

Chapter 2

Site Description

Abstract The Bijambare protected area is located around 25 km north of Sarajevo, and nowadays encompasses 490 ha of coniferous forest and meadows as well as several karst features. The average elevation is between 900 and 950 m. Available climatic data are limited, but based on a few partial sources an average temperature of 6.2 °C and precipitation of 917 mm year⁻¹ can be estimated. At the contact between Triassic impermeable quartz sandstone and limestone, waters from two main streams sink underground before re-emerging at the Orlja spring. In the area there are 8 known caves and, among them, Srednja Bijambarska cave is the longest (533 m of explored passages) and adapted as show cave. Srednja Bijambarska cave has a relatively simple morphology that for the scope of this work can be divided into 4 elements: the entrance section, the main channel, the narrow passage and the “Music hall”.

2.1 General Overview of the Area

2.1.1 *Bijambare Protected Landscape*

Bosnia and Herzegovina (BiH) shares a large portion of Dinaric karst and carbonate rocks cover around 65 % of its territory (Čičić 1998). Nevertheless, karst and karst features represent at present the most undervalued and understudied portion of this country (excluding places where hydropower, forestry and ore extraction interests prevail).

The Bijambare area (Fig. 2.1) is located around 25 km due north of Sarajevo, and around 40 km by car. The region represents the North edge of the Nišići highland (around 900–950 m a.s.l.) and at the same time one of the last carbonate

Material from this chapter has been originally published in Milanolo S, Mulaomerović J (2008) Speleološka istraživanja na području “Zaštićenog pejzaža Bijambare” (Speleological researches on the territory of the “Protected landscape Bijambare”). Naš Krš 40-41: 3–24.

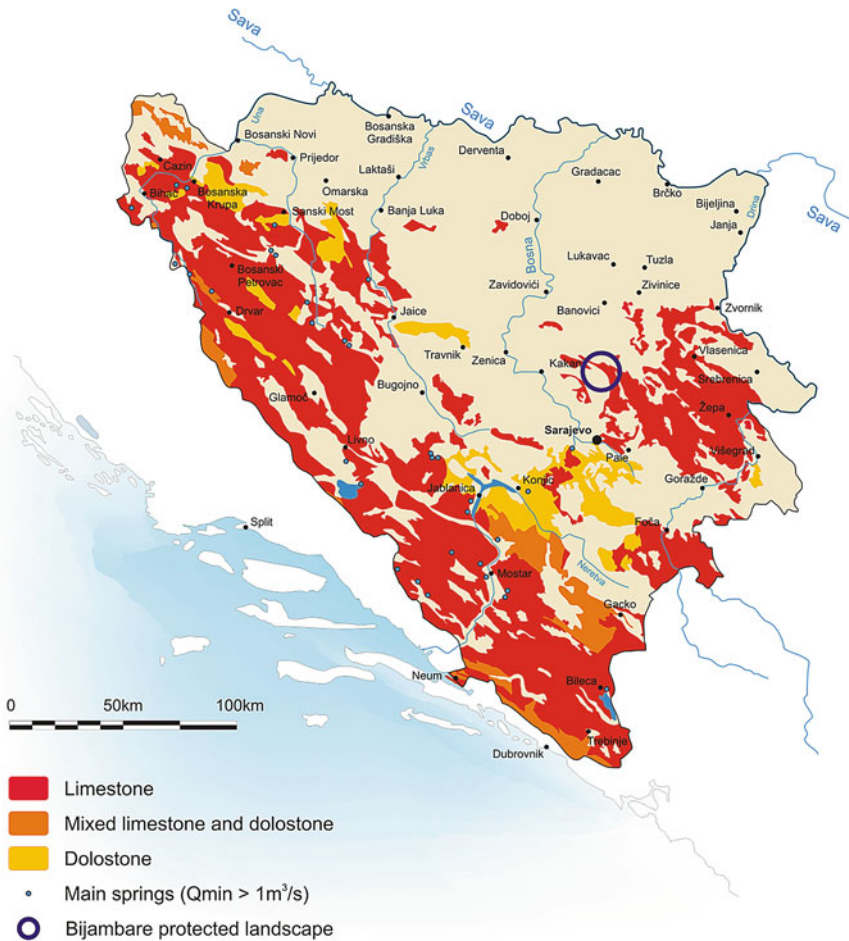


Fig. 2.1 Overview of main carbonate outcrops in Bosnia and Herzegovina. Redesigned and simplified from the 1:500,000 hydrogeological map of former Yugoslavia

outcrops of the large karst area North-East of Sarajevo (mainly centered on the Romanija massif).

In late 2003, around 367 ha of coniferous forest, marshes, pastures, including several caves, swallow holes, dolines and other karst features were declared protected (see Figs. 2.2 and 2.3). This early surface has been expanded in 2009 to 490 ha.

Bijambare is at present one of the three protected areas within Sarajevo region (Kanton Sarajevo) and, based on protection level and aims it is classified as fifth level of IUCN scale: protected landscape (Dudley 2008).



