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Contribution to the Genesis of Thermal Water of the North-east Perimeter of the Zenica-Sarajevo Basin, Bosnia and Herzegovina

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Abstract

The phenomena of thermal waters in the north-eastern periphery of the Zenica-Sarajevo Basin are caused by the geological structure, structural-tectonic and hydrogeological characteristics of the terrain. The genesis has not been fully addressed before. This paper presents the study of the genesis of thermal waters based on the geological structure, structural-tectonic and hydrogeological characteristics of the terrain, and the physiochemical and isotopic composition of water. The results provide a new contribution to the structure of this part of the Zenica-Sarajevo Basin and create a more realistic foundation for the future research of thermal water in this area.

Keywords

Zenica-Sarajevo Basin, thermal waters, genesis, hydrogeochemistry

1. Introduction

The thermal water springs of the north-eastern perimeter of the Zenica-Sarajevo Basin (*Sidica, Tičići, Ribnica, Kraljeva Sutjeska, Toplik* and *Sedra*) appear to be approximately linear from Zenica in the northwest, through Kakanj and Visoko, to Breza in the southeast (see **Figure 1**).

The genesis of thermal water of the north-east perimeter of the Zenica-Sarajevo Basin was not sufficiently perceived and understood in the past. A small number of authors from the region studied this topic. Remarkable results were published by **Josipović (1971), Đerković (1971), Miošić (1981), Miošić (1982), Slišković (1987), Skopljak, (2006)** and **Skopljak & Vlahović (2011)**.

In his *Mineral, Thermal, and Thermo-mineral Waters on the territory of Bosnia and Herzegovina,* Josipović (1971) states that thermal water in the area of Kakanj is mildly hypothermic, with a temperature of 24-32°C, a normal pH value, and a mineralization value of 0.5-1.5 g/l, and it contains dissolved hydrocarbon, sulfate, calcium, and rarely magnesium and sodium ions. Josipović stated that the phenomenon of thermal waters in Kraljeva Sutjeska is outside the Sarajevo-Zenica tertiary Basin, located on its north-eastern edge (**Josipović, 1971**). While describing the thermal water in the vicinity of Kakanj, he states the following: “Thermo-mineral waters occur on the perimeter of the basin (Ribnica, Radići and Tičići) on the border of Oligo-Miocene sediments and limestones of the Upper Cretaceous. These waters are likely of primary accumulation origins. Thermal water in Ribnica is low in mineralization as a result of interference of river water and thermal mineral water in the area right next to the source” (**Josipović, 1971**). The sedimentary origin of these waters casts a shadow of a doubt on the similarities between ion interaction with the thermal waters in the area of the Kraljeva Sutjeska, and, to some extent, with thermal mineral waters of Ilidza, near Sarajevo. Josipović does not exclude the possibility that these spring waters are of similar origin.

In his paper on the *Results of Previous Studies on Mineral, Thermal, and Thermo-Mineral Waters of Central Bosnia*, **Đerković (1971)** provides a description of thermal waters at Sedra in Breza, Ribnica, Tičići and Kraljeva Sutjeska near Kakanj. Regarding the genesis, **Đerković (1971)** stated that thermal water is generated by the infiltration of atmospheric water that sinks, is heated and then re-emerges on the surface. For thermal water at Ribnica, he believes that the water re-emerges at the north-south fault, from the limestone and coarse-grained brecciated limestone and sandstone.

In his work on *Genetic Categorization of Mineral, Thermal and Thermo-Mineral Waters of Bosnia and Herzegovina*, **Miošić (1982)** incorporates thermal waters of the north-east perimeter of the Zenica-Sarajevo Basin into a hydrogeological structure of the “artesian basin and inter-mountain depressions”, describing the zone of the Sarajevo-Zenica depression. Regarding the

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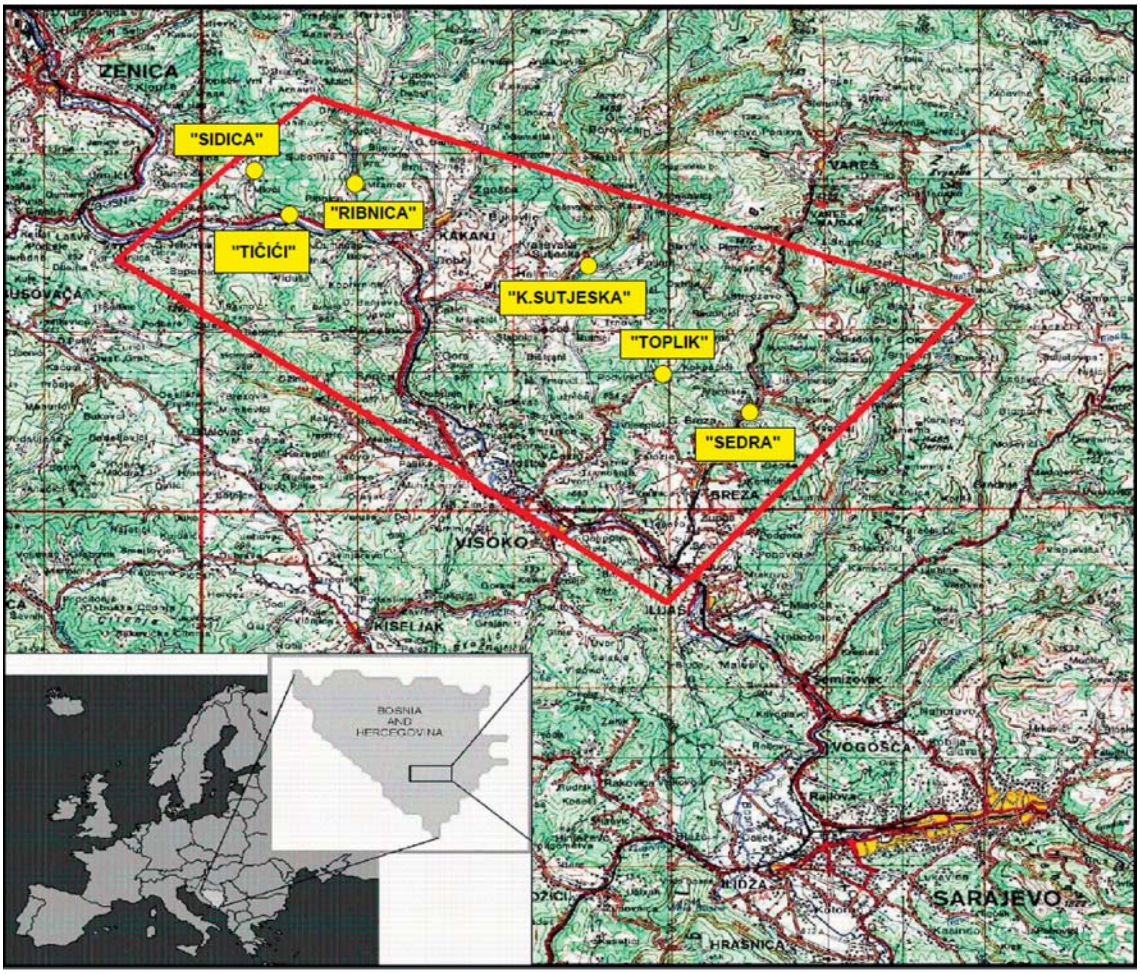


Figure 1: Study area of thermal water springs of the north-east periphery of Zenica-Sarajevo Basin

genesis of thermal waters in this area, **Miošić (1982)** states the following: "The primary gas composition at Ribnica, Kraljeva Sutjeska and Sedra is changed by the infiltrating atmospheric gases, as is shown by the changes in gas composition. While Radići and Tičići have a significant content of CO_2, Sedra and Kraljeva Sutjeska have a 10 times smaller amount of gases. The deposition of ferrous compounds and traventine in Sedra and Kraljeva Sutjeska implies the reducing conditions that prevail in the primary reservoir. According to **Josipović (1971)**, the silicified cavities in limestone confirm the assumption of intense hydrothermal processes in the Tertiary, which indicate that the "thermal waters are partly the remains of those events in Kraljeva Sutjeska (**Miošić, 1982**). Miošić also claims that the water is predominantly of atmospheric origin and that their current accumulation does not originate from hydrthermal conditions. Fault tectonics cause the ascension of water that is being heated by fast convection of the primary aquifer that is in the deeper horizons (**Miošić, 1982**).

In his paper on the *Hydrogeological and Hydrothermal Characteristics of Thermo-mineral Waters at Ribnica and Tičići near Kakanj*, **Slišković (1987)** claims the following: "The accumulation of thermal water in Ribnica and Tičići near Kakanj is formed in the floor of Oligo-Miocene sediments and Jurassic-Cretaceous flysch at the depth of 1500-2500 m below the ground surface in carbonate environments. Hot water circulates to the surface of the terrain though young (neotectonic) faults, to a depth of about 400-600 m where it mixes with the descendent underground streams of cold water until they erupt at the earth's surface along the faults." The upward movement of thermal mineral water ends in Upper-Cretaceous, partly brecciated and flysch-like limestones (calcarenites), that represent the primary and secondary groundwater aquifer. The primary aquifer is in the southern zone under the thick layers of the Oligo-Miocene Sarajevo-Zenica Basin. The secondary aquifer is on the northern edge of the pool towards the Jurassic-Cretaceous flysch. The entire Oligo-Miocene and Miocene sediments represent an overburden insulator for the thermal waters which are formed in the Cretaceous limestones. Based on the geological and hydrogeological developed model, he concludes the possibility of the formation of the primary aquifer thermal waters even in the Anisian T_2^1 limestones, which are located in the area of Kakanj, most probably at depths of 1500 to 2500 m ".

