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KARST AREA OF ZABUČJE-GRADINA

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Abstract: Karst areas of western Serbia, such as the Valjevo and Pešter karsts, are well known and researched, but there are smaller and less well-researched units, such as the Zabučje–Gradina karst unit. This paper presents the basic geomorphological characteristics of the Zabučje–Gradina karst unit. The focus of the research is on karstological characteristics, with a special emphasis on the distribution of sinkholes and valleys in the karst. Detailed analysis using GIS tools has enabled the definition and consideration of the processes that led to the creation of specific karst forms, including sinkholes and fossil valleys. The spatial distribution of sinkholes is also shown, as well as the relationship of their distribution to the slope of the terrain on which they are located. Analysis in QGIS has determined that, as in Miroč, sinkholes in this area are also located at small slope angles, up to 12° at most. In the research area, valleys are classified as active, dry and relict, and this characteristic and arrangement of them were used for further reconstruction of paleoflows. The existence of epigenetic incision of the Đetinja into the limestone bedrock was also established. Special emphasis was placed on speleological objects in the Drežnica Valley, such as the Potpećka, Pipalska and Todorova caves, which represent significant objects in the research of karst processes and karst hydrology of this area.

Keywords: karst, sinkhole, paleoflows, karst valley, epigeny

Introduction

Small karst units in Serbia, such as the Zabučje–Gradina karst unit on the right side of the Đetinja valley, between the Užice–Zlatibor highway in the west and the Roška ploča pass in the east, are interesting for geomorphological study due to the combined action of karst erosion, fluvial erosion and tectonic forces (Ćalić & Milošević, 2005). The Potpeć Cave, as part of this area, has been thoroughly explored, developed for tourism and is known to the general public throughout Serbia. However, its hinterland and immediate surroundings are unknown even to the local population, which leaves room for further research.

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Previous research in this area was related to geographical, geological and archaeological research of the Potpeć Cave and its hinterland. Žujović (1893) was among the first to explore the cave, and it was already known at that time that it was connected to the Drežnica Valley. It was established that the river descends in the Drežnica Valley and emerges in the Potpeć Cave (Živković, 1907). Cvijić explored the Potpeć Cave and stated that the Petnica River, which springs from it, receives its water not only from the abyss in the Drežnica Valley, but also from the surrounding area, based on the amount of water that gushes out from the springs (Cvijić, 1914). Further research into the Potpeć Cave continued in the second half of the 20th century (Lazarević, 1959), which led to the preparation of a report for the tourist development of the cave (Lazarević, 1981). In his 1959 paper, Lazarević described the basic speleological, hydrological and geomorphological characteristics of the cave, also writing about its hinterland (Drežnička dolina), while in his 1981 book he elaborated on the previously mentioned chapters in more detail and described the process of further research and tourist development of the cave (Lazarević, 1959; Lazarević, 1981). A significant contribution to the understanding of the geological, geographical and paleogeographic characteristics of this area was also made by Ršumović (1960) in his doctoral dissertation "Relief of the Goliska Moravica Basin". Although this area does not currently belong to the aforementioned basin, but to the Đetinja basin, due to events in geological history, it describes in detail both the Drežnica Valley and the entire valley of the presumed Zlatibor River all the way to Mačkat.

The aim of the work is to supplement the current knowledge about this karst entity as well as to present it in a new way. This relatively small area has a certain number of interesting features: three karst surfaces, one large and several small dry karst valleys, hanging valleys, one large and several smaller speleological objects, two deep gorges cut by allogenic flows, etc. All of the above specificities, in a relatively small area, make the studied area significant for physical geography, speleology and karstology research.

Researched area

The Zabučje–Gradina karst unit is located in western Serbia, south and southeast of Užice (Fig. 1). The area has a Dinaric trend and covers an area of 63.3 km^2. The length of this karst unit is 16 km in the northwest–southeast direction, the maximum width is 6.5 km in its southeastern part, while it gradually narrows towards the northwest (Dimitrijević et al., 1978). The altitude of this karst unit ranges from about 400 m near the Potpećka Cave to 931 m at the top of Gradina. In addition to the Drežnica Valley, whose bottom is about 600 m above sea level, the rest of the karst unit mainly consists of three karst areas with an altitude of 700–800 m, which are differentiated by gorges of short and partly intermittent streams of the Bukovac and Derventa rivers. From the northwest to the southeast, there are the karst areas of Zabučje, Ljubanj and Košuta. In addition to the above, this unit also includes the hamlet of Rogandžići, in the far northwest, the Drežnička Valley and the Lipovec massif in the far south. Since the karst area of Zabučje is larger, more striking, intensively eroded and is located in the northwest, and the Gradina mountain in the far east, the entire karst unit is called Zabučje–Gradina. The northwestern and northern border is formed by the gorge of the valley side of the Đetinja River from Užice to Sevojno. In the east, the border is the end of the Middle Triassic massive limestones, where the basement-older Lower Triassic and Jurassic limestones are exposed (Dimitrijević et al., 1978). The southeastern border descends in several places to the course of the Veliki Rzav and reaches the course of the Prištavica River. The eastern and southeastern border is strongly