Fig. 2.2 View of Bijambare protected landscape area from Gornja Bijambarska pećina (Upper Bijambare cave)

2.1.2 Geology

Based on the 1:100,000 geological map (Vareš and Vlasenica sheets), the area is characterized by almost parallel geological structures with approximate direction NNW-SSE. Starting from the west, up to 2 km from Bijambare caves, the bedrock is composed by chert—carbonate rocks from Jurassic-Cretaceous age, extending over large part of Nišići highland. Towards the Bijambare protected area, Triassic rocks trusted over the Jurassic-Cretaceous and therefore, proceeding east, it can be found Triassic quartz sandstones with few outcrops of middle Trias (Ladinic) limestone. Further east, Bijambare caves develop close to the hidden passage between quartz sandstone and lower Triassic (Anisic) limestone. This carbonate rocks strip has an average width of 1–2 km and it is further confined to the east by Jurassic marlstones and calcarenites and by another occurrence of Triassic quartz sandstone. Along current path of Bijelila creek, recent quaternary fluvial material has been deposited. A general overview of the Bijambare area geological settings is given in Fig. 2.4.

The Bijambare caves are located close to the hidden passage between the impermeable quartz sandstone and the limestone along a fault that dictates the direction of the last tract of Bijelila valley and as well of the touristic cave.

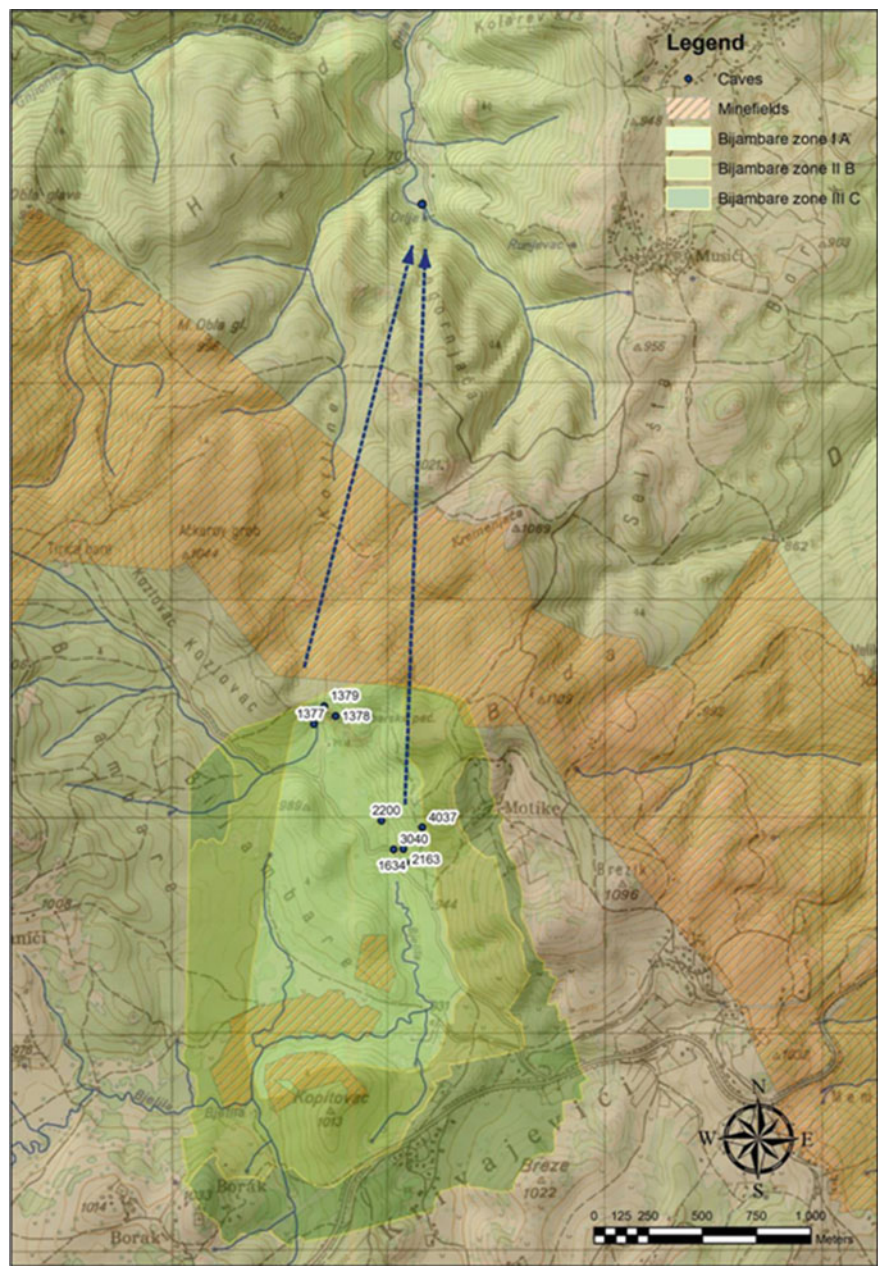


Fig. 2.3 The 2003 border of Bijambare protected area with internal zoning. Known caves are shown and labeled by their cadaster number. *Two dot lines* connect the main sinking streams to the Orlja spring