Skopljak, (2006) in the work "Groundwater interrelations of Ilidza near Sarajevo" and **Skopljak & Vla-**

hovic (2011) in the work *"The origin of mineral waters and Kiseljak near Sarajevo, Bosnia and Herzegovina,"* show that mineral water southwest periphery of the Zenica-Sarajevo Basin primarily have the genesis of evaporites permian sediments.

Based on earlier studies of the genesis of thermal waters of the north-east perimeter of the Zenica-Sarajevo Basin, it can be concluded that the inquiry of the genesis of thermal water in this area had not been fully resolved, and that the answers should continue to be searched for through hydrogeological and hydrochemical investigations and trials.

The aim of this paper is to give a contribution to understanding the genesis of thermal waters north-east periphery of the Zenica-Sarajevo Basin on the basis of geological, structural-tectonic and hydrogeological characteristics of the terrain, and hydrogeochemical research conducted in the wider area.

To solve hydrogeological unknowns, hydrogeochemical methods were used, which included defining the hydrochemical type of water, the correlation of the main components in the water, genetic classification calculation of ion relations and mixing diagrams. As a complement to the knowledge obtained, hydrogeochemical methods in determining the genesis of thermal water was used as well as isotopic composition of thermal water at the site Tičići based on correlation isotope δ18O and δ2H (**Craig, 1961**).

2. Study area

Thermal waters of the north-eastern perimeter of the Zenica-Sarajevo Basin spring in the extreme south-western slopes of the Ravan and Zvijezda mountains, in the area that gradually transforms into the valley of the Zenica-Sarajevo Basin and the valley of Bosnia. This terrain is characterized by large differences in altitudes, from approximately 450 m a.s.l. in the valley of Bosnia to 1300 m a.s.l. at the mountain peaks.

The largest and most important waterways in the north-eastern periphery of the Zenica-Sarajevo Basin are: the rivers Bosnia, Stavnja, Goruša, Trstionica, Zgošća and Ribnica. The area located on the north-eastern perimeter of the Zenica-Sarajevo Basin is characterized by a moderate continental climate. The average annual precipitation is about 975 l/m^2 and the average annual temperature is 11.2°C. Thermal water springs (*Sidica, Tičići, Ribnica, Kraljeva Sutjeska, Toplik* i *Sedra* (see **Table 1**) have been located in the north-eastern periphery of the Zenica-Sarajevo Basin.

Table 1: Thermal waters of the north-eastern periphery of the Zenica-Sarajevo Basin (Federal Institute for Geology of Bosnia and Herzegovina, 2010)

ID	Source	Location	Q_{min} (l/s)	Miner. (mg/l)	T_{water} (°C)	Municipality
1.	**Sidica**	X=4890830 Y=6502737 Z=575	0.2	438.85	17	Zenica
2.	**Tičići**	X=4888013 Y=6504245 Z=383	3.5	927	26	Kakanj
3.	**Ribnica**	X=4889708 Y=6506352 Z=390	10-30	800	29	Kakanj
4.	**Kraljeva Sutjeska**	X=4885550 Y=6516575 Z=485	50	691.66	21	Kakanj
5.	**Toplik**	X=4879775 Y=6520125 Z=565	1.5	550.81	13.5	Visoko
6.	**Sedra**	X=4877337 Y=6522837 Z=530	-	1121	20	Breza

Geological setting

Thermal waters are located in the north-eastern periphery of the Zenica-Sarajevo Basin. According to the geotectonic zoning by **Hrvatović (2006)**, three distinct tectonic zones can be identified: **1) Non-native Paleozoic and Triassic formations** (Mid-Bosnian Schist Mountains) built mainly of Paleozoic formations; **2) Bosnian flysch** which represents the clastic-carbonate formation of Jurassic-Cretaceous and Upper Cretaceous flysch deposits and **3) Post-orogenic Neogene and Quaternary sediments** with limnic deposits and Zenica-Sarajevo Basin coal (see **Figure 2**).

Šarić (2015) shows the position of the thermal water sources in relation to the tectonic units that are closely related to the terms of their appearance, or genesis (see **Figure 3**).

Geological Structure

The geological structure of the field of research to the basic geological map (Pamic, et al 1978) participate rocks Paleozoic, Mesozoic and Cenozoic (see **Figure 4**). Paleozoic rocks are made of Silurian-Devonian (S, D and Upper Permian (P_3) metamorphites. Silurian-Devonian deposits are represented by quartz-sericite schists. Upper Permian deposits are represented by conglomerates, sandstones, shales, and most likely, as in other parts of the Mid-Bosnian Schist Mountains, marly limestone with layers and lenses of gypsum. Deposits of Upper Permian lay transgressively through the Silurian-Devonian formations. The thickness of the gypsum layer is in the range between 30-40 m.

Mesozoic sediments are mainly represented by the sediments of Jurassic-Cretaceous and upper Cretaceous flysch and Triassic limestones (**Hajdarević, 2012**). Middle Triassic sediments are found in the south-western rim of the basin. These sediments are about 200 m thick massive dolomites, dolomitic limestones, limestone

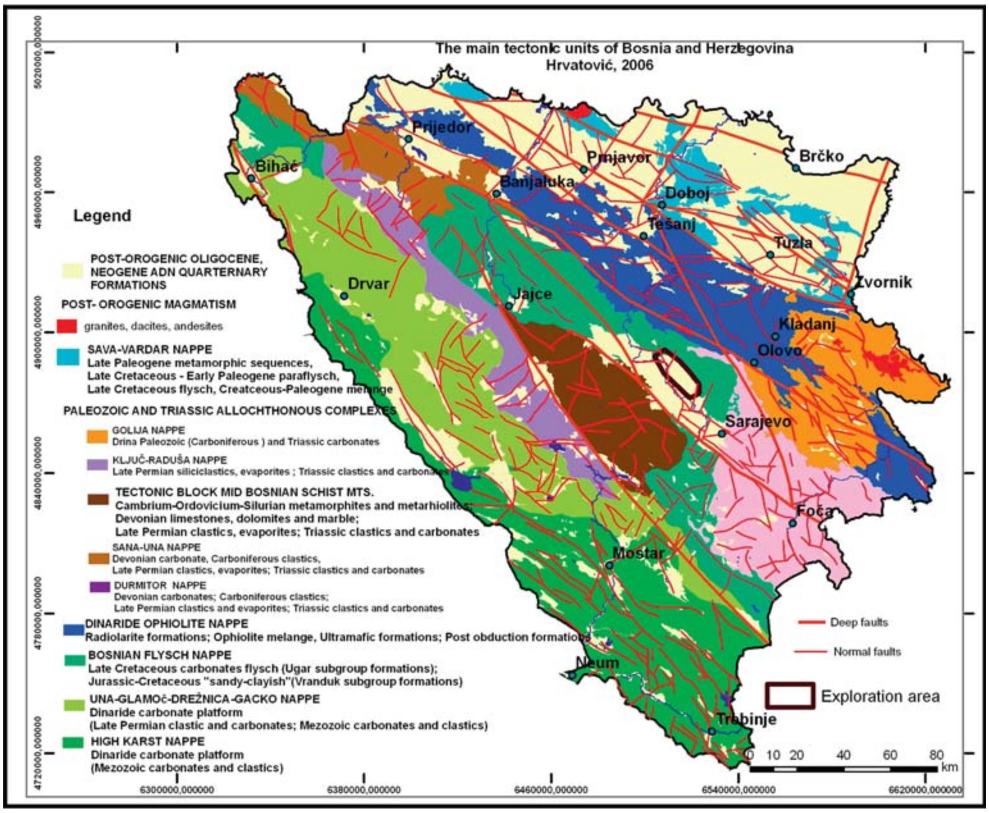


Figure 2: The main tectonic units of Bosnia and Herzegovina (**Hrvatović, 2006**)

