CAVES, DENUDED CAVES AND COLLAPSE DOLINES AS PAST HYDROLOGICAL PATTERN INDICATORS OF THE GRABOVICA PLATEAU, THE DINARIC KARST (BOSNIA AND HERZEGOVINA)

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Abstract
The Grabovica Plateau is a corrosion plain in southern Bosnia and Herzegovina. The whole area is characterised by a through-flow karst system, where subsurface streams submerging at Duvanjsko polje are directed towards springs at Livanjsko polje. In this study, we conducted morphographic and morphometric investigation of surface and subsurface features, especially collapse dolines, denuded caves along with active and inactive cave systems. We interpreted morphogenesis and past hydrologic pattern within the area.

Keywords: collapse doline, denuded cave, geomorphology, speleology, hydrology

JAME, DENUDIRANE JAME IN UDORNICE KOT KAZALNIKI NEKDANJEGA HIDROLOŠKEGA DELOVANJA PLANOTE GRABOVICA (BOSNIA IN HERCEGOVINA)

Izvleček
Planota Grabovica je korozijska uravnava v južnem delu Bosne in Hercegovine. Za celotno območje je značilen pretočni kras, kjer podzemni tokovi, ki ponikajo na Duvanjskem polju, odtekajo v smeri izvirov na Livanjskem polju. V tej raziskavi smo izdelali morfografske in morfometrične analize površinskih in podzemskih oblik, predvsem udornic, denudiranih jam ter aktivnih in reliktnih jamskih sistemov. Interpretirali smo morfogenezo in preteklo hidrološko delovanje proučevanega območja.

Ključne besede: udornica, denudirana jama, geomorfologija, speleologija, hidrologija

1 INTRODUCTION

The Dinaric Alps are located in the western Balkan Peninsula almost parallel to the eastern Adriatic coast. They are a large contiguous mountain range elongated in the northwest-southeast direction, with a total length of 645 km and a width of approximately 150 km. The Dinaric Alps are divided into distinct stripes where surface morphology as well as hydrology are significantly influenced by local lithological settings. Fluvial relief on non-carbonate rocks prevails in the inland and towards the east while central and western parts of the Dinaric Alps typically host karstified carbonate bedrock. The part of the Dinaric Alps that exhibits well-developed karst is usually referred to as the Dinaric Karst (Mihevc, Prelovšek, 2010). Characteristic features associated with the Dinaric Karst are extensive mountain ranges, large corrosion plains and intramontane basins that host karst poljes (Bognar, 1992; Bonacci, 2004; Bognar, 2006; Mihevc, 2010; Pahernik, 2012; Bonacci, 2013). Surface is dissected by middle and small-scale karst features such as dolines, collapse dolines, uvalas, denuded caves, canyons and dry valleys.

The Grabovica Plateau is situated within the Dinaric Karst between Livanjsko and Duvanjsko Polje in the southern Bosnia and Herzegovina. It is expressed as a levelled corrosion plain built of karstified carbonate bedrock with surface positioned high above the watertable level and as such differentiated from the surrounding landscape. Bulk of waters from Duvanjsko Polje in the east are submerging into one ponor and are flowing in the subsurface westwards towards the springs in a wide steephead valley on the southern part of Livanjsko Polje. Therefore the area is an example of through-flow karst.

The Grabovica Plateau is well recognised within the Dinaric Karst for its high density of large collapse dolines that are erratically dispersed upon the plateau. Those huge collapse dolines are locally known as *samogradi* (singular: *samograd*; plural: *samogradi*). Up to now some speleological investigations regarding collapse dolines, ponors and spring cave systems were conducted in this area (Malez, 1964; Božičević, 1971; Božičević, 1985; Kovačević, 2013; Ozimec, 2015). However, none of them has applied an integral approach to study these features as palaeoenvironmental indicators.

During systematic geomorphologic investigation, we encountered a series of extensive denuded cave systems on roughly planated surface of the Grabovica Plateau. Those systems are among the longest identified denuded cave systems within the Dinaric Karst so far. Denuded caves, active and inactive cave systems and collapse dolines are direct indicators of past and present hydrologic function of the areas with developed subsurface drainage, especially the areas of through-flow karst. Together with previously provided morphochronological (Mandić et al., 2013) and speleological data (Šumanović, Buntić, 2013; Marković, Ozimec, 2017) it is conceivable to reconstruct geomorphologic dynamics along with hydrologic functioning of the area. This reconstruction is the main aim of our research and we successfully achieved this through systematic morphographic, morphometric and morphostructural analysis of subsurface cave systems, collapse dolines and denuded cave systems on the surface.

