

Contribution to the understanding of the origin of caves in the valley of Slatinska Reka (Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, Puralo and Slatinski Izvor)

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Abstract



There are five caves in the river valley of Slatinska Reka, a tributary of the river Treska: Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, Puralo and Slatinski Izvor. The morphology of caves, the cross-section of the passages, the micro-relief forms, and cave sediments were analyzed in order to determine the caves' origin. The results showed that the main controlling factor in the karst development has been the evolution of the river Slatinska Reka, which was dependent on the evolution of the Treska valley as a regional base-level controlling factor. Also, the tectonic and geologic conditions control the karst development in the area. All caves have "normal" epigenic development. Paragenesis driven by allogenic sediment input shaped cave development. The caves Gorna Slatinska Peštera, Slatinska II, and the higher level of the caves Ovčarska Peštera and Puralo date from the same period, whereas the lower level of the caves Ovčarska Peštera and Puralo, as well as the Slatinski Izvor were formed later. The Slatinski Izvor cave is the youngest one in the study area.

Keywords: cave development, Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, Puralo, Slatinski Izvor

Introduction

Karst terrains have a specific nature and unique hydrogeological characteristics, so they require specifically adapted investigation methods. Speleological investigations are some of the suitable methods. Caves transmit the great majority of groundwater in karst areas. They are formed along groundwater paths of greatest discharge and solution aggressiveness, and their patterns depend on the mode of groundwater recharge. Palmer (1991, 2007) identified several plan-view cave patterns: branchwork, maze, and ramiform. Sinkhole recharge forms branchwork caves that join as tributaries that join downstream as higher-order passages. Flood water can form anastomotic caves

which consist of curvilinear tubes that intersect in a braided pattern with many closed loops. Flood water and diffuse recharge can form network and spongework caves.

The cave rock relief and longitudinal and transversal sections of passages give insight into the way of the water flow through the cave, the mechanism of shaping the cave, and the most important stages of its development (Knez et al. 2011). Mesoforms may reflect the mode that passage was formed. Phreatic passages are formed under totally waterfilled conditions, by corrosion that is symmetric and directed radially out from the passage axis, producing a nearly tubular cross-section. Their features are circular, elliptical, or lenticular cross-section shape, and a looping behavior, usually with large scallops. Tubular passages also

Submitted: 30.04.2025

Accepted: 16.06.2025

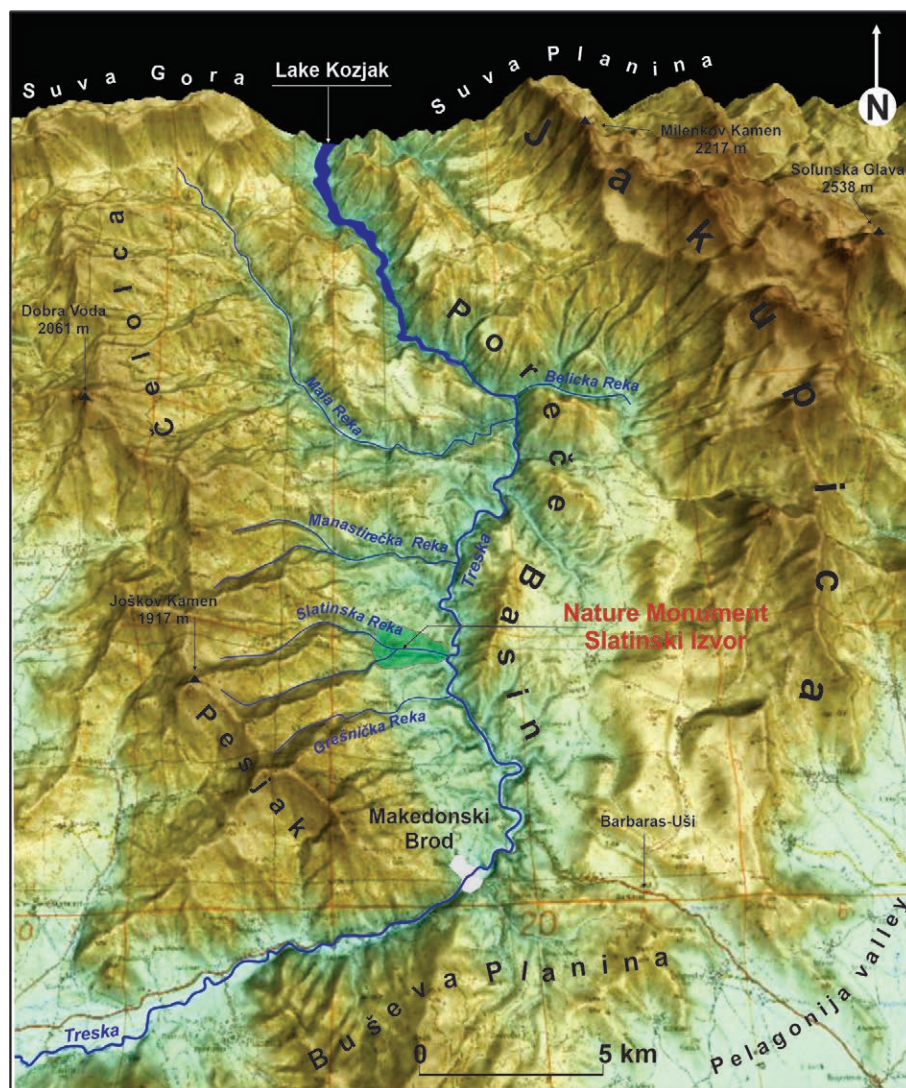


Figure 1. Geographical position of the study area.

develop in epiphreatic settings, where passages may stay dry for a long period, but during floods, they are completely water-filled and act as phreatic tubes. Vadose passages include shafts and canyons, where water is driven by gravity (Lauritzen and Lundberg 2000, Ford and Williams 2007). Microforms are usually superimposed onto passage walls, and they indicate modifying processes that operated subsequent to the formation of the main passage (Lauritzen and Lundberg 2000). According to the factors that influence their origin, Slabe (1995) divided them into the following groups: rocky forms due to water flow, along-sediments cave rocky forms, rocky form due to trickling and dropping of water, below-ice rocky forms, rocky forms due to condensation moisture, biogene furrows, and rocky forms due to rock disintegration.

Caves within the phreatic zone can be modified by influxes of sediments which force dissolution on a restricted portion of the conduit perimeter, thus forcing speleogenesis in a certain direction, usually upwards, by process of paragenesis (Renault 1968). Influxes of sediment into a cave alter the way cave passages

develop, either by alluviation in a vadose environment, forcing lateral corrosion and the development of alluvial notches, or by upwards dissolution in a phreatic environment, developing half tubes, anastomoses, and pendants (Farrant and Smart 2011).

