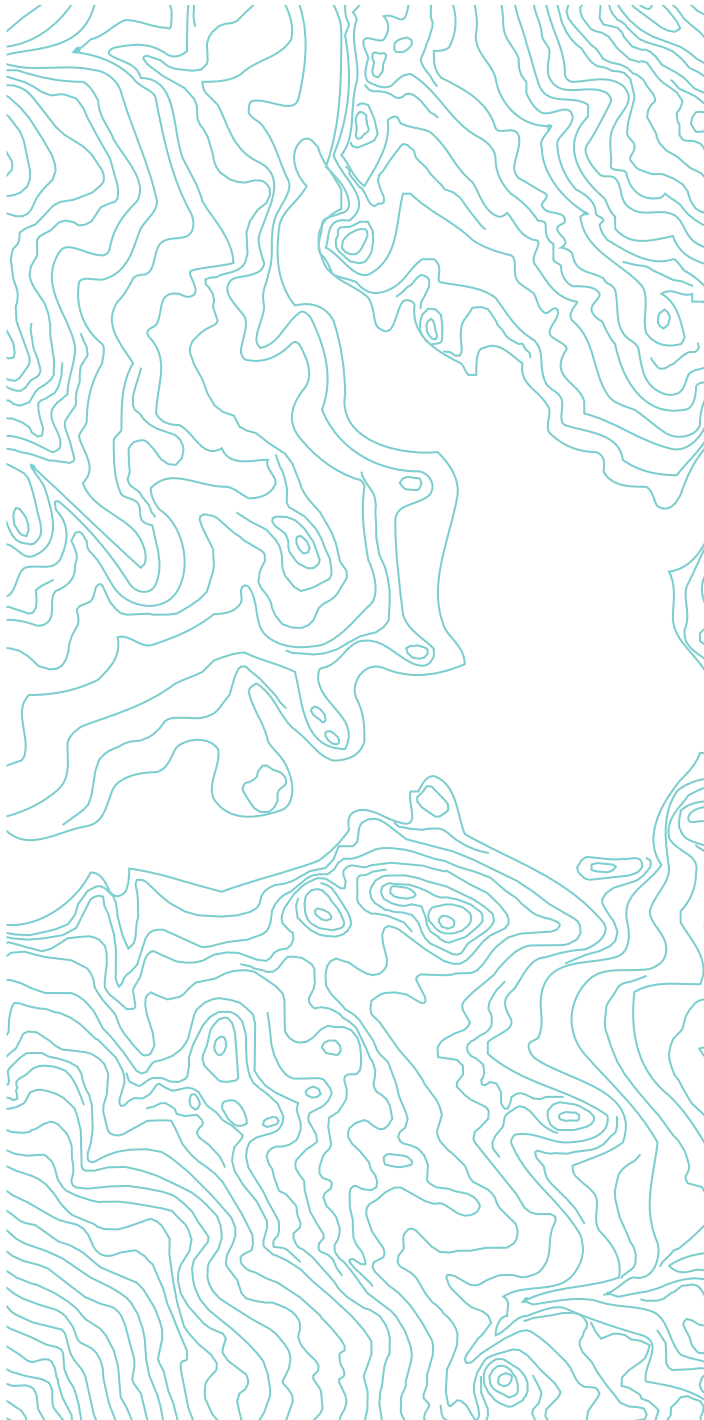




19th SERBIAN  
**GEOLOGICAL CONGRESS**

GEOLOGY FOR SUSTAINABLE SOLUTIONS  
Borsko lake 3. – 6.6.2026.

**FIELD TRIP  
GUIDE**





**The field guide of the 19<sup>th</sup> Congress of geologists of Serbia:  
GEOLOGICAL MOSAIC OF THE BOR DISTRICT**

The Borsko lake, Serbia  
June 3-6, 2026

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## Table of content

1. Welcome note .....	1
2. Taming the river power - the Borsko lake dam .....	9
3. “Floor is lava” – volcanites of the Bor area .....	15
4. Hidden treasures of the Kučaj-Beljanica limestone massif.....	23
5. Compass roulette – the Zlot geomagnetic anomaly .....	31
6. Royal wellness – The Brestovačka spa .....	37

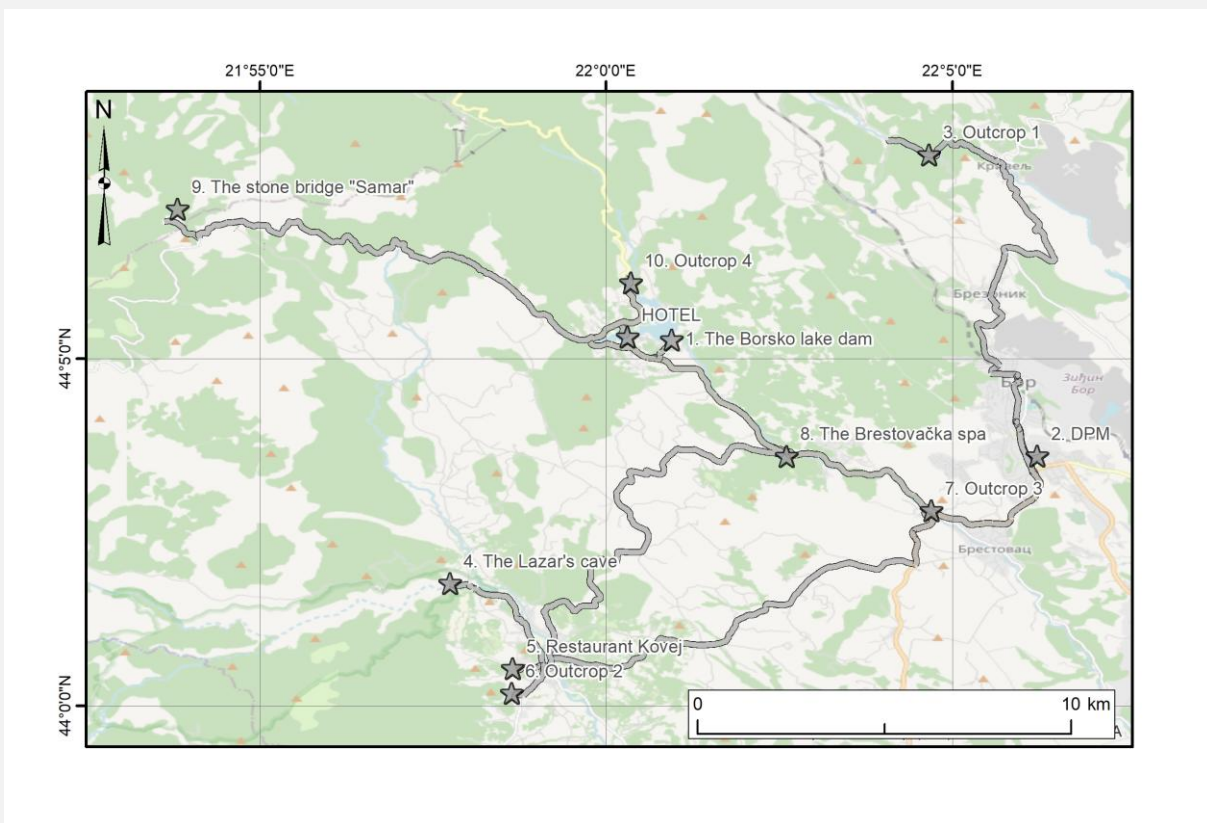


## Welcome note

Miloš Marjanović<sup>1\*</sup>

<sup>1</sup>University of Belgrade, Faculty of Mining and Geology; e-mail: [milos.marjanovic@rgf.bg.ac.rs](mailto:milos.marjanovic@rgf.bg.ac.rs)

The overall tour map view:



## FIELD TOUR GUIDE

Dear participants,

Welcome to our geological field tour through the remarkable landscapes of the Bor area, a region distinguished by its diverse volcanic formations, karst phenomena, mineral resources, and rich historical and cultural heritage. This excursion will take you back-and-forth in time, along geological and historical footprints that have shaped these parts until present. You will embark this journey in a good company of our small crew: prof. dr **Dragan Milovanović**, dr **Ana Mladenović**, prof. dr **Vesna Cvetkov**, dr **Rastko Petrović**, and myself. Together with our host guides from the **Touristic organization of Bor**, the **Museum of mining and metallurgy**, the **Energana power plant** and **Dundee Precious Metals** company, we will try our best to close you in with intricate and intriguing geological phenomena within our field of expertise, as well as touristic and historical features. Throughout the day, you will have the opportunity to overview volcanic formations of varying composition and age, which collectively record the complex evolution of the region and consequently, entailed its industrial sprout and sprawl. In addition, you will be able to enter breathtaking geomorphological and hydrogeological localities, witness the “dancing” of the compass needle due to a strong geomagnetic field, and get an insight into past and contemporary engineering and mining activities that have shaped the development of the Bor area (Figure1). You will also be able to try specialties of traditional local cuisine and feel the well-known hospitality of this area.

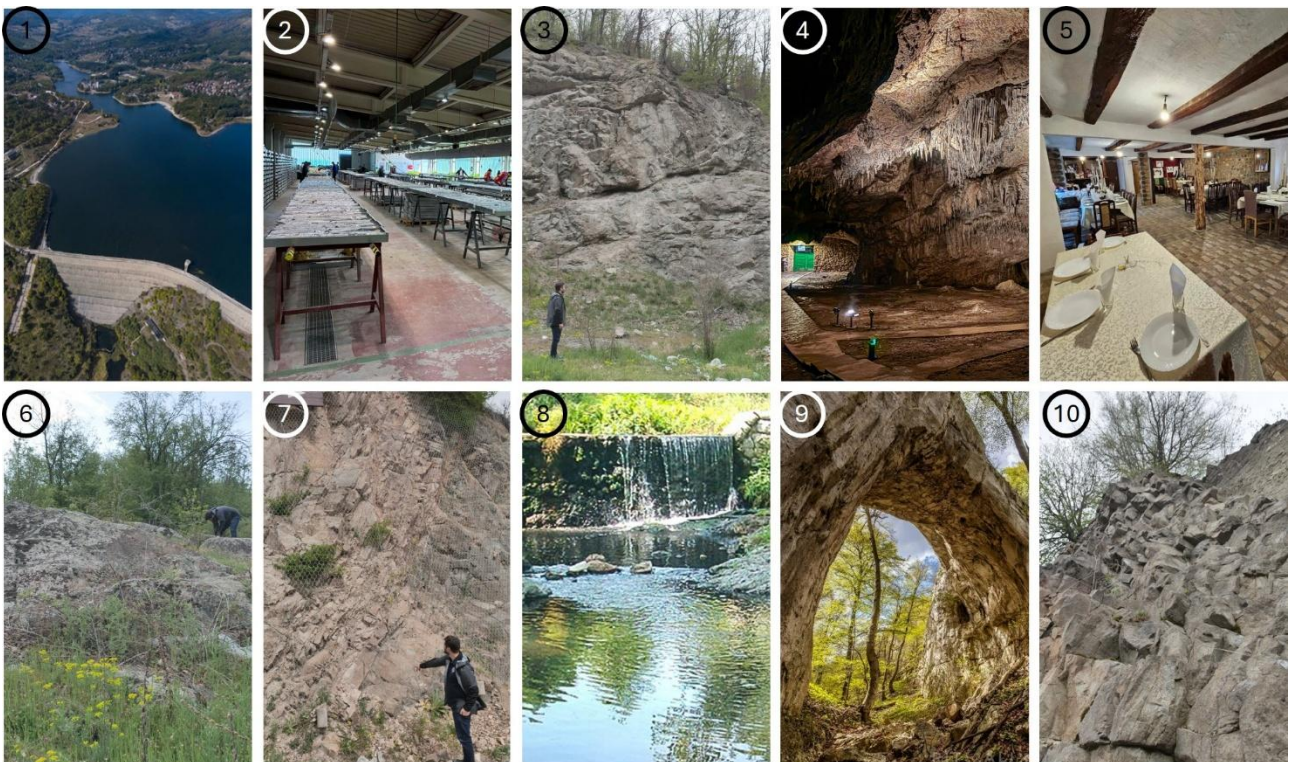


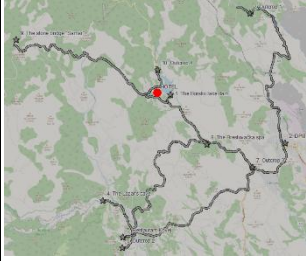
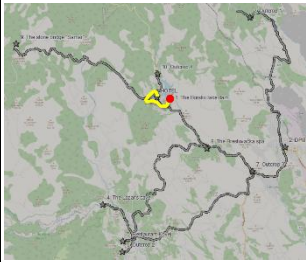
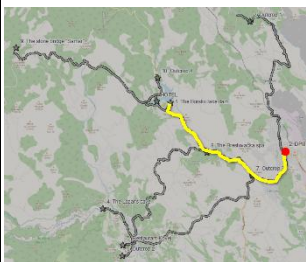
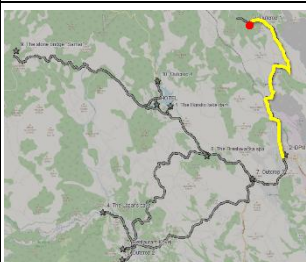

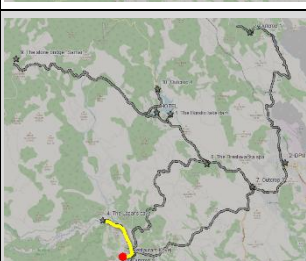
Figure1. Field trip locations collage (in visiting order): 1) the Borsko lake dam; 2) the DPM facility; 3) andesite quarry in Veliki Krivelj; 4) the Lazareva cave; 5) restaurant “Kovej”; 6) latite outcrop and geomagnetic anomaly near Zlot; 7) trachyte outcrop near Brestovac; 8) the Brestovačka spa; 9) the stone bridge “Samar”; 10) outcrop of andesite-basalt near the Borsko lake.

We hope this excursion will provide not only valuable scientific insight and field experience, but also an opportunity for professional exchange, interdisciplinary discussion, and appreciation of the exceptional geological diversity of this area.