2 STUDY AREA

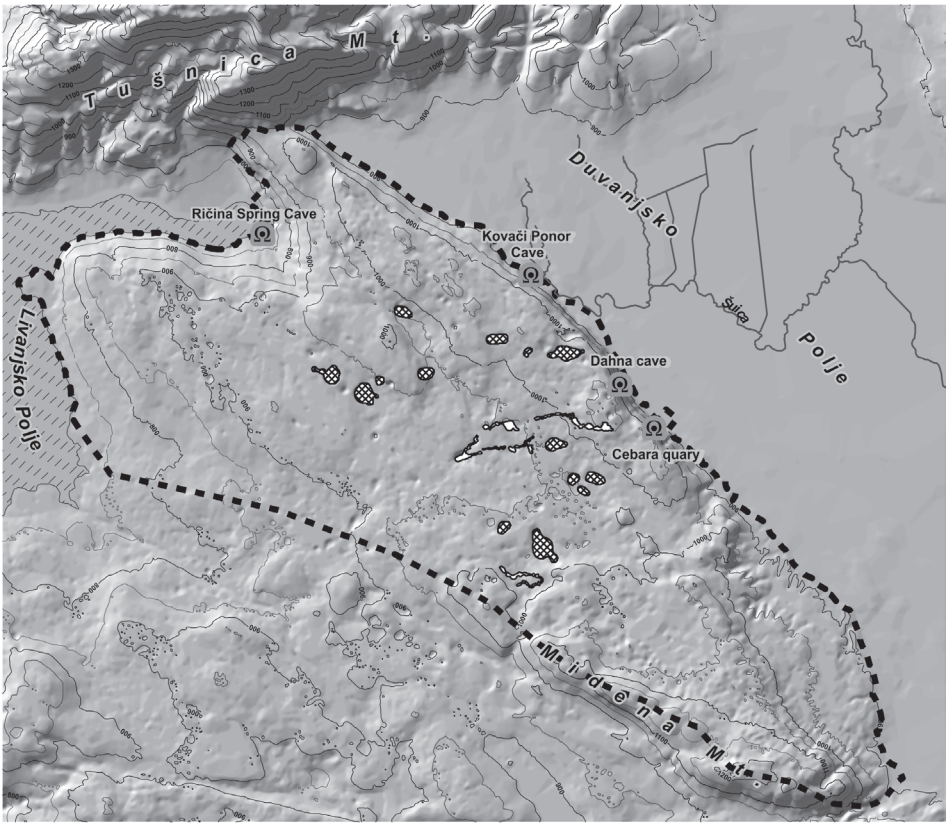
The Grabovica Plateau is a well-confined levelled karst area between two poljes: Duvanjsko polje towards northeast and east and Livanjsko polje on the west (Figure 1). The southeastern part of Livanjsko Polje, which runs along the Grabovica plateau, is inundated by artificial lake named Buško Blato. The plateau is elongated in the northwest-southeast direction, having a longer axis of ≈18 km and shorter of ≈8 km. It covers an area of ≈125 km^2. Eastern limit of the plateau towards Duvanjsko polje is at the elevation of ≈860 m. Just above the eastern edge, there is a 200 meter-high structural escarpment rising steeply to the highest section of the plateau at 1060 m a.s.l. The other areas of the plateau are roughly levelled and slightly inclined towards western limits at Buško Blato where elevations are ≈700 m.

Lithological setting of the Grabovica Plateau is rather uniform. The whole area is a syncline with dip of the axis towards northwest. As a result, the youngest bedrock is Paleogene limestone exposed as a narrow strip at northwest perimeter. The Paleogene bedrock is delimited by bedded and massive limestone of Upper Cretaceous age. Majority of the plateau is built of a well-bedded Upper Cretaceous limestone underlying the Lower Cretaceous beds. The latter that are built of dolostone and dolomitized limestone are located in a narrow strip close to the southeastern margin of the area. Majority of the tectonic unconformities are orientated in the northwest-southeast direction. The most expressed tectonic disconformity is running along a steep escarpment on the verge of Duvanjsko Polje, separating the plateau from Duvanjsko polje. The floor of Duvanjsko polje consists of marl and sand of Pliocene and Miocene age as well as Quaternary alluvium (Raić, Papeš, 1968; Raić et al., 1976).

Direction of subsurface flow within the karstified plateau is from east and southeast towards the west (Roglić, 1940). The most dominant ponor in the area is Kovači located at the edge of Duvanjsko Polje where Šuica River is submerging. The river is discharging majority of waters from Duvanjsko Polje towards spring at the western edge of the plateau. The main spring named Vrilo is located at the end of extensive steephead valley on the northwestern border of the Grabovica Plateau. The spring is annually flooded due to oscillation of water within the reservoir.

The majority of the Grabovica Plateau is poorly vegetated therefore great variety of small-scale karst features are exposed to the surface with a number of dolines, collapse dolines and other non-rounded karst depressions of various origins. First geomorphological literature about the area was provided by Roglić (1940) who interpreted the area of Duvanjsko polje as a result of Pliocene inundation. He interpreted steep escarpments alongside the polje as abrasion terraces. Succeeding research was focused on hydrological settings of the area (Malez, 1964; Božičević, 1971; Kovačević, 2013; Ozimec, 2015; Marković, Ozimec, 2017) for purposes of a water reservoir construction in the area of the Buško Blato. Following research was focused on the morphometry and morphogenesis of some local collapse dolines (Božičević, 1985). The last geomorphological research of the area comprises a detailed morphometric description of a wider area of Duvanjsko polje (Radoš et al., 2012; Radoš, Magaš, 2012).

Figure 1: Map of the Grabovica plateau.
Slika1: Karta planote Grabovica.



3 MATERIALS AND METHODS

Analytical geomorphologic approach (Pavlopoulos et al., 2009) was applied to study the Grabovica Plateau. Basic morphographic analysis was focused on collapse dolines and denuded cave sections, because these features are direct karst surface indicators of the past and present hydrologic setting of the area (Mihevc, 1998; Mihevc, 2001; Šušteršič, 2006; Mihevc, 2010; Waltham et al., 2010; Gabrovšek, Stepišnik, 2011). Extensive field mapping in the area was supported by remote sensing data and preceding geomorphologic and geologic literature. The study of collapse dolines was focused on slope morphology and sediment infills. Detail morphometric analysis was performed by means of spatial analysis performed in ArcGIS 10.3.1 using a 20 m resolution digital elevation model (DEM). First, contour lines of different equidistance, slope angle and shaded relief were extracted from the DEM. Polygons of all detected collapse dolines and denuded caves were drawn using a combination of different topographic layers and taking into account the data collected in the field. Finally, the statistics of extracted polygons were calculated using the *Zonal Statistics as Table* and *Polygon Volume* tools.

Additionally a speleologic study of important cave systems was performed in the field and supported by results of previous researches (Mandić et al., 2013; Šumanović, Buntić, 2013; Marković, Ozimec, 2017). Speleologic investigation was focused on small-scale features on the cave walls and ceilings, sediment fills as well as analysis of cave system long profiles, which indicate speleogenetic environments (Mihevc, 2001; Šušteršič, Šušteršič, Stepišnik, 2003; Ford, Williams, 2007).

