COBISS: 1.01

GEOLOGICAL INFLUENCE ON THE FORMATION OF SAMAR NATURAL BRIDGE AND COLLAPSE VALLEY OF RAVNA RIVER FROM THE NE KUČAJ MOUNTAINS (CARPATHO-BALKANIDES, EASTERN SERBIA)

POMEN GEOLOGIJE ZA NASTANEK NARAVNEGA MOSTU SAMAR IN UDORNE DOLINE RAVNA REKA V SEVEROVZHODNEM DELU GORE KUČAJ (KARPATSKO-BALKANSKO GOROVJE, VZHODNA SRBIJA)

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Abstract UDC 551.435.8:55(497.11-11)

Aleksandar S. Petrović & Ivana Carević: Geological influence on the formation of Samar natural bridge and collapse valley of Ravna River from the NE Kučaj Mountains (Carpatho-Balkanides, eastern Serbia)

The paper deals with the description of Samar natural bridge and collapse valley of Ravna River in eastern Serbia aiming to suggest an interpretation of their origin and development, in relationship with lithological and tectonic conditions, karst processes, and petrological analyses. In this study we present the geological setting, detailed morphology and hypothesis on the genesis of these karst landforms. The relationship between surface karst development and the geology is considerably acknowledged. The major contribution of the paper is to propose a framework for considering how recrystallization of limestone can affect the weathering potential of karst landforms and to introduce a term collapse valley. Finally, this study shows that the weathering potencial of the Samar natural bridge is decreased concerning the diagenetic changes these limestones underwent.

Key words: Natural bridge, collapse valley, eastern Serbia, recrystallization, weathering.

Izvleček UDK 551.435.8:55(497.11-11)

Aleksandar S. Petrović & Ivana Carević: Pomen geologije za nastanek naravnega mostu Samar in udorne doline Ravna Reka v severovzhodnem delu gore Kučaj (Karpatsko-Balkansko gorovje, vzhodna Srbija)

V članku obavnavamo naravni most Samar in udorno dolino Ravna Reka v vzhodni Srbiji. Njun razvoj pojasnujemo s specifičnimi litološkimi in tektonskimi pogoji, procesi zakrasevanja in petrološko analizo. Posebej poudarimo povezavo med razvojem kraških površinskih oblik in geologijo območja. Glavni prispevek študije je concept, v katerem opišemo, kako rekristalizacija apnenca vpliva na zakrasevanje, poleg tega pa uvedemo termin udorna dolina. V študiji pokažemo, da je preperavanje apnenca na območju mostu Samar tesno povezano z diagenetskimi spremembami v preteklosti.

Ključne besede: naravni most, udorna dolina, vzhodna Srbija, rekristalizacija preperevanje.

INTRODUCTION

Natural bridges or natural arches are very rare features in relief and usually are protected as geoheritage. Their origin may be different. The most significant weather eroded arches are formed in the sandstones (Bruthans *et al.* 2014). Term natural bridge also applies to water eroded arches (Gavrilović 1974). Still others may be produced by cave roof collapse. They are "a residual portion of the roof of a subsurface karst cavity which has not collapsed" (Field 2002). Most natural bridges of eastern Serbian Carpatho-Balkanides belong to this group (Gavrilović 1998; Ćalić-Ljubojević 2000).

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Received/Prejeto: 27.08.2014

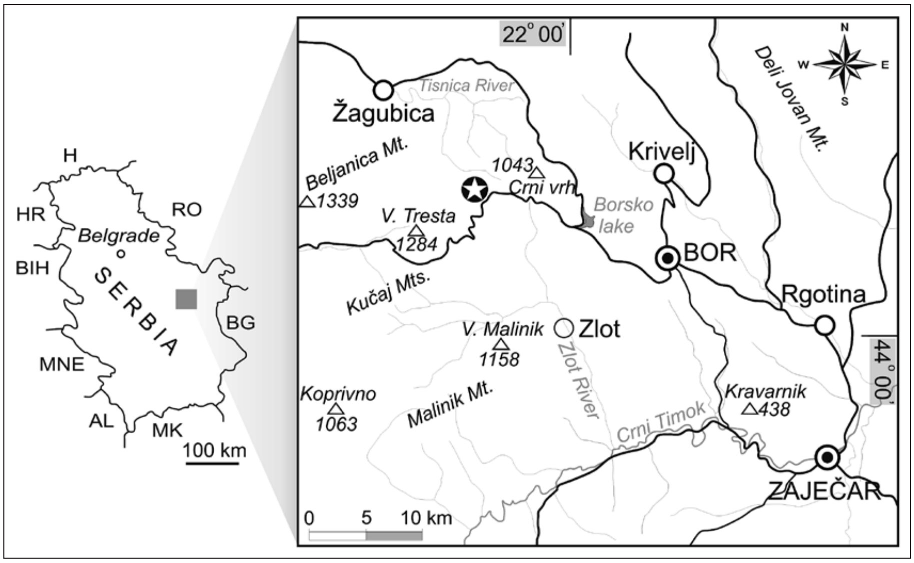

Fig. 1: Location map of the Ravna River doline and Samar natural bridge (star) from the NE Kučaj Mountains (Carpatho-Balkanides, eastern Serbia).