About 30 caves are explored in the karst terrain of the Poreče Basin (Petreska 2007). In the river valley of Slatinska Reka, as part of the Poreče Basin, five caves are investigated. Speleological facts, morphometric features, and dating times for some caves are published by several authors (Jovanović 1928, Kolčakovski and Aloski 1984, Vasilevski and Petreska 2002, Carlin 2003, Petreska 2007, Gičevski 2012). For these caves, Jovanović (1928) determined their morphological and geological (chronological) age by comparing them with the age of the river terraces in the Poreče basin. This comparative chronology was applied for the first time in Macedonian speleology and therefore represents a necessary geomorphological model for all future cave research, providing a solid scientific basis for modern speleomorphology (Petrović 1988). However, the passage patterns, micro-relief forms, and cave sediments, which



Figure 2. Karst terrains of the Slatinska Reka river valley, photo by B. Gičevski.

are important for determining speleogenesis, have not been investigated so far.

The aim of this study is to determine the cave development and evolution of the caves in the river valley of Slatinska Reka based on the analysis of the speleological features.

Study area

The investigated area is located in the middle part of Treska drainage basin, in the Poreče Basin, namely in the river valley of Slatinska Reka, and it is a part of the protected area Monument of Nature “Slatinski Izvor” (Figure 1).

The studied area belongs to two tectonic units: the Western Macedonian zone and the Pelagonian horst-anticlinorium. The Western Macedonian zone is on the west side of the study area, and it is composed of Paleozoic quartz-sericite schists and metasediments, metarhyolite tuffs, muscovite-chlorite-quartz schists, and epidote-chlorite-amphibole schists, which are moderately permeable rocks with fissure porosity,

and Mesozoic aplitic granite with fissure porosity. Quaternary sediments are represented by moraines in the upper parts of the river valley. The Pelagonian horst-anticlinorium is on the east side of the study area, and it is composed of Precambrian dolomite marbles that are tectonically crushed, well karstified (Figure 2). In the karst area, there are five caves: Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, Puralo and Slatinski Izvor (Figure 3). Carbonate rocks are covered with Pliocene sediments (gravel, sands, clay) which are highly-permeable rocks with intergranular porosity. Quaternary sediments are represented by alluvium that fills the river bed of Slatinska Reka and have intergranular porosity (Dumurdžanov et al. 1978, 1979).

Both tectonic units are separated by a fault that can be traced for more than 100 km (Arsovski 1997), and the Pelagonian horst-anticlinorium is drawn over the Western Macedonian zone (Dumurdžanov et al. 1979). There is a reverse fault in a NW-SE direction and a covered fault on the river bed of Krušeska Reka in the same direction.

The sources of the rivers Krušeska Reka and Markoska Reka are in a non-carbonate environment,

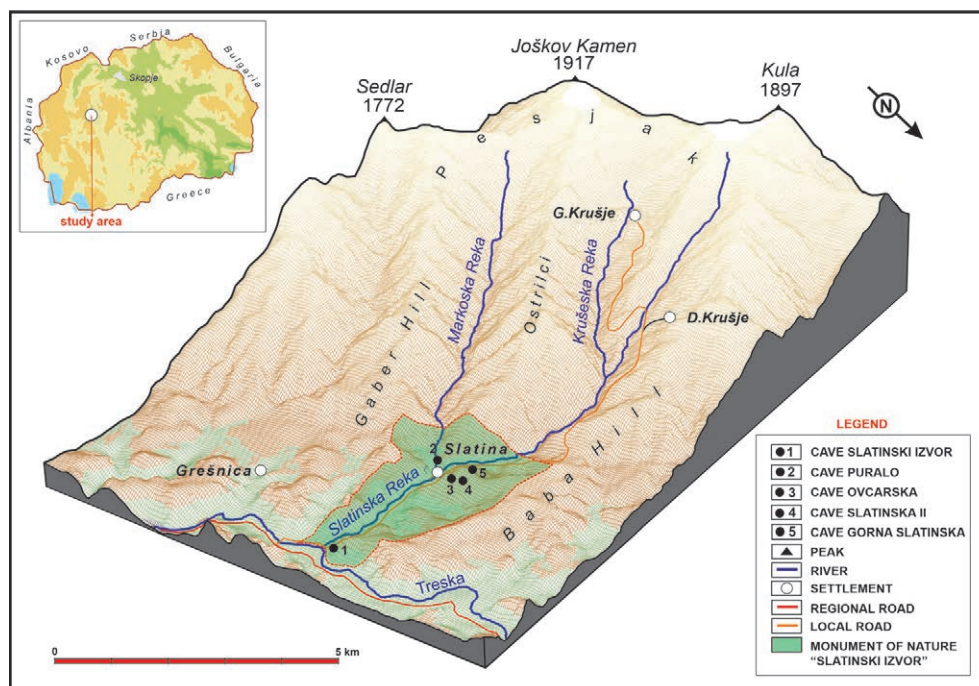


Figure 3. Position of the caves in the river valley of Slatinska Reka.

and at contact with carbonate rocks, ponors are developed and river waters sink underground, and continue to flow underground. The river Slatinska Reka is created with the confluence of the rivers Krušeska Reka and Markoska Reka, and downstream from the ponors, the river water losses constantly increase.

In the researched area, there are three springs (Gičevski et al. 2015). The largest and most important spring is Slatinski Izvor which serves as a cave entrance for the Slatinski Izvor cave. It is captured for the water supply. The salt spring Solenica is located on a tectonic contact with marbles and schist formations. The water is gathered in two small pools that are covered by a man-made structure. The spring Slanište is situated at the same fault zone as the spring Solenica, and it is captured for water supply.

Materials and methods

The fieldwork included classical speleological field methods which involve conventional field research, by visiting and researching the terrain. Entrances of the caves were recorded by GPS Garmin Montana 680.

For the morphological analysis, published cave maps (Kolčakovski and Aloski 1984, Carlin 2003, Vasilevski and Petreska 2002, Petreska 2007) were revised and added with new data. Cave surveying was done using Leica laser distance meter (DISTO D 330i), Suunto compass, and a clinometer (SU-51-TANDEM). The preparation of the cave maps was done using the software CorelDraw.

Speleological investigations were used to interpret the environment in which the caves were formed. Cave morphology was studied based on the horizontal cave pattern (Palmer 1991, 2000) and by identifying specific

Table 1. Basic information about the caves in the valley of Slatinska Reka.