**On behalf of the Organizing Committee and the Field Trip Team, I wish you a productive, enjoyable, and inspiring field trip!**

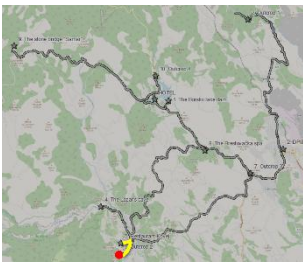
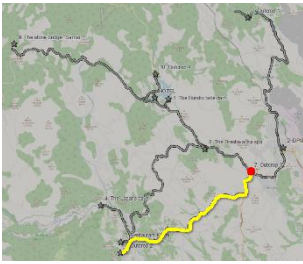
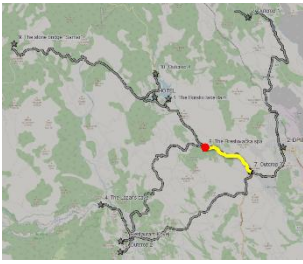

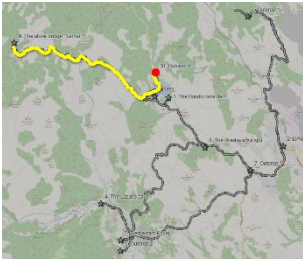
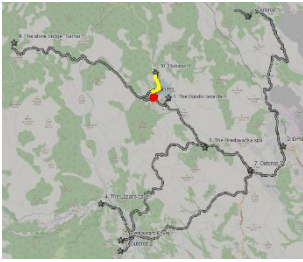
prof. dr Miloš Marjanović

**The tour route and schedule (pre-lunch)**

#	Location	Timeline	Route snippet	Comment
Start	Hotel "Jezero"	07:45 - 08:00		<ul style="list-style-type: none"> <li>Gathering in front of the Hotel "Jezero" and splitting into two groups:                             <ul style="list-style-type: none"> <li><b>Group 1:</b> bus shuttle</li> <li><b>Group 2:</b> van shuttle</li> </ul> </li> </ul>
1.	The Borsko lake dam	08:15 - 09:05		<ul style="list-style-type: none"> <li>Introduction on the dam features by the Energana Power plant host</li> <li>Presentation of the engineering geological background of the dam construction in jointed andesite mass, by prof. dr M. Marjanović</li> </ul>
2.	The DPM facility	09:35 - 10:15		<ul style="list-style-type: none"> <li>Mandatory <b>alcohol test</b> at the entrance of the facility (zero tolerance)</li> <li>Introduction to the recent mineral ore research by the DPM company host with guided overview of the core repository</li> <li>Refreshment/<b>toilet</b> break</li> </ul>
3.	Outcrop 1 near Veliki Krivelj	10:45 - 11:05		<ul style="list-style-type: none"> <li>Presentation of the hornblende-biotite andesite outcrop in an old rock quarry site, with an insight into the first phase of volcanism, by prof. dr D. Milovanović</li> </ul>
4.	The Lazar's cave	12:05 - 13:05		<ul style="list-style-type: none"> <li>Splitting in two even visitor groups:                             <ul style="list-style-type: none"> <li><b>Group 1:</b> guided tour through the <b>cave</b> and then short <b>10' hike</b> to the canyon viewpoint (insight into Kučaj-Beljanica limestone massif)</li> <li><b>Group 2:</b> short <b>10' hike</b> to the canyon viewpoint (insight into Kučaj-Beljanica limestone massif) and then guided tour through the <b>cave</b></li> </ul> </li> </ul>
5.	The "Kovej" restaurant	13:15 - 14:25		<ul style="list-style-type: none"> <li>Lunch break with predefined menu:                             <ul style="list-style-type: none"> <li>roast <b>veal meat with</b> vegetables</li> <li>homemade whey bread</li> <li>seasonal salad</li> <li>homemade desert</li> <li>soft drink</li> </ul> </li> <li>Refreshment/<b>toilet</b> break</li> </ul>

**FIELD TOUR GUIDE**

**The tour route and schedule (after-lunch)**

#	Location	Timeline	Route snippet	Comment
6.	Outcrop 2 and geomagnetic anomaly near Zlot	14:35 - 15:15		<ul style="list-style-type: none"> <li>• Presentation of the latite outcrop near Zlot, a geological rarity, by prof. dr D. Milovanović</li> <li>• Presentation of the Zlot geomagnetic anomaly by prof. dr V. Cvetkov (possibly with magnetic measurement demonstration)</li> </ul>
7.	Outcrop 3 near Brestovac	15:40 - 16:00		<ul style="list-style-type: none"> <li>• Presentation of the albite trachyte dyking through the andesites on an outcrop in a road cut near Brestovac, exempling the second phase of the volcanism, by prof. dr D. Milovanović</li> </ul>
8.	The Brestovačka spa	16:10 - 17:00		<ul style="list-style-type: none"> <li>• A guided tour of the historical museum exhibition “The Duke’s Miloš Inn” (in several groups)</li> <li>• Refreshment/<b>toilet</b> break</li> <li>• Presentation of the hydrothermal features and hydrogeological setting of the spa, linking the karst massif, volcanism and tectonics, by dr R. Petrović</li> </ul>
9.	The stone bridge “Samar”	17:35 - 19:00		<ul style="list-style-type: none"> <li>• Hiking about <b>25’</b> off the road, to the location, and back</li> <li>• Presentation of the stone bridge and other karst features of the site, and conclusion of the limestone plateau characteristics of the Kučaj-Beljanica massif by dr A. Mladenović</li> </ul>
10.	Outcrop 4 near the Borsko lake	19:20 - 19:45		<ul style="list-style-type: none"> <li>• Presentation of the andesite-basalt with prismatic jointing (semi-columnar) on an outcrop in abandoned rock quarry near the Borsko lake, concluding remarks on volcanic activity in the Bor area, by prof. dr D. Milovanović</li> </ul>
End	Hotel “Jezero”	19:50 - 19:50		<ul style="list-style-type: none"> <li>• Return to the Hotel in the evening hours</li> </ul>

## Important tips and hints

Although we can be rest assured that you are experienced field workers, coming from different geological or other scientific and engineering backgrounds, we will share a few suggestions to make sure that you will be safe and sound and make the most of the trip ahead.



### Dress code.

We suggest a standard field work outfit for the day, including **long sleeves and trousers**, sun blocking **hats** and sunglasses, and **appropriate shoes** for hiking, possibly specialized **shoes with protective cap** if you have a pair (it may be required for visiting the core repository of the DPM at location No. 2). Bear in mind that light rain or even intense showers can surprise us, so bring foldable raincoats and umbrellas. In the case of rain or thunderstorms, some activities might be cancelled or shortened.



### Cheers!

On the field trip day and even on **day before**, we suggest **restraining alcohol consumption**. Our visit to the DPM facility, the [location No. 2](#), implies obeying the house rules, and one of them is **zero alcohol tolerance**, which is **checked** at the entrance gate (breathalyzer alcohol-test). Since the visit is scheduled in the morning window, it is possible that alcohol resides if overconsumed during the previous evening. Please, consider this suggestion with caution, because you may be denied entering and end up waiting outside until the others finish the visit. We encourage you to keep up with **restraining during the entire day**, because we will endure a long day on the field, possibly with some of you **driving** back home after the trip ends, and for your own and safety of the others, sobriety is well appreciated.



### Bon appetite!

Should you have some **specific dietary demands** it will be important to inform us **in advance**. These include food allergies, fasting, vegetarian, vegan or other limitations and preferences. The restaurant “Kovej” will be preparing a fixed menu including veal meat, seasonal vegetables and wheat pastry, so if your diet inclines differently, let us know, the restaurant will gladly fix you up with your dish.



### Doctor's orders.

If you face some **health issues**, chronically or acutely, during the days preceding the field trip, please bear in mind that some locations may require moderate physical activity, such as hiking uphill or moving on uneven ground, staircases, limited lighting conditions (in the cave). Also, if you suffer from some related phobias (heights, closed space, etc.), **let us know in advance**. If feeling fatigue after [location No. 8](#) (the Brestovačka spa), you can inform us to avoid visiting remaining two locations since we will be passing by the Hotel and can leave you there, if needed.

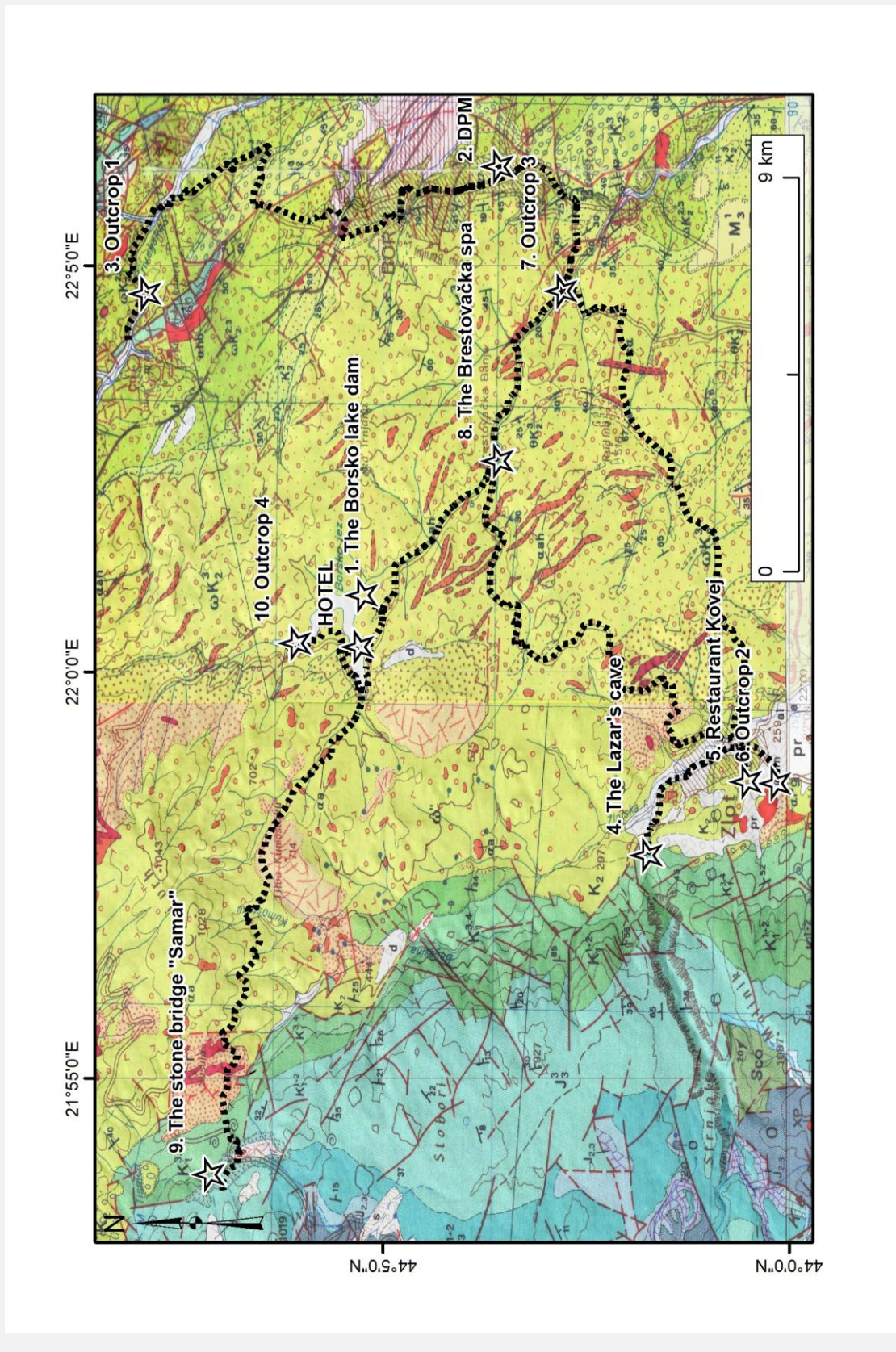


### At a crossroad.

We would like to draw your attention to potentially **high traffic** while visiting [location No. 7](#). It is a busy crossroad between Bor, Brestovac and Brestovačka spa, featuring heavy duty trucks, passenger cars, and public transport buses. Our outcrop is on the curve where visibility is reduced, and the space for moving around is limited to a tight zone between the curb and the rigola. Although we will undertake some **precaution measures** (marking the spot from both sides and signaling speed reduction) please, avoid sudden side steps and turns, moving backward for taking a photo, etc.

## Geological map of the route

The geological tour map view (from Basic geological map 1:100k):



## Taming the river power - the Borsko lake dam

Miloš Marjanović<sup>1\*</sup>

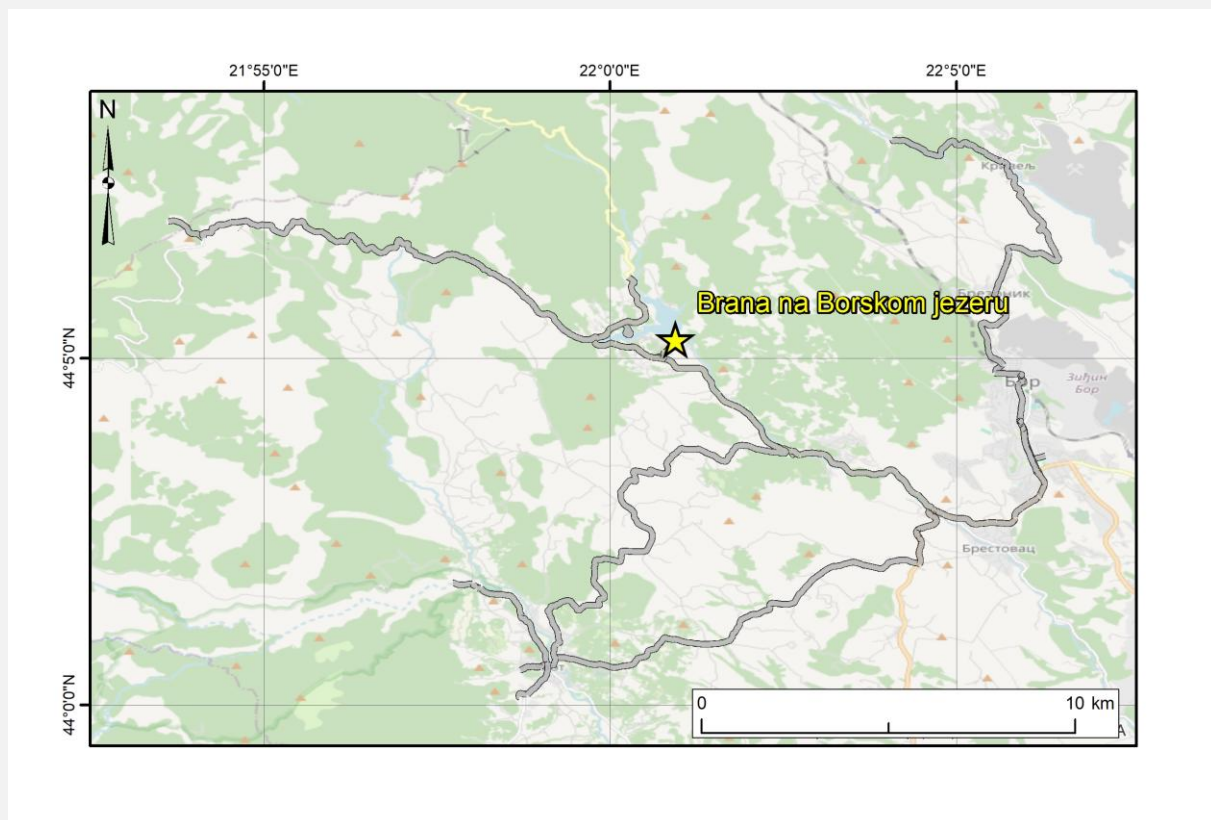
<sup>1</sup>University of Belgrade, Faculty of Mining and Geology; e-mail: [milos.marjanovic@rgf.bg.ac.rs](mailto:milos.marjanovic@rgf.bg.ac.rs)

**Location number: 1**

**Name:** The Dam on the Borsko lake

**Coordinates (lat/lon):** 44.088/22.016

**Map view:**



## 1. Introduction

Our first stop takes us to a site which links engineering and geological knowledge to tame the power of the river. The industrial development after the 2<sup>nd</sup> World War was intense in Serbia, and a large mining system, such as Bor, required a reliable water source. To fulfill the requirements a large hydro-energetic project was deployed targeted at designing a dam and accumulation with multiple functionality: technical water supply, small hydro-power plant and touristic area. For this purpose, a dam was designed on the Brestovačka river, about 23 km from its confluence into the Crni Timok river and some 10 km from the City of Bor. The chosen site for the basin includes local watersheds created by the Brestovačka river together with two tributaries, the Marecova river and the Valja Žoni river, bordering the watersheds of the Kriveljska river to the NE, the Borska river to the E, the Crna river to the NW, and the Zlotska river to the SW. The design was put into execution in 1957. and completed within two years (Figure 1).