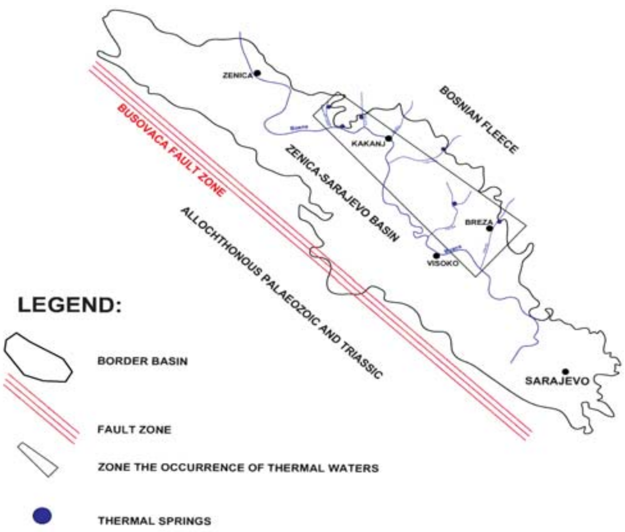
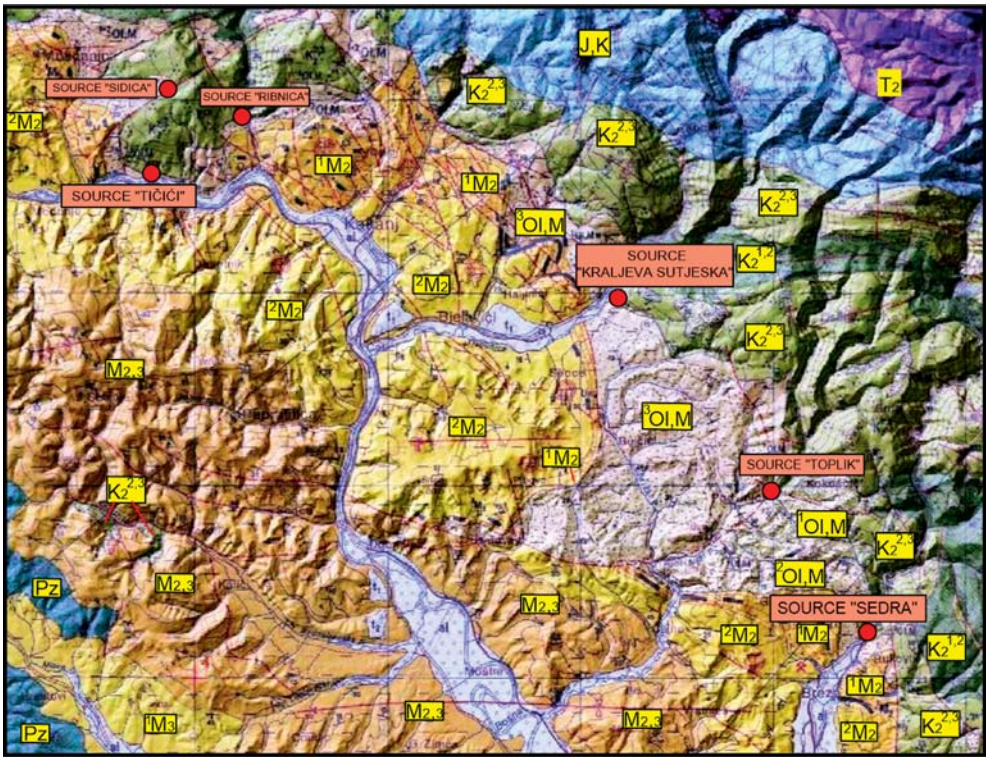


Figure 3: Geotectonic setting of the thermal water springs Sc, 1:100 000 (**Šarić, 2015**)

breccias and massive limestones in the basement of the Miocene series. Jurassic-Cretaceous flysch represents a large part of the flysch complex built of marls, sandstones and shales, and some breccia limestones. The total thickness of this stratigraphic zone is about 600 m. The sediments of the Upper Cretaceous consist of Cenomanian-Turonian ($K_2^{1,2}$) and Turonian-Senonian ($K_2^{2,3}$) flysch made of limestone breccias, limestones, sandy limestones, clays and sand pit cherts, varied limestones such as calcarenites, arenites, calcrudites and marl micrites lying transgressively over the Jurassic-Cretaceous flysch. The thickness of the Upper Cretaceous flysch is about 1,000 m (**Mikes et al. 2008**).

The Cenozoic sediments are represented by Oligo-Miocene, Miocene, and Quaternary deposits (**Andric et.al, 2015**). Within the Oligo-Miocene polyfacies complex (Ol, M), there are three distinct units: 1) the basal zone, 2) the travertine limestone zone, 3) and the colored zone. The total thickness of this complex is about 600-700 m. The sediments of the basal zone are represented by sandstones, conglomerates, and ferreous oolitic limestones, marls and clays. Travertine limestones are lumpy and oolitic, and are conglomeratic or brecciated at the base. The sediments of the colorful zone are mainly composed of conglomerates that alternate with sandstones, marls and clays.

Miocene sediments are lacustrine sediments of the Lower-Middle ($M_{1,2}$), Intermediate (M_2) and Middle-Upper Miocene ($M_{2,3}$). The sediments of the Lower-Middle Miocene are represented by the main coal zone consisting of marls, sandstones, conglomerates and clays with major and an Orascom carbon layer. The thickness of this zone is about 150 m. The sediments of the Middle Miocene are represented by roof coal limestone zone with roof coal seams (${}^1M_2$), with a total thickness of about 70 m, and the transition zone (${}^2M_2$) with thinly layered marls and sandstones with a thickness of 350-450 m (**Muftić,1965**). Middle-Late Miocene ($M_{2,3}$)



Legend: **Pz** - quartz sericite shale; **T2** - massive dolomites, dolomitic limestones, limestone breccias and massive limestones; **J,K** - flysch: marl, sandstone and shale; $\mathbf{K_2^{1,2}}$ **-** $\mathbf{K_2^{2,3}}$ - flysch: limestone breccias, limestones, sandy limestones, calcarenites, arenites, calcrudites and marl; **Ol, M** - basal area, travertine limestone and colored zones; $\mathbf{M_{1,2}}$ - main coal zones - marl, sandstone, conglomerates and clay with major and Orascom carbon layer; $\mathbf{M_2}$ - limestone roof seam zone with roof coal seams; $\mathbf{^2M_2}$ - thinly layered sandstones; $\mathbf{M_{2,3}}$ - Lasva series: conglomerate, sandstone and limestone subordinate; **al** - alluvium

Figure 4: Geological map of the area showing the thermal water springs Sc, 1:100 000 (**Šarić, 2015**)

is represented the Lasva series of conglomerates, sandstones, marls and rarely limestones. The total thickness is about 400 to 800 m (**Milojević, 1964**).

Quaternary formations have a greater distribution in the valley of the river Bosnia, and at the mouths of its tributaries. In this region, Quaternary is represented by alluvium (al) composed of gravel of various degrees of grit, with frequent sands and clays.

Tectonics

The tectonics of the terrain were analyzed by using the structural forms downloaded from the available Basic geological map sheet Vares (**Pamic et al 1978**) and **Hrvatović (2006)** paper on the geotectonic zoning. Two main nappes dominate this area: 1) the Bosnian flysch Nappe and 2) the Durmitor Nappe.

The Bosnian flysch Nappe consists mainly of flysch formations deposited from Liassic to the Paleogene. This nappe is largely thrusted on the Raduški Nappe and the tectonic block of the Mid-Bosnian Schist Mountains. In the thermal water zone, the Bosnian flysch Nappe is made of Jurassic-Cretaceous and Upper Cretaceous flysch sediments, drawn on the Triassic and Paleozoic sediments. The Durmitor Nappe is made of predominantly Triassic carbonate rocks and Paleozoic formations of south-eastern Bosnia. It covers a wide area of Vares in the north-west to Foca and Cajnice in the south-east. The Durmitor Nappe is largely thrusted on the Bosnian flysch Nappe. In Vares, the Ophiolite Nappe is thrusted over the Durmitor Nappe, while in the south-east, in the area of Romanija and Devetak, the Golijska Nappe is partially thrusted over the Durmitor Nappe.

On the geological cross-section (**Hrvatović, 2006**) between Sarajevo and Vares, a thick Bosnian flysch Nappe is thrusted over the non-native Palaeozoic-Triassic formation in the south-west (see **Figure 5**). In the north-east, the Triassic formations are thrusted on top of the Bosnian flysch at the forefront of the Durmitor Nappe. The basement of the Bosnian flysch is most likely composed of Triassic sediments, while limnic deposits with coal were deposited over flysch in the Zenica-Sarajevo Basin.

According to **Kamberović (2009)**, there are a few types of faults in the study area: deep faults (Busovačka

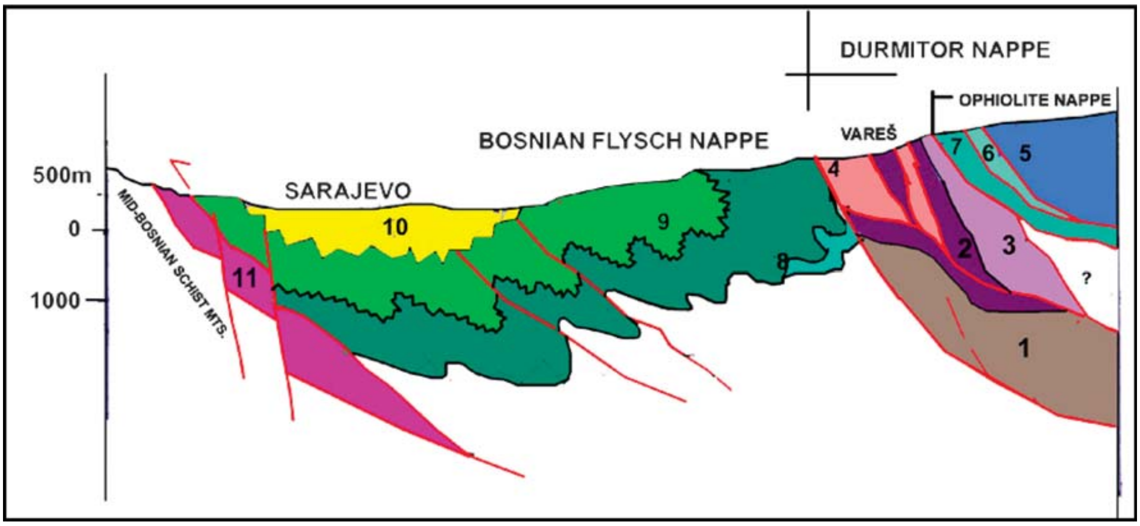


Figure 5: Sarajevo-Vares geological cross-section (Hrvatović, 2006) Legend: 1 - Eastern Bosnia Paleozoic; 2 – Silica-clastic sediments of the Lower Triassic, 3 - Anisian limestone, 4 - Ladinian cherts, breccias, tuffs and limestone; 5 - ophiolitic mélange; 6 - "Wild" flysch; 7 - Bosnian flysch Base; 8 - J,K - para flysch; 9 - Upper Cretaceous and Paleogene flysch; 10 - Sediments of the Sarajevo - Zenica Basin, 11 - Triassic formations (**Hrvatović, 2006**).

faulted zone), diagonal faults (along the river Lašva and Bosnia to Kakanj, along the Papratnice River to the river Bosnia, faults (Dobrinja-Podvinjci, Ćatići-Kraljeva Sutjeska), and transverse faults (Moscanica-Modrinje, Kakanj-Visoko, Haljinići-Luznica, Arnautovići-Cajno and along the Stavnja River). These faults have had a major role in the occurrence of thermal waters in the north-eastern periphery of the Zenica-Sarajevo Basin.