Cave	Entrance altitude (m a.s.l.)	Total length (m)	Hydrological function	Cave passage pattern	Hydrogeological zone
Gorna Slatinska Peštera	591 579	336	dry	branchwork	vadose
Slatinska II	589	126	dry	anastomoses	vadose
Ovčarska Peštera	579	268	dry	branchwork/ anastomoses	vadose
Puralo	575	985	River cave	branchwork	epiphreatic
Slatinski Izvor	521	3942	River cave	branchwork/ anastomoses	epiphreatic

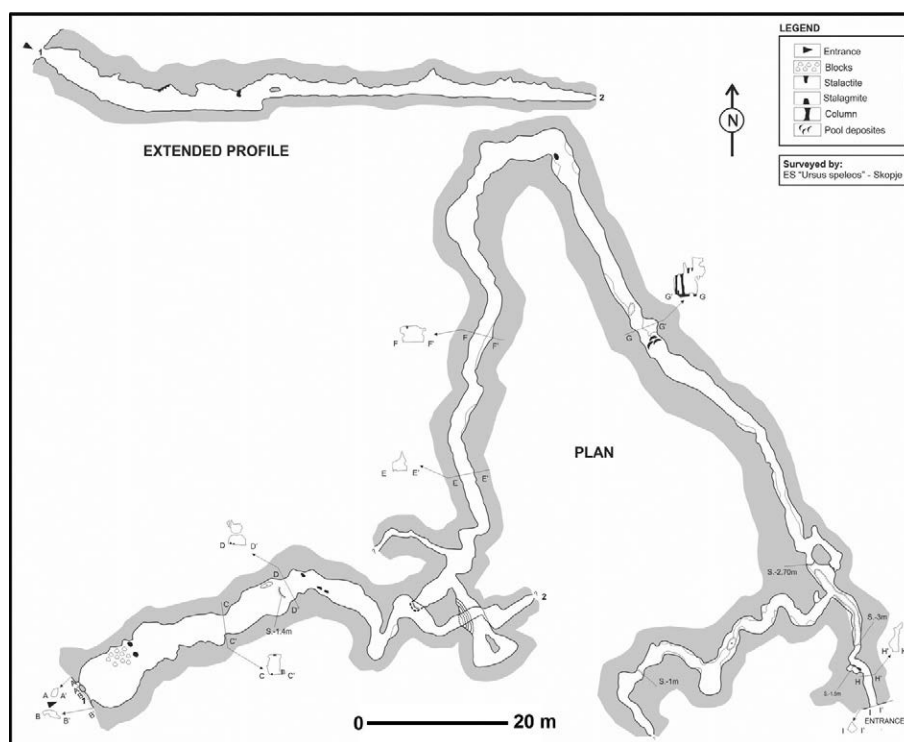


Figure 4. Cave map of Gorna Slatinska Peštera

meso- and microscale morphology in cave passages (Bögli 1978, White 1988, Lauritzen and Lundberg 2000), in order to investigate the character of the host aquifer.

Results and discussion

In the study area, there are five caves (Table 1): Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, Puralo, and Slatinski Izvor. In order to determine the cave's origin, the morphology of the caves, the cross-section of the passages, micro-relief forms, as well as, cave sediments are analyzed. Speleothems, as cave sediments, are grouped according to the environment in which they form.

Cave Gorna Slatinska Peštera

The cave Gorna Slatinska Peštera is situated on the left side of the river Krušeska Reka. The first speleological data were presented by Jovanović (1928). The cave presents a natural tunnel with two entrances. The first one is on 591 m a.s.l., and the second one is on

579 m a.s.l. The cave is located in vadose zone. In plan-view, cave passages constitute a branchwork pattern. The passages are distributed in two elevations. From the higher entrance, the passage is positioned inversively. The total length of the cave is 336 m (Figure 4).

In cross-section, the passages have phreatic semicircle morphology, where passages did not form at distinct fissures. The second type is drawdown vadose passages, where the phreatic part was first and fixed the position of the trench (Figure 5).

Most of the recorded micro-relief forms are formed due to former water flow (Gičevski 2012). The traces of the former ground flow are preserved along almost the whole main passage. These micro-relief forms are presented with scallops, wall notches, water level horizons, ceiling channels, potholes, and three natural bridges. The fossil river bed is covered with breakdown debris that is collapsed from the cave ceiling and clay. According to the environments in which speleothems are formed, they belong to three groups: speleothems formed by flowing and dripping water (stalactites, stalagmites, columns), speleothems formed by capillary water (welts), and pool deposits (mammillaries).

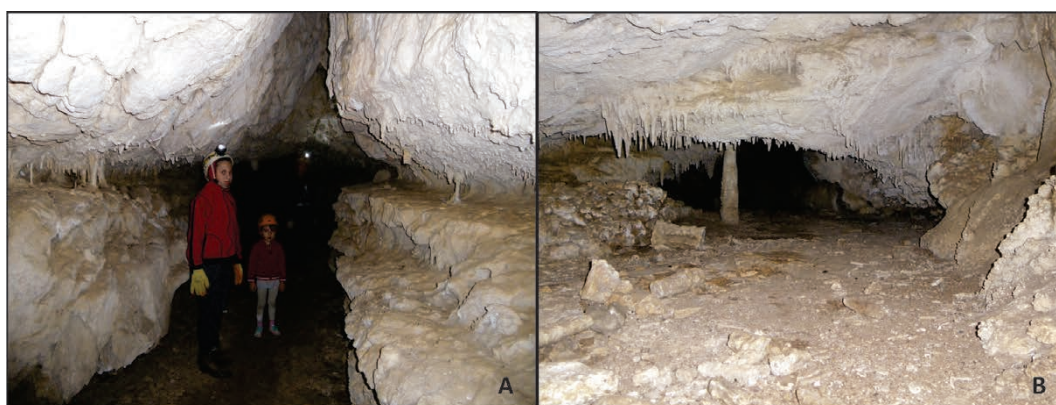


Figure 5. Cross-section of the passages: A-drawdown vadose morphology, B-phreatic passage, photo by B. Gičevski.