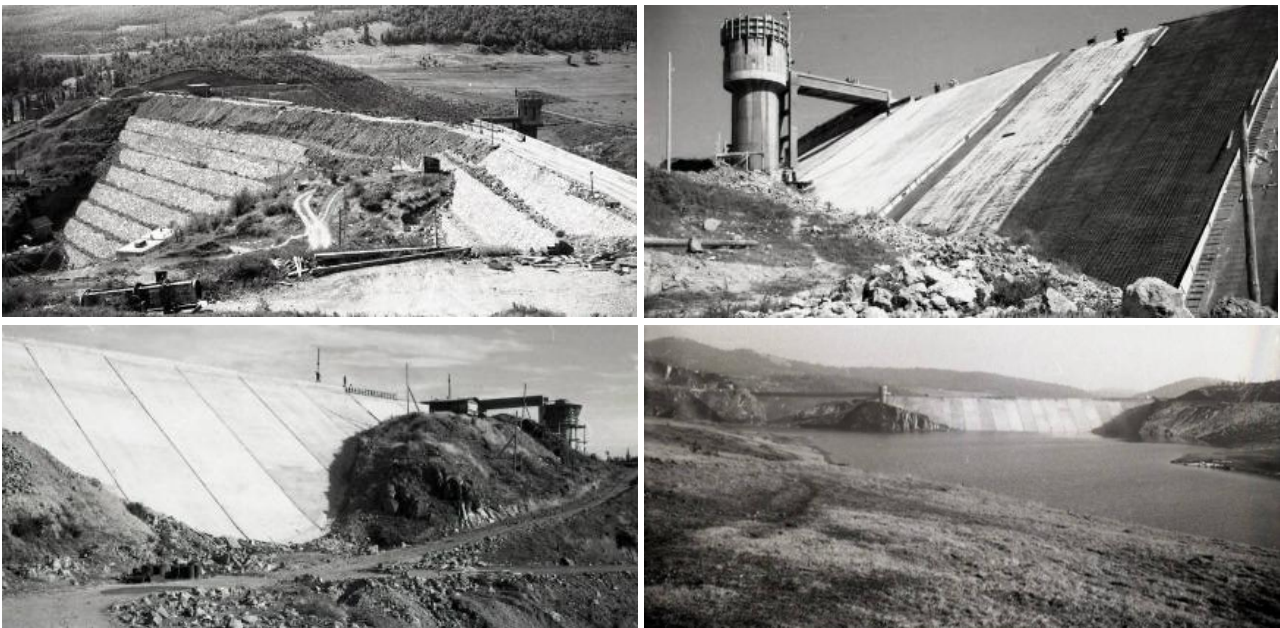


Figure 1. Archive footage of the dam construction (sequence from upper left to lower right): downstream face with multiple berms; upstream face with the spillway shaft and waterproofing; upstream face with concrete coating; filling of the accumulation in 1959 (source: [www.borskojezero.info](http://www.borskojezero.info)).

The Dam is classified as a high dam (>15 m), and by its construction it falls into the gravitational earth dam type, meaning that its wide base is filled with earth material upward toward the narrow crest. The accumulation on the other hand, was footprinted over the watersheds which were scarcely populated and enclosed two tributaries, which gave the lakes authentic branching look (Figure 2).



Figure 2. Aerial view and top-down footprint of the Dam and lake on the Brestovačka river (source: [www.google.maps.org](http://www.google.maps.org)).

The dam is waterproofed by isolating layer and concrete coating from the upstream side, whereas the downstream scarp remains covered with stone, broken into 8 narrow berms. Technical features of the dam at the time of its construction had enlisted it among the largest engineering endeavors, and one of the highest of its type in the wider region (Figure 3):

- total dam height  $H = 55$  m;
- crest length is  $L = 350$  m;
- crest altitude  $Z = 440$  m.a.s.l.;
- width at the base  $W_b = 135$  m;
- width at the crest  $W_c = 3.5$  m;
- dam body volume  $V = 345\,000$  m<sup>3</sup>;
- maximal overflow capacity  $Q_{max} = 210$  m<sup>3</sup>/s.

It comprises of several facilities including: the dam embankment, shaft spillway, water intake structure, bypass spillway and side channel to the left flank side (which was used for diverting river flow during construction), chute spillway to the right flank side, the bottom outlet, and a small hydropower plant of 36-80 kW of installed power (currently not in use) in front of the valve chamber.

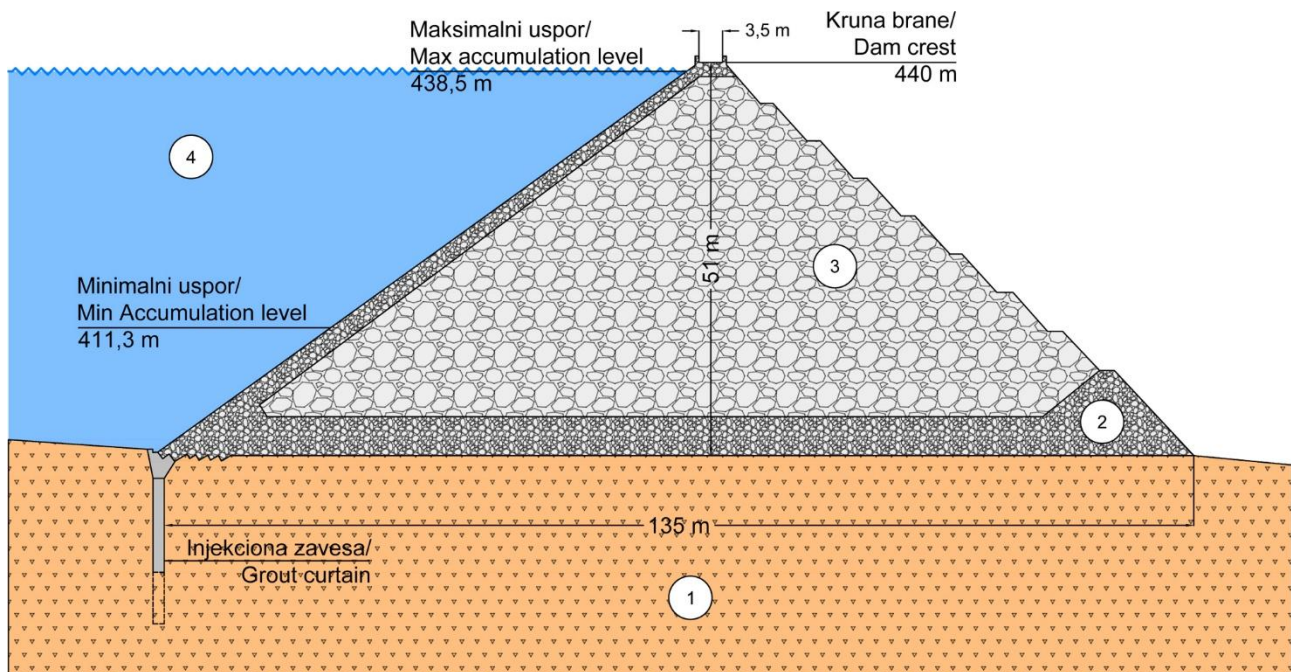


Figure 3. Cross section through the dam body: 1) brecciated andesite bedrock; 2) compacted rock fill; 3) rock muck fill; 4) water accumulation.

The accumulation area at maximal level is 79 ha, while its volume is 10.5 Mm<sup>3</sup>. The watershed surface area is 32.6 km<sup>2</sup>, from which the water discharges into accumulation about 175 l/s on averages. The amount of seepage water suffices the level for biological minimum downstream.

The dam is regularly monitored on annual basis, using high accuracy surveying methods according to the Monitoring Design, and findings are regularly reported. It is also within the seismic automatic surveillance network. There is also, warning system installed downstream, which is currently in reconstruction.

## 2. The Borsko lake earth-concrete dam

The geological context of the wider dam site area, i.e., the Brestovačka river valley is fairly homogenous in lithological but also not overcomplex in structural sense. The entire valley is carved into brecciated andesite varieties and their epiclastic equivalents of late Cretaceous age, locally protruded by the younger 2<sup>nd</sup> and 3<sup>rd</sup> phase andesite varieties. The dikes are elongated in NW-SE direction, aligning the river valley orientation. Local tectonics, which is a part of the large Timok synform pattern, also appoints to this direction, coupled with transecting SW-NE striking faults (Figure 4). The thickness of the volcanic formation is over 500 m, with interface boundaries to bedrock dipping SW by 20-30°.

## FIELD TOUR GUIDE

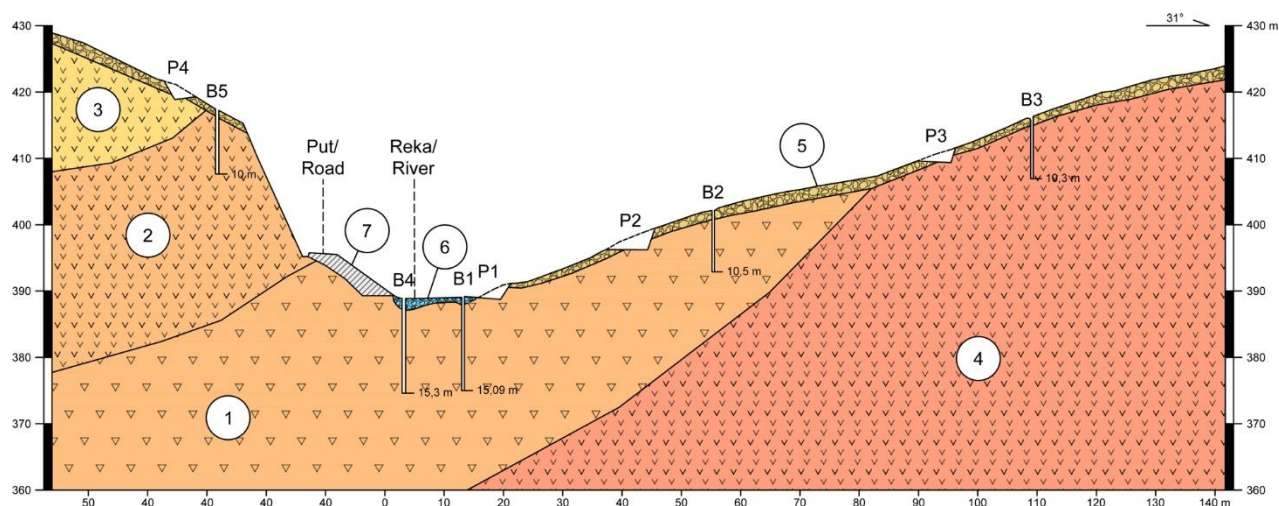


Figure 4. Engineering-geological cross-section in vicinity of the dam site: 1) brecciated andesite; 2) columnar jointed andesite-basalt; 3) highly jointed andesite; 4) fresh andesite; 5) weathered andesite; 6) river deposits (chiefly gravel and sand); 7) road embankment.

The engineering-geological aspect is apparently more complex, which have entailed substantial quantity of various investigation works, from detailed mapping of the dam site and accumulation footprint, multi-phased drilling and pitting, various laboratory analysis of collected samples, to large scale *in situ* tests, such as block direct shearing, packer tests, etc. The dam site is positioned in jointed rock massif, locally with columnar and other specific generic jointing types, which are challenging for prevention of seepage and modeling the strength parameters to assess the ground stability under such variety of loads that this project imposes (dam weight load, accumulation water, dynamic load from the induced seismicity and lake level fluctuations, as well as local earthquakes). For this reason, the upstream base of the dam is fitted with grout curtain. An offset double-row array of boreholes is used on the left flank and triple on the right flank. The spacing between the adjacent boreholes was 1.5-3 m, with depths of 10-15 m. The consolidation and contact grouting was performed through the concrete coating from the base level of the upstream embankment using the cement-based grout mass with dry mix consumption ranging 7-533 kg/m (per meter of the curtain). Anticipated grouting pressure is set to a minimum of 1.5 vertical stress at the location under full load (constructed dam and accumulation field to the maximum elevation level of 438.5 m.a.s.l.).