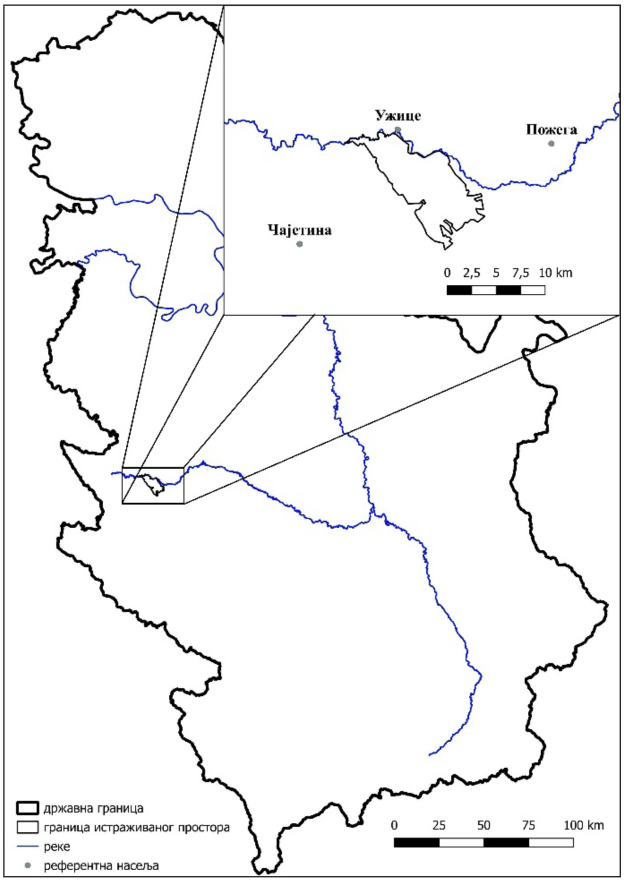

Figure 1. Location of the Zabučje-Gradina karst complex.

fractured by a fault system. To the southwest, this area rises gently towards a large area that Cvijić (1914) designated as the Mačkat abrasion surface.

The Zabučje–Gradina karst unit is geologically homogeneous: almost the entire surface is made up of layered and massive Middle Triassic limestones (T2) (Fig. 2). To the northwest, this zone continues across Đetinja, where it is broken by a series of faults (Dimitrijević et al., 1978). In addition to layered and massive Middle Triassic limestones, Miocene sediments can also be observed (conglomerates and sands with dolomite, 1M), then thinner sections of layered Lower Triassic limestones and dolomites (T12), sandstones, claystones, marls and limestones (T11) and quartz conglomerates, sandstones, quartz breccias and siltstones (T11) in the area towards Đetinja, which lie in the bed of the Middle Triassic limestones and are exposed only in the extreme border parts on steep sections. Below them, on the valley floor of Đetinja, Carboniferous phyllites (F) and metamorphosed sandstones are also present (Dimitrijević et al., 1978). The Potpeć Cave was formed at the contact of Triassic limestones and quartz conglomerates, sandstones, quartz breccias and siltstones (Dimitrijević et al., 1978). East and southeast of Gradina, the massive Middle Triassic limestones are lost and here, on the topographic surface, Lower Triassic limestones and shales are exposed, as well as highly folded Jurassic limestones, sandstones, hornfels and clays (J2,3) (Roška ploča pass). In the south and south-southwest, younger, Cretaceous layered and sandy-marly limestones (K22) also come to the surface, which are downgraded along the entire fault that forms the western border of the area, and to the northwest they are covered by Miocene sediments. These sediments also occur at the very bottom of the Drežnica Valley, around the abysses of the former Zlatibor River, as well as in Zbojštica. The fault that forms the western border almost along its entire length also follows the boundary between Miocene sediments and Middle Triassic limestones, except in the upper part of the Drežnica Valley where the sediments lie over Triassic sediments (Dimitrijević et al., 1978). This shows that sedimentation continued even after the faulting, i.e. that the river that flowed there continued to flow even after the intense faulting.