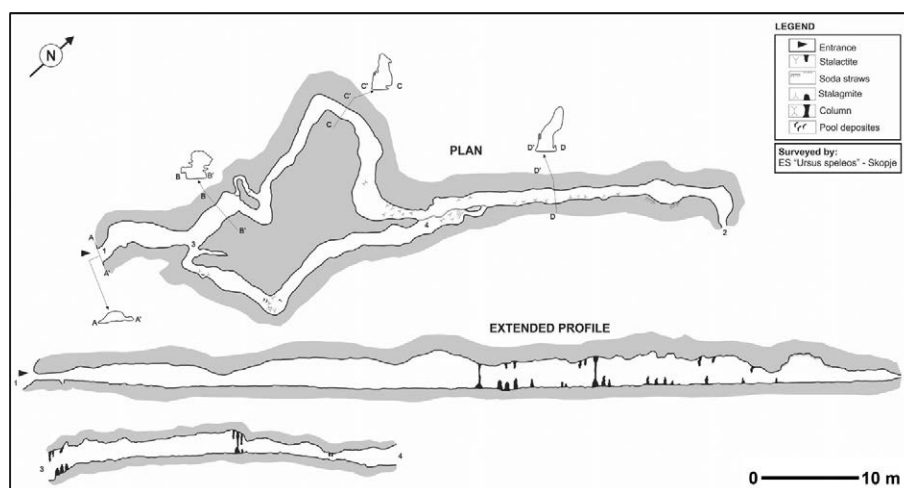


Figure 6. Cave map of Slatinska II

Cave Slatinska II

The cave Slatinska II is located on the left side of Krušeska Reka valley. The cave was first explored and published in literature (as III Slatinska Peštera) by Jovanović (1928). The entrance is at 589 m a.s.l., 33 m above the river bed. The cave consists of a single horizontal passage, that is located in the vadose zone and formed along the strike of the strata, with a SW-NE orientation (Figure 6). Slatinska II is a small cave formed from a simple cave passage. The total length of the cave is 126 m.

The cave has an anastomosing pattern in a plan-view. In cross-section, the passage exhibits a phreatic elliptical morphology and a vadose cross-section, where the phreatic part was initially established and fixed the position of the trench (Figure 7).

Traces of the water flow through the formerly flooded cave are scallops and ceiling pockets. The position of the scallops indicates that they were formed from a water flow that was heading from the entrance of the cave. Ceiling pockets represent individual forms that are mostly controlled by the fissures within a rock.

The cave floor is covered with small pieces of rocky material collapsed from the cave ceiling and clay. Speleothems can be found at the end of the passage in the form of flowstones, dripstones, welts, coralloids and mammillarias.

Cave Ovčarska Peštera

The cave Ovčarska Peštera is located on the left side of Slatinska Reka valley, e.g. 23 m above

the confluence of Krušeska Reka and Markoska Reka. The entrance is at 579 m a.s.l. The first data for the entrance part of the cave were presented by Jovanović (1928). The cave is located in a vadose zone. Morphologically, the passages have formed on two levels. The passages in the higher elevation have a SE-NW direction, they are 74 m long and have two almost circular halls. Both cave levels are connected by 14 m deep shaft. The passages in the lower elevation have a SW-NE direction which are formed along the strike of the strata, and have 135 m. Throughout the whole passage, there are cave expansions which are mutually divided into sections. The total length of the cave is 268 m, and the height difference between the highest and lowest points is 28 m (Figure 8).

According to the cave patterns, the cave is a branchwork cave with passages that join as tributaries, whereas in the lower cave level, the cave passages in the southern part have features of an anastomosing cave. In cross-section, most of the passages have a phreatic elliptical morphology, elongated along the bedding plane. At places where the fossil river bed is noticed, drawdown vadose morphology is characterized, but it is clear that the phreatic part was first of all. The cave passages, later, were modified by paragenesis, mostly by alluviation in vadose passages. The remnants of sediments through the cave, rounded pebbles and cobbles on the floor (their dimension are the highest in comparison with the other caves in the study area), alluvial notches are the marks of this process. Additionally, some flowstone deposits with gravel on the lower side are



Figure 7. A-passage which represents a shift from phreatic to vadose conditions, B-phreatic passage, C- the entrance part of the cave, photo by B. Gičevski.

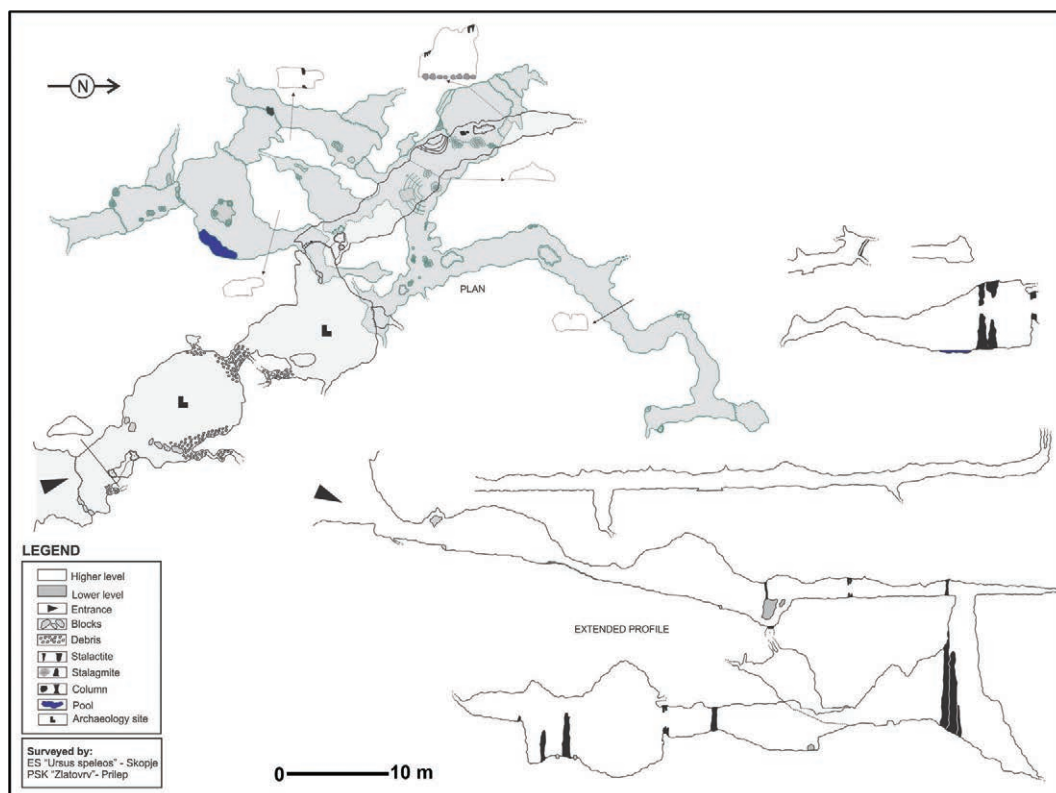


Figure 8. Cave map of Ovčarska Peštera

visible on the ceiling, having been exposed after the removal of coarse fluvial sediments.