### 3. References

- Antonijević I., Kalenić, M., Đorđević, M., Lončarević, Č., Čučulić, M., Skuletić, T., 1976. Osnovna geološka karta SFRJ 1:100 000, list Bor, Savezni geološki zavod, Beograd
- Stojanović, D., Radulović, D., Georgijev, P. (1955). *Main construction Elaborate on the Dam on the Brestovačka river and the Borsko lake accumulation*



## “The floor is lava” – volcanites of the Bor area

Dragan Milovanović<sup>1\*</sup>

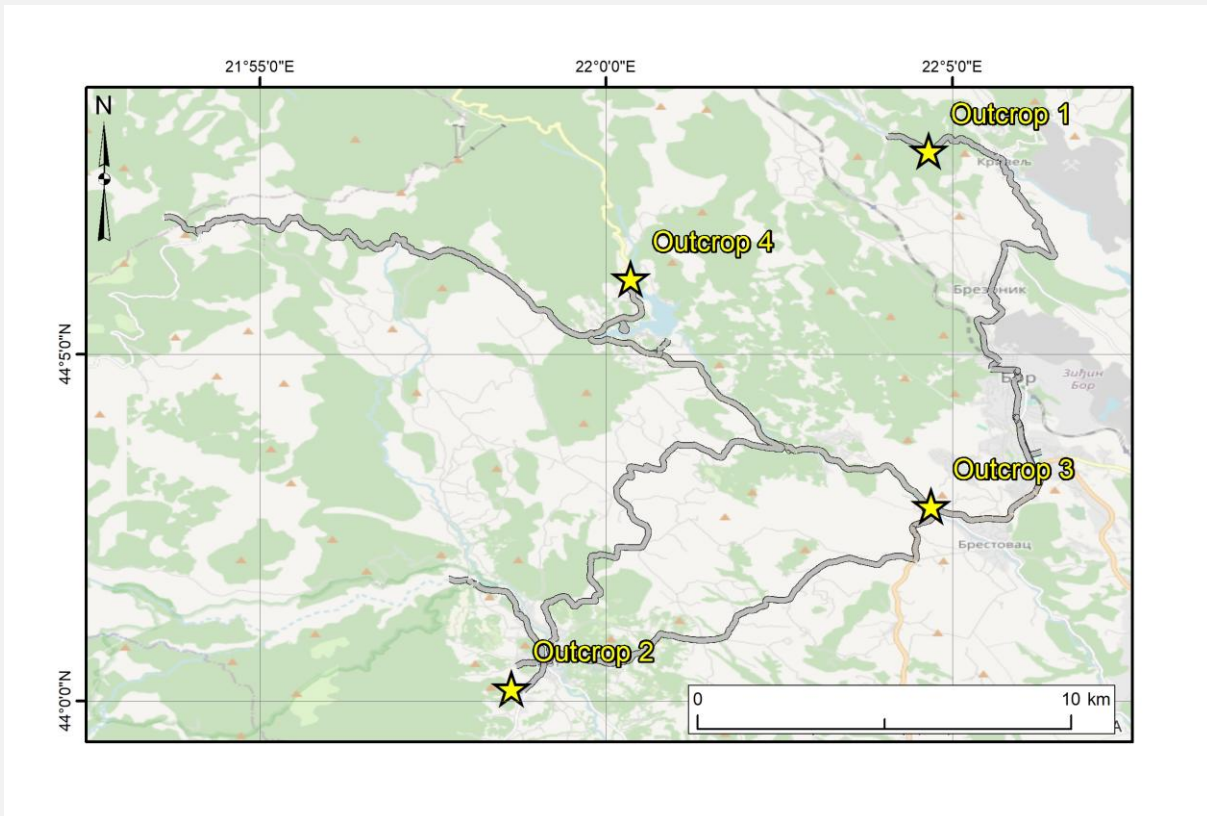
<sup>1</sup>University of Belgrade, Faculty of Mining and Geology; e-mail: [milovdr@gmail.com](mailto:milovdr@gmail.com)

**Location number:** 3, 6, 7, and 10

**Name:** Outcrop 1, Outcrop 2, Outcrop 3, Outcrop 4

**Coordinates (lat/lon):** 44.132/22.078, 44.003/21.977, 44.047/22.078, 44.102/22.006

**Map view:**



## 1. Introduction

Today we will visit several outcrops of the most important volcanic rocks that belong to the Timok Eruptive Complex (TEC)<sup>1</sup>. The TEC is a trench-synclinal structure, belonging to a wider system, the Carpathian-Balkan volcanic arc. It is formed on a base of autochthonous Jurassic and Lower Cretaceous sediments (Figure 1). As a marine basin, it began its evolution with the deposition of Albian basal conglomerates and sandstones (SE part of the area), which will continue with the expansion and deepening of the basin until the end of the Cenomanian, after which volcanic activity begins in these areas. It continues intermittently until the middle Maastrichtian and at the end of the Maastrichtian, when it ceases to exist as a marine basin.

The TEC is represented by volcanic, plutonic, and sedimentary-volcaniclastic rocks derived from subcrustal, contaminated magma(s). Volcanic rocks formed within three stages during the Upper Cretaceous. They are of andesitic, andesite-basalt and latite composition. The plutonic rocks correspond mainly to monzonite composition. The igneous activity lasted from 105 Ma through 65 Ma, but locally up to 60 Ma. The sedimentary and volcanoclastic constituents were formed in the Upper Cretaceous. They concordantly overlay the autochthonous base of Jurassic-Lower Cretaceous sediments.

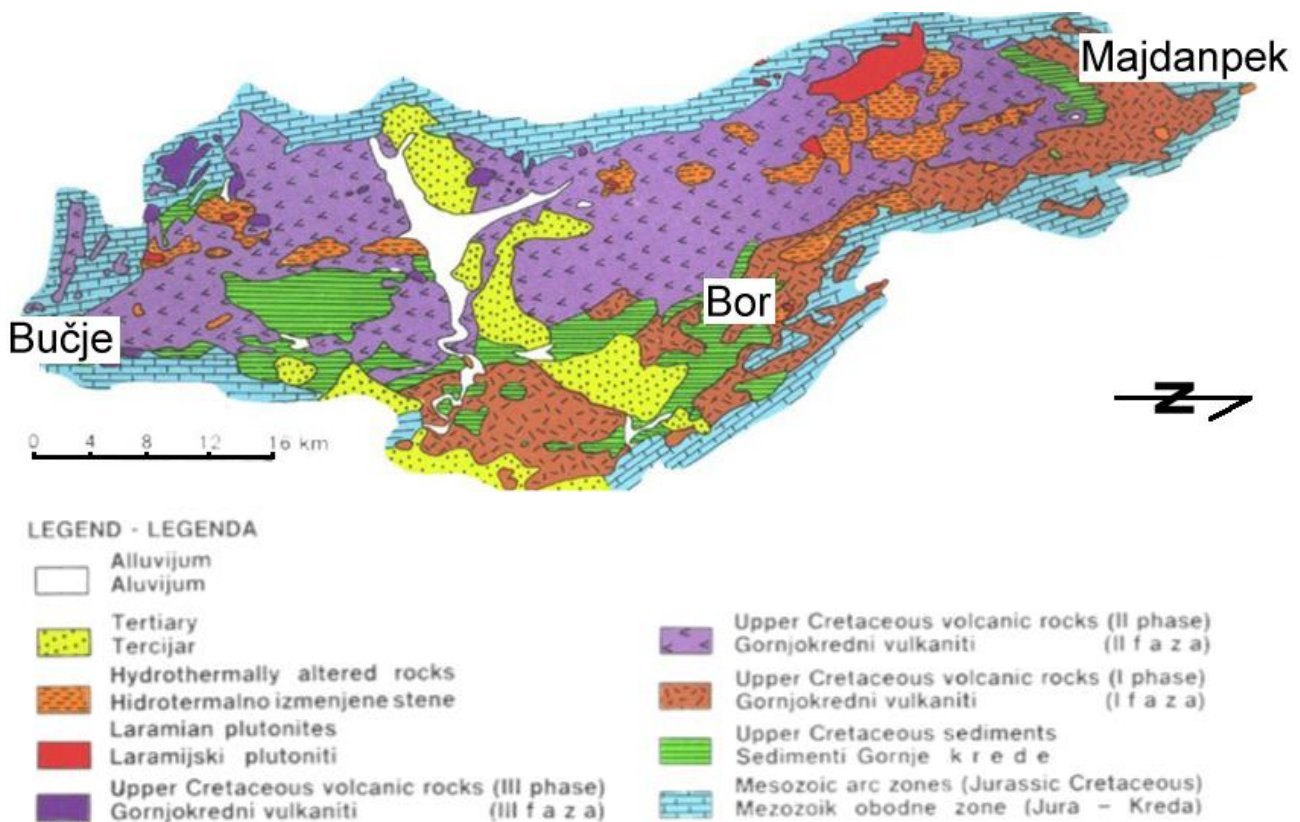


Figure 1. Geological map of the Timok Eruptive Complex.

The Bor metallogenic zone is associated with a rift-graben environment, where volcano intrusive complexes developed. It can be traced from Majdanpek to in the north, to the Bučje in the south (Figure 1). Ore mineralization is of Upper Cretaceous age (Senon) and is related to subvolcanic and hypo-abysal rocks and certain structures as the environments in which they took place.

The main ore association of the Veliki Krivelj deposit includes pyrrhotine, cubanite, valerite, pyrite, chalcopyrite, bornite with small content of sphalerite and galena. The ore is characterized by very low gold content. Mineral resources of the Veliki Krivelj deposits are > 540 Mt ore, 0.35% Cu, 0.068 g/t Au.

<sup>1</sup> Part of the material is overtaken from Field trip guide in the framework of the XVI Serbian geological Congress, by the courtesy of M. Banješević.

## 2. The “Timocite“, a hornblende-biotite andesite near Veliki Krivelj – Outcrop 1

At the section crop out hornblende-biotite andesites appear as lava dome or cryptodome facies. Outcrop of hornblende biotite andesite is near village Veliki Krivelj (Figure 2). They are made of hornblende phenocrysts, biotite and pyroxenes are found (in older, lower levels) and zonal plagioclase (40-50% An average). The groundmass is made of plagioclase microlites, rare grains of pyroxene and biotite and glass. Their columnar to platy jointing and phenocrysts of hornblende are visible at the outcrop. Hornblende andesite belongs to the I volcanic phase, isotopic age is around 84 Ma. In the continuation, along the road, there are several outcrops of brecciated andesites of the same composition. They were interpreted as lateral facies of the same dome/cryptodome.

Volcanism began in the Turonian when hornblende andesites of the I volcanic phase were formed in several larger structures. The outpouring is thought to have been in terrestrial, subaerial conditions, and ended before the deposition of the faunistically proven Turonian/Coniacian. The magmas that produced andesites were rich in water. These processes generated hydrothermal copper ore occurrences and copper ore deposits, the most famous of which are in the Bor mining area. The hornblende andesite of Timok is most often overlying by the Metovnice epiclastites.



Figure 2. Upper image – outcrop of hornblende-biotite andesite near Veliki Krivelj; bottom left – fluidal texture of oriented hornblende; bottom right – sample with phenocrysts of hornblende up to 5 cm. in size (photo by D. Milovanović).

## 3. Latite near Zlot – Outcrop 2

Occurrences, outcrops of latite occur SW of the village of Zlot. Compared to other volcanics, they have a small distribution. These rocks belong to the final volcanic activity and correspond to the III volcanic phase. Isotopic age was not done (Boljevac latite is 78.6 Ma.) The latites are imprinted in the volcanics of the second phase (andesite-basalts, and their pyroclastites). On the outcrop, paralleliped irregular secretion can be observed

**FIELD TOUR GUIDE**

(Figure 3). They are porphyry structures, with phenocrysts of andesine (on average it contains 40 to 45% An), sanidine, biotite which lying in a holocrystalline groundmass. They belong to the moncosyenite type of magma. In terms of their mineral and chemical composition, they differ significantly from volcanites I and II phase. In the same zone south of the village of Zlot, there is a geomagnetic anomaly that is over a hundred times higher than the remanent magnetization of the TEO volcanic rocks. In this area, there are occurrences of alkaline pyroxene basalts in which acicular magnetite and titanomagnetite occur that make up to 10% of the volume of the rock (Figure 3, bottom right), which may be the cause of the anomaly.

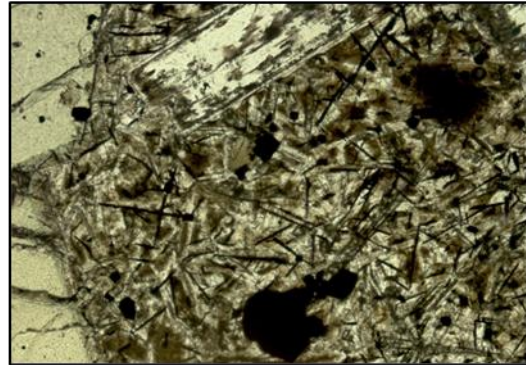


Figure 3. Outcrop of latite. Bottom left picture is rock sample. Lower right is picture photomicrograph of alkaline basalts with needles of magnetite and titanomagnetite. Nikol parallel, longer side of photo 2 mm. (photo by D. Milovanović).

**4. Albite trachyte near Brestovac – Outcrop 3**

Hyaloclastic and autoclastic deposits of pyroxene and amphibole bearing basaltic andesites II volcanic phase are cut by albite trachyte dyke. Their outcrops can be found along the road to Bor- Brestovačka spa (Figure 4). The albite trachyte breach (dyke) is 10 to 12 m thick. Albite trachyte is fresh, belt-like color and porphyry structure. It is made of phenocrysts of albite, biotite and hornblende (less abundant) lying in a hypocrySTALLINE groundmass. A fluid texture defined by oriented biotite flakes and hornblende inclusions in the ground mass was also observed. On some parts of the contact with the phase II pyroclastics, the texture of chilled margin can be observed. A zircon U/Pb analysis on albite trachyte gave two ages around 81 to 82 Ma.



Figure 4. Outcrop of albite trachyte near Brestovac. Bottom left picture is porphyry structure with fluidal texture, bottom right picture is rock sample with an enclave (caught piece) of andesite basalt (photo by D. Milovanović).

## 5. Andesite-basalt near the Borsko lake – Outcrop 4

Andesite basalts are the most common volcanic rocks of the Timok eruptive area. They belong to the II volcanic phase, which was poured mostly submarine and forms the core of the Timok trench syncline. The outpouring of andesite-basalt on the eastern flank of the syncline began in the lower Senonian, and after a hiatus, continued until the upper Santonian/Campanian. Submarine activity took place at depths where the internal pressure in the lavas is significantly higher than the pressure of the water column, and in such conditions pyroclastic deposits were almost exclusively formed (depths significantly less than 2000 m), which probably existed throughout the Upper Cretaceous. Isotopic age is between 78-84 Ma. The rocks are fine-grained, porphyry structures, built of small phenocrysts (1 to 2 mm) of labrador and even bitovnite (59-90% An), augite (in older levels) and sporadic hornblende. The groundmass is cryptocrystalline to microcrystalline and makes up about half of the volume of the rock. It is made of plagioclase microlite, pyroxene and glass which is why it is dark gray and gray-black in color. Secondary minerals include zeolite, chlorite, palagonite, calcite, etc. which were mostly created by the alteration of glass. They often form secondary veins up to a few millimeters thick that cut irregularly, mainly along the columnar jointing and another discontinuities. Andesite-basalts build pyroclastic deposits in which rare outpourings of lava occur, which are located on this outcrop where columnar jointing are observed (Figure 5).



Figure 5. Outcrop of andesite-basalt near the Borsko lake with columnar and parallelepiped jointing. Bottom left picture is rock sample, bottom right picture is detail of columnar jointing (photo by D. Milovanović).