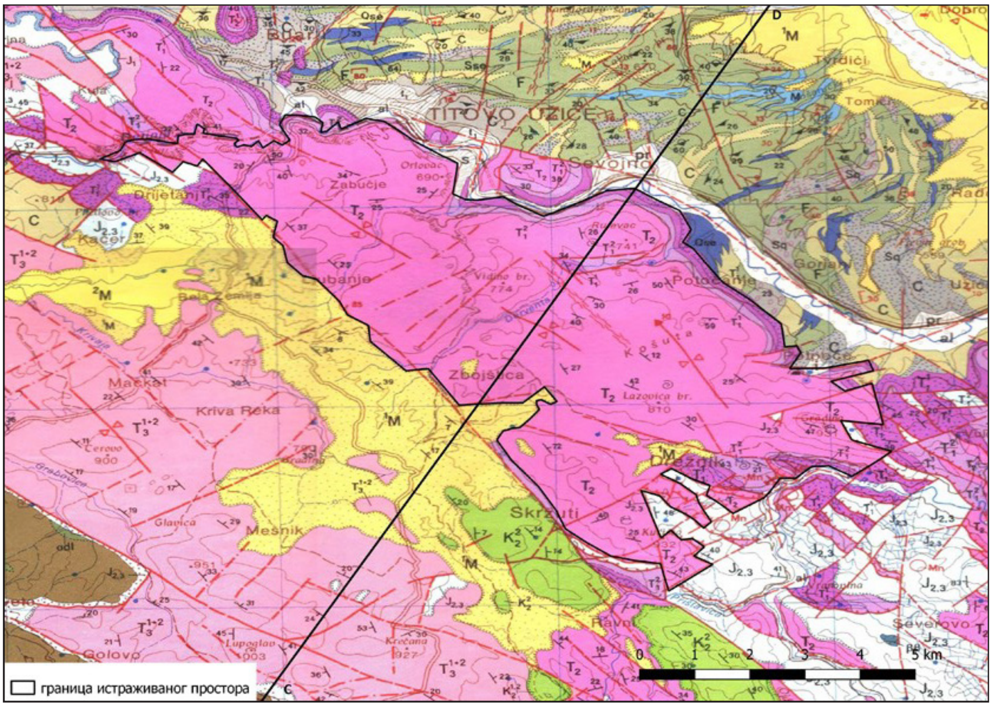

Figure 2. Geological map of the Zabučje–Gradina area (excerpt from the Basic Geological Map 1:100000, sheet K 34–4 Titovo Užice, edited by the author).

The Zabučje–Gradina karst unit can be morphologically divided into several smaller sub-units (Fig. 3). The small karst units alternate in the northwest–southeast direction and their boundaries are the valleys of watercourses. Their altitudes are between 700 and 750 m, while the valley floors of the Derventa and Bukovac rivers have an altitude of 650 to 400 m. The Drežnička valley is at 600–650 m, and the altitude of the Lipovec massif ranges from 700 to 930 m.

Going east-southeast, the first karst unit is the surface of Zabučje. Its border is the valley of an unnamed stream to the west, and to the north and east it is also limited by a steep section of the right valley side of the Đetinja, in places up to 300 m high, and in the southeast by the deep, in some places up to 150 m deep Bukovac gorge. In the southwest is the geological border of limestone and Miocene and Lower Triassic sediments. The area of this area of Zabučje is 6.6 km². It reaches its highest altitude in the far southwest, while its lowest is in the far east, around 620 m.

Figure 3. Hypsometric map of the Zabučje-Gradina karst area (Compiled by the author based on isohypses from topographic maps 1:25000 Titovo Užice 528–2–3 and 528–2–4).

Southeast of the Zabučje area is the Ljubanj area (9.5 km²), which is separated from it by the Bukovac gorge. The highest point is 792 m Šanac. On the northern border of the Ljubanj area, at the place where the Bukovac emerges from its gorge, there is a smaller amphitheatrical extension, at the bottom of which is the strongly karst-captured Živkovića spring, which drains one part of the area.

Further to the southeast, there is the largest and most sparsely populated area, Košuta (15.5 km²). This area also slopes gently to the northeast: in the southwest are Andrića brdo, Vrh, Lazovića brdo, Zeravsko brdo, Anište, and from there it begins to climb steadily to the peak of Gradina (931 m). In the northeast is Lakićevića rock. The marginal areas of Košuta have the most dry karst valleys, as many as 9, of which Prisoje, Pavlovića do and Mali do towards the Derventa gorge, and Dolovi above the Potpećka cave stand out. This surface is the most rugged and on it you can also notice the gorges, the "sea of rocks" that cover the gorges, the midriff that separate the two gorges (Fig. 4).