The cave's rocky relief on the higher cave level resulted in evidence ceiling pockets, scallops, and a natural bridge. The ceiling pockets are formed predominantly along the cracks. Large scallops incised in the passage which follows to the shaft indicate slow water velocity of former ground flow. The natural bridge is developed at the entrance part of the cave. Micro-relief forms on the lower cave level are harder to detect due to the deposited sediments and speleothems. Potholes are developed in the wall, at places where the rock is hard. Some of them are filled with pebbles. Alluvial notches are discontinuous and meander from one cave wall to the other.

The floor of the lower cave level is covered with debris, blocks, and speleothems that have fallen from the ceiling. Sand, gravel, and pebble deposits can be seen on the passage floor, walls, and ceiling. Speleothems on the higher cave level are almost not present at all. In the lower cave level, they are represented with speleothems formed by flowing dripping water (flowstones, stalactites, stalagmites, columns), speleothems formed by capillary water (helictites, welts), and pool deposits (subaqueous coatings, needles, subaqueous coralloids, folia) (Figure 9).

Cave Puralo

The cave Puralo is located in the river valley of Markoska Reka, 30 m above the river bed. The entrance is at 575 m a.s.l. Vasileski and Petreska (2002) gave the first data about the cave.

The cave passages are formed between a fault that separates Pelagonian and Western Macedonian tectonic units and an obvious fault that passes the river bed of Krušeska Reka. They are generally oriented in NW-SE direction, with parts developed along NE-SW-oriented fissures. Morphologically, the passages are separated in two levels (Figure 10).

The higher cave level is 22 m long and oriented towards NE. At 10 m from the entrance, there is a shaft which is 11 m depth and connects both cave levels. The lower cave level is represented by a larger cave expansion (Big Hall) with dimensions: 70 m long and 13.5 m wide. The exploration conducted by Slovenian and Macedonian speleologists in 2011 resulted in the recording of new 250 m long cave passages which are separated from the Big Hall in the SE direction. The total length of the cave Puralo is 985 m. In plan-view, cave passages constitute a branchwork pattern. In cross-section, the higher cave level has a phreatic elliptical morphology, developed along bedding (Figure 11). The lower cave level has also phreatic morphology, partly elongated along fissures, partly along bedding. In the vadose section, the passages are roughly followed by fissures, but they are also influenced by former phreatic parts. The lower cave level is modified by paragenesis,

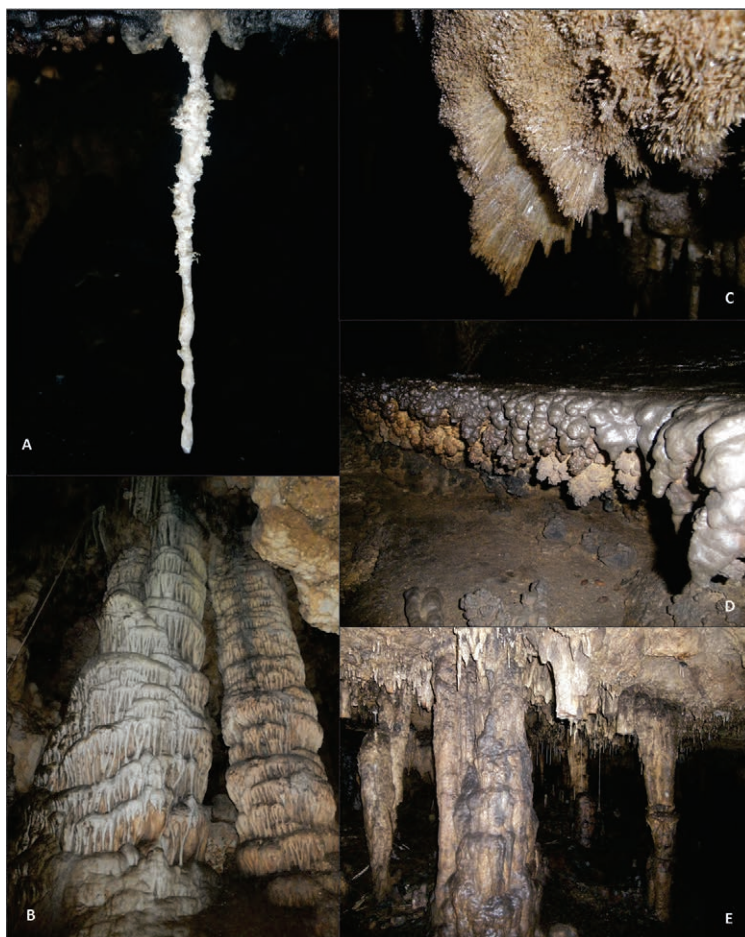


Figure 9. Speleothems in Ovčarska Peštera: A-stalactite, B-column and stalagmite, C-needles, D-subaqueous coatings (mammillaries), and subaqueous coralloids, E-stalactites, stalagmites, and column, photo by B. Gičevski.