3. Hydrogeological setting

The area of research and thermal water became part of hydrogeological field "Bosnian flysch" and periphery hydrogeological field "Post-orogene neogene formacije" or periphery Zenica-Sarajevo Basin (**Skopljak et al 2011**). In the thermal waters zone of the north-east perimeter of the Zenica-Sarajevo Basin, there are two basic hydrogeological rock characteristics:

- Permeable rocks
- Impermeable rocks

Permeable Rocks

- permeable rocks with intergranular porosity
- permeable rocks with intergranular and/or fracture porosity
- permeable rocks with fracture porosity
- permeable rocks with cavernous-fracture porosity.

Permeable rocks with intergranular porosity are alluvial and terraced layers (al, t_1, t_2). Hydrogeological parameters, on average, have the following values: T = 15-50 m^2/day; q = 0.1-0.3 l/s/m and Q max = 0.5-2.0 l/s (**Geological Survey of Sarajevo, 1988**). Drinking water aquifers were formed in these layers in the expanded river valleys. The underground water reserves in these aquifers are limited due to the small distribution and thickness of the alluvial deposits, and are also limited by fluctuations in the flow and water levels of the rivers that feed them.

Permeable rocks with intergranular and/or fracture porosity are the deposits of the "Lasva series" ($M_{2,3}$). Hydrogeological parameters, on average, have the following values: T = 15-30 m^2/day. Limited quantities of ordinary water appear in these rocks, partly under pressure, which are discharged at the springs, mainly with small yields (Qmax = 0.5-2.0 l/s).

Permeable rocks with fracture porosity are separated into three classes: High *permeable rocks with fracture porosity* are found in the Upper Cretaceous deposits ($K_2^{2,3}$). The transmissibility of this formation is different depending on the representation of the individual members; weak in shale and marl facies, and good in limestone and brecciated limestones facies. Hydrogeological parameters, on average, have the following values: T = 50-100 m^2 /day; Qmin = 0.5-5.0 l/s (**Geological Survey of Sarajevo, 1988**). These rocks have a hydrogeological function of ordinary cold water aquifers and secondary aquifers of the thermal waters in the north-eastern periphery of the Zenica-Sarajevo Basin. *Medium-permeable rocks with fracture porosity* are found in the lower Oligo-Miocene (^{1,2}Ol, M, ^{2}Ol, M). The transmissibility of these deposits is relatively poor to good, and hydrogeological parameters, on average, have the following values: T = 15-50 m^2/day; Qmin = 0.05-5.0 l/s. Limited quantities of ordinary water are found in these rocks, partly under pressure, which are discharged at the springs, mainly with very small yields (Q <1.0 l/s). *Low*

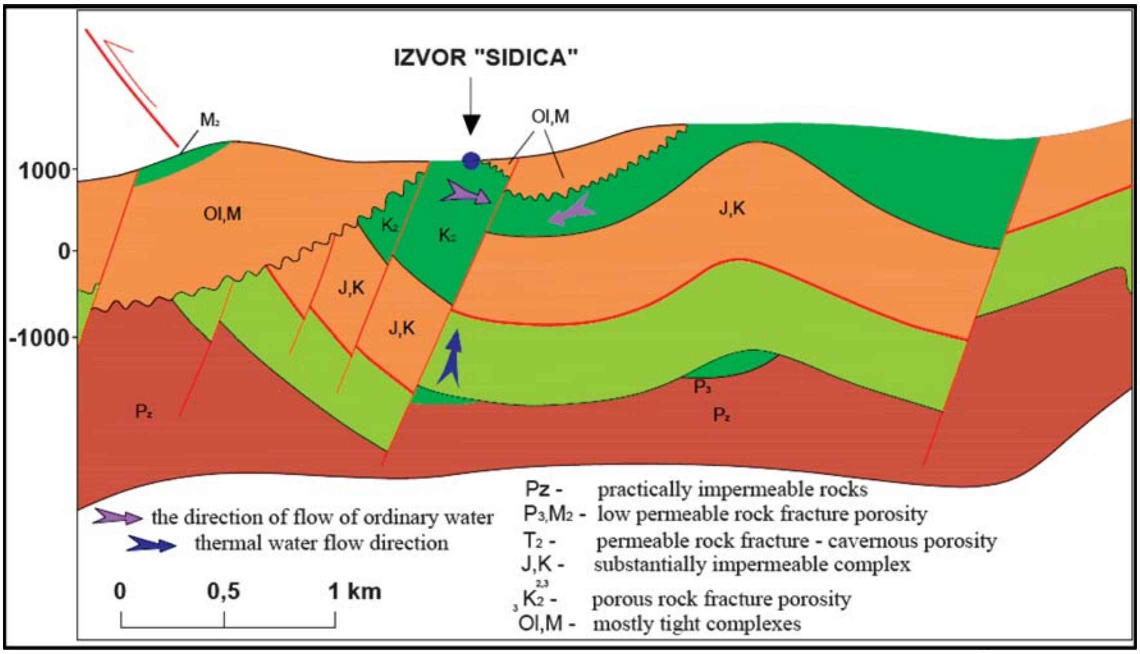


Figure 6: Hydrogeological profile of thermal water at Sidica near Kakanj Sc: H/V 1:100 000 (**Šarić, 2015**)

permeable rocks with fracture porosity are found as deposits of the Upper Permian and Middle Miocene (P_3,$^1M_2$). The transmissibility of these deposits is relatively poor, and the yield of the spring is Qmin = 0.05 to 2.0 l/s. The Middle Miocene deposits have the hydrogeological functions of ordinary cold water aquifers, while the deposits of the Upper Permian, near the source of plain water of the sulphate type, have important hydrogeological functions of the thermal waters aquifer in the north-eastern periphery of the Zenica-Sarajevo Basin.

Permeable rocks with cavernous-fracture porosity are represented in the Middle Triassic (T_2) sediments. Transmissibility of these deposits is mainly good and hydrogeological parameters are, on average, T = 15-300 m^2/day (Geological Survey of Sarajevo, 1988). These rocks have the hydrogeological features of ordinary cold water aquifers in Vares and thermal water aquifers in the north-eastern periphery of the Zenica-Sarajevo Basin.

Impermeable Rocks

Mostly impermeable rocks are classified into two groups:

- mostly impermeable complexes
- practically impermeable rocks.

Mostly impermeable complexes are represented by clastic Jurassic-Cretaceous (J, K) and Upper Cretaceous flysch ($K_2^{1,2}$), higher levels of Oligo-Miocene (^{1}Ol, M, ^{3}Ol, M), Lower-Middle Miocene ($M_{1,2}$), the transition zone of the Middle Miocene ($^2M_2$) and the Upper Miocene ($^1M_3$). Water permeability in these rocks is very poor so that they do not form aquifers. The transmissibility of these deposits is very low T≤15 m^2/day, and the yield of the spring appears to be very small Q ≤ 0.05 l/s.

Practically impermeable rocks are Silurian-Devonian in age (S, D). These are the deposits without an aquifer with no transmissivity and springs that do not appear at the surface.

4. Materials and methodology

The genesis of thermal waters in the north-eastern periphery of the Zenica-Sarajevo Basin is determined by analysis of the geological structure, tectonic relations and the hydrogeological characteristics of the terrain, and analysis of hydrogeochemical indicators and the isotopic composition of water.

We analyzed the sources "Sidica", "Tičići", "Ribnica", "Kraljeva Sutjeska", "Toplik" and "Sedra", which were used in laboratory values obtained with hydrogeochemical and isotopic indicators of water. Geological structure, structural-tectonic and hydrogeological characteristics of the area of the thermal water were analyzed through geological and hydrogeological profiles.