We use the term collapse valley for generally gorge like valley originated by collapse of a roof of an underground stream (Nicod 1997). Formation of natural bridges by collapsing the roof of the cave is conected with the genesis of collapse valley. Examples of natural bridges that were created in this way is possible to find all over the world (e.g. the Rakov Škocjan gorges in Slovenia, the Marble Arch gorge of Ulster, the Da Xiao Cao Kou gorge of the Yijiehe River in Guizhou, and the Río Peruacu gorge in Minas Gerais, Brazil) (Ford & Wiliams, 2007).

The study area is situated on the NE slopes of Kučaj Mts. in the eastern Serbian Carpatho-Balkanides within the Getic tectono-stratigraphic unit (Kräutner & Krstić 2003) located between 22°05' to 22°06'E longitude and 44°07' to 44°06'N latitude (Fig. 1). This region has been geotectonically considered as part of the Kučaj-Svrljig tectono-sedimentary zone within the Karpatikum (Andjelković 1978; Andjelković & Nikolić 1980) and by Karamata & Krstić (1996) it was attributed to the Kučaj terrane, one of the several large Alpine geotectonic units of the eastern Serbian Carpatho-Balkanides (Fig. 2A).

The greatest area of Kučaj Mountains preserves a very thick succession of carbonate deposits ranging from Late Jurassic-Early Aptian in age characterized by the dominance of karstic landscapes.

The main objective of this research study is to present a comprehensive study on the formation and evolution of Ravna River collapse valley with interpretation of petrological study and formation of the Samar natural bridge on the NE slopes of Kučaj Mts and to introduce a term collapse valley. In order to accomplish these tasks, field work, including geomorphological mapping and rock sampling, was performed. Laboratory work included thin sections preparation and microscopic study. It is important to mention that the present study is part of a larger research objective which aims to give an insight into the evolutionary development of the collapsed valleys in eastern Serbian Carpatho-Balkanides.

MATERIALS AND METHODS

Geomorphological and sedimentological investigations have been carried out on Ravna River valley and Samar natural bridge in eastern Serbia. Accurate measurements of dimensions were made using Trimbl Juno handheld computer and Leica DISTO A3 laser distance meter in combination with the 1:25,000 topographic maps (sheets Jasikovo, Velika Tresta and Zlot), the geological maps 1:25,000 (Crni Vrh) and 1:100,000 (Žagubica) (Antonijević *et al*. 1970). All analytic and field data was involved in geomorfological map, created using GIS software (ArcMap10.2.2).

Limestone samples were collected from the base, wall and arch of the Samar natural bridge at approximately 1 m and 1.5 m intervals. All samples collected were prepared in the laboratory in the form of thin sections for microscopic observation in order to determine texture (matrix) and grain composition of the rock. The thin sections of the samples were investigated by using a BIOPTICA Polarization microscope BPL3000P Model. Microphotographs were taken by the digital Leica EC3 camera connected to the microscope. Our interpretations include a classification of carbonates based on the schemes of Duncham (1962) and Flügel (2010). The thin-sections are housed in the collection at the Faculty of Geography, University of Belgrade, under inventory numbers which are referred to in the text.