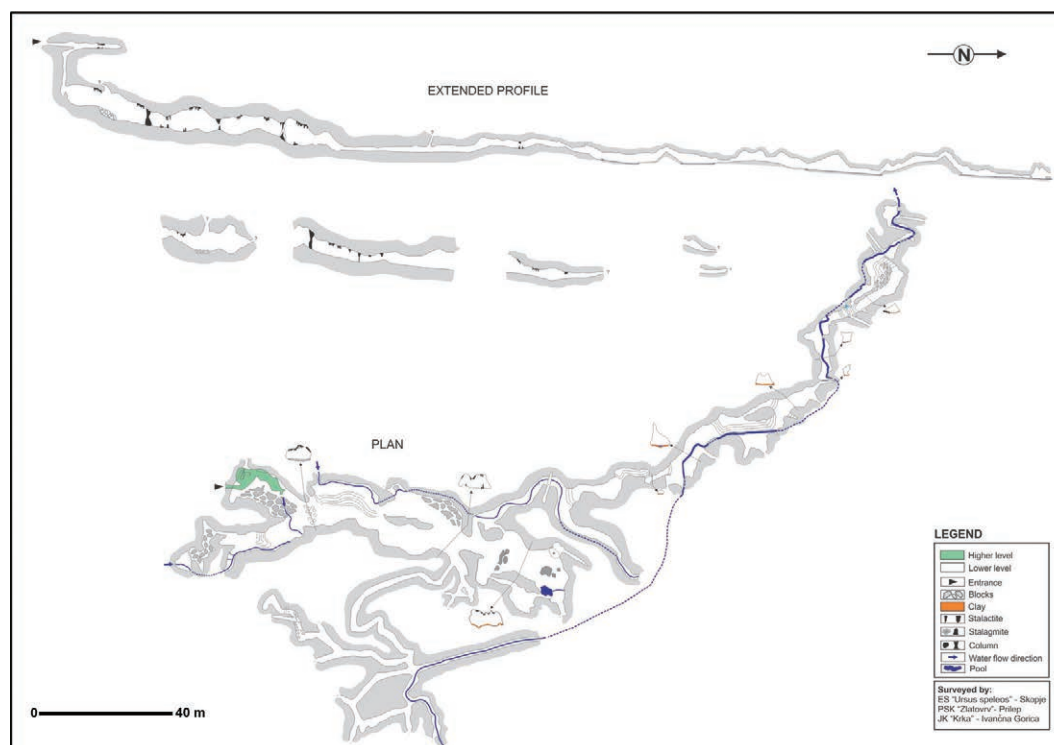


Figure 10. Cave map of Puralo cave.



Figure 11. A cross-like shape of cave passages: A-fissure-oriented passage, B-fissure-guided vadose passage, C-fissure-oriented passage, D-passag which represents a shift from phreatic to vadose conditions, E-the entrance part of the cave is formed in bedding-plane, photo by B. Petkovski (A, C, D) and B. Gičevski (B, E).

e.g. the process of alluviation was characteristic for all passages of the lower level. Also, the two periodic water flows, which are recorded in the lower level, their river beds are engraved in sand and clay.

Micro relief forms (Figure 12) in the cave confirmed the paragenetic development. Pendants and ceiling half-tubes are frequent forms in the lower cave level. Alluvial notches are noticed at places where former groundwater flow cut laterally the passage walls. Ceiling pockets are typically arranged in groups and extend along the fissures. Sometimes, they are part of ceiling channels. Large scallops are characteristic of the upper parts of the walls, and smaller scallops are noticed at the lower parts of the walls. This indicates that the first one was shaped by slower water flow, while the second one was shaped by faster water flow.

Clay is the most widespread sediment that fills the passages. The river bed is engraved in sand and clay. Mud cracks can be found in some parts of the floor. Conglomerates can also be found, filling voids on the walls and ceiling. Sand, gravel, and pebbles are widespread in the southern part of the lower cave level.

Breakdown blocks completely cover the floor of the Big Hall (larger than 3x3 m).

The cave is rich with speleothems, which are found in both levels. They are presented with speleothems formed by flowing and dripping water (stalactites, soda straws, stalagmites, columns, draperies, conulites), speleothems formed by capillary water (helictites), and pool deposits (rimestone, folia).

Cave Slatinski Izvor

The cave Slatinski Izvor is situated on the left side of the Slatinska Reka Valley, with an entrance at 521 m above sea level, 0.5 m above the riverbed of Slatinska Reka, and 1 m above the riverbed of Treska. The cave was first discovered by Kolčakovski and Aloski (1984) where the morphometric characteristics of the first 800 m of the cave were analyzed in detail. Carlin (2003) has published a plan for the cave.

The cave has three entrances. The spring Slatinski Izvor serves as an entrance to one of the openings, and the other entrances are dry. The cave is located in an

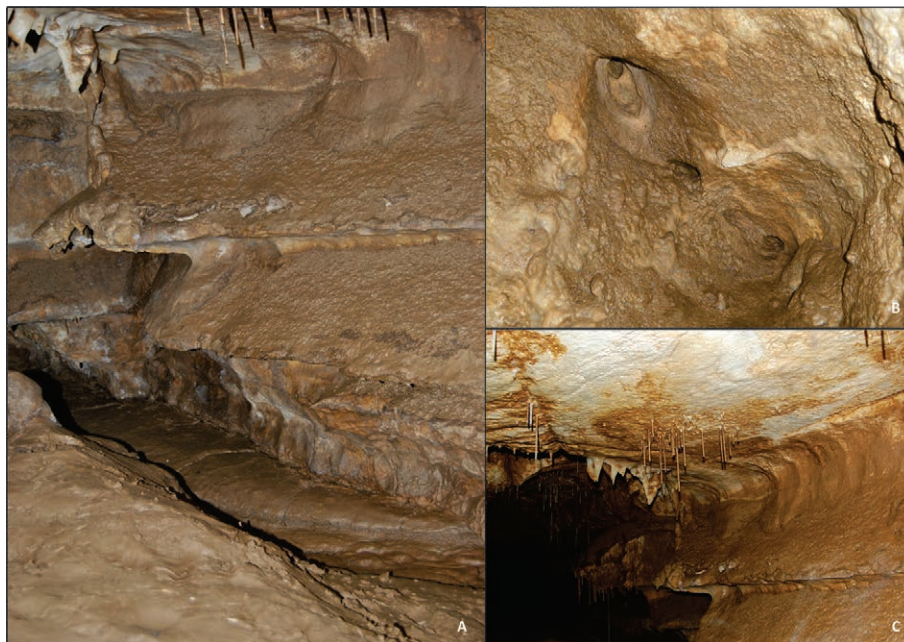


Figure 12. Relief forms in the cave Puralo: A-alluvial notches and scallops, B-ceiling pockets, C-alluvial notches, photo by B. Gičevski.

epiphreatic zone which is a transitional zone between the phreatic zone and vadose zone. The cave consists of horizontal passages, generally oriented in SE-NW direction. Up to 800 m from the cave entrance, the passage follows the ground river. The biggest cave expansion (Big Hall) is nearly 400 m away from the entrance. The length is 55 m, and the biggest width is 25 m. From here till the end of the cave, the main passage is dry. The cave lake, which visually is not connected to the ground river flow is located in a fissure passage. Its width is the same as the width of the passage (about 1 m), the length is 2.5, and the depth is nearly 3 m. On three locations, the main cave passage ramifies in canyon cave passages. In the longest passage (Canyon), which is 500 m long, in a length of 300 m, there is a groundwater flow which ends in a siphon. At around 300 m before the cave ends, there is a small cave widening as a result of the ruined rocky material of the ceiling. The last 500 m of the cave is mainly developed in SW direction along the strike of carbonate rocks. The total length of the cave is 3942 m.

Mostly, in plan-view, cave passages constitute a branchwork pattern. At three locations in the cave where the ceiling is low the free flow of the former groundwater river was impeded, water circulated along multiple pathways, dissolving out openings along bedding-plane partings, and an anastomotic maze was formed (Figure 13).