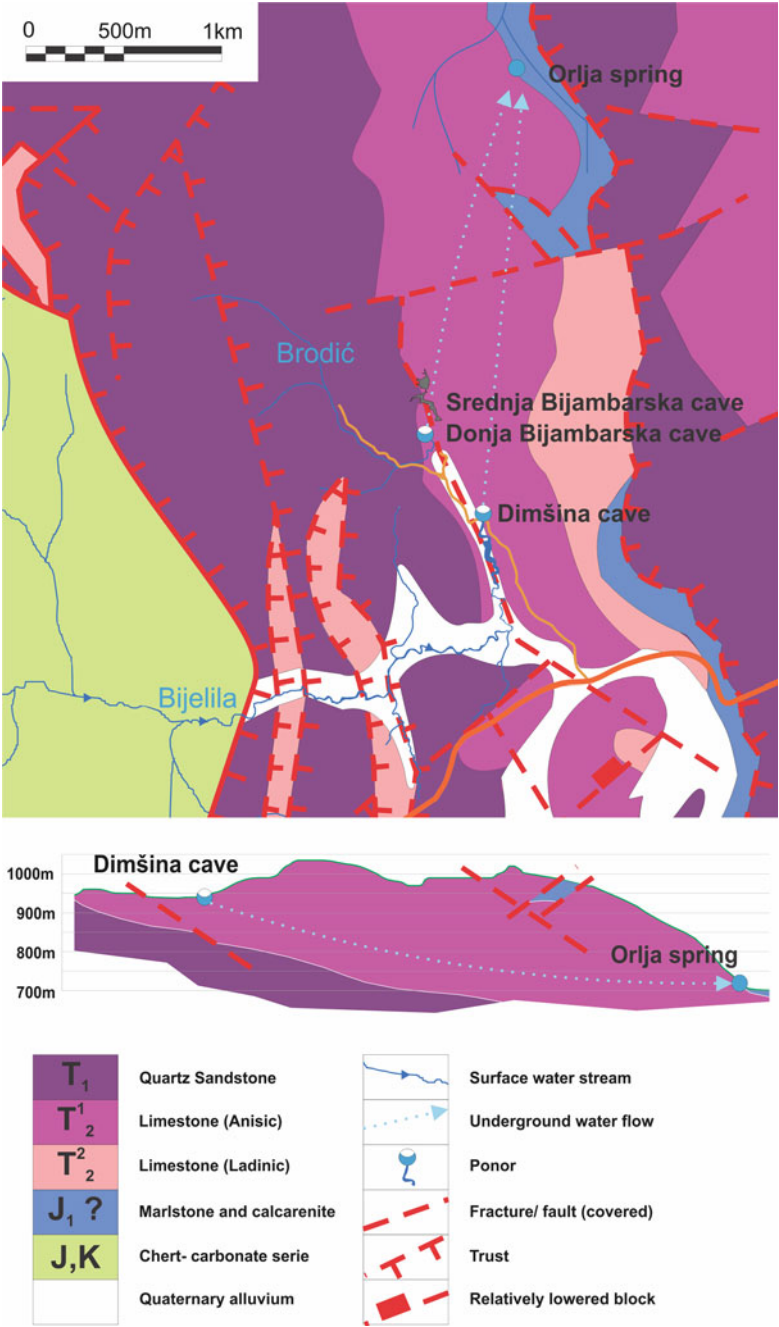


Fig. 2.4 Geological settings in the Bijambare region

Table 2.1 Analysis of a rock sample from Srednja Bijambarska pećina (Middle Bijambare cave).
Unpublished data

Element	Analysis result (%)
Humidity	0.09
Weight loss at 1100 °C	43.57
Calcium oxide (CaO)	52.74
Magnesium oxide (MgO)	1.63
Silicon dioxide (SiO ₂)	0.19
Phosphor oxide (P ₂ O ₅)	0.07
Iron (III) oxide (Fe ₂ O ₃)	0.15
Sulfates as SO ₃	0.09
Chlorides (Cl)	0.01
Total	98.54
CaCO ₃	94.40
MgCO ₃	3.40

An analysis of a rock samples from the Ledenjača cave shows a carbonate fraction over 99 %, where the remaining impurities were mainly clay (Milanolo et al. 2006). The same sample, under the microscope presented yellowish-reddish fractures probably due to the presence of iron.

Another rock sample taken from last chamber of the touristic cave was analyzed at HEIS laboratory in Sarajevo using standard gravimetric and volumetric methods. The results are presented in Table 2.1 (unpublished data).

Based on the geological map and rock analysis, it is evident that the main cave develops inside massive limestone with relatively low concentrations of magnesium and other impurities.

2.1.3 Hydrology

The hydrology of Bijambare area is dominated by two allogenic water streams: Bijelila and Brodić creeks, both originating from the adjacent area of impervious not carbonate rocks and sinking shortly after they reach a contact with limestone. Bijelila creek, whose watershed spans roughly 35 km² (COOR 2006) over the Nišići highlands, delivers the majority of the water contribution. Before sinking completely underground, it flows for around 500 m over carbonate rocks partially or completely covered by quaternary alluvial sediments and forming a temporary lake when the capacity of swallow hole is insufficient (e.g. heavy rain or snow melting periods).