## 6. References

- Antonijević I., Kalenić, M., Đorđević, M., Lončarević, Č., Čučulić, M., Skuletić, T., 1976. Osnovna geološka karta SFRJ 1:100 000, list Bor, Savezni geološki zavod, Beograd
- Đorđević, P., Knezević, V., Milovanović, D. 1982. Application of hydrothermal alteration models in prospection and investigation of copper deposits. X Yugosl. Geol. Congr., 2, 133-138, Budva.
- Đorđević, P., Karamata, S., Knezević, V., Milovanović, D. 1981. Note on the age of dyke rocks in Timok eruptive area. CR Seances Societe Serbe Géol. pour l'annee 1980, 71-71, Belgrade.
- Đorđević A., Mekić N., Milićević V., Starčević M., Milovanović D. 1998. Prilog objašnjenju porekla Zlotske geomagnetne anomalije. I kongres geofizičara Jugoslavije. Zbornik radova, Beograd, pp. 53-59.
- Đorđević, M., Banješević, M. 1995. Geološka karta Jugoslavije, Južni deo Timočke eruptivne oblasti 1:50 000. Izdanje Saveznog ministarstva za privredu SR Jugoslavije 1996, Beograd.
- Jelenković R., Milovanović D., Koželj D., Banješević M. 2016. The Mineral Resources of the Bor Metallogenic Zone. Geologia-Croatia, vol.69, No 1, p. 143-155.
- Kalenić M., Hadži Vuković M. 1973. Osnovna geološka karta SFRJ 1:100.000 list Kučevo. Savezni geološki zavod. Beograd
- Kalenić M., Hadži Vuković M., Dolić D., Lončarević Č., Rakić M. 1980. Osnovna geološka karta SFRJ 1:100.000 tumač za list Kučevo. Savezni geološki zavod. Beograd.
- Kalenić, M., Đorđević M., Krstić, B., Bogdanović, P., Milosaković, R., Divljan, M., Čučulić M., Džodžo., Rudolf., Jovanović Lj. sa saradnicima navedenim u uvodu tumača., 1976. Osnovna geološka karta SFRJ 1:100.000 tumač za list Bor. Savezni geološki zavod. Beograd

- Karamata S., Đorđević P. 1980. Origin of the Upper Cretaceous and Tertiary magmas in the eastern part of Yugoslavia. Bulletin Academie des Serbe des Sciences et des Arts.
- Karamata, S., Knezević, V., Đorđević, P., Milovanović, D., Miličić, M. 1981. Alterations in the copper deposit and their significance for explanations of ore genesis. 12 Congress Carpatho-Balkan Geol. Assoc., September 8-13, Abstracts, Bucharest.
- Karamata, S., Knezević-Djordjević, V., Milovanović, D. 2002. A Review of The Evolution of Upper Cretaceous - Paleogene Magmatism In The Timok Magmatic Complex and The Associated Mineralization. Geology and Metallogeny of Copper and Gold Deposits In The Bor Metallogenic Zone, 24-25 October 2002, 15-28, Bor lake.
- Knezević, V., Đorđević, P., Milenković, P., Milovanović, D., Zivković, P., 1982. Hydrothermally altered rocks and their significance for copper mineralization in the Timok eruptive area. IV Meet. Investigat. copper mineral., Bor.
- Milovanović, D. 2014. Field trip guide in the framework of the XVI Serbian geological congress, Donji Milanovac, 22-25 May, 2014. P.1-49. (Editor).
- Milovanović, D., Karamata S., Banješević M. 2005. Petrology of alkali basalts of Zlot, Timok Magmatic Complex. Tectonophysics 410, 501, 509.
- Rakić, S., Zivković, P., Milovanović, D. 1982. Occurrences of native copper in the area of Vlaole (Eastern Serbia). X Yugosl. Geolog. Congr, 2, 331-336, Budva.

## Hidden treasures of the Kučaj-Beljanica limestone massif

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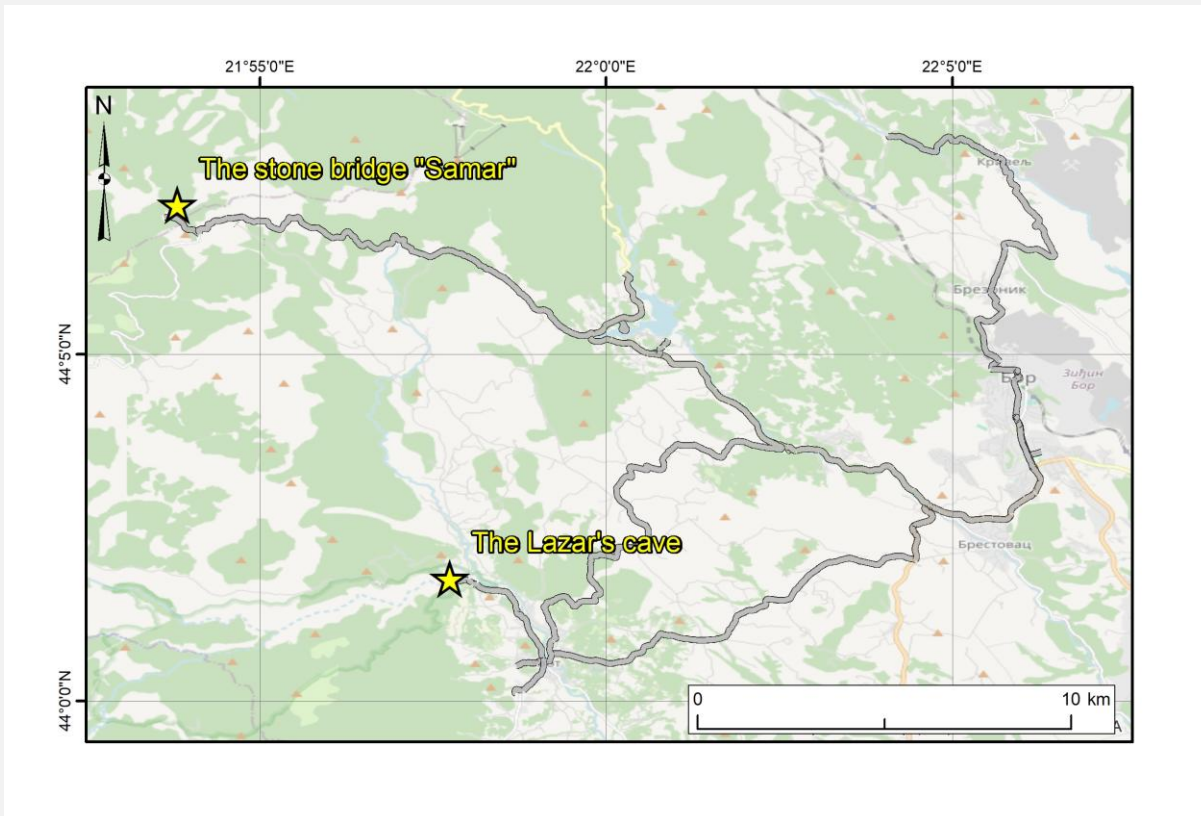
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**Location number:** 4, 9

**Name:** The Lazareva cave, The stone bridge "Samar"

**Coordinates (lat/lon):** 44.029/ 21.962, 44.119/21.897

**Map view:**



## 1. Introduction

Our next stops welcome us at the outskirts of the Kučaj–Beljanica massif, which is part of the unified Carpatho-Balkan arc and can be defined as an anticlinorium whose axis trends NNW–SSE. The limbs of this anticlinorium are built of Mesozoic carbonate rocks, while its core contains Paleozoic rocks.

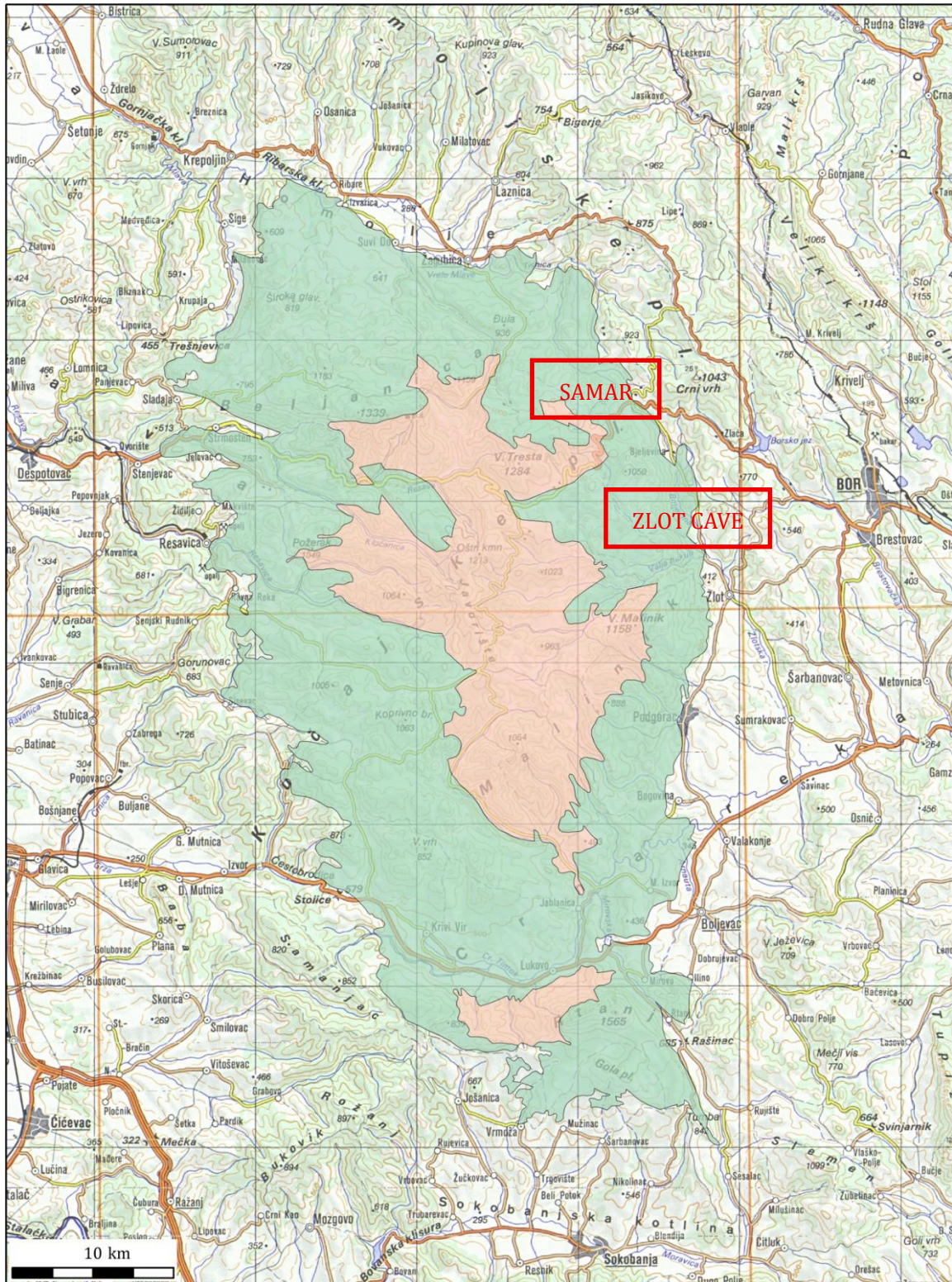


Figure 1. Map of the Kučaj – Beljanica massif. Paleozoic rocks in pinkish color, Mesozoic rocks in green color.

The entire Carpatho-Balkan orogen is characterized by a system of east-verging thrust sheets formed during the Austrian (around 128 Ma) and Laramian (around 80 Ma) phases of the Alpine orogenic cycle. For this reason, the Kučaj–Beljanica massif is bordered on all sides by major fault structures that are significant at the scale of the whole orogen in Serbia. These are the Mlava Fault, which forms the northern boundary of the massif; the Zlot Fault to the east; the Lukovo Fault to the south; while the western boundary of the Kučaj–Beljanica massif is defined by a thrust sheet of red Permian sandstones (the Gornjak–Ravanica zone) overlying the area of the Kučaj–Beljanica massif. In that sense, the Kučaj–Beljanica massif represents a structurally lower unit relative to the Gornjak–Ravanica zone, which lies further to the west.

From a geomorphological viewpoint, the Kučaj–Beljanica massif area is dominated by primarily karst processes, although fluvial and slope processes are also present due to the complex geological structure of the terrain. The sparsely developed river network is directed from the central parts of the massif toward the perimeter, which is composed of carbonate rocks.

The carbonate rocks of the Kučaj–Beljanica massif are characterized by a large number of surface and subsurface relief forms. Based on numerous speleological investigations and drilling results, intense and deep karstification of the carbonates across the entire karst area of the Kučaj–Beljanica massif has been observed. Earlier studies indicate that the karst process has deeply affected the carbonate complex of the massif. The intensity of this geomorphological process is uneven across parts of the terrain, but it has been determined that in certain zones it has been deepened well below the local erosion base level. This primarily relates to already documented occurrences of siphonal circulation in the discharge zones of some springs of the massif, as well as occurrences of dry cave channels in the upper parts of certain speleological features.

Surface morphology of karst forms on the Kučaj–Beljanica massif is highly developed, with almost all surface forms present except for karst poljes. Among surface microforms, karren are most common, while among macroforms there are dolines, natural bridges, uvalas, and dry valleys. In addition, subsurface karst forms are intensely developed. The Kučaj–Beljanica massif, together with the Miroč mountain, likely has the largest number of explored speleological objects in Serbia, with over 150 recorded in this area alone. The longest caves in the massif are Lazareva (Zlotska) Cave (more than 16 km of explored passages) and Bogovinska Cave (more than 5 km of explored passages). Lazareva Cave is by far the longest explored cave in Serbia. Some of the deeper caves of eastern Serbia are also located here; the best known are Mijajlova jama (over 150 m deep), Suvi Tisavac, Tisova jama, etc.

## 2. The Lazareva cave and canyon

The Lazareva (Zlotska) Cave is the longest cave in Serbia, with over 16 km of explored passages to date (Robert Mišić, personal communication). It is located 3 km from Zlot and 21 km from Bor. The cave entrance is positioned at an elevation of about 290 meters, on the left side of the Lazareva River. From a hydrogeological point of view, Lazareva Cave is a spring-type cave. Immediately near the cave entrance, in the bed of the Lazareva River, water emerges at the surface as a strong karst spring. The cave has been adapted for tourism since 1953, and the tourist trail is about 1 km long.

The first description of the cave was given by Felix Kanitz, while Felix Hoffmann was the first to begin exploring the cave in 1882. The cave was also explored by Jovan Cvijić in 1889. Systematic speleological research continued from the 1960s and in the form of multi-day expeditions continues to this day. A major contribution to the exploration and mapping of the cave was made primarily by speleologists from Bor and eastern Serbia, who led investigations involving members of all other speleological clubs from Serbia and abroad.

Lazareva Cave was declared a natural rarity and protected as a natural monument in 1949. The Environment Protection Institute of Serbia declared Lazareva Cave a geosite of Serbia in 2005. It is also located within the territory of the Lazarev Canyon natural monument.