From the entrance of the cave to 800 m, the passage has a phreatic elliptical morphology, developed along fissures or bedding planes. Vadose morphology is characteristic upward from the Big Hall. Cross-sections are typical of drawdown vadose morphology, where the phreatic part was first and fixed the position of

the trench. A trapezoid cross-section is characteristic for the Big Hall where the groundwater river caused the widening of the cave passage, and cave walls were undermined and large rocky blocks collapsed (Figure 14).

The cave passages are modified by paragenesis, either by alluviation in vadose passages, or by upwards dissolution in phreatic passages. The first one caused a lateral incision of the passages, and it is characteristic upward from the Big Hall. Vadose canyons are incised with well-rounded pebbles and cobbles mostly composed of marble, quartz, and schists filling the floor. Alluvial notches are found at places where former groundwater flow was in contact with the wall. The second one, paragenesis is characteristic mostly for the first 800 m in the cave, but also deeper into the cave where the cave roof is low. Paragenetic development at these places is due to sediment infilling. At places, remnants of clay deposits can be seen on passage walls and ceiling, although most of the cave walls are covered with flowstone deposits. Anastomoses and half tubes are common where bedding plane partings are the dominant openings. They are found in dry passages, but also in the passages where the water flow exists today. Ceiling pendants are formed along the sloping walls of cave passages that are nearly filled with clay, sand, and gravel. Scallops are formed on the perimeter of the notches, but also on the cave walls. Ceiling pockets are a typical feature for the first 800 meters of the cave. Few samples of „čers“ are recorded in the active river passage, where groundwater river flows over such „čer“.

Cave sediments are represented by: clay sediments, sand sediments, gravel and pebble deposits, and mud cracks. The composition of these materials (marble,

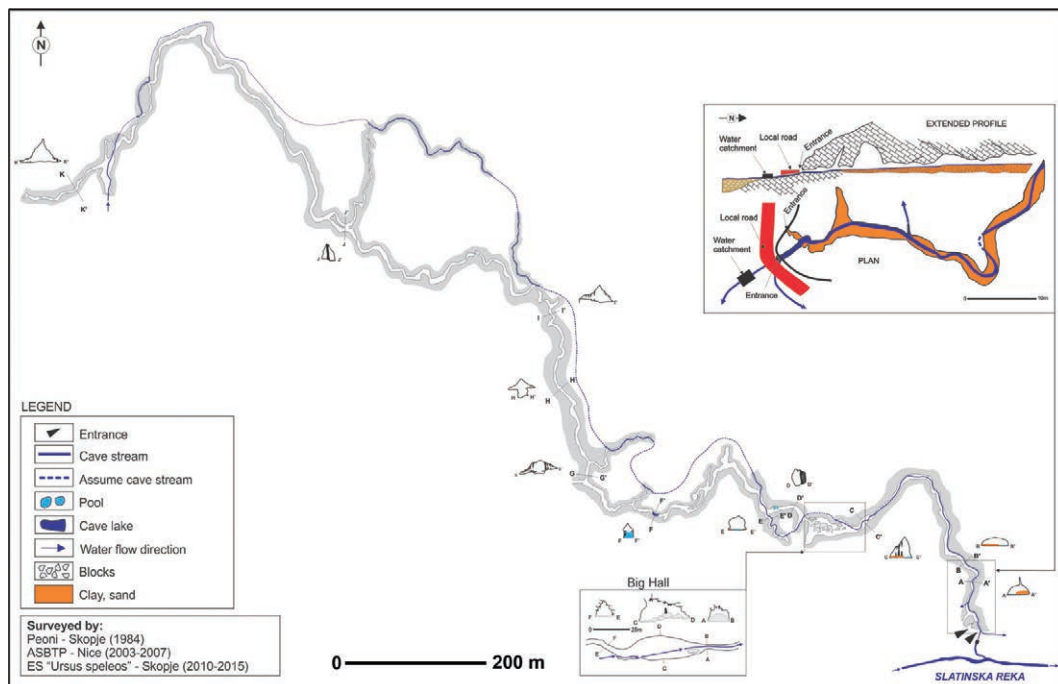


Figure 13. The plan of the cave Slatinski Izvor.



Figure 14. A cross-like shape of the cave passages: A-fissure oriented passage, B-vadose passage in younger stage, C-passage which represents a shift from phreatic to vadose conditions, D-a bedding-plane phreatic passage (clay masks the floor), E-breakdown trapezoid vadose passage, photo by B. Gičevski (A, B, C, D) and P. Malinger (E).

quartz, quartz-sericite schists) proves that their origin is from a non-carbonate environment, i.e., they entered the cave by an allogenic stream flowing. The floor of the Big Hall is completely covered with breakdown material (10-12 m in length, and 4-5 m in width).

According to the environments in which speleothems are formed in the cave, they belong to three groups: speleothems formed by flowing and dripping water, speleothems formed by capillary water and pool deposits (Gičevski et al. 2015). Stalactites, soda straws, stalagmites, columns, flowstones, draperies, helictites, shelfstone, subaqueous coralloids, bulbous stalactites, raft cones are impressive speleothems in the cave.

Factors that influenced the evolution of the caves and the wider area

The evolution of the study area, as well as the wider area, is mostly affected by the evolution of the Balkan Peninsula. Thus, during the Pleistocene time, the central part of the Balkan Peninsula was the site of increased relative uplift at a time when the region of the Aegean Sea was undergoing continued subsidence. In Macedonia, many of the lakes were buried and disappeared. At this time, the river Vardar and its drainage system (including Treska valley) were developed by rapid headward erosion (Dumurdzanov et al. 2004). This resulted in the regulation of the fluvial development and incision of valleys, as well as controlling the base-level position of karst systems. In the study area, karst surface morphology is influenced

by this incision, developing fluviokarst surface morphology with the allogenic river through the valley. The main controlling factor in karst development has been the evolution of the river Slatinska Reka which was dependent on the evolution of the Treska valley as a regional base-level controlling factor. The incision of Slatinska Reka remains the primary controlling factor in cave development, as it lowers the base level of karst terrains (Figure 15).

The sources of the sinking streams Slatinska Reka and its tributaries Krušeska Reka and Markoska Reka are in a non-carbonate environment. In contact with carbonate rocks, streams sink underground as a point input (ponors) into the karst system, thus determining an allogenic recharge. Rocks of non-carbonate neighboring environment, as well as Neogene sediments, which cover the carbonate rocks, have played an important role in cave development, also by supplying the sediment material, which after accumulation in cave passages, forced paragenetic development. Today, the output of this karst system is the spring Slatinski Izvor which serves as the entrance of the same cave.

