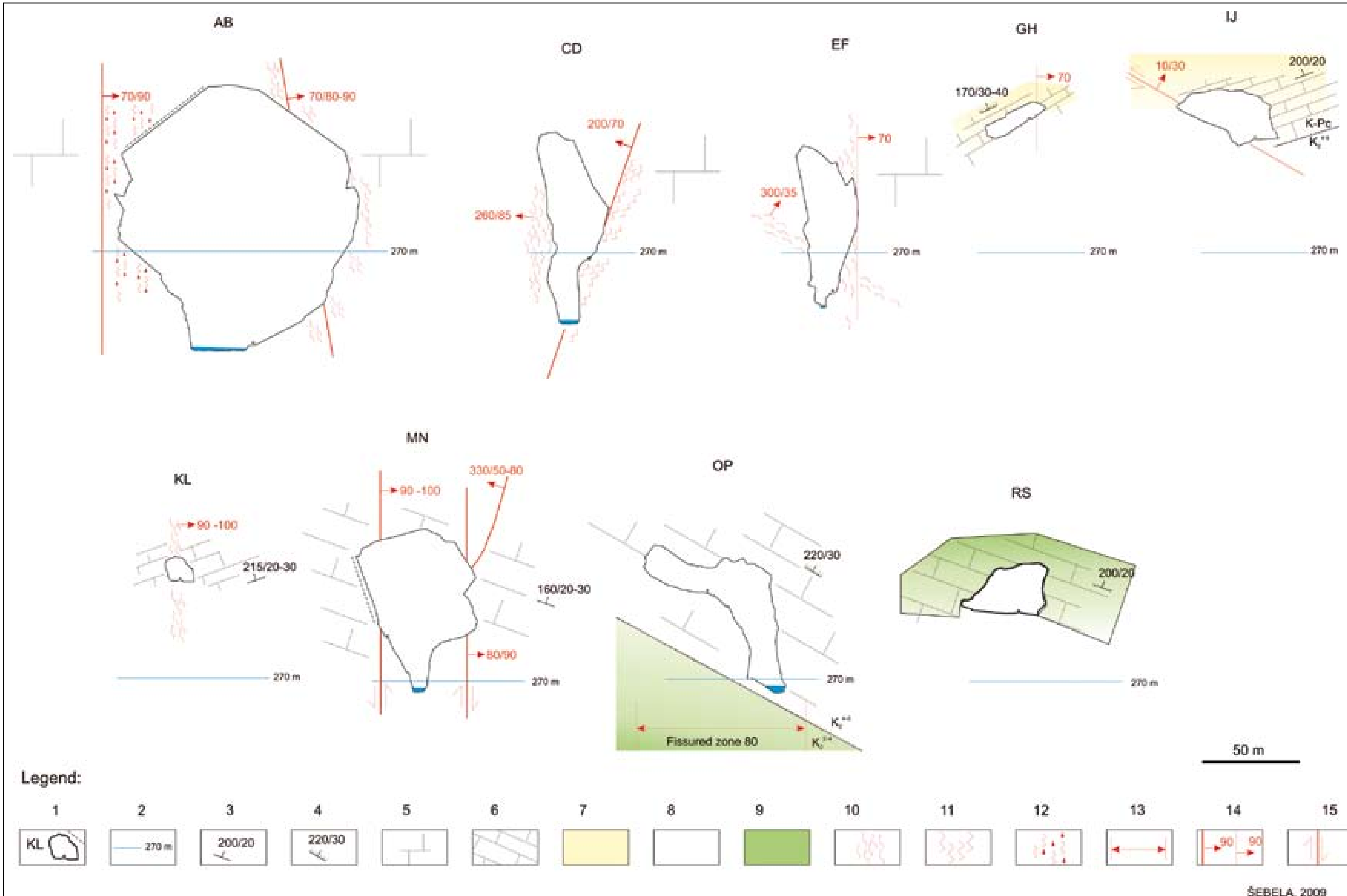


Fig. 4: Geology of nine cross sections. 1- cross section, dash line does not show the real profile, 2- altitude above sea level of the ponor at W side of Velika Dolina, 3- strike and dip direction of bedding-plane, 4- strike and dip direction of interbedded slip, 5- massive to thick bedded limestone, 6- bedded limestone, 7- Liburnian Formation (K-Pc), 8- Lipica Formation, (K_2^{4-5}), 9- Sežana Formation (K_2^{2-4}), 10- fissured zone, 11- broken zone, 12- crushed zone, 13-fissured zone with dip direction 80°, parallel to the cross section OP, 14- well expressed fault with dip direction/less expressed fault with dip direction, 15- vertical displacement of fault.