GEOLOGICAL SETTING

Within the wider study area the oldest rocks are represented by Precambrian low-crystalline schists (Antonijević *et al*. 1970, Fig. 2B). They are transgressively overlain by Ordovician metasandstones and argillites. Marine sedimentation started in the area during the Middle Jurassic, characterized by the accumulation of terrigenous and carbonate sediments (Carević *et al*. 2011). Upwards they are followed by Oxfordian and Kimmeridgian limestones with cherts. The greatest area is occupied by Tithonian reef limestones conformably overlain by "Neocomian" carbonate deposits and Barremian/Early Aptian Urgonian limestones (e.g. Jankičević 1978, Jankičević 1996, Sudar *et al*. 2008, Carević *et al*. 2014). The Late Jurassic-Early Cretaceous deposits are widely distributed in the eastern Serbian Carpatho-Balkanides and represent part of the Getic carbonate platform. The platform attains about 60 km in width and extends over more than 200 km (Grubić & Jankičević 1973) as an elongated arch from Romanian southern Carpathians northward towards the Serbian-Bulgarian border eastward. In Serbian Carpatho-Balkanides and Romanian southern Carpathians geologically-controlled karst features have been developing over a geologic timescale (Tîrlă & Vijulie, 2013). They are unconformably overlain by Upper Cretaceous volcanoclastic-sedimentary Timok Group of Formations (Ljubović-Obradović *et al*. 2011). The Paleogene is represented by intrusions of granitic rocks, skarns, marbles, hornfels and pyroclastics. Dacites and subordinately andesites of Ridan-Krepoljin belt were effused 74 to 70 Ma ago, but a rejuvenation, connected to an intrusive impulse occurred 60 Ma ago (Karamata *et al*. 1994). Quaternary deposits consist of diluvium and talus cones.

FORMATION OF THE COLLAPSE VALLEY OF RAVNA RIVER

Ravna River is located about 12 km southeast of Žagubica city and 13 km northwest from the village of Zlot, on the NE slopes of Kučaj Mts. in Eastern Serbia (Fig. 1). The karst area that has developed in Late Jurassic-Early Aptian limestones occupies the biggest part of Ravna River drainage area (20,5 km^2). This short river, 7,4 km long, flows in the upper part through metasandstones and argillites, where it is a perennial stream. After making a contact with limestones, river water begins to sink in the riverbed. Downstream of the natural bridge Samar, after having spring in riverbed, permanent flow is persistent again. Only during the rainy summer (ex. 2014) Ravna River is a perennial stream all year round.

The valley of Ravna River (Fig. 3) is intersected by a pair of active faults, which are followed by lifting up of a ground in the upstream part of valley (Gavrilović 1998). A change in valley bottom gradient, tectonic breccia and textural change in limestones, indicate persistence of these active faults. Average gradient in upstream part of valley is 32 ‰. In 600 m long central part of the valley, the gradient rises up to 94 ‰, while the downstream part till the confluence with Tisnica River, has a significantly smaller bottom gradient of 30 ‰.

Tectonic uplifting of upstream part of valley has caused local sinking of Ravna River and a formation of a cave system downstream of the sink. Cave exit was 2,8 km upstream from the present mouth, on the former contact between limestones, conglomerates and sandstones. This contact is indicated by remains of Upper Cretaceous sediments in Ravna River drainage area and it's surrounding (Figs. 3). Faster cutting of river valley in conglomerates and sandstones enable building a narrow and high cave channel. After a later collapse of the cave roof, a collapse valley, 600 m long was formed (Fig. 3a) (Gavrilović 1998).

The persistent remains in the present relief of Ravna River collapse valley indicate former existence of a tunnel cave. It is gorge like part of valley (Fig. 4a), two side cave channel (Fig. 4b and 4d) and Samar natural bridge (Fig. 4c). The collapse valley is narrow, with very steep sides. The Samar natural bridge is situated in the deepest part of collapse valley. Two former side cave chan-