Hydrogeochemistry methods included: 1) the definition hydrogeochemical water type, 2) the correlation of the main components, 3) the calculation of ionic relationships, 4) genetic classification and 5) mixing diagrams. Hydrochemical water type is defined by Piper diagram (**Piper, 1953**). Genetic Code Sulinowo water was determined by the classification (1948) based on the value of the relationship of the major ions: Na-Cl, Na-Cl-SO4-Na and Cl-Mg. The correlation of the main components is affected through the relationship of calcium and sulfate ions and mineralization and temperature. Diagram mixing was done for the sources Tičići and Rayon by the method of real (**Bogomolov & Silin-**

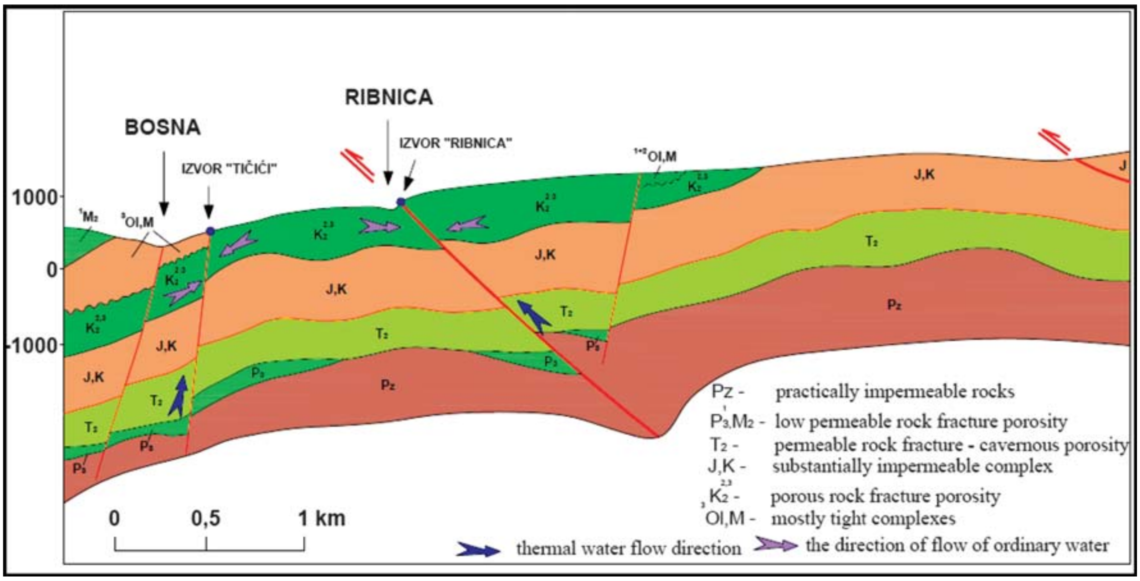


Figure 7: Hydrogeological profile of thermal water at Tičići and Ribnica near Kakanj Sc: H/V 1:100 000 (**Šarić, 2015**)

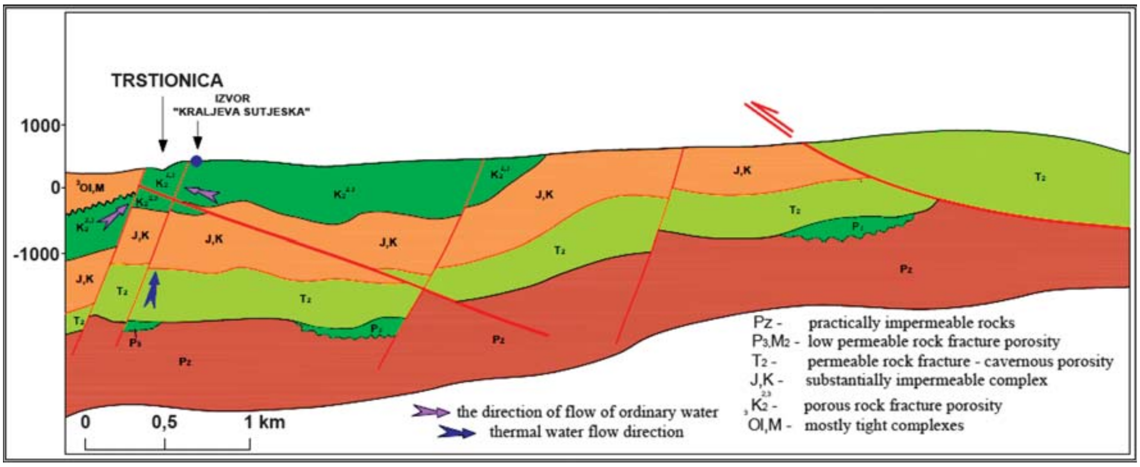


Figure 8: Hydrogeological profile of thermal water at Kraljeva Sutjeska near Kakanj Sc: H/V 1:100 000 (**Šarić, 2015**)

Bekchurin, 1955). As a complement to the knowledge obtained, hydrogeochemical methods in determining the genesis of thermal water was used, and isotopic composition of thermal water at the site Tičići based on the correlation isotope $\delta^{18}O$ and $\delta^{2}H$ (**Craig, 1961**).

5. Discussion

The study of the genesis of thermal waters in this paper was carried out based on geological structure, structural-tectonic and hydrogeological characteristics of the terrain, and the physio-chemical and isotopic composition of water.

"Sidica" thermal water spring

Sidica Spring is located in the region of the identically-named village, 1 km south of Mošćanica, west of Zenica. The spring appears to be on the contact between Oligo-Miocene and Upper Cretaceous deposits (see **Figure 6**).

The spring is a fracture-type spring with the characteristics of entrance. The discharge of the spring is 0.2 l/s, the mineralization is 438 mg/l and the temperature is 17°C. Chemically, the water is a hydrocarbonate-calcium-magnesia type.

"Tičići" thermal water spring

Tičići Spring represents the most significant occurrence of thermal waters in the area of Kakanj, and beyond. At this site, the thermal water discharges in a form of a spring. The spring is of the knotted type and emerges to contact the Lower Miocene sediments (M_1^{1}) and limestones of the Upper Cretaceous ($K_2^{2,3}$) (see **Figure 7**). Two sources of thermal waters were identified at this

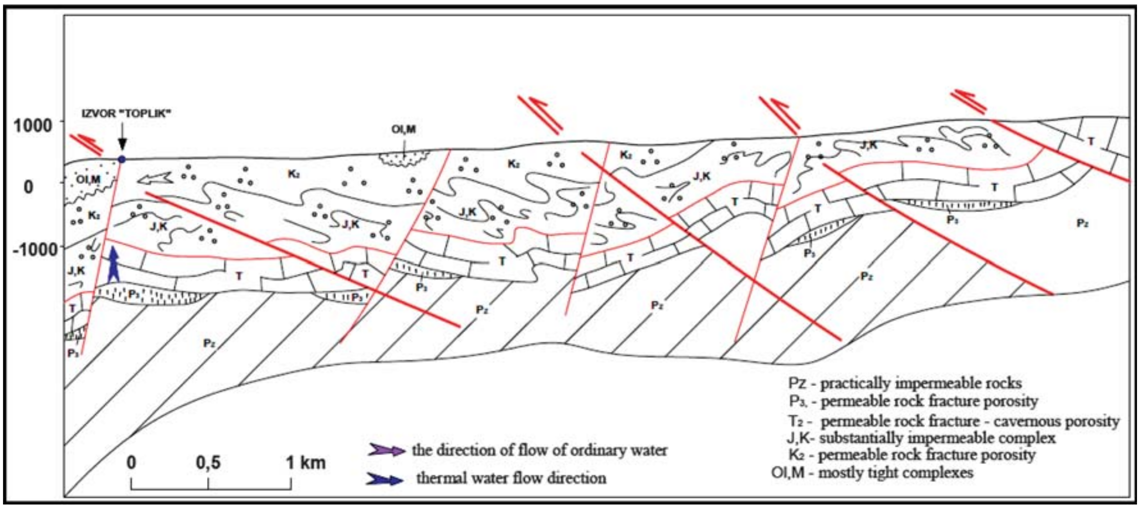


Figure 9: Hydrogeological profile of thermal water at *Podvinjci near Visoko* Sc: H/V 1:100 000 (**Šarić, 2015**)

site; the first spring is on the right side of the highway and discharges 2.5 l/s with a temperature of 24-27°C; the second spring parallel to the highway axis that discharges 0.5 l/s with a temperature of 22°C. The results of the spring water quality sampling indicate that the water is of the hydrocarbon-sulphate-calcium-sodic type with a mineralization of about 1000 mg/l (**Miošić, 1977**).

In 1985-1986, a drilling program was conducted at the Tičići Spring, with drilling boreholes IT-1 and IT-2 (Slišković, 1987) After drilling IT-1, a hydrological relationship between Banja Spring and Tičići Spring was established. Banja Spring had the discharge increased to 30 l/s with a temperature of approximately 50°C.

The exploration drilling of IT-1 was conducted in 1985. The depth of the drillhole was 300.5 m, with a final diameter of 101 mm. The basic parameters of the drillhole IT-1 showed a discharge of 30 l/s and a temperature of 54 ° C. The exploration drilling of IT-2 was conducted in 1986. The depth of the drillhole was 203 m. The drilling was carried out just above the Sarajevo-Zenica highway in the exact same geological environment as IT-1 that was 350 m away from IT-2. The final hole diameter was 86 mm. The drilling program was terminated, and a concrete block was built over it. The basic characteristics of the drillholes showed a discharge of 22 l/s and a temperature of 39°C.

"Ribnica" thermal water spring

In the vicinity of the village Ribnica near Kakanj is a documented occurrence of a thermal water spring, which is now buried beneath the landfill Vrtlište (see **Figure 7**). According to the available data, the spring emerged at the contact between Oligo-Miocene sediments and the Upper Cretaceous limestones (**Josipović, 1971**).