Fig. 5: Gentle folds in Tiha Jama, thickness of bedding-planes = 0.7 m (Photo: S. Šebela).

lines are not straight but curved. Cross-Dinaric oriented tectonic lines are detected on the northern edge of Velika and Mala Dolina. The most eastern fault line running through the Reka ponor (Fig. 2) corresponds to the wider fault zone that, according to Rijavec (2008), cuts and displaces Divača Fault.

Fig. 6: Tectonised bedding-plane, Okno between Velika and Mala Dolina (Photo: S. Šebela).

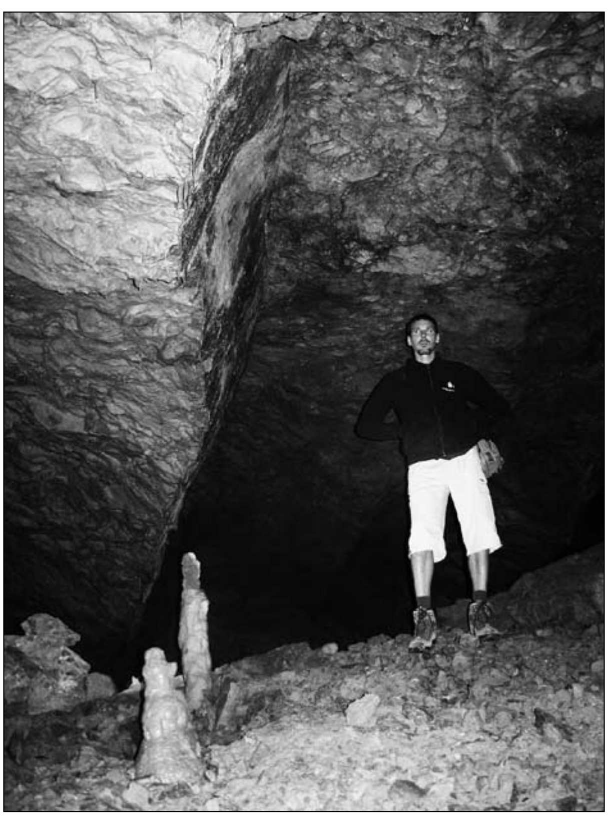


Fig. 7: Cross-Dinaric oriented fault in Podorna Dvorana (Photo: S. Šebela).

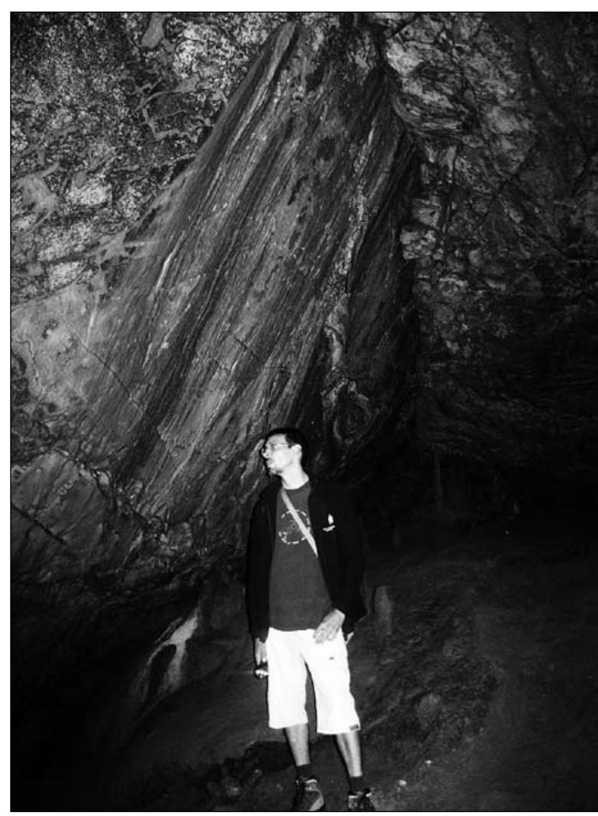


Fig. 8: North-south oriented fault between Podorna Dvorana and Velika Dvorana (Photo: S. Šebela).