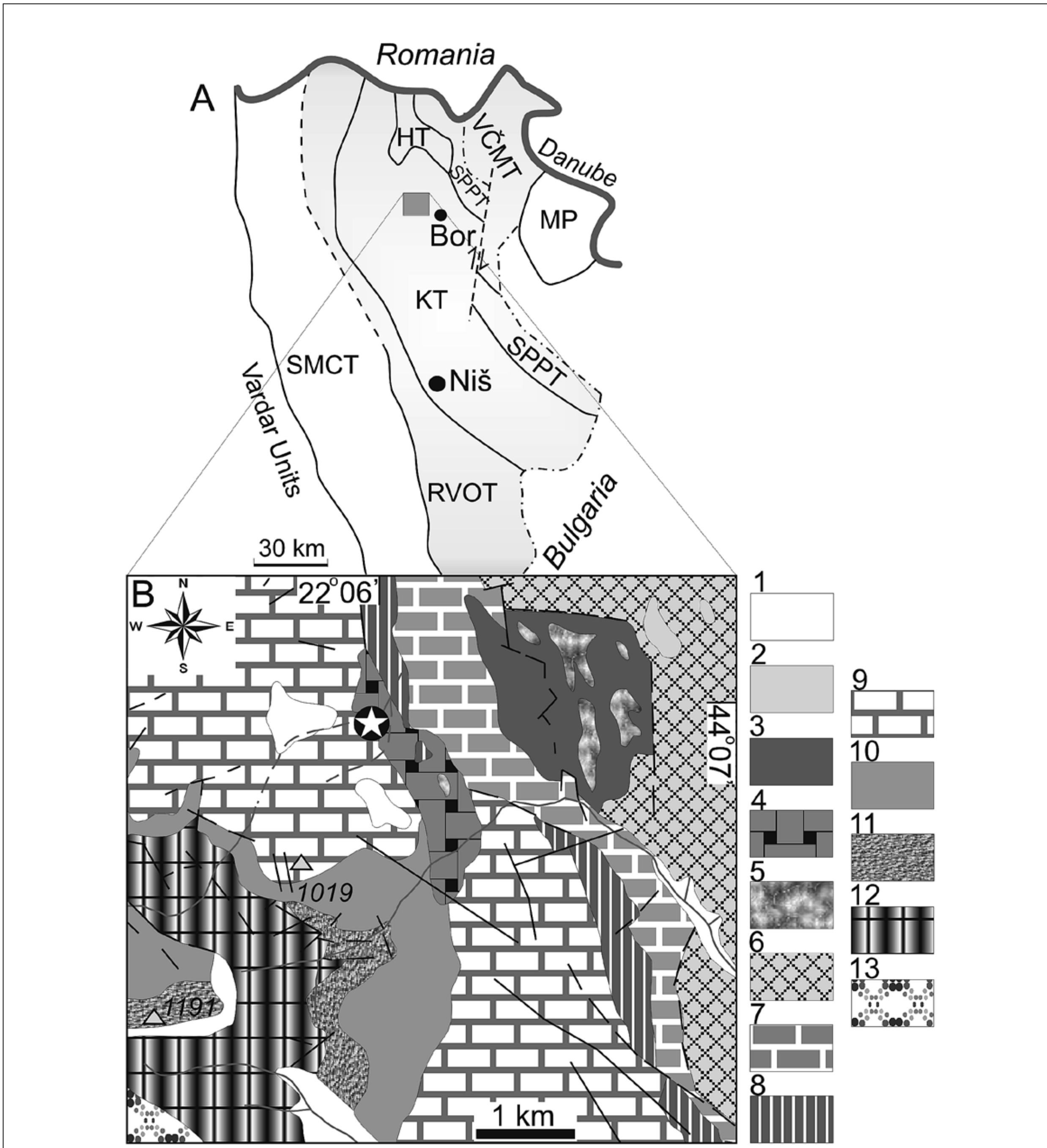

Fig. 2: a) Location map of the Ravna River valley and Samar natural bridge (star) from the NE Kučaj Mountains (Carpatho-Balkanides, eastern Serbia). b) Locality map of the investigated area in eastern Serbian Carpatho-Balkanides. A, Composite terranes of eastern Serbian Carpatho-Balkanides (shaded) as part of Balkan peninsula after Karamata & Krstić (1996): VČMT, Vrška Čuka-Miroč terrane; SPPT, Stara Planina–Poreč terrane; KT, Kučaj terrane; HT, Homolje terrane; RVOT, Ranovac–Vlasina–Osogovo terrane; MP, Moesian plate; SMCT, Serbian–Macedonian composite terrane. B, Geological map of the wider area of investigated locality (locality indicated by star) modified after Antonijević et al. 1970. 1, Quaternary deposits; 2, Paleogene dacitic-andesitic rocks; 3, Paleogene pyroclastics; 4, Paleogene skarns, marbles, hornfels; 5, Paleogene granites; 6, Upper Cretaceous volcanic agglomerate, breccia, tuffs, marly limestones; 7, Urgonian limestones; 8, "Neocomian" limestones; 9, Tithonian reef limestones; 10, Oxfordian and Kimmeridgian limestones with cherts; 11, Undifferentiated Middle and Upper Jurassic limestones; 12, Ordovician metasandstones and argillites;13, Precambrian schists.