All analyzed caves have „normal“ epigenetic karst development. The cave Gorna Slatinska Peštera was formed in a phreatic to vadose setting. It was fed by a stream which had the same direction as Krušeska Reka. The age of the caves was determined by Jovanović (1928). Near the village Gorna Belica (nearly 20 km in NE direction), he recorded a fluvioglacial terrace that belongs to the glacial period Würm, and it is at the same height as the cave entrances. It connects and indicates that the cave passages date from the same time as the

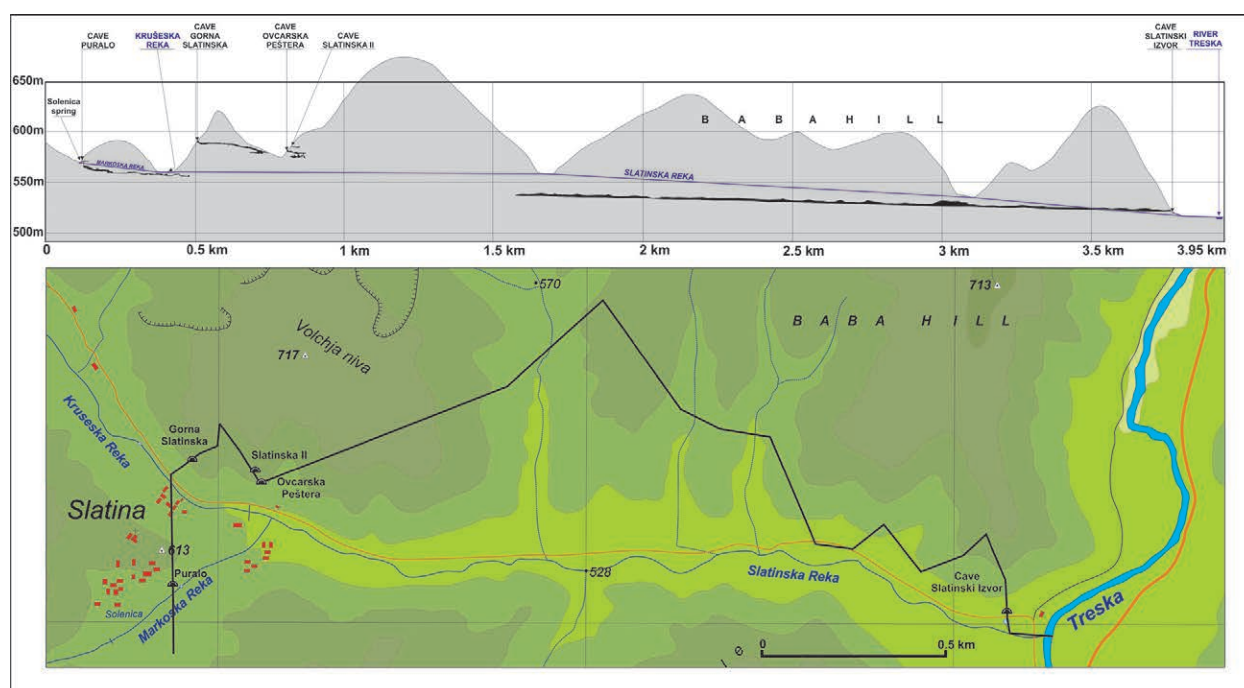


Figure 15. Schematic illustration of the investigated caves vs Slatinska Reka. The black line on the lower map is the location of the cross-section.

terrace. Also, he connected the caves Gorna Slatinska, Slatinska II, and Ovčarska Peštera (higher level) with this glacial period. The upper level of Puralo, since it is at the same altitude as the mentioned caves, belongs to the same age. The lower cave level of the caves Ovčarska Peštera and Puralo, as well as the cave Slatinski Izvor was formed later, parallel with the incision of the river valley of Slatinska Reka.

Tectonics has a strong effect on the patterns of the cave Puralo. Thus, the influence of joints on caves is readily apparent in fissure-shaped passages. It is developed between faults, the regional fault between Pelagonian and Western Macedonian tectonic units, and an obvious fault under the river Krušeska Reka.

Paragenesis played an important role in cave development. The cave passages of Slatinski Izvor, Ovčarska Peštera (lower cave level), and Puralo (lower cave level) are modified either by alluviation in vadose passages, or by upwards dissolution in phreatic passages. The paragenetic development suggests aggradation in the river valley of Slatinska Reka.

Slatinski Izvor is the youngest cave in the study area. It is an active spring cave and represents the main outflow of groundwater from the karst system. It is a cave with vadose passages leading to the epiphreatic passages formed by the sinking waters of Slatinska Reka. Considering the allogenic sediments in the cave, the input area is the contact between non-carbonate and carbonate rocks, e.g. the upstream parts of Slatinska Reka. This is also proved by the tracing experiment (Gičevski et al. 2016).

Conclusion

The study area represents a contact karst area where allogenic waters of Slatinska Reka and its tributaries flow from a non-karst environment and sink into the karst area and modify the landscape. This type of karst is formed under the influence of alluviation, where the hydrological influence of the rivers is the most important factor. The incision of Slatinska Reka was and still is the main controlling factor in cave development by lowering the base level of karst terrains. Also, the tectonic and geologic conditions control the karst development in the study area.

According to the conducted investigations of the morphology of the caves, the cross-section of the passages, micro-relief forms, and cave sediments for the caves Gorna Slatinska Peštera, Slatinska II, Ovčarska Peštera, and Slatinski Izvor, the speleogenesis of the caves is detected. All analyzed caves have "normal" epigenic development. The caves Gorna Slatinska Peštera, Slatinska II, and the higher cave level of the caves Ovčarska Peštera and Puralo date from the same period, probably the Würm. The lower cave level of the caves Ovčarska Peštera and Puralo, as well as the Slatinski Izvor cave, was formed

later, parallel with the incision of the river valley of Slatinska Reka. Paragenesis played an essential role in cave development. The cave passages of some caves (Slatinski Izvor, Ovčarska Peštera, Puralo) are modified either by alluviation in vadose passages or by upwards dissolution in phreatic passages. The paragenetic development suggests aggradation in the river valley of Slatinska Reka. Nowadays, the karst spring Slatinski Izvor as an entrance of the youngest cave in the study area, represents the main outflow of groundwater from the karst aquifer.

Further research using dating techniques on cave sediments is required to determine the precise age of the caves, reconstruct the phases of speleogenesis, and define the development of the landscape.

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