The fossil fauna of Lazareva Cave is represented by remains of cave bear, cave lion, and cave hyena. The present fauna of the cave includes arthropods and bats. Over 20 species of bats (Ivana Budinski, personal communication) have been recorded in the cave, and endemic arthropod species (Dragan Antić, personal

**FIELD TOUR GUIDE**

communication) are also present, such as *Speleocyclus plutonis*, *Serbosoma lazarevensis*, *Pseudosinella problematica*, *Onychiurus trojan*, and *Arrhopalites zloti*.

Lazareva Cave also contains a very significant archaeological site, featuring three prehistoric cultural horizons. The artifacts found in Lazareva Cave are officially the oldest copper finds in Serbia.

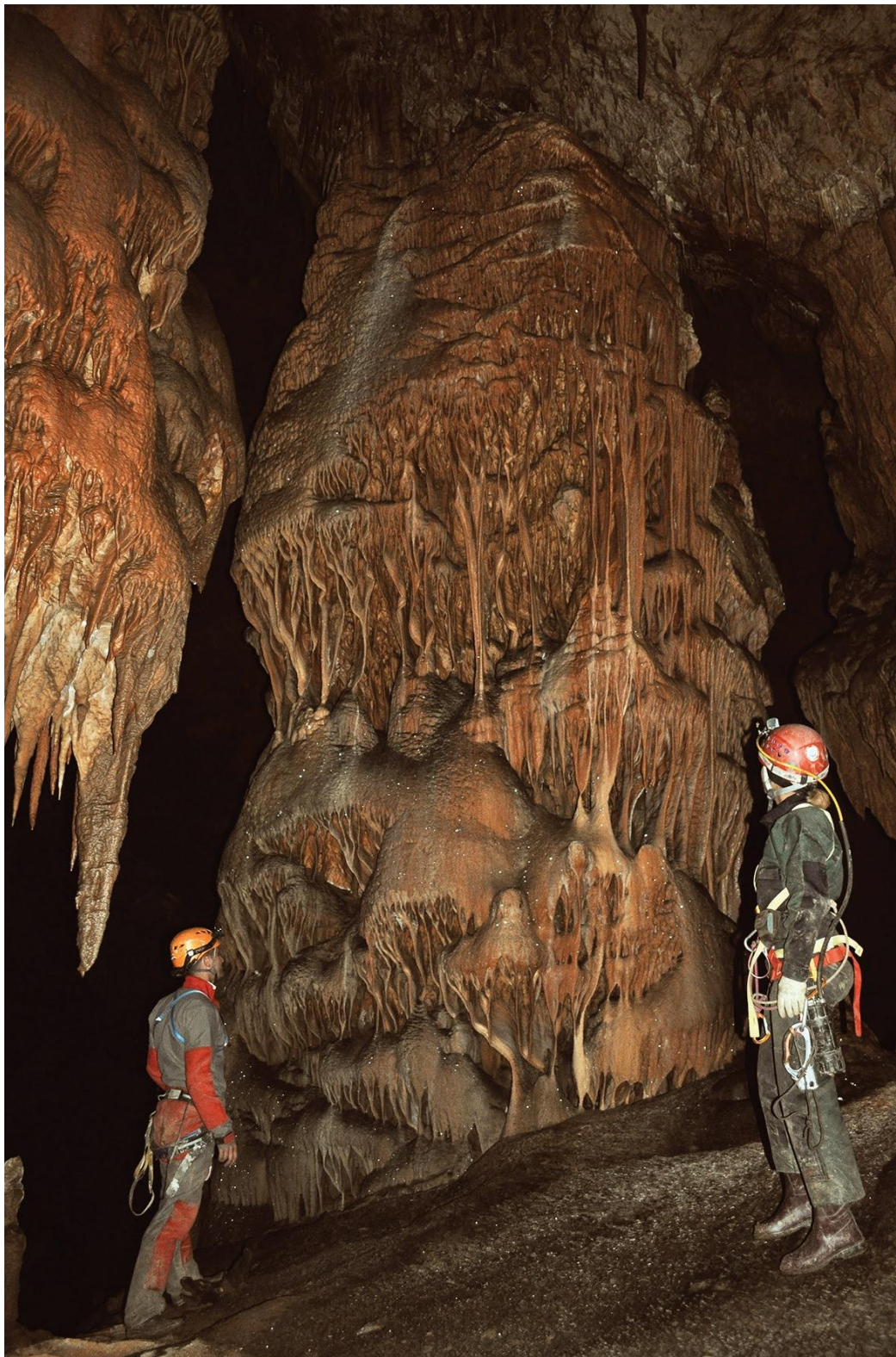


Figure 2. Giant stalagmite inside the Lazareva cave (photo – Jelena Čalić)

### 3. The stone bridge “Samar”

The Samar natural bridge is a stone bridge now located in the valley of the Perast stream. In addition, on the right valley side there are several larger caves, one of which is inside the bridge itself.

The Samar natural bridge most likely formed along an active fault, at the point where the Perast stream sinks. The activity of this fault is inferred from an abrupt change in the vertical river profile of the Perast stream. The fault was mapped within the Cave in the Samar bridge — it generally trends NNW–SSE and contains a hydraulically developed fault breccia about 2 m wide (Mladenović et al., 2019). The Samar bridge is of fluvial-karst origin. It represents a remnant of a cave in the Perast valley through which this stream once flowed (Petrović and Carević, 2015). The bridge is 10 m long, 14 m wide, and 15 m high.

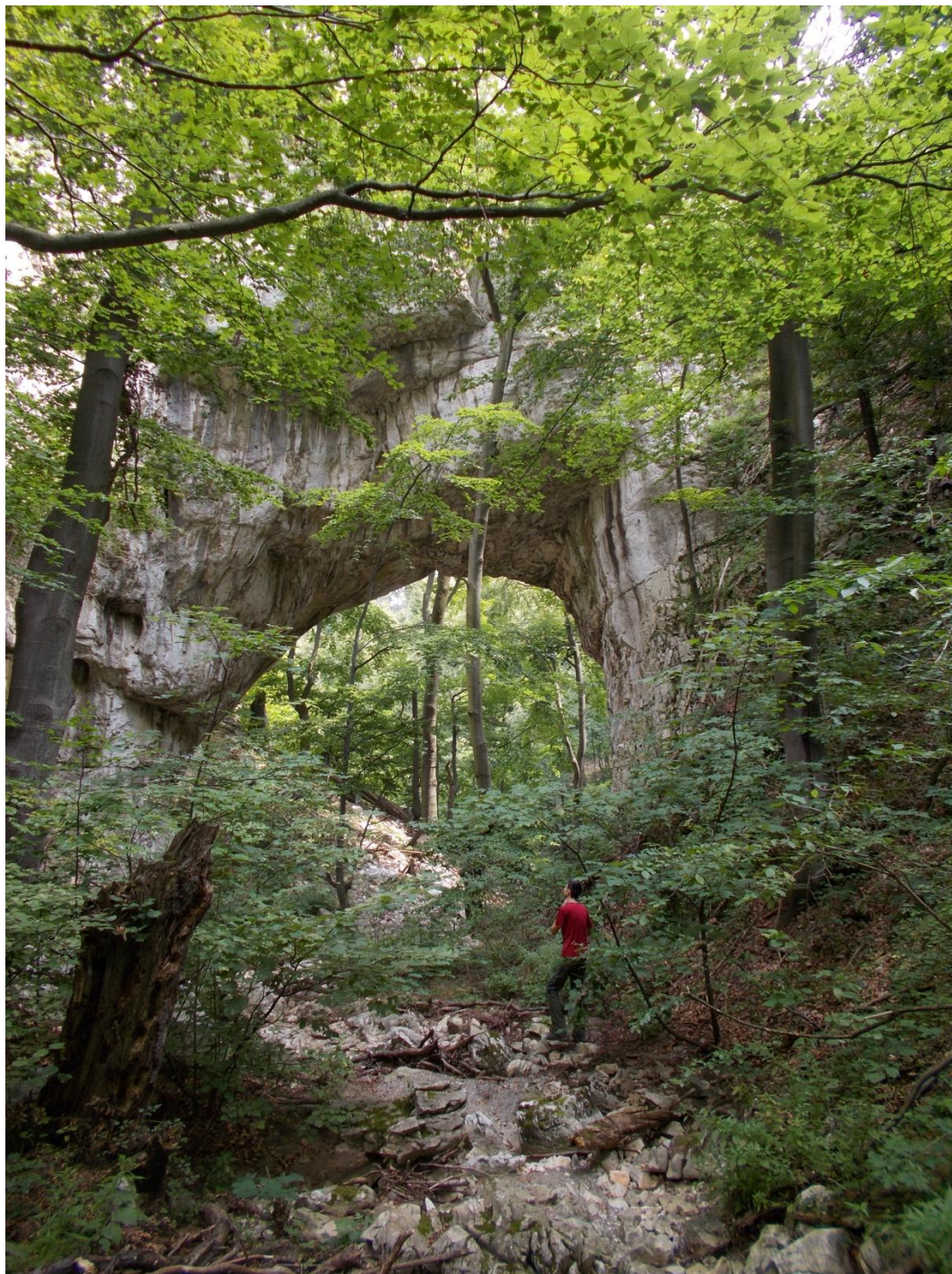


Figure 3. Samar natural bridge (personal archive)

#### **4. References**

- Mladenović, A., Mandić, M., Jovanović, K., Paskota, G. 2019. Pećina u prerasti Samar – primer strukturno kontrolisane pećine u rasednoj zoni. Knjiga apstrakata 9. Simpozijuma o zaštiti karsta, Beograd. pp. 5. ISBN 978-86-907923-4-4.
- Petrović, A., Carević, I. 2015. Geological influence on the formation of Samar natural bridge and collapse valley of Ravna River from the NE Kučaj Mountains (Carpatho-Balkanides, eastern Serbia). *Acta Carsologica*, 44 (1).



## Compass roulette – the Zlot geomagnetic anomaly

Vesna Cvetkov<sup>1\*</sup>

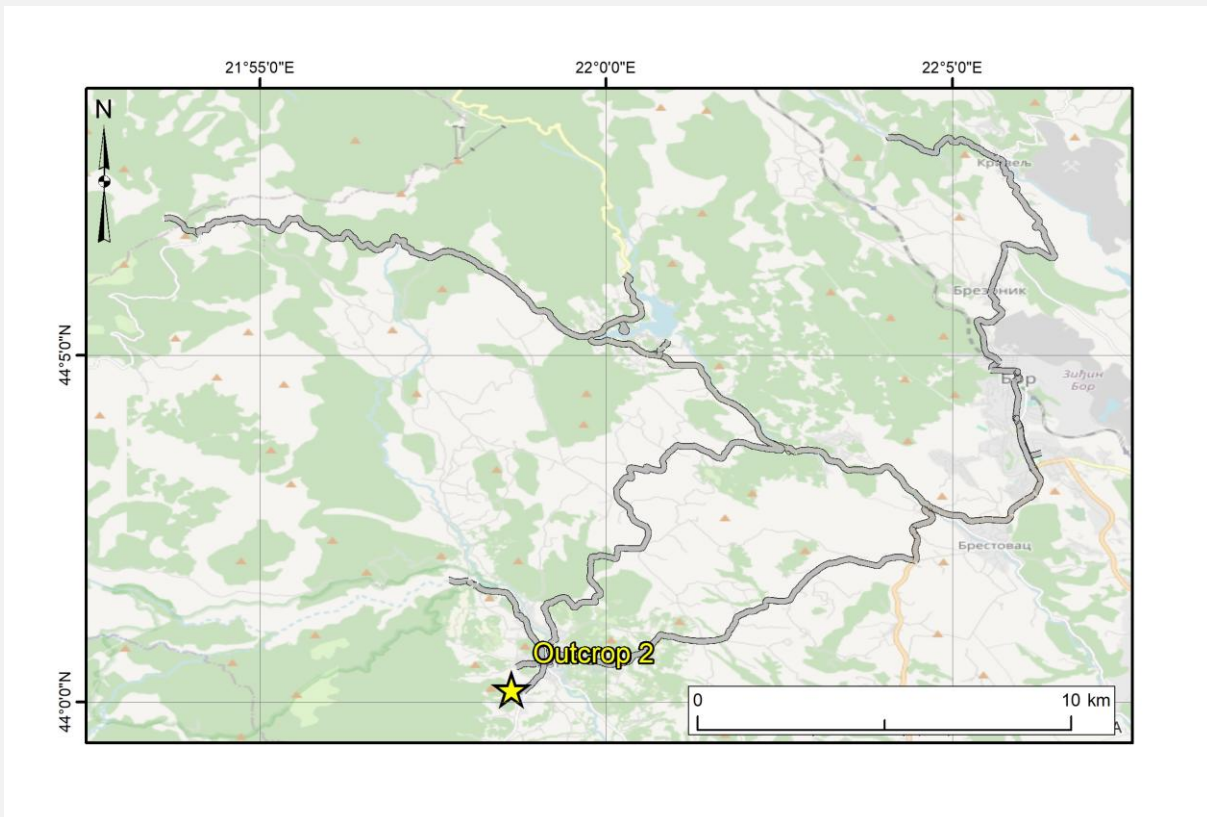
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**Location number:** 6

**Name:** Outcrop 2

**Coordinates (lat/lon):** 44.003/21.977

**Map view:**



## 1. Introduction

While we are in the zone of the Zlot village, where we have already seen some geological treasures, we will now address something that is not that apparent, a local turmoil in the fabric of the Earth's magnetic field. The Zlot anomaly is located approximately 15 km SW from Bor (Figure 1). It is discovered in the early 1980's during continuous geophysical investigations within the Timok Magmatic Complex (TMC). The anomaly occurs within an area of about 4.5 km<sup>2</sup> or approximately 2 x 2 km patch. In addition to the magnetic anomalies, positive gravity anomalies have also been detected across most of the area, spatially coinciding with the geomagnetic maxima (Bilibajkić et al., 1985/86). In a word, it is a mysterious place where your compasses and pendulums might behave unusually.