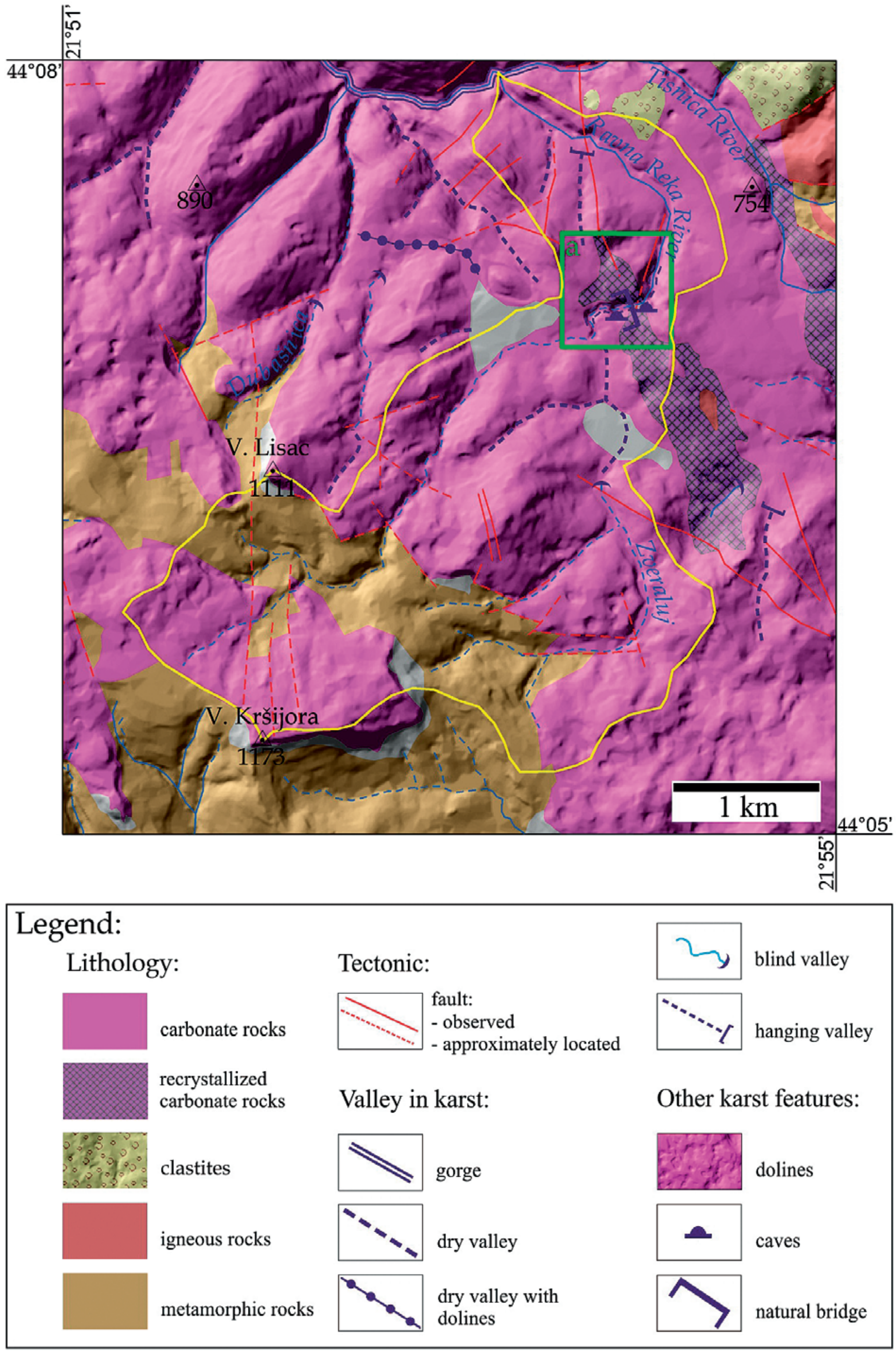

Fig. 3: Geomorphological map of Ravna River drainage area (yellow line) and its surrounding.