In 2007 (Gabrovšek *et al.*) Brihta Jama and the western part of Mariničeva Jama were mapped to determine the geological and geomorphological characteristics of a well-expressed and well-known fault line coming from the surface to the SE edge of Mala Dolina (Figs. 9 and 10). The same fault has already been mentioned by Pavlovec (1965-66) as a very clear example of a curved tectonic line coming from the surface to the underground

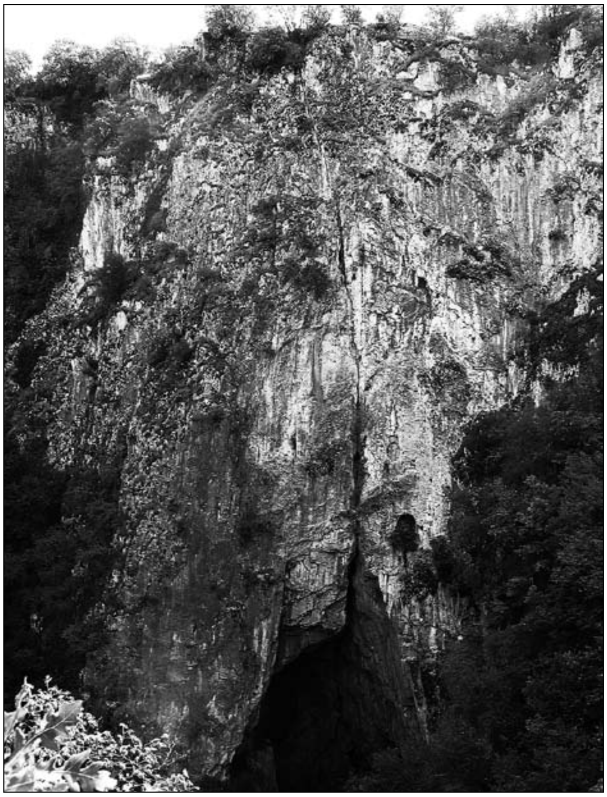


Fig. 9: Fault with general direction of E-W and dip direction towards SW in SE brink of Mala Dolina (Photo: S. Šebela).

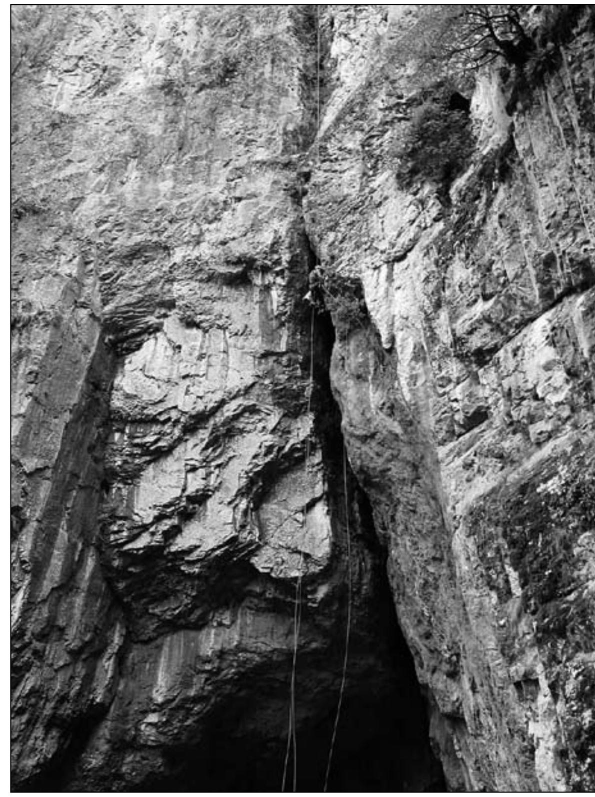
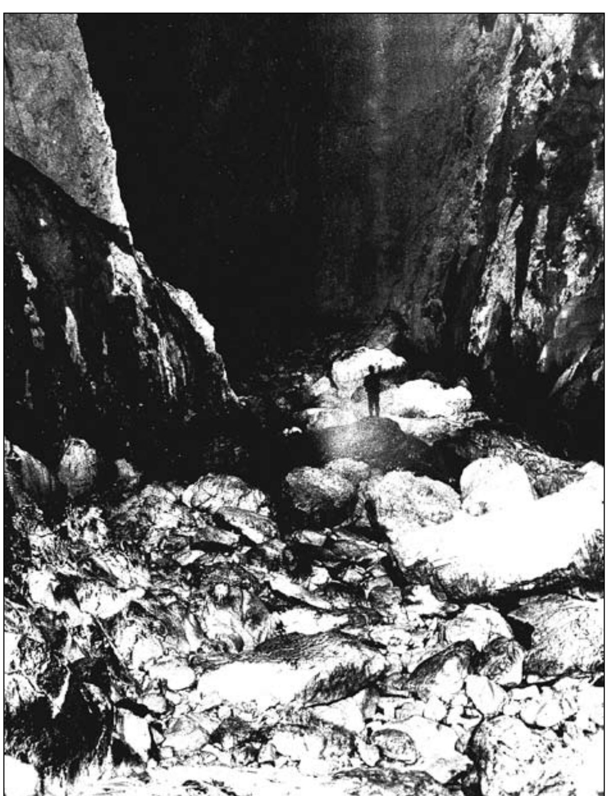