4 RESULTS

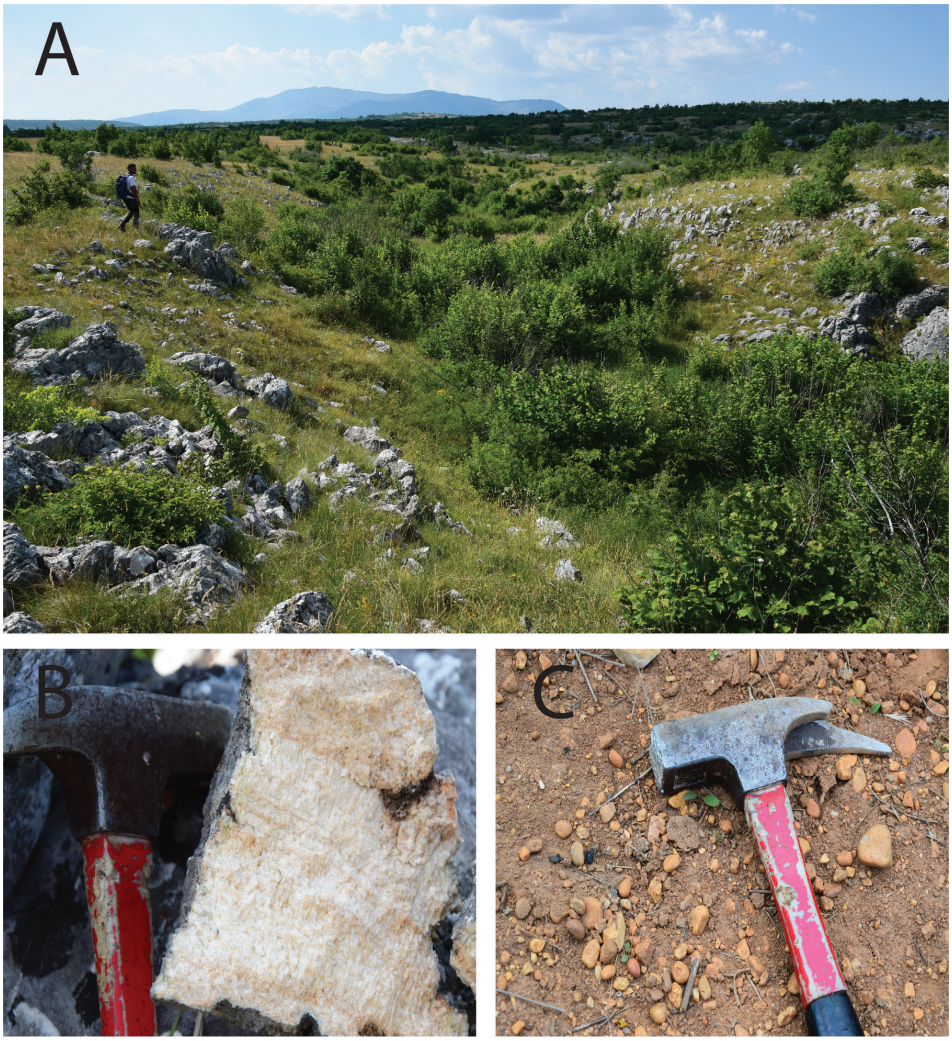
Majority of the study area is functioning as well-developed karst due to dominance of limestone lithology. Karst surface of the plateau is roughly levelled and covered by karren, dolines, sporadic conical hills, denuded cave passages and a number of collapse dolines. The latter two are the most essential surface karst features for reconstructing past and present hydrological functioning of the area (Mihevc, 2001; Šušteršič, 2006; Waltham et al., 2010; Gabrovšek, Stepišnik, 2011; Kaufmann, 2014).

A number of denuded cave passages were identified on the surface. Their morphology resembles non-active fluvial channels with floors usually covered by non-carbonate alluvium derived from Duvanjsko polje and its hydrologic hinterland. Within a fine grained cover a large number of quartz pebbles and flowstone chunks are exposed on the surface. Even though they are river channel-like forms, their association with fluvial morphogenesis is negligible while in well-developed karst entire drainage system is diverted into a subsurface. Additional evidence of their subsurface origin are flowstone deposits that are exclusively subsurface cave precipitates.

Two grouping of denuded cave passages were identified in the study area (Figure 2). The northern denuded cave system ≈3 km south of Kovači Ponor is composed of interconnected dolines and elongated depressions, which are up to 30 m wide and 20 m deep. Common length of denuded cave passages is ≈4.5 km. The whole system is located on

a levelled surface, which is slightly inclined towards west. Eastern sections of denuded passages are positioned at an elevation of 1030 m while the elevations at its westernmost stretches are ≈900 m. Majority of the denuded cave system floors are covered by clayey sediment with fine sand. In some sections quartz pebbles and large pieces of flowstone are to be found.

Figure 2: Part of the northern denuded cave system (A) with chunks of flowstone (B) and quartz pebbles (C) (photo: M. Žebre).
Slika 2: Del severnega sistema denudiranih jam (A) s kosi sige (B) in kremenovimi prodniki (C) (foto: M. Žebre).



The southern denuded cave system is a rather uniform 1.6 km long channel-like depression. It is positioned roughly 2.5 km towards southwards of the northern denuded cave system. Well-expressed corridor within steep rocky sides has elevations ranging between 1000 and 960 m a.s.l. It is positioned within levelled surface that is slightly dipping towards west. Dimensions of its cross-section are up to 40 m wide and 15 m deep. Same deposits cover the floors of corridors as in the northern system.