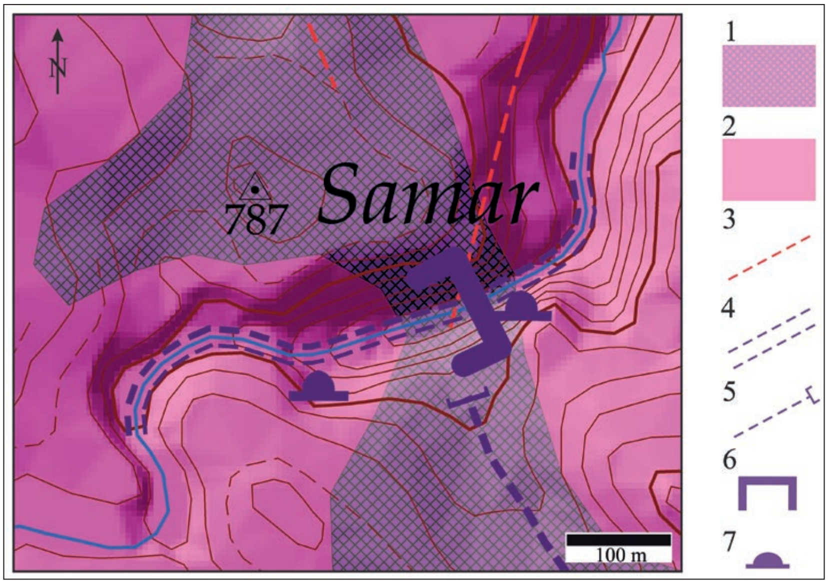

Fig. 3a: Geomorphological map of Ravna River collapse valley: 1, recrystallized carbonate rocks; 2, carbonate rocks; 3, fault, approximately located; 4, collapse valley (gorge); 5, hanging valley; 6, Samar natural bridge; 7, cave.

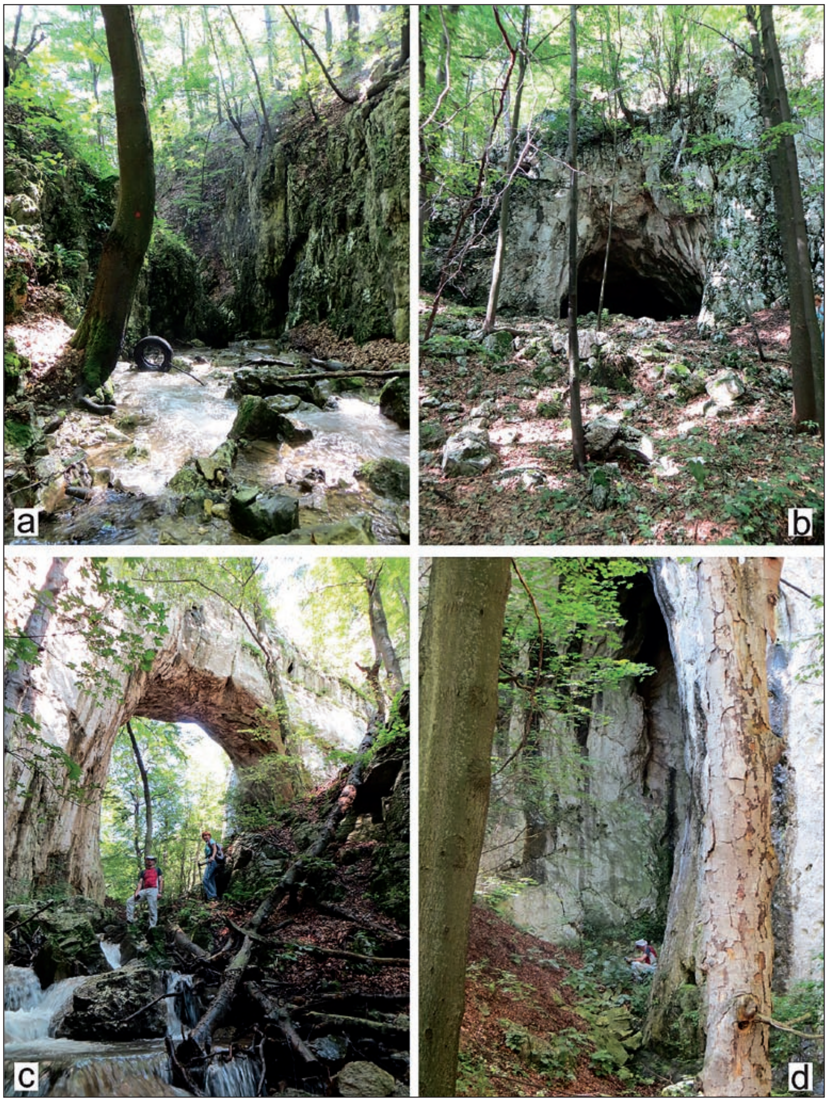

Fig. 4: Remains of a former cave in Ravna River valley. a, narrow part on entrance in gorge of Ravna River; b, entrance in side cave channel at the beginning of canyon; c, natural bridge Samar; d, entrance in cave situated in the right wall of Samar natural bridge (photographs by A. Petrović).

nels today form separate caves. The first is located on the right side of valley, immediately after the entrance in the canyon (Fig. 4b). Cave is 215 m long (Gavrilović 1998). The second cave is downstream, situated in the right wall of the natural bridge (Fig. 4d). Cave entrance, 8 m high and 4 m wide, raises 10 m above the Ravna River bottom. After the entrance small hall is located (12 × 7 m) and a 50 m long channel oriented to SW.