Fig. 10: Close look of the same fault as on Fig. 6. Western part of Mariničeva Jama (Photo: S. Šebela).



cave. On a geological map done by Gospodarič (1984) the fault with general direction E-W dips towards the SW and runs from Mahorčičeva Jama to Okroglica, which is in accordance with the data presented on Fig. 2. The Western end of the fault is on the western brink of Mala Dolina, where it is cut by a N-S oriented fault (Gospodarič 1984). Regarding field data (Fig. 2), the E-W oriented fault stops already on the eastern edge of Velika Dolina, where it is cut by fissured to broken zone in general N-S orientation.

In 1983 Gospodarič determined the prevailing two systems of tectonic zones in the cave to be strike-slip faults in NNE-SSW and WNW-ESE directions. The same author mentioned »into faults transformed bedding-planes« and »short dislocations in E-W direction«.

Detailed structural geological mapping (Fig. 2) confirmed Gospodarič's (1983) well-expressed short dislocations in the E-W direction. The E-W oriented fault from Mala Dolina can be traced 800 metres farther to the west

Fig. 11: Southern part of Martelova Dvorana, loking towards south (Photo by courtesy of Karst Research Institute ZRC SAZU).

in Hankejev Kanal as strong broken zone (Fig. 2). In the southern part of Velika Dvorana in Tiha Jama the fault 10/30 with reverse vertical displacement can probably be correlated with the same tectonic phase as the E-W oriented fault from Mala Dolina. Such structures are probably remaines of older tectonic phases because they are cut by younger structures and preserved just as short dislocations.

In Brihta Jama two fault systems were found. The southern system is 230/60, and the northern 250-260/80 (Fig. 2). At the entrance to Brihta Jama there are strong parallel faults 50/90 and 260/85. All these tectonic structures cut an E-W oriented fault.

In Hankejev Kanal fissured and broken zones in Dinaric and cross-Dinaric orientation prevail (Fig. 2). Dinaric oriented zones generally cut cross-Dinaric ones, but locally both zones can interweave. At Swidovo Razgledišče a strong broken zone in Dinaric orientation (250/85) is dipping towards SW. The subvertical cross-Dinaric fault (150/90) cuts the zone 250/85 but with no reliable indication of displacement. The southern part of Putikova Dvorana is developed inside broken zone with dip direction 40° and dip angle of 80-85° towards NE. The northern part of Martelova Dvorana morphologically follows strong broken zone 320-330/80-85 that cuts all other structures. The widest part of Martelova Dvorana (Fig. 11) is developed within a Dinaric oriented tectonic zone, 70/80-90, that is crushed at the western side and fissured at the northern side.

CONCLUSIONS

The long-held desire to accomplish a detailed structural geological map of Škocjan Caves, as has already been done in the case of Postojna Cave (Šebela 1998), is finally making progress. In the sense of Čar's method (1982), detalied structural geological mapping at the scale 1:500 was performed and results are given on Figs. 2 and 4.