The Drežnica Valley is located between the Kosut plateau in the north and the Lipovec massif in the south. After the Đetinja valley, it is the lowest part of this area. The bottom around the last abyss is located at 590 m above sea level, while

Figure 4. The crater on the surface of Kosut (photo: A. Petrović).

the largest part of the valley is at an altitude of between 600 and 650 m. The valley is tectonically predisposed: covered faults are located on its northern and southern edges (Dimitrijević et al., 1978). Ršumović (1960) states that the Drežnica Valley was the most downstream part of the course of the former Zlatibor River. According to his hypothesis, the Zlatibor River flowed over the area that is now covered by Miocene sediments (west of the Zabučje–Gradina area), from the area of the Zlatibor peridotite massif, through the source parts of the present-day streams of the Gumbur stream, Bukovac and Derventa, and flowed into the Veliki Rzav in present-day Drežnik. The river flowed over Miocene lake sediments from an earlier period, but it also brought peridotite gravel (which is not indigenous to this area) from Zlatibor to them. The Zlatibor River valley was then severely fractured by transverse faults that it could have overcome for a time by cutting through the fault lines, but through backward erosion, the Bukovac and Derventa streams pirated the central parts of its course. After this disorganization, only a short stream of the Drežnička River remained, which originated near Zbojštica and flowed eastward, flowing into the Veliki Rzav. Over time, the Miocene cover was eroded and the Drežnička River came to a bed of massive Triassic limestones that it could not overcome and began to sink, first into the lowest abyss (Todorova pećina), then into Pipalska pećina, the abyss near Jezero and the abyss near Vidića bara, thus leaving a hanging valley, about 100 m above Veliki Rzav (Ršumović, 1960). The lowest part of this valley was succeeded by the Milutinovića stream, a left tributary of the Veliki Rzav, 1.75 km long.

Ršumović (1960) also states that there must have been a valley even older than the one through which the Zlatibor River flowed, and that it continued straight to the southeast (through today's Skržute) near today's Zbojštica (it did not turn into the Drežnica Valley) and ended at the Prištavica River, a left tributary of the Veliki Rzav, i.e. that the Drežnica Valley was marginally epigenetically incised due to the existence of Miocene sediments that covered the topographic surface. The downstream part of this paleovalley was inherited by the course of the Savića stream.

The last entity of this area is the Lipovec massif in the far south. Lipovec is about 2.2 km wide and elongated (about 5 km) mountain of the Dinaric direction, with an altitude of 932 m (Kućište) and a relative altitude of about 330 m. The northwestern part of this massif is flatter and shorter, with the appearance of ravines, while further southeast it rises and is heavily dissected by shorter streams flowing north, east and south.

The hydrological characteristics of this area are similar to those in other areas where karst relief is present. The surface is relatively dry. Two streams, Bukovac and Derventa, rise southwest of the karst area, on Miocene sediments, then reach limestone where they cut deep gorges that differentiated this once homogeneous area. Both streams, in the gorges, become occasional streams (Ršumović, 1955).

Methodology and material

The research required for the preparation of this work can be divided into three phases. The first phase is the desk research phase, and it began with the study of satellite images and topographic maps, which allowed the author to examine the entire terrain, not just the area covered here. Also, during this phase, the existing literature dealing with this issue was researched. The second phase is the field research phase, which was carried out on three occasions: in May 2023, October 2023 and September 2024. Field research involves going to the field, visiting it, examining the entire area and collecting photographs. The last phase is again desk research, when the data collected in the first and second phases were shaped using GIS tools, mostly by analysis in the QGIS program (Novković, 2022). The density of boreholes was calculated based on data from topographic maps at a scale of 1:25,000 (TK25), while the Copernicus DEM layer with a resolution of 1″, i.e. about 30 m, was used to calculate the slope angles at which they are located.

The scientific research process was supplemented and rounded off by field research, which was particularly useful in observing certain phenomena and processes in this karst entity. Karst valleys can be classified into three types: active, dry and relict. Active valleys still have an active or periodically active river flow today. Dry valleys have retained their shape that existed before shortening, their bottoms have a constant slope towards the former mouth but do not have an active flow. Relict valleys are those whose bottoms have been completely destroyed by karst processes, most often by series of sinkholes. The only evidence of fluvial processes in these valleys is the highly dissected thalweg (Petrović et al., 2016). All this information helped in classifying karst valleys in the studied area, and examples are given for each type.