A continuous record of water flow on this stream is not available and the only existing data (four measurements) report the range of flow rates between 26 and 191 L s⁻¹ (Đerković 1971; COOR 2006). In the tourist infrastructure reconstruction project report (COOR 2006), a correlation with the hydrological station on Stavnja

River (near Vareš) is presented (based on the three parallel measurements) and is used to estimate minimum and maximum flow of Bijelila creek.

The sinking area comprises several small ponors located over a wide area on the side of the temporary lake and a main sink connected with Dimšina cave. Furthermore, Ledenjača cave acts as ponor during extreme precipitation events.

Brodić creek with a catchment area of about 2.5 km² (COOR 2006) has approximately 10–15 times lower recharge than Bijelila creek. The three flow measurements range from 4 to 11 L s⁻¹.

The whole Brodić water stream sinks into Donja Bijambarska cave, located just below the touristic cave. Despite the lower water contribution, this sinking point is the largest (in the sense of portal dimensions) of the entire area, and in the past was equipped with a water mill just few meters before the cave entrance. Local people reported that during extreme precipitation events, water level may rise several meters flooding the entire cave. This is testified by several large wood pieces stacked to the cave roof and it points to a flow restriction in the underground channels.

Water sinking in the Bijambare protected area emerges at the surface at Orlja spring, around 2.5–3.0 km north and at 230 m lower elevation (Fig. 2.5). Connection has been verified by dye tracing Bijelila creek using 50 kg of natrium fluorescein. The tracer breakthrough time was 6 days, the peak concentration was recorded on the 7th day and maximal residence time of 20 days was detected (Đerković 1971). Fluorescein recovery was estimated to be around 81 %. Relatively long retention and dilution point to slow flow velocities, typical for small conduits and relatively large water storage volume. There are no data on other studies including autogenic water recharge from mountains and plateau located along the path from Bijambare to Orlja spring. During the tracing test Đerković (1971) reported a flow of Bijelila creek of around 30 L s⁻¹ and a flow at spring of 100 L s⁻¹.

It should also be mentioned that, at the Orlja location, two springs are actually present and located only few tens of meters apart. One spring drains the water from Bijambare. The relatively cold water comes out from a siphon inside a short (4–5 m) cave. The second is mild thermal water used in a nearby swimming pool and spa which are nowadays abandoned. In Đerković (1971) there are no indications to assess if this source of thermal water was monitored during the dye tracing test and consequently if there is a cross-contamination between these two water sources.

2.1.4 Climatic Characteristics

Based on the general climate division of Bosnia and Herzegovina (Federalni Hidrometeorološki Zavod 2011), the Bijambare area belongs to the pre-mountain—mild continental zone. However, considering the relatively high elevation (around 1000 m a.s.l.), strong mountain-alpine type influence can also be expected. Based on the isotherms and isohyets from the vulnerability mapping of the territory of



Fig. 2.5 Orlja spring

Federation of Bosnia and Herzegovina (HEIS and IPSA 2008), an average temperature between 6 and 7 °C, and a yearly average precipitation between 1125 and 1375 mm can be expected (see Fig. 2.6).

Other sources of data can be derived directly from meteorological stations in Sarajevo (about 25 km South at the elevation of 630 m) or from Sokolac (30 km South-East at the elevation of 900 m). The station at Nišići only 3 km away has not been active since several decades.

During the project for the reconstruction of Bijambare vacation complex, a short analysis of climatic conditions was conducted (COOR 2006). The work is based on extrapolation of recorded temperatures from Sokolac meteorological station during the period 1962–1971, resulting in an average temperature of 6.2 °C, which is in agreement with the range provided by Fig. 2.6. The historical precipitation data recorded at Nišići meteorological station during years from 1970 to 1973 show an average yearly precipitation at Bijambare of 917 mm, which is significantly lower than the range provided by Fig. 2.6 and even lower than Sarajevo: 932 mm (Federalni Hidrometeorološki Zavod, bez datuma).

Temperature at Bijambare has been measured since late 2006 as a part of this study and the results are discussed in Chap. 5. Regarding precipitation, daily data have been retrieved from Sarajevo meteorological station since 2006 and presented in Fig. 2.7a. During the 5 years of this study a general increasing trend from 961 mm during 2006 to 1088 mm during 2010 can be noticed. Although the



Fig. 2.6 Average temperatures (*white lines*) and precipitations in the Bijambare region. Elaborated from data included in HEIS and IPSA (2008) (color figure online)