SAMAR NATURAL BRIDGE: MORPHOLOGICAL AND SEDIMENTOLOGICAL CHARACTERISTICS

The most significant remain of the former cave is natural bridge Samar. The bridge is formed in a massive reef limestone of Tithonian age, up to 400 m thick. It is 6 m long, 15 m high and 12 m wide at an elevation of about 720 m a.s.l. The bridge appears to be a remnant of a former cave thus indicating a speleogenic origin. One

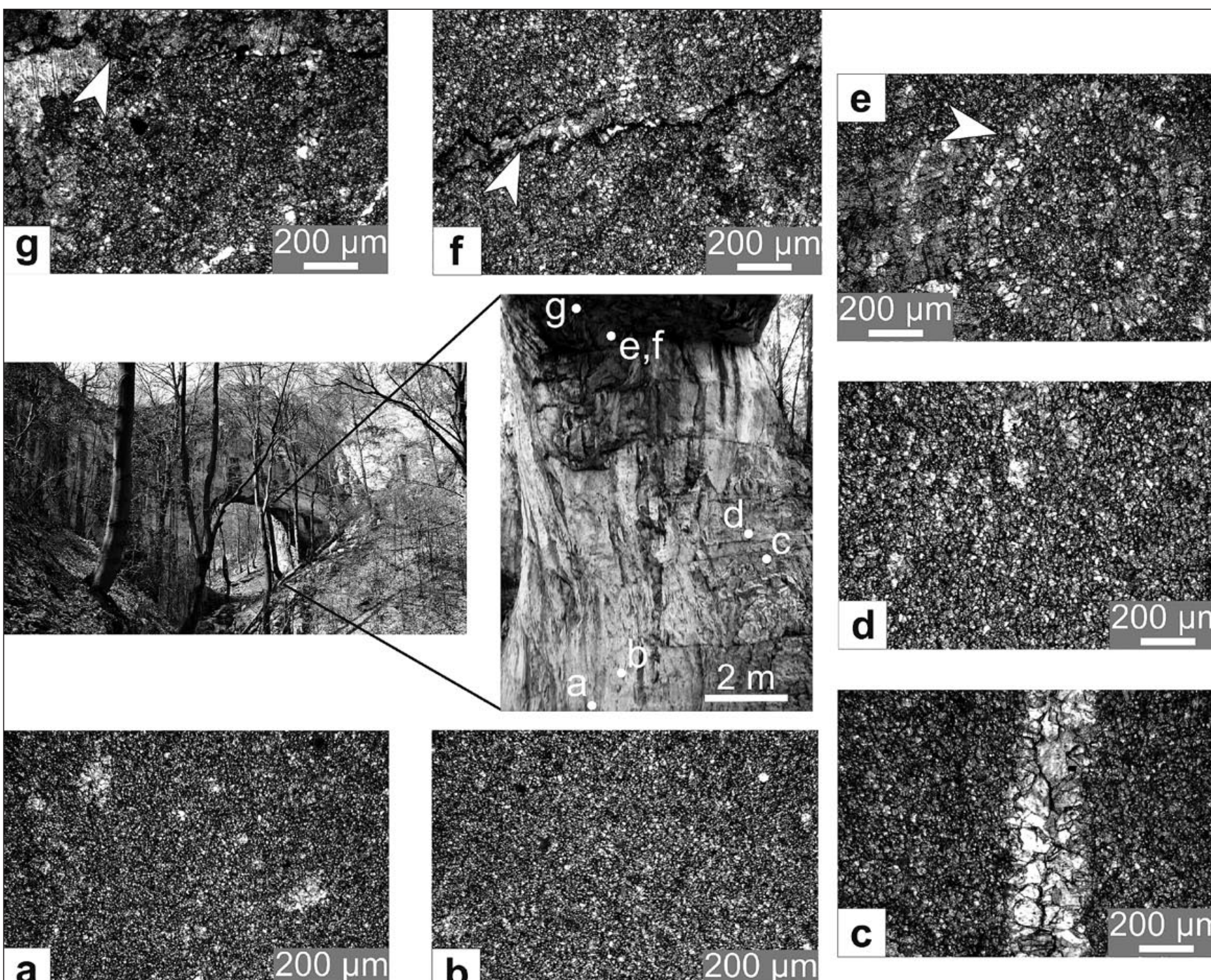

Fig. 5: Samar natural bridge from the NE Kučaj Mountains (Carpatho-Balkanides, eastern Serbia) and thin-section photomicrographs of the Late Jurassic limestones showing characteristic recrystallized fabrics of the Samar natural bridge. a) microsparite resulted by aggrading recrystallization of the former micritic matrix, sample SP 1. b) recrystallized cement with no preserved relics, sample SP 2. c,d) recrystallized cement with vein filling by sparry calcite fabric, c, sample SP 3; d, sample SP 4. e) recrystallized cement. The outline of the circle structure suggests a crinoids? whose skeleton has been replaced by calcite (white arrow), sample SP 5. f,g) low amplitude stylolites in a recrystallized cement (white arrows). The dark stylocumulate consists of Fe-oxides, f, sample SP 5; g) sample SP 6.