A more detailed description by **Đerković (1971)**, who worked on describing Ribnica, states the following: "This water emerges at a north-south fault from limestone flysch and grained brecciated limestones and sandstones." (**Đerković 1971**). The source of this scattered-type thermal water appeared about in the riverbed of Ribnica River. Its abundance was difficult to determine due to mixing with the Ribnica River, but is estimated at 10-30 l/s. The mineralization of water at the spring is 684 mg/l and the temperature is 28.9°C. Geochemically, the thermal water Ribnica is a hydrocarbonate-sulphate-calcium-magnesia type. After detailed hydrogeological research at this site, two drillholes RB-1 (see **Figure 7**). and RB-2 were explored, which indicated about 100 l/s of thermal water (**Slišković, 1987**) The well RB-1, at a depth of 40 m, had an optimum discharge of 40 l/s and a temperature of 28°C. The well RB-2, at a depth of 180 meters, had an optimum discharge of 80 l/s and a temperature of 30°C with the pressure of 0.04 bar at the mouth of the well.

"Kraljeva Sutjeska" thermal water spring

The thermal water spring at Kraljeva Sutjeska is located just above the mouth of the stream Bukovac in the Trstionica River. Thermal waters appear at the contact of the cracked and karstified limestone of Upper Cretaceous (see **Figure 8**). The spring of the thermal water is of the knotted type.

The mineralization of water at the source is 691.66 mg/l with a temperature of 21°C. Given that the source was capped and redistributed to the water supply system, it is not possible to measure the discharge. According to **Josipović (1971),** the discharge of the main spring is around 25 l/s. Geochemically, the thermal waters are of hydrocarbonate-sulphate-calcium-magnesia type.

"Toplik" thermal water spring

The thermal water spring Toplik is located in Podvinjci, north-east of Visoko. The spring emerges at the contact of Oligo-Miocene and Upper Cretaceous deposits (see **Figure 9**). The thermal water spring is of the knotted type. The mineralization of water is 550.81 mg/l

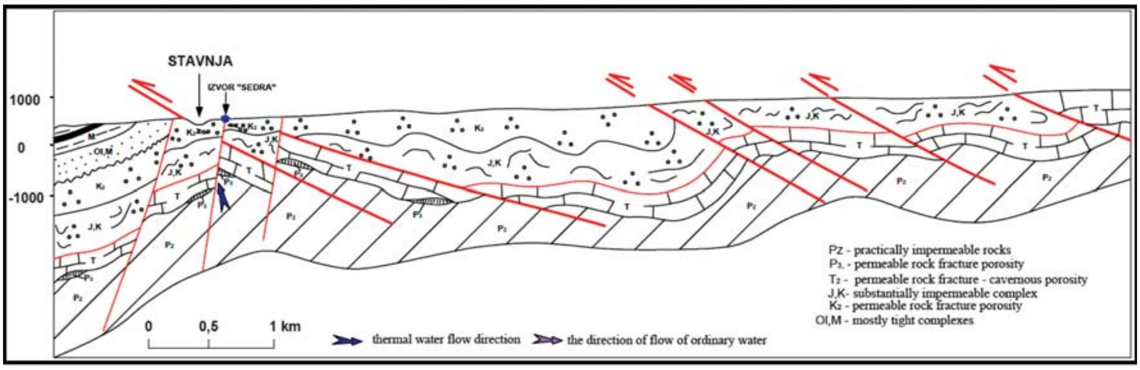


Figure 10: Hydrogeological profile of thermal water near Breza Sc: H/V 1:100 000 (**Šarić, 2015**)

with the temperature of 13.5°C. The spring discharge, according to the available literature, is about 3 l/s.

"Sedra" thermal water spring

The thermal water spring Sedra is located about 2 km from Breza, on the left side of the river Stavnja, below the Breza-Vares road. The spring is of the scattered type and emerges from the Cretaceous flysch sediments close to the Tertiary sediments (see **Figure 10**). The mineralization of water was 1121 mg/l, with a temperature of 19.3°C. The source Sedra, according to **Đerković (1982)**, has an overall yield of about 32 l/s.

Genetic types of the thermal waters of the north-east perimeter of the Zenica-Sarajevo Basin were determined by using Sulin's diagram, based on the value of the relationship of the main ions: Na/Cl, Na-Cl/SO_4, and Cl-Na/Mg. The diagram shows that all the analyzed thermal waters in this area have Na-Cl/SO_4<1, that is, they are of the sulphate-sodic type and originate from a terrestrial environment (see **Figure 11**).

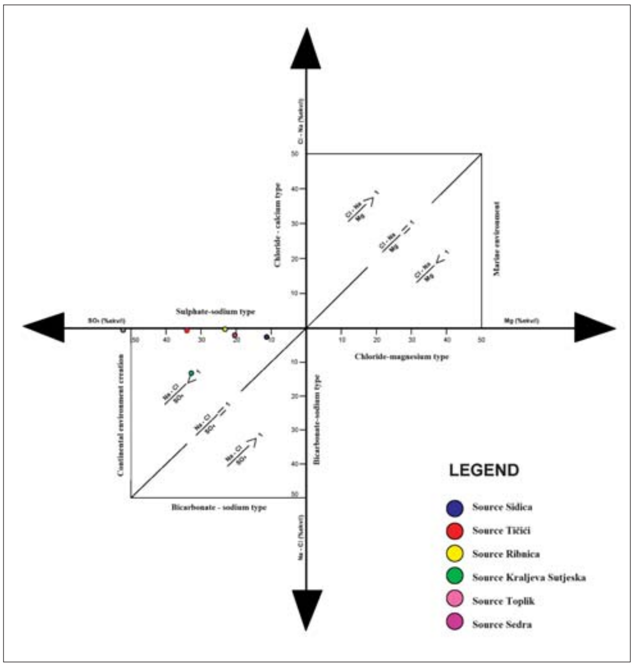


Figure 11: Sulin's diagram for the genetic classification of thermal waters of the north-east periphery of the Zenica-Sarajevo Basin (**Šarić, 2015**)

The study of the genesis of Tičići thermal water was done based on the isotopic composition of water by employing deuterium (^2H) and oxygen 18 (^{18}O) (**Pezdić, 1985**). The content of deuterium in Tičići thermal water near Kakanj ranges from -80.0% δ^2H to -80.10% δ^2H, and oxygen from -11.16% δ^2O to -11.17% δ^2H (see **Table 2**).

Table 2: Isotopic composition of thermal water at Tičići near Kakanj (**Pezdić, 1985**)

Location	T °C	$\delta^{18}O$	$\delta^{18}O$
Tičići IT -1	58,0	-11,16	-80,1
Tičići IT -2	59,2	-11,17	-80,0

These isotopic values indicate the atmospheric origin of the thermal water (see **Figure 12**), because the content of ^{18}O and ^2H of thermal water and precipitation lay in the so-called middle right, reproduced by the equation $H = (8x\delta18O) + 10$. From the diagram, we conclude that the thermal waters in Tičići were created in the Pleistocene, during the period of cold climate. In the future, it is necessary to do isotopic tests on all thermal springs in the north-eastern perimeter of the Zenica-Sarajevo Basin in order to define their genesis and regularity of appearance.

The testing of thermal and cold waters in this area was performed by the analysis of their mixtures, the correlation of the chemical composition and temperature, as well as the relationships between sulphate, chloride and calcium in the groundwater. Testing of the mixing of thermal water is of great importance for determining their relationship with drinking water.

The diagram of thermal water mixture in the north-eastern part of the Zenica-Sarajevo Basin shows that the thermal waters have a mixed origin (see **Figures 13 and 14**).

Water mixing most likely occurs in the area of Upper Cretaceous sediments, between a cold (drinking) water from the karst aquifers formed in the limestones of the Upper Cretaceous, and thermal waters, most likely with much higher temperatures that originate from the Triassic sediments, which are in contact with the Upper-Permian evaporites. Water mixing occurs at great depths without the influence of the daily climate fluctuations and other factors.

The further evidence for water mixing comes from Tičići from the borehole IT-1 at a depth of 300.5 m. The thermal water temperature at depth was 54°C, while the temperature at the spring located in the immediate vicinity of the well was 26°C. As was demonstrated, the thermal waters of the north-eastern perimeter of the Zenica-Sarajevo Basin have a relationship with the Upper Permian sediments containing gypsum and anhydrite (evaporates).

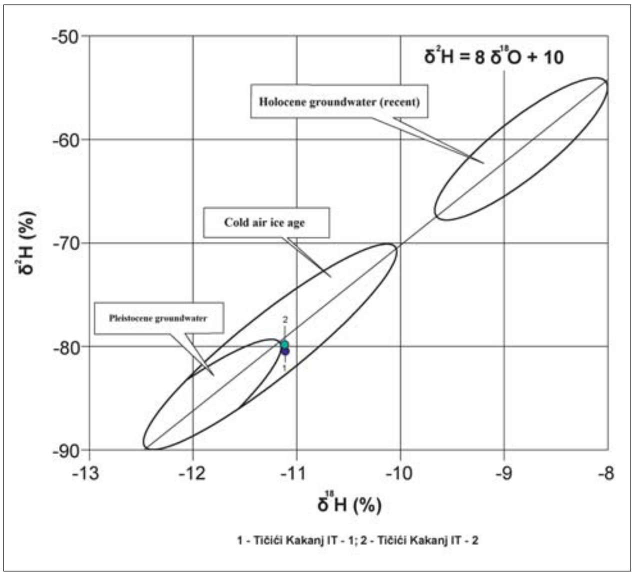


Figure 12: The correlation between $\delta^{18}O$ and $\delta^{2}H$ of thermal waters in Tičići (**Šarić, 2015**)

The Upper Permian sediments with gypsum were found at the site Kondžilo, Javorci and Prževine in the south-western part of the Zenica-Sarajevo Basin, so that they are to be expected in its north-eastern perimeter, as well, a hypothesis that is supported by the study of the genesis of thermal waters in this area. In the future, it is necessary to perform a broader chemical analysis of all thermal springs in the north-eastern perimeter of the Zenica-Sarajevo Basin in order to define their genesis, regularity of occurrence and mixing. The relationship of thermal waters and evaporates was determined by using sulfate and calcium, as is shown in the diagram (see **Figure 15**).