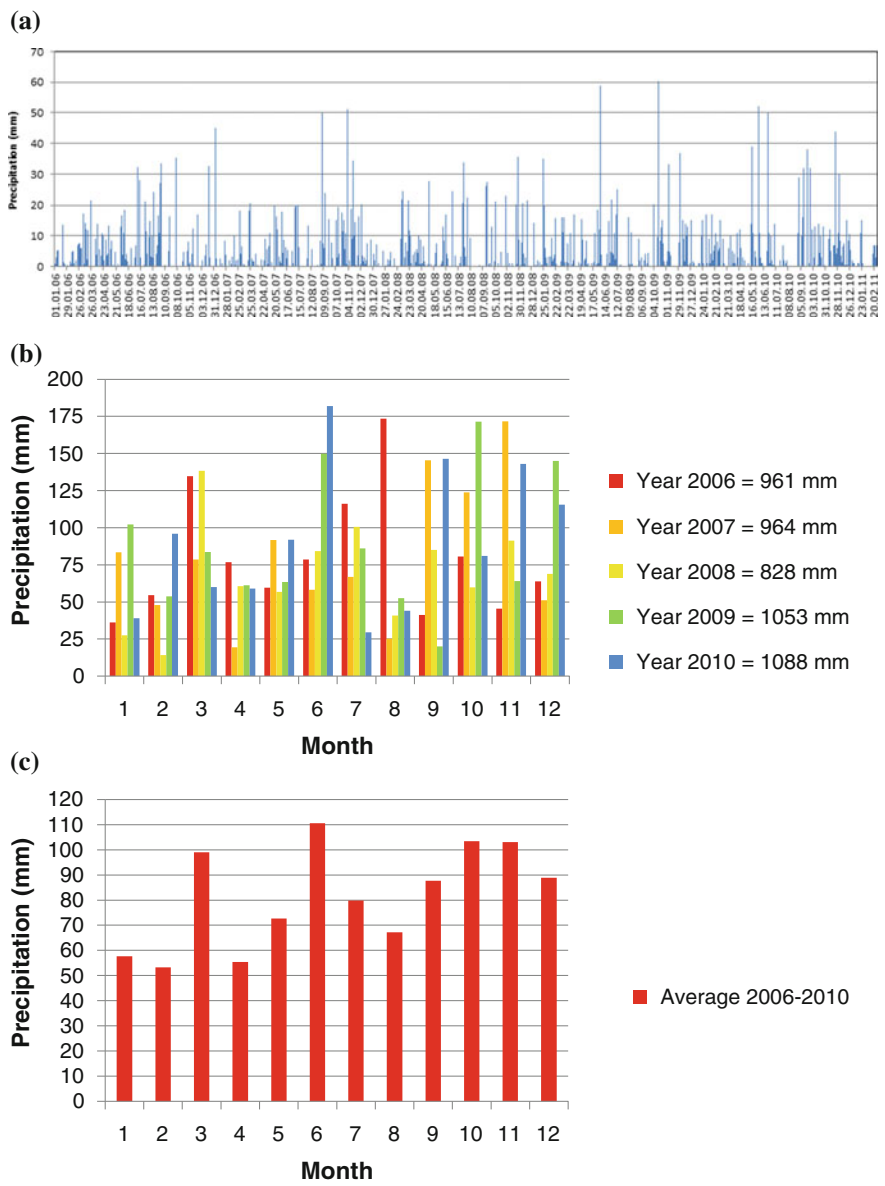


Fig. 2.7 a Daily precipitation at Sarajevo meteorological station for the period January 2006–February 2011; b Monthly precipitation for each single year; c Average monthly precipitation during the whole period

Bijambare reconstruction study (COOR 2006) estimated maximum amount of precipitation in July and minimum in December–January, at least from the period of this study data from the Sarajevo station cannot be fitted by any general seasonal

trend. From Fig. 2.7b it is evident how maximum precipitation occurred in August (2006), November (2007), March (2008), October (2009) and June (2010) while minimum precipitation occurred in: January (2006), April (2007), February (2008), September (2009) and July (2010). This does not exclude that a statistical analysis over a much longer period may show relevant seasonal trend. Average monthly precipitation values over the period 2006–2010 are presented in Fig. 2.7c.

Regardless of direct seasonality of precipitation, other phenomena, such as snow melting and evapotranspiration, surely introduce an important seasonal control on the water balance: the first, by accumulating water during the winter in the form of snow and then by releasing it during a relatively short period at spring while second by reducing the effective infiltration mainly during hot summer months.

2.2 Caves

2.2.1 *Speleological Explorations*

It is difficult to say when first speleological investigations of Bijambare caves commenced. The oldest signatures in the cave interior indicate the end of 19th century, when numerous foreign workers of Austro-Hungarian Monarchy came to Bosnia and Herzegovina and participated in exploitation of forest and mine resources, in construction of roads and railways. They are followed by members of first Bosnian and Herzegovinian hiking clubs, such as: “Prijatelji prirode” (Friends of nature), “Kosmos” (Cosmos) and HPD Bjelašnica, who left their signatures in Bijambare caves, as well as in many other caves in closer Sarajevo surroundings. Unfortunately, these first explorers did not leave any written documents, drawings or photographs.