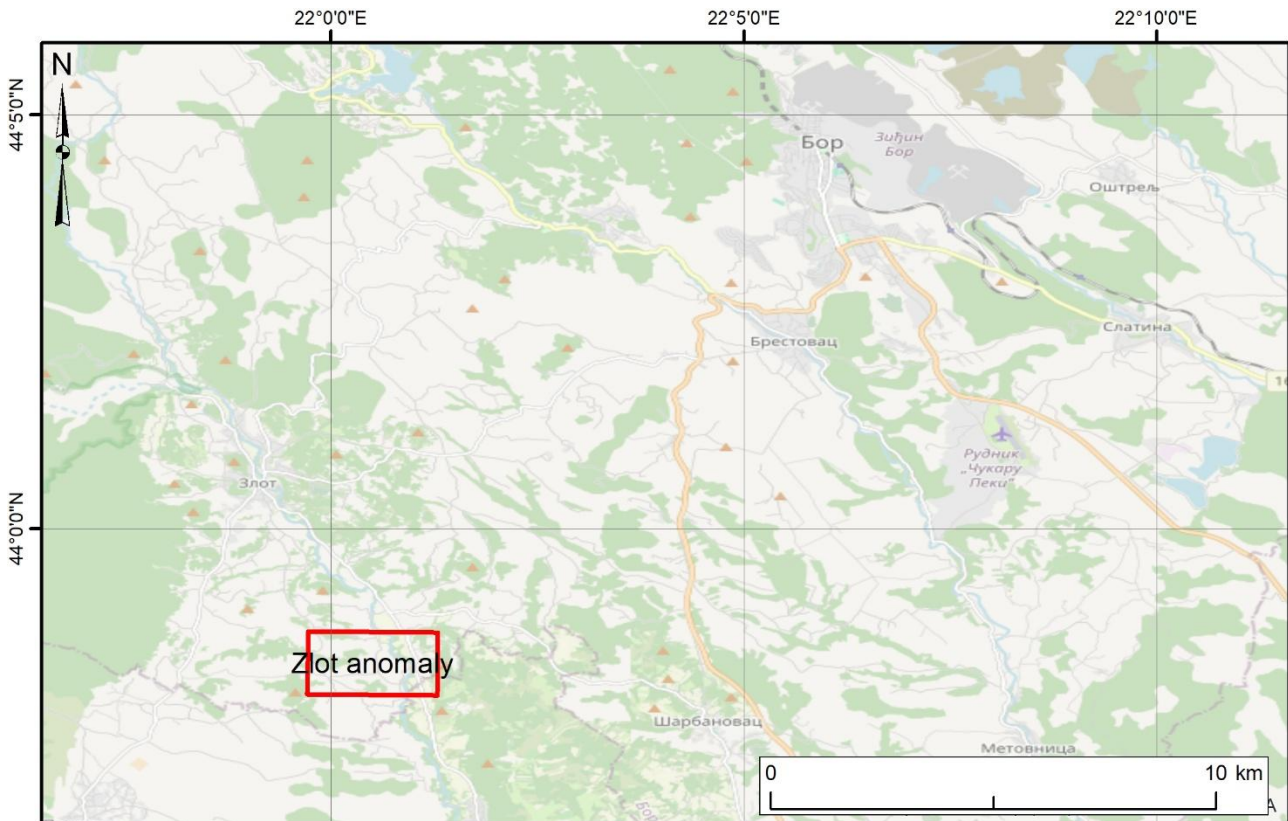


Figure 1. Geographic location of the Zlot geomagnetic anomaly.

## 2. Geomagnetic anomaly

The intensity of the vertical component of the Earth's magnetic field exceeds the normal field values for that region ( $Z_{n1960}=40200\text{nT}$ ). In addition to the field intensity, which exhibits extreme variations over a very small area, significant variation in declination is also observed, as shown in Figure 2. In a structural sense, the Zlot geomagnetic anomaly consists of a complex zone of positive anomalies striking WNW-ESE, localized along the middle course of the Zlot River. This zone comprises several local maxima of the vertical component with intensities exceeding 45000 nT, as well as an associated negative N-S striking magnetic anomaly reaching up to -29000nT.

The anomalous values of the Earth's magnetic field over all known iron ore deposits in the former Yugoslavia cannot be compared with the intensity of the Zlot anomaly, as their maximum intensities are up to four times lower. Furthermore, the geomagnetic field values over the world's most famous iron ore deposits (e.g., Kursk Magnetic Anomaly) exhibit similar or lower intensities compared to the Zlot anomaly.

Detailed geophysical and geological investigations, including five deep boreholes with a total drilling depth of 988 m, did not reveal the primary source of this geomagnetic anomaly (Figure 2). The rocks displaying the highest magnetization intensity encountered in the boreholes are latites with varying modal ratios of pyroxene, amphibole, and biotite (Bilibajkić et al., 1985/86). All latite samples exhibit very high values of natural remanent magnetization (NRM). This magnetization was acquired in multiple phases, with some

occurrences of >20m thick layers with exceptionally high NRM intensities. Compared to other volcanic rocks of the TMC, the rocks from the anomalous zone show a 70 to 100-fold increase in NRM intensity. On the other hand, magnetic susceptibility is only slightly elevated, though in exceptionally rare cases, it is 2 to 3 times higher than the typical values for the TMC.

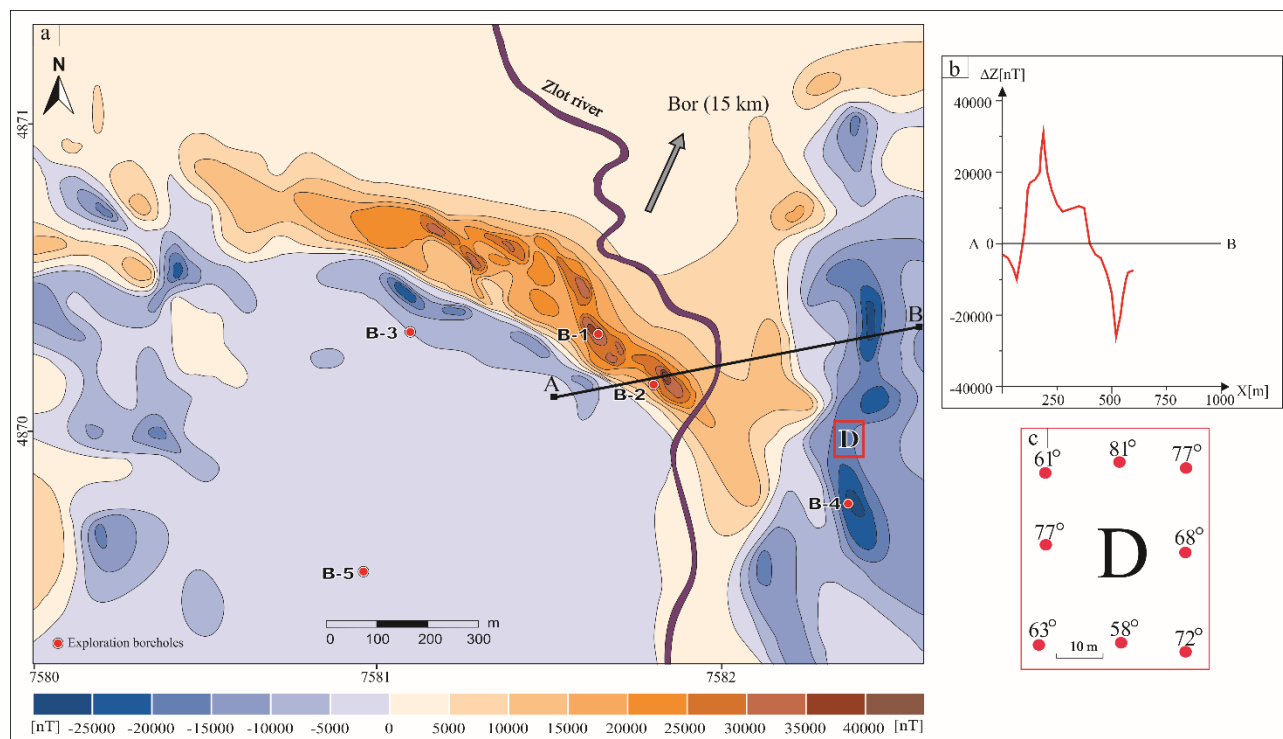


Figure 2. Zlot geomagnetic anomaly: a) The anomaly map of the vertical component of the Earth's magnetic field ( $\Delta Z$ ), Gauss - Kruger projection, b) Change in the intensity of  $\Delta Z$  along the A-B profile, c) Change in declination ( $D$ ) within the area of the Zlot geomagnetic anomaly (Bilibajkić et al., 1985/86, Starčević & Đorđević, 1996).

Microscopic examinations of ore and petrographic thin sections revealed that among the ore minerals, only magnetite is present, in amounts slightly higher than usual for this rock type. Two generations of magnetite were identified: granular (intratelluric), formed at temperatures above 1000°C, and acicular (needle-like), formed at lower temperatures. Bilibajkić et al. (1985/86) suggest a correlation between the abundance of acicular magnetite and the high NRM intensities, proposing that if their spatial distribution exhibited a specific regularity, it could be directly linked to the magnitude of the NRM intensity. However, no regular pattern has been identified in the distribution of acicular magnetite within the groundmass, to date. Milovanović et al. (2005) classify these pyroxene latites as alkaline basalts and state that the high NRM is a consequence of a single-domain or pseudo-single-domain magnetic structure of the magnetite (Mekić, 1997; Đorđević et al., 1998; Milovanović et al., 2005). Considering that the intensity and stability of the NRM acquired by a mineral during its formation under the influence of the geomagnetic field are significantly influenced by grain size, shape, and magnetic domain state, Cvetkov et al. (2014) determined, following the successful thermal demagnetization of all samples at 580°C and based on IRM, Lowrie, and Cisowski tests, that the main magnetic carrier in the pyroxene latites is multidomain magnetite (Figure 3).

FIELD TOUR GUIDE

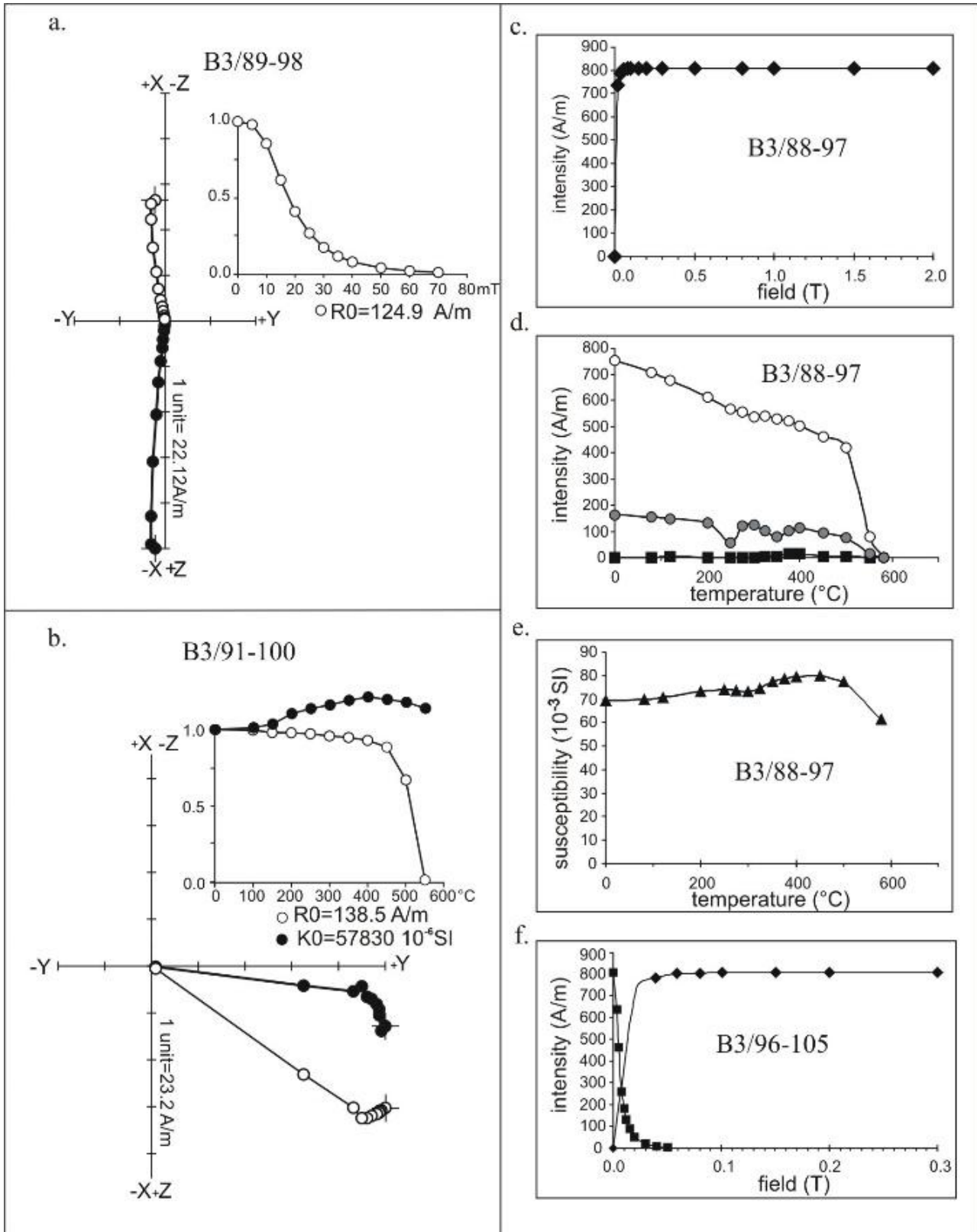


Figure 3. Laboratory paleomagnetic measurements of samples from borehole B-3 within the Zlot anomaly: a) demagnetization curve for demagnetization with alternating field; b) demagnetization curve for thermal demagnetization (Zijderveld diagrams: open circles/dots - projection of NRM in horizontal/vertical plane, intensity/susceptibility versus temperature curves: dots/open circles - susceptibility/intensity); c) IRM acquisition; d) behavior of 3-component IRM (Lowrie, 1990) on thermal demagnetization, hard (squares), medium (dots) and soft (open circles) components acquired in fields 2.92T, 0.1T and 0.02T respectively; e) susceptibility monitored during thermal demagnetization of 3-component IRM; f) Cisowski test (1981), IRM acquisition curve (diamonds) and demagnetization curve of IRM with alternating field (squares).

It occurs in the form of very fine acicular crystals ranging from 0.1 to 25 mm in length within an intersertal to pilotaxitic groundmass. In addition, the occurrence of several larger grains of oval to idiomorphic shapes with a range of 0.03 to 0.1mm in size are also observed, either dispersed in the rock mass or as inclusion in pyroxene.

In conclusion, this is an extremely interesting geophysical topic that yet awaits its full demystification in the more detailed research in the future.

### 3. References

- Bilibajkić, P., Bilibajkić, D., Veljović, D. 1985/86: Zlotska geomagnetska anomalija. Nafta-gas-Geofizički institut, Vesnik, XXVI/XXVII, serija C, 13-30.
- Cisowski, S. 1981: Interaction vs. non-interaction single domain behavior in natural and synthetic samples. Phys. Earth & Planet. Inter., 26 (1-2), 56-62.
- Cvetkov, V., Lesić, V., Vasković, N., Sretenović, B. 2014: Paleomagnetic investigation of borehole B3 from the area of Zlot geomagnetic anomaly (Eastern Serbia). XVI Kongres geologa Srbije, Donji Milanovac, Zbornik radova, 686-690.
- Đorđević, A., Mekić, N., Milićević, V., Starčević, M., Milovanović, D. 1998: Comments on the origin of Zlots geomagnetic anomaly. Proceedings, 1st Congress of Yugoslav Geophysicists, 542-551.
- Lowrie, W. 1990: Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. Geophysical Research Letters, 17, 159-162.
- Mekić, N. 1997: Analiza Zlotske geomagnetske anomalije na osnovu geofizičkih i geoloških ispitivanja. Magistarski rad, Rudarsko-geološki fakultet, Beograd.
- Milovanović, D., Karamata, S., Banješević, M. 2005: Petrology of alkali basalts of Zlot, Timok Magmatic Complex (Eastern Serbia). Tectonophysics, 410, 501-509.
- Starčević, M., Đorđević, A. 1996: Geomagnetic Map. Geological Atlas of Serbia 1:2,000,000. Ministry of Mining and Energy of the Republic of Serbia and Geological Institute - GEMINI.