In the area of the Grabovica Plateau there are 14 large collapse dolines. They are irregularly distributed across the central part of the plateau. Their volumes vary from ≈0.5 up to ≈4 Mm^3. The origin of small-sized collapse dolines is a result of the collapse of the cave chambers that are positioned close to the surface. Some smaller collapses even have continuation into cave chambers at their lower sections (Šumanović, Buntić, 2013; Marković, Ozimec, 2017). Large-volume collapse dolines are a result of undermining by subsurface flow along tectonically unstable zones (Šušteršič, 2003; Waltham et al., 2005; Šušteršič, 2006; Gabrovšek, Stepišnik, 2011). Their sizes are not a result of cave chamber volumes but rather dynamics and period of subsurface undermining.

Collapse dolines of the Grabovica Plateau can be divided into two types due to their morphology. A group of four northernmost collapse dolines that are positioned

Figure 3: A collapse doline Veliki Samograd with steep rocky slopes (photo: U. Stepišnik).
Slika 3: Udornica Veliki Samograd s stenastimi pobočji (foto: U. Stepišnik).

close to the trough-flow corridor between Kovači Ponor and Vrilo Spring have common steep rocky slopes with extensive scree underneath that are reaching their floors (Figure3). Some of the floors are covered by small patches of fine grained residual from the slopes. The northernmost collapse doline has a funnel-shaped depression within its floor indicating ongoing undermining in a subsurface. According to the morphographic classification (Waltham, et al., 2005; Ford, Williams, 2007) they can be defined as young collapse dolines.

All other collapse dolines in the area have mostly balanced slopes (Kaufmann, 2009; Stepišnik, Kosec, 2011) that are dissected by scarce rocky walls and patches of sediment. Floors are gentle and flattened by fine grained slope material. They can be classified as a mature-type collapse dolines (Waltham, Bell, Culshaw, 2005; Ford, Williams; 2007).

The area is a trough-flow karst as waters are submerging on the western side and emerging in springs on the eastern side of the Grabovica Plateau. Surface and subsurface karst that is significantly modified by point recharge and point discharge processes is referred to as contact karst (Mihevc, 1991; Mihevc; 2001). The entire north-eastern stretch of the Grabovica Plateau along Duvanjsko Polje is a geologic contact between karstified carbonate and non-carbonate lithology, therefore it is a ponor type of contact karst. The main discharge point from Duvanjsko Polje is at Kovači Ponor where Šuica River is submerging at the end of small blind valley at ≈850 m a.s.l. Kovači Ponor is ≈2km long hydrologically active cave system, which is conducting waters in northwest direction towards Ričina Spring. The whole cave system is subhorizontal, positioned entirely in epiphreatic zone. Majority of the explored stretch of the cave system has floor filled with fine grained alluvium and limestone pebbles and there are no accessible phreatic loops (Kovačević, 2013; Šumanović, Buntić, 2013; Marković, Ozimec, 2017). Hydrologic function, position on the contact karst and organization of cave passages suggest that whole system is of paragenetic origin.

Another extensive cave system named Dahna is located ≈3 km southeast of the Kovači Ponor. The entrance to the cave is at an elevation of ≈940 m, ≈80 m above the polje floor and the whole length of explored passages is about 1100 m (Šumanović, Buntić, 2013). The entire stretch of explored cave system is positioned completely within a vadose zone. Majority of cave passages are horizontal to subhorizontal and of various dimensions oriented regularly towards the west. Some vadose zone shafts and collapse chambers are dissecting the system. The floor along the entire stretch of the system is covered with alluvium and flowstone deposits. Position and orientation of the passages with sediments within suggest that the cave is of paragenetic origin which was later modified by collapsing and vertical seepage processes in vadose zone.

An important speleogenetic object is exposed within a quarry on a steep slope ≈80 m above the polje floor, close to the village Cebara. It is positioned ≈800 m southeast of the cave system Dahna. The whole object is an exposed cross profile of a cave passage which is completely infilled by alluvium and flowstone. The profile is 20 m high and 17 m wide with lower section on elevation ≈940 m. The infill is composed of upward coarsening succession of flowstones, clays, fluvial gravels and block-breccia. The latter consists of collapse boulders reaching up to 5 m in diameter. The gravely beds contain an operculi

Figure 4: Aerial photograph of the steephead valley of Ričina Spring (photo: U. Stepišnik).
Slika 4: Zračni posnetek zatrepne doline izvira Ričine (foto: U. Stepišnik).

accumulations of freshwater snail *Bythinia* (Mandić et al., 2013), backing an evidence of riverine or lacustrine origin of the sediment (Mandić et al., 2013). Lower section of a profile encompasses 1.5 m thick bone bed interval containing fossil bones, tusks and teeth. They were classified as *Anancus arvernensis* (Mandić et al., 2013), which had a peak distribution in Europe in the Late Pliocene and the stratigraphic range from the Late Miocene to the Early Pleistocene (Mandić et al., 2013).

A spring type of contact karst is positioned on the north-west limit of the Grabovica Plateau, where subsurface streams emerge on the surface, (Mihevc, 1991; Mihevc, 1998). Subsurface streams are focused at Vrilo Spring which is positioned at head of 1 km wide and more than 4 km long steephead valley. The cave system of Vrilo Spring is a main drainage spot of the Grabovica Plateau. The entrance is at an elevation of ≈710 m and it consists of up to 30 m wide and 15 m high horizontal passages with a total length of ≈2,500 m explored passages. A direction of the system is oriented towards the east (Šumanović, Buntić, 2013; Marković, Ozimec, 2017). The cave system is roughly horizontal, positioned mainly within epiphreatic zone, having sections which are permanently inundated. Some of the passages are modified by collapsing.

5 DISCUSSION

The Grabovica Plateau is situated in the Dinaric Karst in-between Duvanjsko and Livanjsko Polje. The whole plateau is well karstified, where subsurface streams are discharging in the direction from Duvanjsko towards Livanjsko Polje (Roglić, 1940).