The first popular texts about Bijambare area were written by famous Bosnian hikers Čurčić (1940) and Kumičić (1944) in the mountaineering periodical but during very unfortunate times—period of the World War II. The first more serious effort to evaluate the Bijambare area originates from the middle of 20th century, as part of the activities of the Republic Institute for Protection of Cultural Monuments and Natural Rarities of Bosnia and Herzegovina, especially in works of Rzehak (1958), Baucic and Rzehak (1959).

Within scientific circles, the Bijambare caves were of interest from the earliest 20th century. The coleopteran *Anthroherpon stenocephalum* from Srednja Bijambarska cave (Fig. 2.8a) was already described in the European scientific literature in 1901 (Apfelbeck 1901). Unfortunately, speleo-biological research almost ended there. Much later, continuing with the planned concept of expert evaluation of this area, Mirko Malez carried out significant pioneering speleological explorations of Gornja, Donja and Srednja caves, with excavations aimed at paleontological and archeological investigations (Malez 1968).

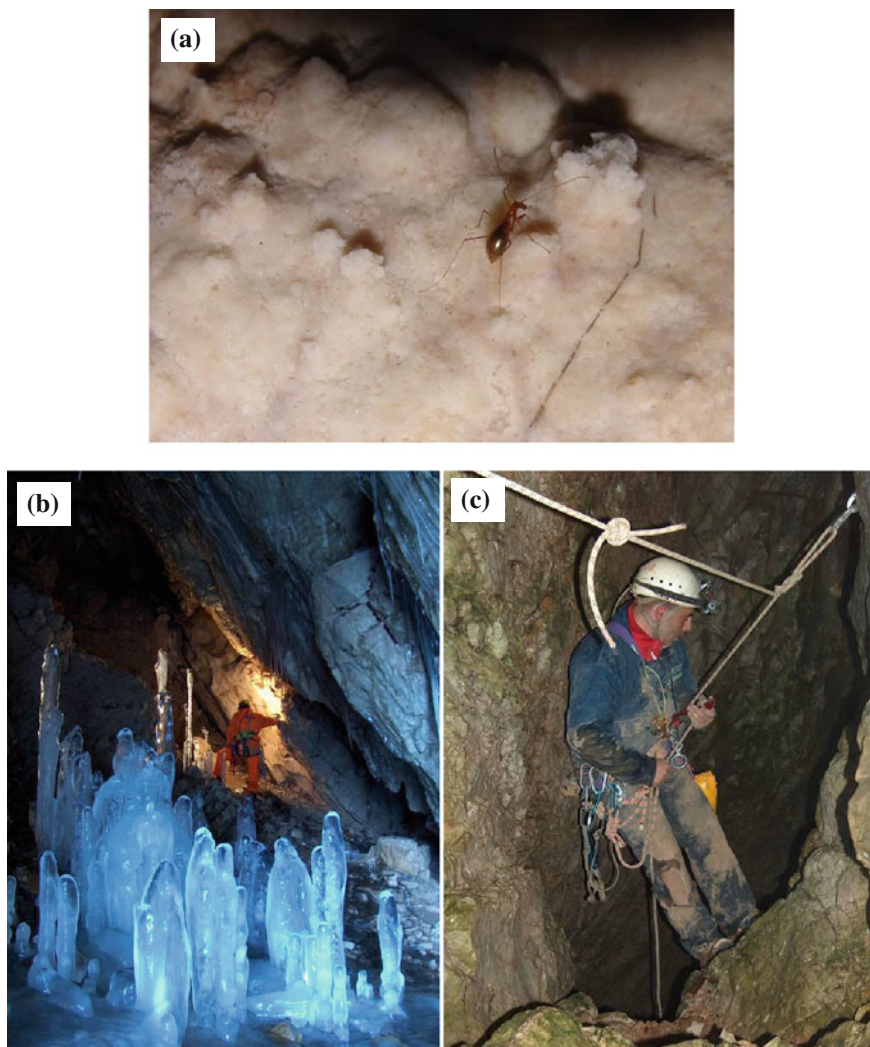


Fig. 2.8 **a** *Anthroherpon stenocephalum*; **b** Ice stalagmites in Donja Bijambarska cave; **c** Explorations in Dimšina cave

In the examined area, six caves were known and recorded before 2006 into the speleological cadaster (Mulaomerović et al. 2006). However, information for the Gornja and Srednja caves only were published in the scientific literature (mainly in the work of Malez 1968), while for all the other objects just the name and a few basic data were recorded.

In order to define an inventory of speleological objects in the area and to create valuable documentation for their protection and touristic evaluation, systematic

Table 2.2 Known speleological objects in the Bijambare protected area

Name	Cadaster N.	Length (m)	Depth (m)	Coordinates G.K.	Elevation (m)
Srednja (Glavna) Bijambarska ^a	1379	533	−24	6540707 E 4883506 N	959
Ledenjača	2200	323	−51	6540971 E 4882977 N	935
Donja Bijambarska	1377	148	+6/−11	6540660 E 4883422 N	930
Đuricina	1634 ^b	142	−28	6541072 E 4882846 N	950
Gornja Bijambarska	1378	112	+10	6540759 E 4883460 N	980
Dimšina	3040 ^c	108	−30	6541028 E 4882845 N	935
Ledenica	2163	41	−18	6541083 E 4882784 N	940
Nova pećina	4037	28	−12	6541160 E 4882947 N	980

^aShow cave^bThis cave is registered two times in cadaster: number 1554 with the name Djuricina pećina^cInserted in cadaster as “Ponori Bijelila”

explorations have been carried out within the reconstruction project (Milanolo and Mulaomerović 2007, 2008).