## Royal wellness – The Brestovačka spa

Veselin Dragišić<sup>1</sup>, Vladimir Živanović<sup>1\*</sup>

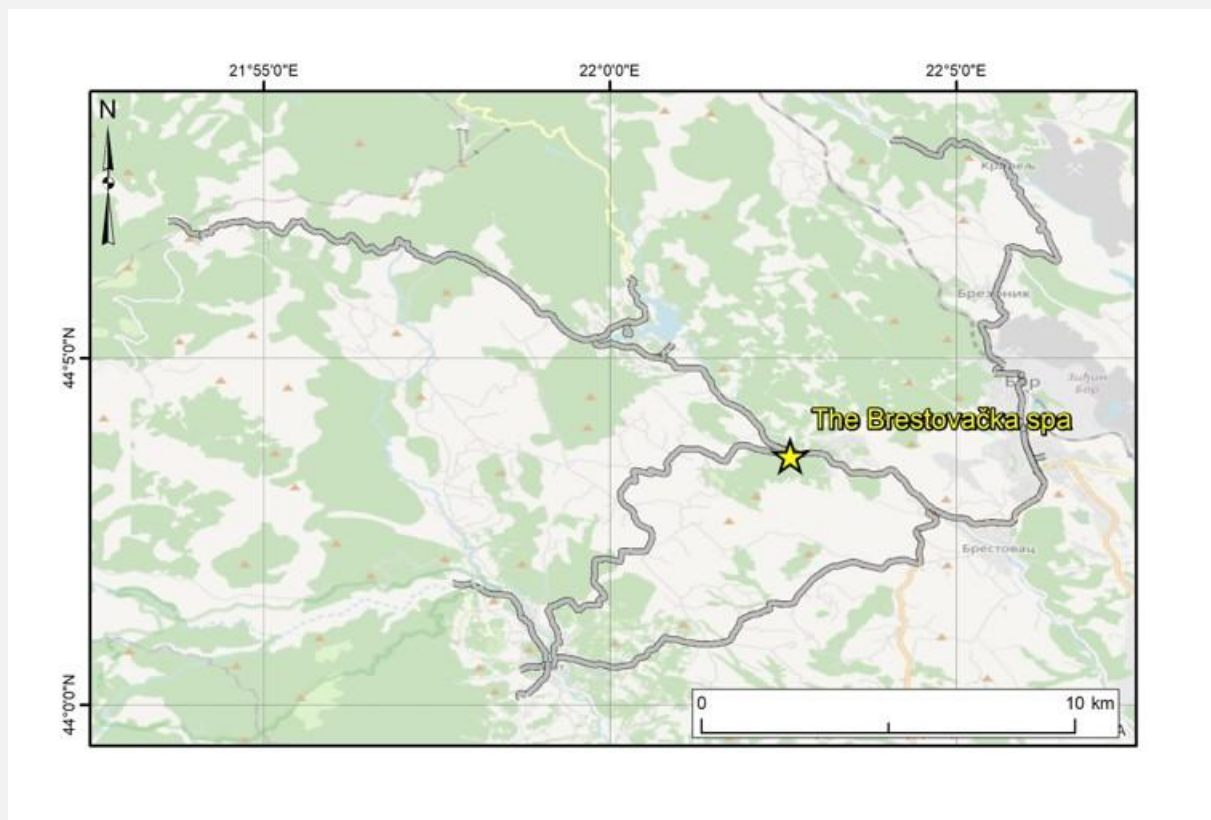
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**Location number:** 8

**Name:** The Brestovačka spa

**Coordinates (lat/lon):** 44.060/22.043

**Map view:**



## 1. Introduction

Our next stop has both an old geological story and long historical tradition to follow it. The Brestovačka Spa is a touristic and balneological marble of Serbia, located in the immediate vicinity of the town of Bor, approximately 10 km to the southwest. Thermal waters in this locality were known since the Roman Empire and have been used for balneological and recreational purposes, as evidenced by archaeological findings. More recently, in the early XIX century Serbian royal dynasties Obrenović and Karađorđević have founded the first glimpses of the spa resort (Figure 1). Since then, it has been expanded and reconstructed several times and still awaits further renovation that would restore its former glory.



Figure 1. The Turkish hammam from early XIX century and deadpans building from early XX century in the Brestovačka spa (source: <https://tobor.rs/>).

## 2. Thermal springs

The area where the thermal waters emerge is composed of andesite-basalts, volcanic agglomerates and breccias, as well as hydrothermally altered volcanic rocks (silicified, kaolinized, pyritized, etc.), often mineralized with copper ores. Thermal springs occur at the intersection of two prominent fault structures trending NNW–SSE and E–W (Figure 2). The main discharge zone is associated with the confluence of the Banjska and Brestovačka rivers. Most thermal springs (7) are located on both banks of the Banjska River in the center of Brestovačka spa. In addition, three other thermal water occurrences have been identified outside the spa center. One is located about 300 m upstream on the right bank of the Banjski stream, the second about 1500 m downstream from the spa, and the third in the bed of the Brestovačka river immediately before its confluence with the Banjska river (Dragišić et al., 1994).

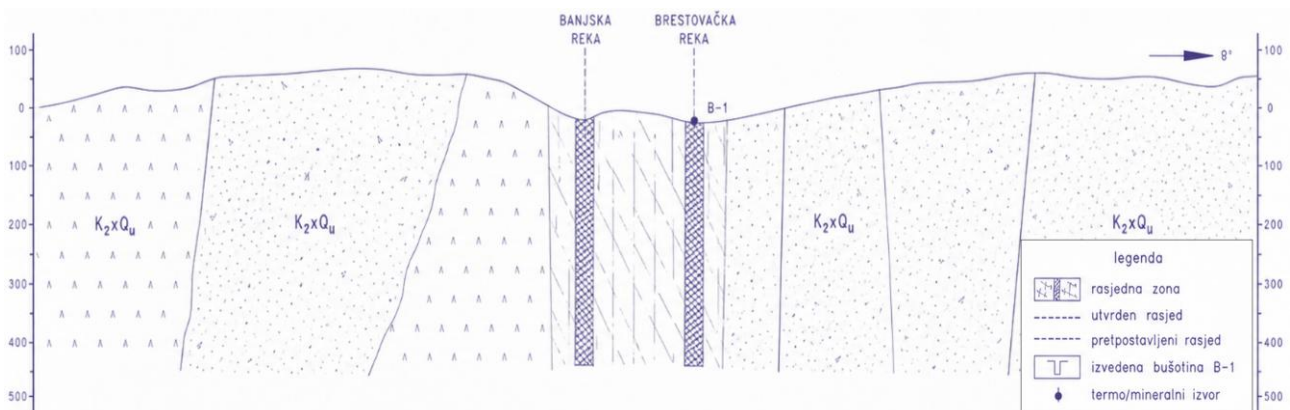


Figure 2. Geological profile through Brestovačka Banja (Filipović & Dragišić, 1989).

In addition to natural thermal water discharges (springs), the spa contains two shallow exploratory boreholes (S-1 and S-2) drilled in 1956 and one deeper thermal-water borehole (B-1) drilled in 1976. Before

drilling S-1 and S-2, the total discharge of the natural springs was about 3.0 l/s, with temperatures ranging between 19 and 41 °C. After drilling these boreholes, the thermal water yield increased by approximately 4.8 l/s, with a temperature of about 41 °C (Dragišić & Stevanović, 1994; Filipović et al., 1995). The highest temperatures are recorded in borehole B-1 (41 °C). The temperature decreases with increasing distance from the spa center, reaching approximately 17.5 °C.

The drilling of exploration borehole B-1 to a depth of 126 m in 1976 resulted in an artesian discharge of 7.0 l/s of thermal water. This caused some smaller springs to dry up and stopped the artesian flow from boreholes S-1 and S-2. Following the drilling of B-1, the total yield of the thermal-water system increased to about 10 l/s. Another exploratory borehole (B-2) was drilled near the restaurant “Srpska Kruna” in 1998. Its total depth was 51.5 m, and yielding of thermal water 3.5 l/s at a temperature of 39 °C. According to their chemical composition, the thermal waters of Brestovačka Banja are weakly alkaline waters with pH values between 8.0 and 8.7, belonging to the sulfate–calcium–sodium hydrochemical type (SO<sub>4</sub>–Ca, Na).

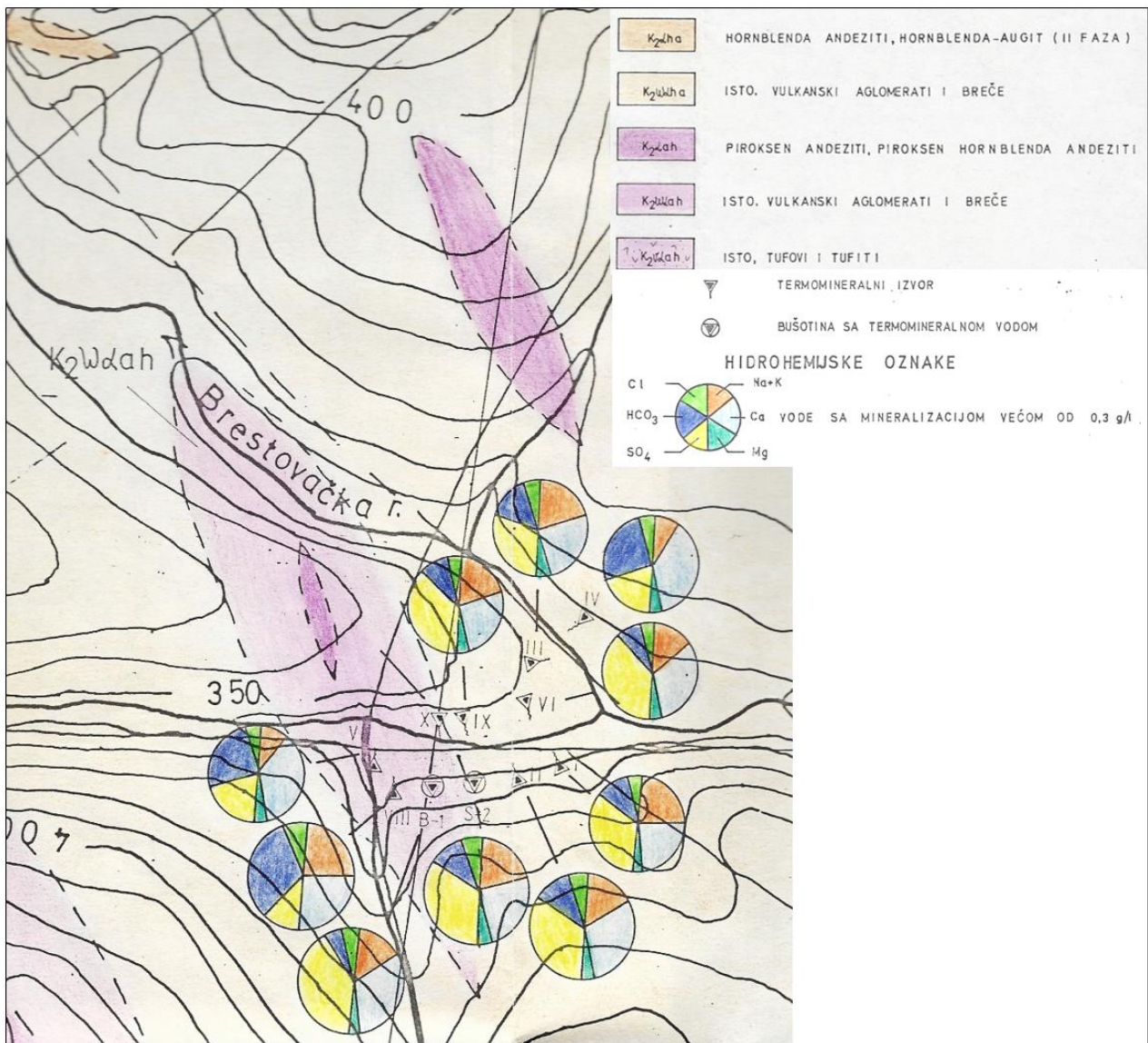


Figure 3. Locations of thermal-water discharge points with hydrochemical characteristics (Filipović & Dragišić, 1989).

Hydrogeological analysis of the wider Brestovačka spa area showed that groundwater formed within andesite-basalts and their pyroclastic equivalents belongs to the bicarbonate–calcium (HCO<sub>3</sub>–Ca) and bicarbonate–sodium (HCO<sub>3</sub>–Na) hydrochemical types (Figure 3). In contrast, sulfate–calcium waters develop within the hydrothermally altered Tilva Njagra zone. Structural and geological investigations have shown that most thermal-water occurrences are associated with a prominent fault zone extending toward the

## FIELD TOUR GUIDE

hydrothermally altered area known in the literature as Tilva Njagra. The hydrochemical model for the genesis of the thermal waters of Brestovačka spa assumes mixing between sulfate–calcium waters and bicarbonate–calcium and bicarbonate–sodium waters infiltrating along the aforementioned fault zone (Dragišić et al., 1994).

Owing to its unique hydrochemical composition, the spa is considered therapeutically beneficial for wide range of conditions, from dermatological, rheumatic and neurological to vascular, but chronic hedonists are traditionally coming for a treat.

### 3. References

- Dragišić, V., & Stevanović, Z. (1994). Characteristics of thermal-water occurrences in fractured aquifers of eastern Serbia. *Geological Annals of the Balkan Peninsula*, 58(1), 247–262, Belgrade.
- Dragišić, V., Papić, P., & Miladinović, B. (1994). On the genesis of the thermomineral waters of Brestovačka Banja. *Geological Annals of the Balkan Peninsula*, 58(2), 281–301, Belgrade.
- Filipović, B., & Dragišić, V. (1989). *Hydrogeological Study of the Thermomineral Waters of Brestovačka Banja*. Faculty of Mining and Geology, Belgrade.
- Filipović, B., Stevanović, Z., & Dragišić, V. (1995). Occurrences of thermomineral waters in the Carpatho-Balkanides of Serbia. *XV Congress of the Carpatho-Balkan Geological Association*, pp. 880–884, Athens, Greece.