The cave system (5,800 m) contains a 3,500 m long canyon-like water channel (ponor 317 m, siphon 214 m) and as well as dry galleries in two levels (310 m and 330 m altitude) where fossil allochthonous and autochthonous sediments are preserved. The underground channels are connected with two 140 m deep collapse dolines (Velika and Mala Dolina) and interrupted by other near lying collapse dolines.

The passages of Škocjan Caves are developed within 300 m thick lithologic column of Cretaceous and Paleocene limestones (Fig. 2). Most of the water channel, including the majority of Šumeča Jama, Hankejev Kanal and Martelova Dvorana, is developed within the 130 m thick Lipica Formation (K_2^{4-5}).

In previous studies Gospodarič (1965, 1983, 1984) made important contributions to the structural geological knowledge of the cave. Knez (1996, 1998) and Mihevc (2001) emphasized the importance of bedding-planes with interbedded slips in the formation of initial cave passages.

Fig. 2 is the first published complete detailed structural-geological map of the Škocjan Caves. It is the result of more years long field mapping and interpretation of aerial photography, both performed by S. Šebela, which was partially presented in Kranjc *et al.* (1992), Šebela (1994) Mihevc *et al.* (1998) and in Gabrovšek *et al.* (2007).

Regarding strike and dip of bedding-planes in the cave (Fig. 2) a gentle synclinal axis was identified NW of Šumeča Jama that is about 200 m west of the position in the map of Jurkovšek *et al.* (1996). Small folds (Fig. 5) were found south of Müllerjeva Dvorana. They represent local deformations, small-scale frictional folds that might correspond to the SE end of the wider deformation zone of synclinal axis. Interbedded slips are probably related to the formation of syncline and small frictional folds and are evidences of folding and thrusting deformations.

By detailed structural geological mapping of the cave passages some interesting slickensides were detected. A reverse fault (10/30) is found in the southern part of Velika Dvorana and a normal fault (350/60) is present in Šumeča Jama. Such fault directions are also visible in Hankejev Kanal and at the northern end of Martelova Dvorana. In Šumeča Jama they are cut by virtually N-S oriented faults, but in Hankejev Kanal they can cut other structures.

In Šumeča Jama on a N-S oriented fault (90-100°) at least three different tectonic movements were detected. On the southern end of the fault this was vertical movement (subsidence of the NW block). In the middle zone horizontal sinistral-lateral movement was found, and at the northern end of the fault vertical movement (subsidence of SE block) has occurred.

The most known (Pavlovec 1965-66; Gospodarič 1983) well-expressed short dislocation in the E-W direction is visible on the eastern side of Mala Dolina (Figs. 9 and 10) and can be traced 800 metres farther to the west in Hankejev Kanal as a definitive broken zone (Fig. 2).

Such structures are probably remaines of older tectonic phases because they are cut by younger structures and preserved just in short dislocations.

The Reka River follows bedding-plane dip direction in Šumeča Jama and the strike direction of bedding-planes in Hankejev Kanal. From the western part of Hankejev Kanal to the ponor in Martelova Dvorana the underground Reka River flows perpendicular to strike direction of bedding-planes with dip direction of the bedding contrary to river flow. Bedding-planes with interbedded slips were especially favourable for the development of initial passages.

The bend of the underground Reka River in Hankejev Kanal is developed at the junction of more fault zones. The zone 250/85 cuts the zone 10/70-200/70. There are also well-expressed faults in general cross-Dinaric trends that can be subvertical or can dip towards NW for 50-70°.

Are there any faults that were active after the formation of cave passages? There are no really good examples, but the most likely candidates appear to be cross-Dinaric oriented faults in Podorna Dvorana (330/60, 340/80 and 330/80; Fig. 7) and a cross-Dinaric oriented fault (330-350/85) that forms the northern edge of Martelova Dvorana (which is responsible for morphological lowering of the underground chamber into the siphon passages). The fact is that faults in Podorna Dvorana are very close to Globočak collapse doline and might be connected with relaxation processes. On the other hand Placer (2007) and Poljak (2000) determined cross-Dinaric oriented faults (Fig. 3) running into the studied area. Also Mihevc (2007) described blind valleys that are about 15-20 km SE from the Škocjan Caves, which show the influence of recent tectonics.

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