The calcium (Ca) and sulfate ion (SO_4) from the thermal waters of the Zenica-Sarajevo Basin mainly originated from the dissolution of gypsum shown in the reaction: $CaSO_4$ x $2H_2O$ à Ca + SO_4 + 2 H_2O. The average value of the Ca/SO_4 is 2-3, corresponding to the interpretation of gypsum dissolution. Diagonal lines in Figure 15, and the values indicate a negative deviation of the evaporite line (Ca/SO_4 = 2-3).

The ratio Ca/SO_4 indicates that the thermal waters in this area are a result of a mix of two types of water; each circulating through the Upper Permian deposits containing gypsum and other waters originating from the limestones. Schoeller's diagram of the thermal waters of the study area (see **Figure 16**) shows that all the thermal

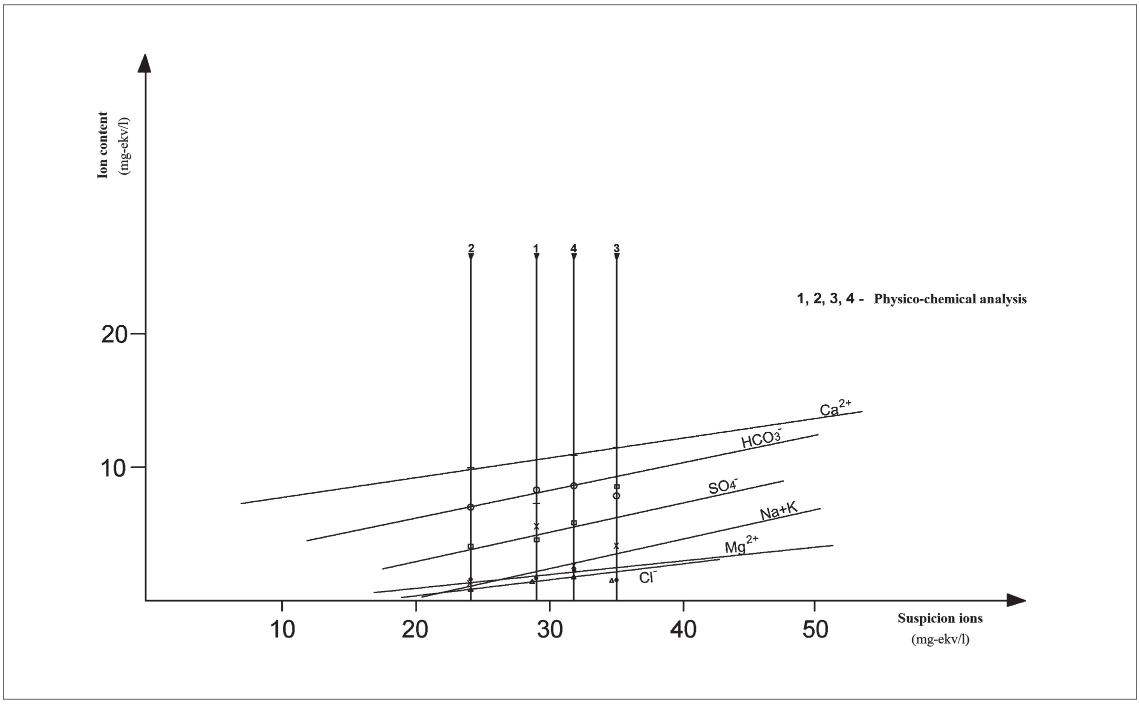


Figure 13: Thermal water mixture at Tičići near Kakanj (**Šarić, 2015**)

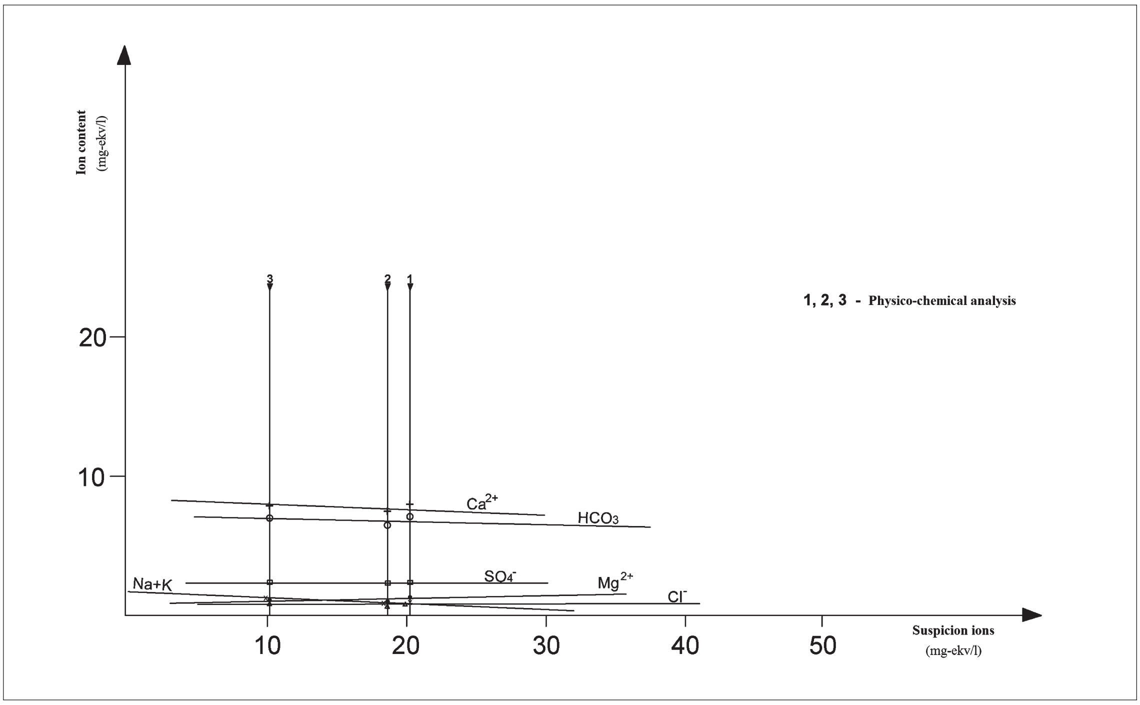


Figure 14: Thermal water mixture at Ribnica near Kakanj (**Šarić, 2015**)

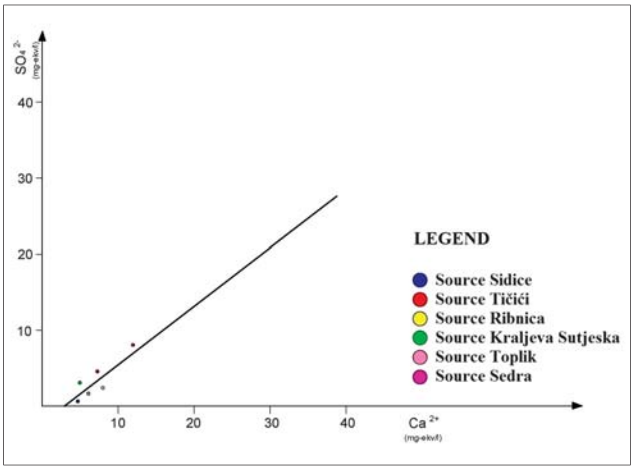


Figure 15: Ca^{2+} vs. SO_4^{2-} in thermal waters of the study area (**Šarić, 2015**)

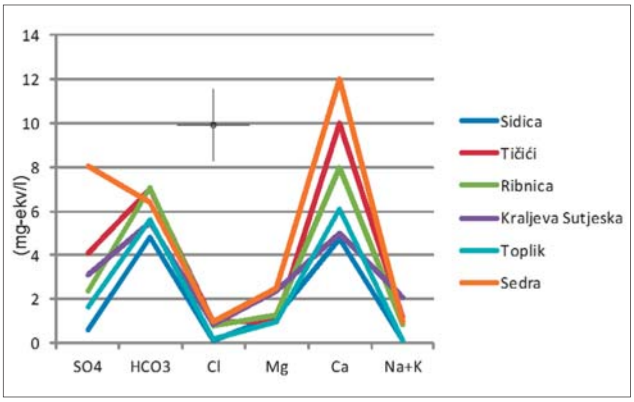


Figure 16: Schoeller diagram of thermal waters from the north-east periphery of Zenica-Sarajevo Basin (**Šarić, 2015**)

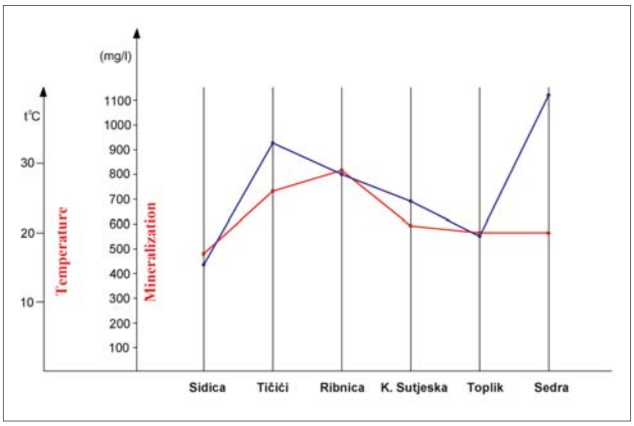


Figure 17: The correlation between temperature and mineralization of thermal waters of the north-east periphery of Zenica-Sarajevo Basin (**Šarić, 2015**)

waters have a very similar ionic composition, which also implies similar conditions of origin, accumulation, flow and discharge.