Although this karst unit cannot be considered a karst belt, some characteristics of contact karst can still be observed. Comparing the karst of the Dževrinske greda on Miroč, which is considered a perfect polygon for studying the karst belt (Ćalić

& Milošević, 2005), with this unit, it can be noted that both units have a non-karst environment, tectonic faults as their boundary, and allogenic flows that have created valleys in the form of gorges. However, the main characteristic that does not allow classifying this unit as a karst belt is its morphometry. Ćalić & Milošević (2005) state that karst belts have a ratio (γ) of length and average width of over 30, and in the Zabučje–Gradina karst unit this parameter is 4.04. Certainly, the characteristics of contact karst are present. Since contact karst itself occurs along the contact lines of carbonate and non-carbonate rocks (Ćalić, 2008), here specifically of Middle Triassic limestones and Miocene sediments, it is most pronounced in places where the Bukovac and Derventa streams pass from sediments to limestones and continue to flow, first as permanent and then as occasional streams. These streams, with their concentrated inflows that are not characteristic of karst areas (Ćalić, 2008), have cut two deep gorges (the Bukovac gorge with a maximum depth of about 150 m, and the Derventa gorge with a maximum depth of about 250 m).

The analysis of the distribution of the holes started from the assumption made by Tamas, Laszlo and Calic (2007) who analyzed the holes on Miroč and concluded that they are mostly located at angles of inclination up to 12°. This analysis was performed here using the QGIS program and the aforementioned Copernicus DEM layer. Another option for this analysis was to use a TIN layer with a resolution of 10 m, obtained based on isohipsis from TK25, but since an overly precise TIN layer can also take into account the sides of the holes themselves as uneven terrain and then show unrealistic data, it was decided to use a less precise DEM layer (Telbisz et al., 2007).

Using GIS, it is possible to partially reconstruct the paleodrainage network of this area, which was done by analyzing isohypses and the arrangement of boreholes from TK25 (Titovo Užice sheets 528–2–3 and 528–2–4), creating the effect of a three-dimensional terrain using a hypsometric map in combination with shaded terrain (Petrović, 2015). Also, using the same methodology, it is possible to categorize existing karst valleys into active, dry and relict (Petrović et al., 2016); all three types have been found in this area.

Results and Discussion

One important condition for the formation of sinkholes, in addition to the geological substrate, is a relatively flat or slightly sloping terrain. An analysis of a large number of sinkholes (over 5000) on Miroč showed that sinkholes are most often formed at slope angles of up to 12° (Telbisz et al., 2007).

Of the total of 573 holes, as many as 564 (98.4%) are located on a slope of 12° or less. By calculating the arithmetic means of all slope angles, the average value is 4.58°, and the largest number of holes is in the category between 3° and 4° (111, i.e. 19.37%). Analyzing the data for altitude, it is noted that the largest number of holes is at an altitude between 700 and 750 m (318, i.e. 55.5%), which corresponds to the altitude of all three karst surfaces. When the next category (corresponding to rounded hills of low relative height that rise from the surface) is added to this data, the altitude zone 750–800 m, in which 118 boreholes (20.6%) are located, it is concluded that a total of 436 boreholes (76.1%) are located in the altitude zone 700–800 m. The mean altitude at which the boreholes are located, obtained by calculating the arithmetic mean, is 720.4 m, while the standard deviation ranges between 678.1 m and 762.8 m (Table 1).

Figure 5. Example of a funnel-shaped (front) and pelvic-shaped (back) sinkholes in a series on the Ljubanj surface (photo: S. Popović)

Table 1. Sinkholes arrangement according to inclination angle and altitude

inclination (°)	Number of sinkholes (in %)	altitude (m)	Number of sinkholes (in %)
0–1	25 (4,36)	500–550	2 (0,35)
1–2	72 (12,57)	550–600	0 (0,00)
2–3	74 (12,91)	600–650	34 (5,93)
3–4	111 (19,37)	650–700	91 (15,88)
4–5	80 (13,96)	700–750	318 (55,50)
5–6	66 (11,52)	750–800	118 (20,59)
6–7	57 (9,95)	800–850	8 (1,40)
7–8	24 (4,19)	850–900	1 (0,17)
8–9	24 (4,19)		
9–10	10 (1,75)		
10–11	10 (1,75)		
11–12	10 (1,75)		
преко 12	9 (1,57)		