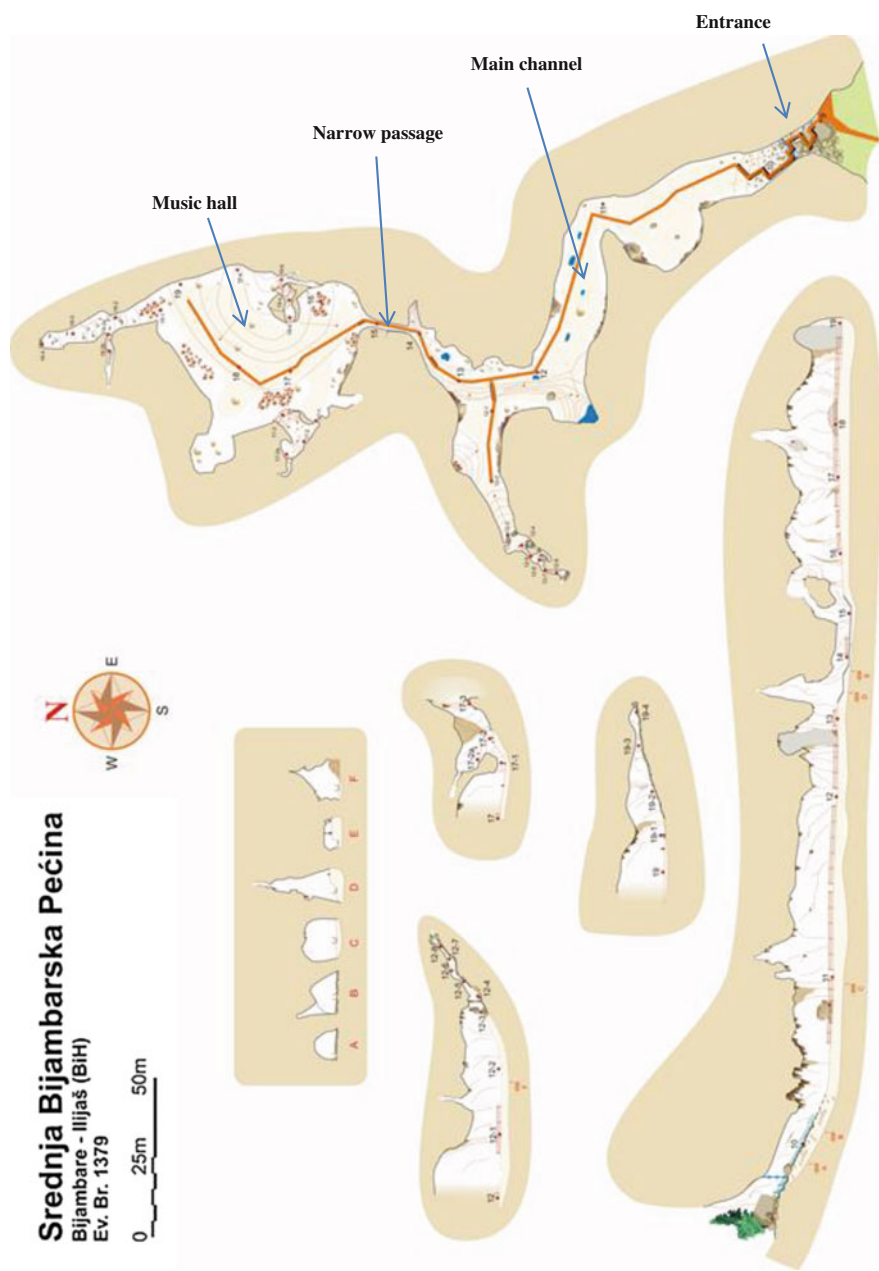
Eight caves (see also Fig. 2.8b, c) have been identified; one of which was completely new to the literature. Basic data are summarized in Table 2.2.

2.2.2 *Srednja Bijambarska Pećina*

This cave is the longest speleological object in the area (533 m including branches) and it is currently used as show cave. A concrete path and illumination is provided along the majority of its length. Although it has been carefully explored in the past, the available survey (Malez 1968) covered only the main channel, without many details of the small lateral conduits. It should be noticed that, based on original protected area borders (as defined in 2003), more than half of the cave was outside the protected area borders, and thus its protection was not fully guaranteed. This situation has been fixed by extending protected area borders in 2009.

Srednja Bijambarska is morphologically simple (Fig. 2.9) and, based on previous published descriptions (Baucic and Rzehak 1959; Malez 1968), it comprises 5 sections: the entrance part and four connected halls.