Therefore, the area can be characterized as a through-flow karst. Converged streams from Duvanjsko Polje are submerging at Kovači Ponor. Subsurface flow is oriented towards the west where it re-emerges at the Vrilo Spring that is located 5 km away and 150 m lower than the ponor, therefore an average gradient of the subsurface flow is 3 %. The Kovači Ponor cave system is a hydrologically active cave of paragenetic origin (Ford, Williams, 2007). It is located approximately at the local watertable level owing to strong influx of a non-soluble allogenic detritus from the polje. Located some 80 m higher and about 3 km towards southeast along the polje edge is Dahna cave system. More than a kilometre long system of horizontal passages with abundance of allogenic sediment covering the floor resembles the speleogenetic settings of Kovači Ponor cave system. Dahna cave system is a non-active cave system of paragenetic origin due to its position above the local watertable level. The cave passage cross section at Cebara quarry is of the same origin. Both Cebara and Dahna have had a function of ponor cave systems while being active within epiphreatic zone. The spatial distribution and especially altitudinal position of the three caves indicate the northwestward migration of the ponor zone along the edge of Duvanjsko Polje. Caves as these are typical for a ponor type of the contact karst along with strong detritus influx. They can be defined as a multi-phase paragenetic cave system (Ford, Williams, 2007), which is organized on various elevation levels (Gams, 1966; Gospodarič, 1976). These findings argue previous assumptions that the initial ponor area of the polje was situated in the northwest followed by migration towards southeast to the present position of the Kovači Ponor (Roglić, 1940).

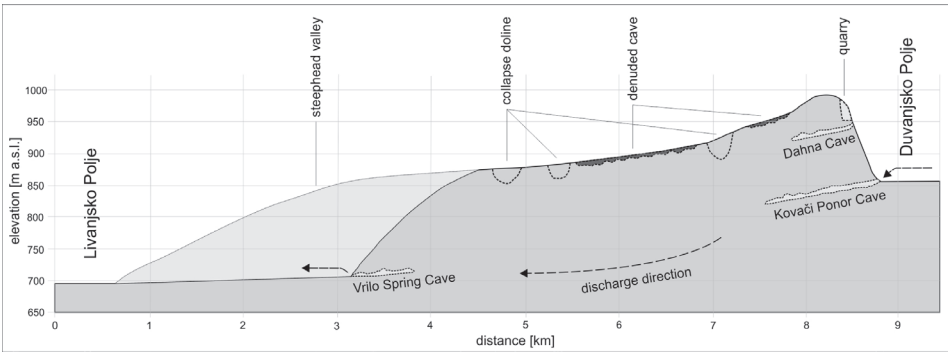
Important indicator for a speleogenetic interpretation of the area is also the cave system of Ričina Spring. The horizontal cave passages at the end of the steephead valley are positioned within epiphreatic zone. There is no evidence of any lower phreatic tubes within the cave system, thus it is likely the cave system in the hinterland of the spring is also a result of paragenesis. Similar examples of extensive paragenetic modification of cave systems are known from the northwestern part of the Dinaric Alps (Gospodarič, 1976; Mihevc, 2001; Gams, 2003). A strong influx of allogenic non-soluble detritus in the ponor zone is supported by autogenic collapse material which can result in a complete remodelling of extensive trough-flow cave systems from the ponors to the springs (Gams, 1965; Gospodarič, 1976; Šušteršič, Šušteršič, 2003; Šušteršič et al., 2003). Results of such remodelling are large horizontal cave systems in epiphreatic zone that are intersected by collapse structures and sumps.

Denuded cave systems which were identified on the Grabovica Plateau are the longest sections of denuded caves documented so far in the whole Dinaric Alps and on the global scale. Sediment deposits in the denuded caves corridors exhibit the same hydrological function and sediment influx as of the recent conditions within active systems Kovači Ponor - Vrilo Spring.

The speleological and topographic setting of the Grabovica Plateau is favourable for development of a long and non-disturbed denuded cave system. The entire plateau is slightly inclined toward the west, having a gradient between 2.2% and 2.5% in the central part, where majority of denuded cave sections are positioned. The gradient is nearly

identical to the gradient of recent paragenetic passages, calculated to 3%. Almost identical gradient of the surface and paragenetic cave systems allowed the entire cave systems to be exposed on the surface due to chemical denudation of the surface (Figure 5). Same hydraulic gradient also suggests that hydrologic and speleologic conditions in the area of the Grabovica Plateau did not change in a longer speleogenetic period.

Figure 5: A cross section sketch of the Grabovica Plateau indicating positions of active, inactive and denuded cave systems and collapse dolines.
Slika 5: Skica podolžnega prereza planote Grabovica z označenimi aktivnimi, neaktivnimi in denudiranimi jamskimi sistemi ter udornicami.



The exposed cross profile of a cave passage in the Cebara quarry, containing remains of the *Anancus arvernensis* (Mandić et al., 2013), is located between 940 m and 960 m a.s.l. About 2 km westward lies a part of the northern denuded cave system at an elevation span between 900 m and 920 m. The average gradient between the two speleogenetic objects is ≈2.5 %, indicating the chronologically related speleogenesis. Stratigraphic range of fauna (from Late Miocene to the Early Pleistocene) found within the cave passage in the Cebara quarry suggests that the same speleological conditions are present in the study area for at least 1.8 Ma (Mandić et al., 2013). Collapse dolines in the area are elongated in the NW-SE direction, which is the general direction of faults in the area (Raić et al., 1976). Fault lines regularly represent less permeable zones within the karst aquifer (Šušteršič, 2006) forcing a concentration of subsurface streams which is favourable for formation of collapse dolines (Gabrovšek, Stepišnik, 2011). Only the floor of the northernmost collapse doline exhibits a funnel shaped depression, which indicates the ongoing undermining in the subsurface. Majority of collapse dolines on the northern side of the plateau also displays active slopes, which are a result of continuous stabilization due to mass removal. On the contrary, the southern collapse dolines have mainly balanced slopes with no evidence of active undermining of their floor. A difference in morphology between the northern and southern collapse dolines additionally points to the migration of subsurface drainage towards the north.