of the first explicit suggestions that natural bridges in eastern Serbia have a speleologenic origin was given by Gavrilović (e.g. 1998, 2005) and Ćalić-Ljubojević (2000). The first attempt to explain how the sandstone bridges remain free-standing is given by Bruthans *et al.* (2014). They show that increased stress within a landform as a result of vertical loading reduces weathering and erosion rates, and when vertical stress increases until a critical value is reached, fabric interlocking of sand grains causes the granular sediment to behave like a strong material enabling the resistance to further erosion. In previous works on carbonate natural bridges it is not yet explained what stabilizes the arch of the bridges.

One thing that all features called bridges and arches have in common is a relatively resistant uppermost lithologic unit that forms the span (Paull 1992) which is in agreement with petrographic characteristics of the Samar natural bridge. The arc of the natural bridge and the walls are resistant recrystallized limestones with no preserved relics, while the microscopic analysis of thin sections in the base of the bridge reveals microspar resulted from the recrystallization of a micritic matrix (Fig. 5a).

Microsparite is a limestone whose fine-grained matrix is developed as microspar and the term is sometimes used simultaneously with microspar (Flügel 2010). The term refers to a fine-grained calcite matrix characterized by calcite crystals ranging from 5 to more than 20 μm in diameter (Folk 1959). The origin is explained by the recrystallization of micrite-sized crystals during recrystallization. Some diagenetic processes involve changes in the fabric of the cement. For these processes of replacement, once loosely referred to as, recrystallization, the term neomorphism is now used to include all transformations (Tucker 2009). The term neomorphism was introduced by Folk (1965) to include all transformations of minerals in the presence of water and it usually refers to an increase in crystal size (recrystallization of micrite to microspar) without any mineralogical change, which is called aggrading neomorphism. Although reef limestones are usually rich in microfauna, no bioclasts have been observed due to the aggrading neomorphism that has destroyed bioclastic grains and produced microspar fabric.

The walls of the bridge are recrystallized limestones with no preserved relics with vein filling by sparry calcite fabric occasionally (Fig. 5b-d) which suggests the formation from meteoric phreatic or vadose waters at a late diagenetic stage (e.g. Chilingar *et al.* 1979; Moore 1989).

The arc of the bridge is resistant recrystallized limestone with common low amplitude stylolites caused by tectonic stress and infilled by Fe-oxides (Fig. 5e-g). Stylolites are irregular, suture-like contacts produced by differential vertical movement under pressure accompanied by solution (Flügel 2010). Following mechanical compaction many sediments are subject to chemical compaction, expressed by pressure solution and the formation of stylolites (Logan 1984).

There is a common assumption that micritic limestones are more heavily affected by weathering than sparitic grain-supported carbonates because of the higher specific surface of fine-grained limestones (Flügel 2010). The weathering potencial of the Samar natural bridge is decreased concerning the diagenetic changes these limestones underwent.

CONCLUSION

The bridge's morphology, petrographic characteristics and the presence of karst landforms in a wider study area all point to a speleogenic origin of Ravna river valley. Tunnel cave existed in central valley part, on 600 m length. Tectonic lifting of upstream valley part and very erodible Upper Cretaceous sediments enable forming of a narrow and high cave channel. After collapse of a cave roof, gorge like collapsed valley was formed.

In addition to geomorphological analysis, a sedimentological evaluation of Samar natural bridge was undertaken. The limestones in which the Samar natural bridge has developed are subjected to extensive diagenetic processes of which the most important are compaction, neomorphism, internal filling and stylolitization.

In the base of the bridge, the micritic matrix has been totally replaced by microspar resulted from the recrystallization of a micritic matrix. Neomorphisms in the limestones of the Samar natural bridge are of the aggrading type, a kind of neomorphism or recrystallization in which the crystal size increases and finer crystal mosaics are replaced by coarser ones thus increasing the weathering resistance of the bridge.

ACKNOWLEDGEMENTS

Two anonymous reviewers are thanked for valuable corrections and helpful comments that helped to improve the original manuscript. The research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project No. 176017 (grant to IC) and Project No. 177023 (grant to AP).

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