Source: Author's processing

The sinkholes at the bottom of the Drežnica Valley are specific, because they are not all on limestone, but on Miocene sediments, but since they are very thin and lie over limestone, sinkholes were also formed on them. These are suffusion sinkholes. Those in this area are also connected to the abysses of the former Drežnica River: Vidića Bara, the abyss near Jezera and Todorova Pećina are located at the bottom of the sinkholes, while Pipalska Pećina is at the end of a short blind valley cut into the valley bottom of the Drežnica River. As already mentioned, Bukovac and Derventa have cut two deep gorges that differentiate the surfaces of Zabučje, Ljubanj and Košuta. On the longitudinal profiles of these rivers, bends can be observed, at Bukovac at a point about 200 m upstream of the transition from sediments to limestones, and at Derventa about 1.2 km upstream. By graphically displaying these longitudinal profiles and converting them into decimals (Fig. 7), it can be concluded that both of these bends are at about 4/10 of the river course, and that they were created by a backward movement of the flow. This is also proven by the unusual phenomenon that the longitudinal profile is significantly flatter in the uppermost, source part of both streams, than in the lower and middle, where it shows the existence of significant drops.

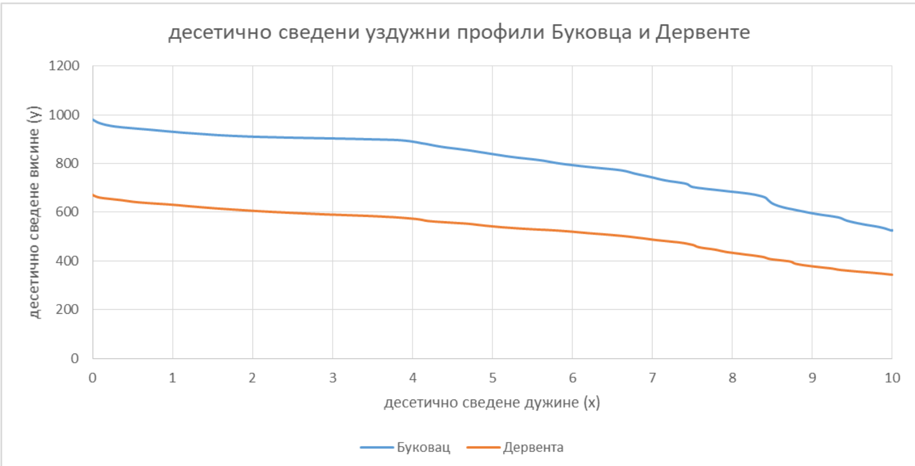

Figure 6. Decimalized longitudinal profiles of Bukovac and Derventa (Author)

Another specificity of this area is that the border of the massive Middle Triassic limestones to the north and northeast does not completely follow the Đetinja valley, but at one point it crosses over to its left side, which can be seen on Sekulića Hill, between Užice and Sevojno. Since the height of the valley sides of the Đetinja at this point is about 620 m above sea level, and at about 650 m northeast of there the height is about 535 m, it can be concluded that this narrowing is a consequence of the marginal epigenetic incising of the Đetinja (Fig. 8).

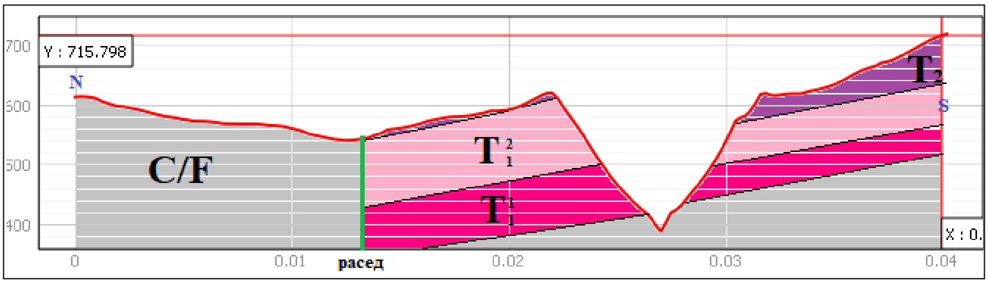

Figure 7. Transverse profile of the Đetinja epigeny near Sekulića Brdo (Compiled by the author based on the Basic Geological Map 1:100000 K 34-4 Titovo Užice).

Due to the specific circulation of water in the karst, river courses and valleys are relatively rare. Limestone and dolomite, as two highly soluble rock types, allow for intensive underground circulation, while the topographic surface is waterless. For this reason, active valleys in the karst are most often formed by allogenic flows that come from other geological substrates and cut through limestone massifs (such as Bukovac and Derventa). Other valleys in the karst are not active. In most cases, they are fossil. They were formed during the period when the limestone substrate was covered, in this case by lake sediments, and when this cover was eroded and when the flows came into contact with the underlying limestone, the flows and valleys were gradually fossilized. Such was the genesis of a large number of short valleys in this area.