6 CONCLUSION

The Grabovica Plateau is a corrosion plain situated between Livanjsko and Duvanjsko Polje in the southern Bosnia and Herzegovina. Karstified carbonate bedrock prevail where surface is positioned high above the local watertable level. Direction of subsurface flow within the karstified plateau is oriented towards the west. The major ponor at Duvanjsko Polje is Kovači Ponor from where subsurface flow is directed towards the edge of the plateau at Livanjsko Polje where Vrilo Spring is positioned.

Surface of the Grabovica Plateau is covered by a number of collapse dolines; additionally we managed to identify large sections of denuded cave systems which are the most extensive of its kind within Dinaric Alps. These surface karst features are in combination with active and-non active cave systems the main indicators of past hydrologic pattern within the area. The aim of the article was to analyse geomorphologic and speleologic settings indicated by the above mentioned features of the area and to provide its past and present hydrologic functioning.

Methods involved morphographic analysis of the surface karst features that included extensive field mapping supported by remote sensing data. Field survey included detailed collapse doline slopes analysis and examination of alluvial deposits within collapse dolines as well as denuded cave systems. Study of subsurface cave systems included field examination of cave features and sediments combined with the data collected within previous speleological research (Mandić et al., 2013; Šumanović, Buntić, 2013; Marković, Ozimec, 2017). The area of the Grabovica Plateau is an exemplar case of trough-flow karst within the whole Dinaric Karst. The cave systems at the inflow part of the plateau exhibit paragenetic speleogenesis which is typical for contact karst cave systems. Strong influx of a non-soluble allogenic detritus into karst resulted in the formation of long subhorizontal cave passages located along the local watertable level. Active and non-active cave systems along the contact exhibit similar morphological and sedimentological settings. Their topographic position along the Duvanjsko polje is a result of gradual migration of the main discharge point towards the northwest while their distribution in distinct elevation levels is typical for multi-phase paragenesis with strong injection of allogenic detritus (Gospodarič, 1976; Ford, Williams, 2007).

Important indicator for speleogenetic interpretation is also position and spatial distribution of the cave system of Ričina Spring. Horizontal passages along with sediment fill in epiphreatic and shallow phreatic zone indicate the ongoing paragenesis also on the outflow section of Grabovica Plateau. The cave system is not remodelled solely by non-soluble allogenic debris that originates from Duvanjsko polje but also form carbonate debris deriving from local cave chamber breakdowns and collapse dolines. Correspondent cases of paragenetic effect escalation by locally derived material were documented in multiple cases from northern Dinaric Karst (Gams, 1965; Gospodarič, 1976; Šušteršič, Šušteršič, 2003; Šušteršič et al., 2003).

Collapse dolines distributed along the plateau exhibit typical morphographic pattern. Majority of collapse dolines in central and southern section of the plateau exhibits typical mature stage of development with balanced slopes and almost complete absence of steep

rocky slopes. On the other hand northern group of collapse dolines is of young development stage with the prevalence of steep rocky slopes and scree underneath them. Some of them have a funnel shaped depressions within their floors as a result of ongoing undermining due to the presence of active subsurface flow. Morphographic differences exhibit gradual migration of subsurface discharge towards the north.

Denuded cave passages on the surface of the Grabovica Plateau are common. Among them two extensive cave systems were recognised by means of remote sensing, fieldwork mapping and sediment analysis. Identified denuded cave systems are the most extensive of its kind on the Dinaric Karst documented so far. Due to the fact that surface of the Grabovica plateau has roughly the same inclination as hydraulic gradient in the subsurface, extended and undisturbed sections of denuded caves are possible. Topographic position of denuded cave systems along with their sediments and inclinations suggest that speleogenetic conditions did not alter since the time of their formation. The latter can be deduced on the basis of paleontological data from Cebara quarry cross profile. Stratigraphic range of fauna found within the profile has a span from the Late Miocene to the Early Pleistocene (Mandić et al., 2013) therefore the age of the cave passage formation can be assessed to at least 1.8 Ma. About 2 km westward lies a part of the northern denuded cave system within the same paragenetic level elevation span as exposed cave passage profile within the quarry. It indicates the same morphochronology of both speleogenetic objects. We can conclude that the speleogenetic conditions did not alter for at least 1.8 Ma.

We conclude that the Grabovica Plateau represents a perfect polygon for future studies of contact karst and paragenetic cave systems, which are completely dissecting subsurface aquifer. All stages of contact karst speleogenesis is accessible starting with active phase, inactive phase, to the final degradation with collapses and conclusive denudation on the surface. Additionally previous research confirmed the existence of paleontological material, which will be crucial for determining the age and enabling accurate interpretations of karst dynamics.

References

Bognar, A., 1992. Pedimenti Južnog Velebita. Hrvatski geografski glasnik, 54, 1, pp. 19–31.

Bognar, A., 2006. The upper part of the Una River Valley between Martin Brod and Pritoka – Geomorphological Characteristics. Hrvatski geografski glasnik, 67, 6, pp. 21–38. DOI: 10.21861/HGG.2005.67.02.02.

Bonacci, O., 2004. Poljes. In: Gunn, J. New York, Fitzroy Dearborn, pp. 599–600.

Bonacci, O., 2013. Poljes, ponors and their catchments. In: Frumkin, A. (ed.). Treatise on Geomorphology. Amsterdam, Elsevier, pp. 112–120.

Božičević, S., 1971. Primjenjena Geološka istraživanja. Naše jame, 13, 1, pp. 108–115.

Božičević, S., 1985. Morfologija i geneza urušnih vrtača. Acta Carsologica, 14/15, 1, pp. 149–162.

Ford, D., Williams, P. D., 2007. Karst hydrogeology and geomorphology. Chichester, Wiley, 576 pp.