In fact, the first three halls are part of a unique channel which extends to the north-west until it merges with another conduit entering from West. A narrow passage, which was partially enlarged by removing the floor sediments during the construction of the first tourist pathway, divides the main channel from the last chamber. This part (4th hall), due to its acoustics is named “Mužička Dvorana”



(Music Hall) and it was probably developed at the junction of several smaller channels (most of them with circular section) that are still partially visible as relicts on the hall ceiling.

The halls range in length from 30 to 80 m, and in width from 18 to 30 m. The height of the halls can reach over 12 m in the “Music Hall”. The whole cave is covered by a thick layer of fine cave sediment, over which different cave decorations, gour, stalagmites and calcite film have deposited.

Three lateral conduits should be mentioned:

- The first one, partially used for tourist visits, stretches to West before the narrow passage leading to the “Music Hall”. Its last part is characterized by small passages within rock blocks and it almost reaches the surface under a valley visible on the topographic map. Unfortunately, the surface above the cave is not accessible due to the presence of minefields. However, it is probable that this part of the cave acts as a temporary swallow hall during high precipitation events. During one visit in a heavy rainy period this channel contained a small water stream.
- The second lateral conduit is the natural continuation of the cave after the “Music Hall”. It ends in a breakdown and it probably reaches a point very close to the surface on the other side of the mountain. This idea is supported by the presence of troglophiles insects typical of cave entrances. Since this channel is at higher elevation than the hall floor it is also the warmer place inside the cave with a temperature approaching 6–7 °C.
- The third conduit is a series of relict passages stretching above the “Music Hall”. The exploration of the area is still not complete but access is possible with climbing aids.

The cave is oriented along a fault, which is probably the main structural element guiding the cave genesis. The cave is a relict ponor which drained the wider Bijambare area in the past.

Morphologies due to turbulent water erosion-corrosion like scallops are completely hidden under the calcite deposition and traces are visible only on the walls before the narrow passage leading to the “Music Hall”. The orientation of the scallops indicates the direction of paleoflow towards the Music Hall.

Recently, the cave has no active streams. Allogenic waters sink into Donja cave about 30 m lower. Drip water drains in two depressions: one in the main channel (occasionally it becomes ponded) and the second in a narrow passage connecting the Music Hall with the main channel. Near this last sinking point there is a small (but permanent) water source located between rock wall and cave sediments.

Large halls, numerous dripstone decorations, immediate surroundings as well as good position on the road Sarajevo-Tuzla were the main motives for the Srednja Bijambarska Cave to be promoted as a tourist amenity. The works started at the end of 1960s and with interruptions they continue to this day with variable levels of intensity and quality.

References

- Apfelbeck V (1901) Drei neue Höhlenkäfer aus Bosnien. Verhandlungen der k. k. zoologisch-botanischen Gesellschaft LI:14–16
- Baucic I, Rzehak V (1959) Bijambarska pecina. Nase Starine Godisnjak Zemaljskog muzeja za zastitu spomenika kulture i prirodnih rijetkosti Narodne Republike Bosne i Hercegovine 6:219–230
- Čičić S (1998) Carbonate facies in geological constitution of the terrain of Bosnia and Herzegovina. Naš Krš 31:3–37
- COOR (2006) Hidrološke karakteristike prostora zaštićenog pejzaža Bijambara. Sarajevo, p 23
- Čurčić V (1940) Pećine u okolini Sarajeva. Hrvatski planinar 8–9:246–253
- Đerković BM (1971) Geološki i hidrogeološki odnosi područja srednje Bosne. Geološkog Glasnika, p 10
- Dudley N (ed) (2008) Guidelines for applying protected area management categories. IUCN, Gland
- Federalni Hidrometeorološki Zavod (2011) Klimatologija (Online). Available at <http://www.fhmbih.gov.ba/latinica/klima.php>. Accessed 21 July 2011
- HEIS and IPSA (2008) Vulnerability study for FBiH, Sarajevo
- Kumičić E (1944) Krivajevičke špilje. Hrvatski planinar 4:67–70
- Malez M (1968) Bijambarske pecine kod Olova u srednjoj Bosni. Glasnik Zemaljskog muzeja Bosne i Hercegovine u Sarajevu, Prirodne nauke, Nova serija 7:154–191
- Milanolo S, Mulaomerović J (2007) Current status of speleological researches in the Bijambare. CESD/COOR, Sarajevo
- Milanolo S, Mulaomerović J (2008) Speleološka istraživanja na području zaštićenog pejzaža Bijambare. Naš Krš 40(41):3–24
- Milanolo S, Cella GD, Burek R (2006) Ledenjača. Labirinti 25:16–25
- Mulaomerović J, Zahirović D, Handžić E (2006) Katastar speleoloških objekata Bosne i Hercegovine. Speleološko društvo “Speleo dodo”, Sarajevo
- Rzehak V (1958) Manje poznate prirodne rijetkosti u Bosni i Hercegovini i potreba njihove zastite. Nase starine 5:105–123

Sources and Transport of Inorganic Carbon in the
Unsaturated Zone of Karst

Milanolo, S.

2016, XIV, 157 p. 61 illus., 26 illus. in color., Hardcover

ISBN: 978-3-319-29307-3