The Drežnička Valley stands out as the largest paleovalley in this area, which, in addition to karst, was also formed by tectonic activity (it was lowered along faults) (Dimitrijević et al., 1978). The flow of the Drežnička River could not overcome the limestone bedrock and began to sink, which led to the creation of the so-called blind valley. An example of such valleys is the Pipalska Valley (Fig. 9). The Drežnička River's sinkhole is Todorova Pećina. The Drežnička River, which flowed in a west-east direction, left a gap east of Todorova Pećina up to 20 m high. Today, a short, occasional stream (east-west direction) flows along this slope, which also sinks in Todorova Pećina. The hanging part of this valley was inherited by the flow of the Milutinovića Stream. Due to the specific geological structure, the springs in the Drežnik Valley are located on the southern edge of the valley, while all the sinkholes are on the northern edge. An example of this phenomenon is the Pipalsko vrelo, which erupts near a small church in Drežnik, flows in a short course to the northeast and plunges into the Pipalska cave. This valley is short, only 120 m, but is significant as a blind valley. Above it is a flattened valley floor, with "sodomies", sinkholes formed by the salination of cave ceilings below them.

Figure 8. Pipalska Valley (photo: A. Petrović).

The valley floors of fossil valleys, especially on the surfaces of Zabučje, Ljubanj and Košuta, are dissected by numerous boreholes, which are arranged in rows. These rows help in the reconstruction of the paleo-relief of the mentioned area. Apart from the allogenic streams of Bukovac and Derventa, there are no active valleys in this area, because all the streams were too short and with too little water to withstand the shortening of the terrain. There are no dry valleys on the surfaces, but they are connected to dry and hanging valleys, with steep slopes and sides, and large height differences between the source and the mouth. Such valleys are called "dolovi" in this area. Named examples of these valleys are on the right side of the Derventa valley: Prisoje, Pavlovića do, Mali do, as well as Dolovi, a paleovalley at the exit point of which into the Đetinja valley is the Potpećka cave. There are many more unnamed ones, such as the valleys below the hamlets of Negovanovići and Nenadići in Zabučje, the valley southeast of Lakićevića stenae, through which the Potočanje road was traced, and others. Relict valleys are present on the surfaces themselves, they are very shortened, but paleorelief reconstruction is carried out on their basis. Using GIS, it is possible to reconstruct the paleodrainage network (Fig. 10) of this area. It shows a dense network of relatively short paleostreams, which failed to overcome shortening when coming into contact with massive Middle Triassic limestones. Some of these paleovalleys are also hanging, such as those on the northern side of the karst surface of Zabučje, which once flowed into an unnamed stream, and today their valleys remain 100–150 m above the stream bed. More examples of these hanging valleys are two valleys on the northern side of the Ljubanj Karst surface, one above the Živković spring, and the other about 850 m further east, which remain to "hang" about 100 m above the present-day valley floor.

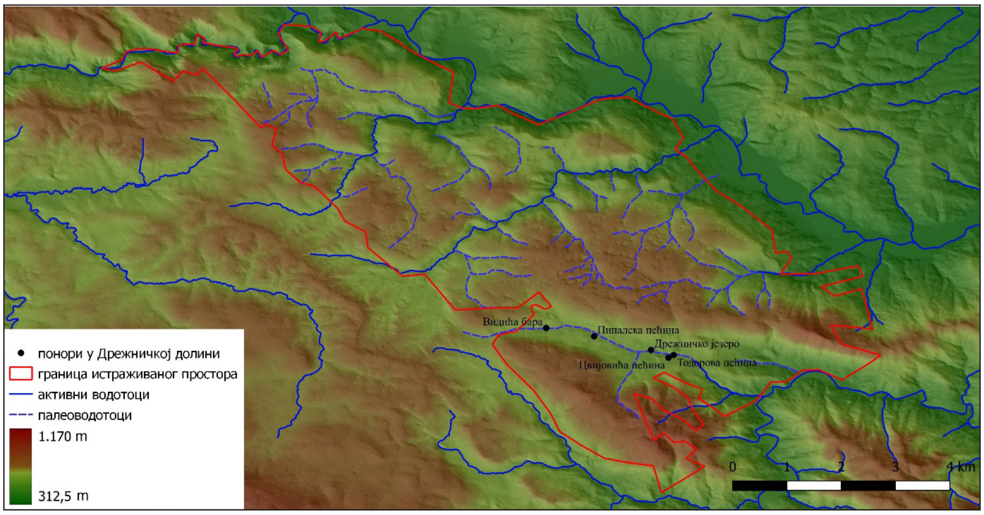

Figure 9. Paleodrainage network of the Zabučje–Gradina karst unit (Author)

Four speleological objects have been identified in the area of the karst complex. The largest and most famous of them is the Potpećka cave, and the only one located on the northern side of the karst surface of Košuta. The others are the Pipalska (Rajkova) cave and the two Cvijovića caves, Todorova and Bezimena. These three caves are located in the Drežnica valley, on the southern side of Košuta.