Gabrovšek, F., Stepišnik, U., 2011. On the formation of collapse dolines: A modelling perspective. Geomorphology, 134, 1–2, pp. 23–31. DOI: 10.1016/j.geomorph.2011.06.007.

Gams, I., 1965. H kvartarni geomorfogenezi ozemlja med Postojnskim, Planinskim in Cerkniškim poljem. Geografski vestnik, 37, 1, pp. 61–101.

Gams, I., 1966. On the hydrology of the territory among the poljes of Postojna, Planina and Cerknica. Acta Carsologica, 4, 1, pp. 5–54.

Gams, I., 2003. Kras v Sloveniji v prostoru in času. Ljubljana, Založba ZRC, 516 pp.

Gospodarič, R., 1976. The quaternary caves development between the Pivka basin and polje of Planina. Acta Carsologica, 7, 1, pp. 1–139.

Kaufmann, G. 2009. Modelling karst geomorphology on different time scales. Geomorphology, 106, 1, pp. 62–77.

Kaufmann, G., 2014. Geophysical mapping of solution and collapse sinkholes. Journal of Applied Geophysics, 111, pp. 271–288. DOI: 10.1016/j.jappgeo.2014.10.011.

Kovačević, T., 2013. MSRE »Ponor Kovači – Ričina 2013«. Speleolog, 61, 1, pp. 66–74.

Malez, M., 1964. Prilog poznavanju speleoloških odnosa na Glamočkom i Duvanjskom polju. Krš Jugoslavije, 4, 1, pp. 172–200.

Mandić, O., Göhlich, U., Hrvatović, H., Mauch-Lenardić, J., Čvorović, B., Glamuzina, G., Radoš, D., 2013. New Proboscidean Site from the High Karst Dinarides in Southern Bosnia and Herzegovina. Neogene to Quaternary Geological evolution of Mediterranean, Paratethys and Black Sea, Istanbul, Regional Comittee of Mediterranean Neogene Stratigraphy.

Marković, J., Ozimec, R., 2017. Speleologija. In: Radoš, M. M., Šumanović, M., Šarac, M. M., Vukadin, V., Marković, J., Lukić Bilela, L., Radoš, D., Ozimec, R. (ed.). Naših prvih 7 ekspedicija. Tomislavgrad - Zagreb, Udruga "Naša baština", pp. 42–51.

Mihevc, A., 1991. Morfološke značilnosti ponornega kontaktnega krasa: izbrani primeri s slovenskega krasa. Magistrsko delo. Ljubljana, Univerza v Ljubljani, Filozofska fakulteta, 206 pp.

Mihevc, A., 1998. Speleogeneza matičnega krasa: doktorska disertacija. Ljubljana, Univerza v Ljubljani, Filozofska fakulteta, 150–150 pp.

Mihevc, A., 2001. Speleogeneza Divaškega krasa. Ljubljana, Založba ZRC, ZRC SAZU, 180 pp.

Mihevc, A., 2010. Geomorphology. In: Mihevc, A., Prelovšek, M., Zupan Hajna, N. (ed.). Introduction to Dinaric karst. Postojna, IZRK ZRC SAZU, pp. 30–43.

Ozimec, R., 2015. Ekspedicija Ponor Kovači – izvor Ričine 2015. Speleolog, 63, 1, pp. 39–42.

Pahernik, M., 2012. Prostorna gustoća ponikava na području Republike Hrvatske. Hrvatski geografski glasnik, 74, 2, pp. 5–26. DOI: 10.21861/HGG.2012.74.02.01.

Pavlopoulos, K., Evelpidou, N., Vassilopoulos, A., 2009. Mapping Geomorphological Environments. Berlin, Heidelberg, Springer, 235 pp.

Radoš, D., Lozić, S., Šiljeg, A., 2012. Morfometrijske značajke šireg područja Duvanjskog polja, Bosna i Hercegovina. Geoadria, 17, 2, pp. 177–207. DOI: 10.15291/geoadria.352.

Radoš, D., Magaš, D., 2012. Morfometrijska analiza prostornog rasporeda i gustoće ponikava Grabovičke zaravni. In: Lučić, I., Mulaomerović, J. (ed.). Međunarodni znanstvenostručni skup »Čovjek i krš«, Knjiga sažetaka. Međugorje - Sarajevo, Centar za krš i speleologiju Sarajevo, pp. 30–31.

Raić, V., Ahac, A., Papeš, J., 1976. Osnovna geološka karta SFRJ. K 33 – 23, Imotski.

Raić, V., Papeš, J., 1968. Osnovna geološka karta 1:100.000 - Tumač za list Imotski K 33 – 23. Beograd, Savezni geološki zavod, 32 pp.

Roglić, J., 1940. Geomorphologische Studie über das Duvanjsko Polje (Polje von Duvno) in Bosnien. Mitteilungen der Geographischen Gesellschaft in Wien, 83, 1, pp. 152–177.

Stepišnik, U., Kosec, G., 2011. »Modelling of slope processes on karst.« Acta Carsologica 40, 2, pp. 267–273.

Šumanović, M., Buntić, I., 2013. Speleologija Duvanjskog kraja. In: Ozimec, R., Radoš, M. M. Tomislavgrad - Zagreb, pp. 615–615.

Šušteršič, F., 2003. Collapse dolines, deflector faults and collector channels. Speleogenesis and Evolution of Karst Aquifers, 1, 3, pp. 1–10.

Šušteršič, F., 2006. Relationships between deflector faults, collapse dolines and collector channel formation: some examples from Slovenia. International journal of speleology, 35, 1, pp. 1–12.

Šušteršič, F., Šušteršič, S., 2003. Formation of the Cerkniščica and the flooding of Cerkniško polje = Nastanek Cerkniščice in poplavljenje Cerkniškega polja. Acta Carsologica, 32, 2, pp. 121–136.