The Potpećka cave is one of the most famous speleological objects in western Serbia. It has been well researched and numerous geologists and geographers have written about it, which is why the emphasis is placed on the other caves mentioned above.

Figure 10. Pipalska Cave (left) and Cvijovića Cave (right)

The Pipalska (Rajkova) cave is the second most upstream sinkhole in the Drežnica valley, located about 900 m east of the Vidića pond (the most upstream sinkhole). It is a chasm with a short, intermittent stream that springs about 120 m south of the Pipalski Vrel spring, and the end of a blind valley. The cave begins with a 36 m long cave channel, followed by a 16 m deep chasm (Lazarević, 1959). After the chasm, the channel is narrow and cascading, and then turns into a shallow one (0.3–0.6 m). A total of 1712 m of the main cave channel has been explored. The White Hall in the cave is particularly noteworthy (Lazarević, 1981).

Todorova pećina is the lowest sinkhole of the Drežnica Valley. It is located at an altitude of 592 m, at the lowest point of the Drežnica Valley. Its entrance is 0.5 m high and less than 0.5 m wide. Two short periodic streams (Lazarević, 1981) descend into it, one of which flows opposite to the flow of the former Drežnica River. The channel descends in a cascade while its height decreases over an estimated length of 15 m. It is believed that it connects even deeper with the channel from Surdup (Lazarević, 1981). The second Cvijovića pećina (Fig. 15) has no specific name, it is located about 115 m southwest of Todorova and is cut into the bottom of the ridge where the hamlet of Cvijovići is located. It is very short (shorter than 2 m).

Vidića bara (the most upstream) and Drežničko jezero–Surdup (between Pipalska and Todorova pećina) are two sinkholes that are not passable and therefore are not considered speleological objects. Locals say that they can often become clogged, creating smaller lakes (hence the name), especially in winter. There was a watermill on Vidića bara that is no longer in operation. According to Ršumović (1960), the first activated sinkhole was Todorova pećina, then Pipalska, Surdup and finally Vidića bara. When all four sinkholes became active, the Drežnička River was completely disorganized.

Conclusion

The paper presents in detail the geological, geomorphological and speleological characteristics of the studied area, as well as its development through different geological periods. The karst processes that shaped the mentioned karst unit are analyzed, with special emphasis on the distribution of sinkholes, abysses and blind valleys. The mentioned speleological objects indicate the richness of the underground karst system, while the presence of sinkholes provides insight into the hydrological reorganization of the river system. The Zabučje–Gradina karst unit represents a unique unit in the area of western Serbia. This paper presents a recapitulation of previous understandings of the genesis of this area, confirmation of these understandings, but also some new conclusions are drawn. A brief description of each of the more important units of this area is given, the longitudinal profiles of Bukovac and Derventa are analyzed, and the epigeny of Đetinja between Užice and Sevojno is described. In the section on sinkholes, a new indicator for this unit is given, namely the density and number of sinkholes, and it is confirmed that sinkholes develop most intensively here too at relatively low gradients. It is also stated that a large number of sinkholes are located in rows, which is explained by the existence of paleowatercourses, on whose ravines later, after shortening, sinkholes developed. A new map was also made there, which is a map on which a detailed representation of the paleodrainage network of this area is made. And finally, a brief overview of speleological objects and sinkholes of this area is given.

Certainly, this work is not a complete and comprehensive analysis of the Zabučje-Gradina karst unit and it leaves room for further research. In future research, the hydrological connection between different speleological objects should be studied, in order to gain a more detailed insight and understanding of underground watercourses. Some of the questions that arise are: Where does the water from the karst surface of Zabučje and Ljubanj drain underground? Are there any other speleological objects in this area, especially in the Derventa and Bukovac gorges? What exactly is the underground connection of the abyss in the Drežnica Valley? What exactly was the genesis of the entire area, and what was the paleodrainage network on the karst surfaces? It is also important to emphasize the importance of preserving these natural objects that have both geological significance and significance for the development of tourism.

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