Šušteršič, F., Šušteršič, S., Stepišnik, U., 2003. The late quaternary dynamics of Planinska jama, south-central Slovenia. [S. l.], British Cave Research Association, pp. 89–96 pp.

Waltham, T., Bell, F., Culshaw, M., 2005. Sinkholes and subsidence : Karst and cavernous rocks in engineering and construction. Chichester, Springer, Praxis, pp. 382–382.

Waltham, T., Bell, F., Culshaw, M., 2010. Sinkholes and subsidence : Karst and cavernous rocks in engineering and construction. Chichester, Springer, Praxis, 382 pp.

JAME, DENUDIRANE JAME IN UDORNICE KOT KAZALNIKI NEKDANJEGA HIDROLOŠKEGA DELOVANJA PLANOTE GRABOVICA (BOSNA IN HERCEGOVINA)

Povzetek

Planota Grabovica je korozijska uravnava med Livanjskim in Duvanjskim poljem v južni Bosni in Hercegovini. Površje v celoti gradi zakrasela karbonatna podlaga in leži visoko nad gladino podzemne vode v krasu. Podzemni tokovi pod zakraselo planoto so usmerjeni proti zahodu. Na Duvanjskem Polju je glavni ponor Kovači, od koder je glavnina podzemnih tokov usmerjena proti robu planote na Livanjskem polju, kjer se nahaja izvir Vrilo.

Na površju planote Grabovica je večje število udornic; poleg njih smo identificirali tudi daljše odseke denudiranih jamskih sistemov, ki so najobsežnejši v Dinarskem

gorstvu. Te površinske kraške oblike so v kombinaciji z aktivnimi in neaktivnimi jamskimi sistemi glavni kazalniki preteklega hidrološkega delovanja na tem območju. Namen raziskave je bila analiza geomorfoloških in speleoloških značilnosti na osnovi omenjenih oblik ter interpretacija preteklega in sedanjega hidrološkega delovanja tega območja.

Metode so vključevale morfografsko analizo površinskih kraških oblik, ki je obsegala obsežno terensko kartiranje, podprto s podatki daljinskega zaznavanja. Raziskava na terenu je vključevala podrobno analizo pobočij udornic in proučevanje sedimentov v udornicah ter denudiranih jamskih sistemih. Proučevanje jamskih sistemov je vključevalo analizo jamskih oblik in sedimentov na terenu ter podatke, zbrane v predhodnih speleoloških raziskavah (Mandić in sod., 2013; Šumanović in Buntić, 2013; Marković in Ozimec, 2017).

Območje planote Grabovica je šolski primer pretočnega krasa na celotnem območju Dinarskega gorstva. Jamski sistemi na pritočnem delu planote nakazujejo na paragenetsko speleogenezo, ki je značilna za jamske sisteme kontaktnega krasa. Izdatni dotok netopnega alogenega materiala v kras je povzročil oblikovanje dolgih vodoravnih jamskih rovov v epifreatični coni. Aktivni in neaktivni jamski sistemi vzdolž stika kažejo identične morfološke in sedimentološke značilnosti. Njihova razporeditev vzdolž Duvanjskega polja je posledica lateralne migracije glavne točke odtoka proti severozahodu, njihova vertikalna porazdelitev v različnih višinskih nivojih pa je značilna za večfazno paragenezo (Gospodarič, 1976; Ford in Williams, 2007).

Udornice na planoti kažejo tipični morfografski vzorec. Večina udornic v osrednjem in južnem delu planote kaže značilno zrelo stopnjo razvoja s prevlado uravnoteženih pobočij in skoraj popolno odsotnostjo strmih skalnatih pobočij. Po drugi strani pa je severna skupina udornic v mladi fazi razvoja s prevlado strmih skalnatih pobočij in melišč pod njimi. Nekatere imajo v dneh lijakaste kotanje, ki so posledica nenehnega spodjedanja zaradi delovanja aktivnega podzemnega toka. Morfografske razlike v udornicah kažejo postopno migracijo podzemnih tokov proti severu, enako kot jamski rovi.

Na planoti Grabovica so pogoste denudirane jame. Na tem območju se nahajajo največji poznani sistemi denudiranih jam na celotnem območju dinarskega krasa. Površje planote ima približno enak naklon kot hidravlični gradient v podzemlju, zato so se na površju razvili obsežni neprekinjeni sistemi denudiranih jam. Prostorska razporeditev sistemov denudiranih jam in njihove sedimentne zapolnitve kažejo na to, da se speleogenetske razmere na območju niso bistveno spremenile vse od časa njihovega oblikovanja. Čas oblikovanja pa lahko opredelimo na osnovi paleonotoloških analiz iz profila v kamnolomu Cebara na robu Duvanjskega polja. Stratigrafski razpon favne iz profila ima razpon od poznega miocena do zgodnjega pleistocena (Mandić in sod., 2013), kar pomeni, da je starost zapolnitve v profilu vsaj 1,8 Ma. Približno 2 km zahodno od profila v kamnolomu se nahaja denudiran jamski sistem v istem paragenetskem nivoju, kar pomeni, da lahko obema geomorfnima oblikama pripišemo okvirno enako starost. Tako lahko zaključimo, da se speleogenetske razmere na območju niso bistveno spremenile vsaj 1,8 Ma.

Na osnovi naših raziskav lahko povzamemo, da je planota Grabovica popoln poligon za študije kontaktnega krasa in paragenetskih jamskih sistemov. Na območju so prisotne vse faze kontaktno kraške spelogeneze od hidrološko aktivnih sistemov,

neaktivnih sistemov do končnega razpada in pojavitve na površju v obliki udornic in denudiranih jam. Poleg tega so predhodne raziskave potrdile obstoj paleontološkega materiala, ki je ključnega pomena za določanje starosti in omogočanje natančnih interpretacij dinamike speleogeneze.