The thermal waters have different mineralization and temperatures (see **Figure 17**). The highest mineralization comes from the water spring Sedra, and the highest temperature comes from the Tičići Spring. There is an increase of temperature with increasing mineralization at almost all springs, except at the Sedra spring. Higher mineralization and lower temperatures of the Sedra thermal water spring can be explained by a lower depth of burial of the Upper Permian deposits in this area.

The Piper plot shows that all the thermal waters of the north-east perimeter of the Zenica-Sarajevo Basin are of

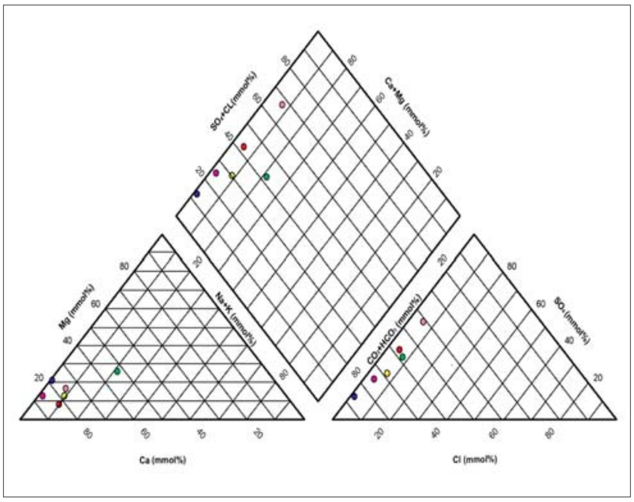


Figure 18: Piper plot of thermal waters of the north-east periphery of Zenica-Sarajevo Basin (**Šarić, 2015**)

the same hydrochemical type or ***sulphate-hydrocarbonate-calcium type*** (see **Figure 18**). The formation of the above hydrochemical type of thermal waters in this region is directly dependent on the chemical composition of the rocks through which they flow. An increased concentration of sulfate in all thermal waters indicates their flow through, and probably the formation within the Permian sediments with lenses of gypsum and anhydrite.

5. Conclusion

Taking into account the results of isotopic analyses, the geological structure, structural and hydrogeological characteristics of the studied area, the genesis of thermal waters of the north-east perimeter of the Zenica-Sarajevo Basin is as follows:

- All occurrences of thermal water have a similar genesis
- Thermal waters are of atmospheric origin
- Thermal waters are of sulfate-sodic type
- Thermal waters originate from a terrestrial environment
- Thermal water accumulates in the basement of Jurassic-Cretaceous flysch
- Thermal waters emerge to the surface through fault zones
- Thermal waters are mixed with cold water at greater depths shielded of the daily temperature fluctuations and other factors
- Thermal waters have different mineralizations and temperatures
- Thermal waters have had almost identical conditions of origin, flow and discharge.

The results of this research contribute to explaining the genesis of the thermal waters of the north-eastern perimeter of the Zenica-Sarajevo Basin, their mineralization, chemistry and temperature. Also, this data contributes to new considerations of geological structure of this part of the Zenica-Sarajevo Basin and its rim, as well as creating a more realistic foundation for the future research of thermal waters in this area. The confirmation of these results for the study of the genesis of thermal waters in the north-eastern periphery of the Zenica-Sarajevo Basin can be obtained by performing large scale isotopic tests on all springs and wells, which is planned to take place in the next phase of the research.

6. References

6.1. Papers

Andrić, N., Sant, K., Matenco, L., Tomljenović, B., Pavelić, D., Mandić, O., Hrvatović, H. and Demir, V. (2015): The link between tectonic and sedimentation in an asymmetric extensional basin: the late Miocene evolution of the Sarajevo-Zenica basin, Bosnia and Hercegovina, Beograd.

Craig, H. (1961) Isotopic variations in meteoric waters. Science 133:1702–1703.

Mikes, T., Christ, D., Petri, R. Dunkl, I., Frei, D., Baldi-Beke, Rettner, J., Wemwr, K., Hrvatović, H. and Eynatten, H. (2008.): Provenance of the Bosnian Flysch, Swiss J. Geosci. 101: 31. doi:10.1007/s00015-008-1291-z, Suplement 1, S31-S54, Basel, Switzerland

Piper, A.M. (1953): A graphic procedure in the geochemical interpretation of water analysis. US Geological Survey Groundwater, Note 12.

Skopljak, F. and Vlahović, T. (2011): The origin of mineral waters in Kiseljak near Sarajevo, Bosnia and Herzegovina, Environmental Earth Sciences, Springer-Verlag 2011, Berlin.

6.2. Papers written in non-English language

Đerković, B. (1971): Rezultati dosadašnjih istraživanja na mineralnim, termalnim i termomineralnim vodama Srednje Bosne, Geološki glasnik 15, p. 279-318., Sarajevo

Josipović, J. (1971): Mineralne, termalne i termomineralne vode u BiH, Geološki glasnik 15, p. 233-277., Sarajevo

Kamberović, E. (2009): Geološka građa središnjeg dijela Zeničko-sarajevskog bazena, Doktorska disertacija, Tuzla

Hajdarević, I. (2012): Strukturno-tektonske karakteristike Bosanskog fliša u slivu Stavnje, Magistarski rad, RGGF, Univerzitet u Tuzli.

Milojević, R. (1964): Geološki sastav i tektonski sklop Srednjebosanskog basena, Geološki zavod u Sarajevu, Posebna izdanja, knj. VII, p. 5-120., Sarajevo.

Miošić, N.(1982): Genetska kategorizacija mineralnih, termalnih i termomineralnih voda Bosne i Hercegovine, Geološki glasnik 27, p. 221-256., Sarajevo.

Muftić, M. (1965): Geološki odnosi ugljonosnih terena Srednjebosanskih ugljenokopa Bile, Zenice, Kaknja i Breze, Geološki zavod u Sarajevu, Posebna izdanja, knj.V, p. 2-108., Sarajevo

Skopljak, F. (2006): Odnosi podzemnih voda područja Ilidže kod Sarajeva, Doktorska disertacija, Posebno izdanje Geološkog glasnika, Sarajevo.

Skopljak, F., Hrvatović, H., Žigić, I. and Pašić - Škripić, D. (2011): Novi prilog hidrogeološkoj rejonizaciji Bosne i Hercegovine, Zbornik radova IV Savjetovanja geologa Bosne i Hercegovine sa međunarodnim učešćem, Sarajevo.

Slišković, I. (1987): Hidrogeološke i hidrogeotermalne odlike termomineralnih voda Ribnice i Tičića kod Kaknja, Geološki glasnik 31-32, p. 195-213, Sarajevo

Šarić, Ć. (2015): Hidrogeološke karakteristike termalnih voda sjeveroistočnog oboda Zeničko-Sarajevskog basena, Magistarski rad, RGGF, Univerzitet u Tuzli.

6.3. Books

Bogomolov, G. and Silin-Bekchurin, A. (1955) Special hydrogeology (in Russian). Gosgeoltechizdat, Moscow

Hrvatović, H. (2006): Geological guidebook through Bosnia and Herzegovina, Herald Geological, Geological Survey of Federation of Bosnia and Herzegovina, Sarajevo.

Sulin, V.A. (1948): Basis of Classification of Natural Waters. USSR, Moscow

6.4. Reports

Federalni zavod za geologiju (2010.): Tumač katastra mineralnih, termalnih i termomineralnih voda FBiH – radni materijal, Sarajevo

Pamić, J., Pamić, O., Olujić, J., Milojević, R., Veljković, D. and Kapeler, I. (1978): Osnovna geološka karta M 1 : 100 000 - list Vareš, Beograd

Pezdić, J. (1985): Istraživanje termomineralnih voda Bosne, FSD „Josef Stefan“, Ljubljana

Stanković, J. Plavkić, J., Lutvić, A. (1988): OHGK list Vareš-radna verzija, Geološki zavod Sarajevo.

SAŽETAK

Prilog genezi termalnih voda sjeveroistočnoga područja Zeničko-sarajevskoga bazena, Bosna i Hercegovina

Pojave termalnih voda na sjeveroistočnome obodu Zeničko-sarajevskoga bazena prouzročene su geološkom građom te strukturno-tektonskim i hidrogeološkim svojstvima terena. Pitanje njihove geneze u prošlosti nije u potpunosti riješeno. U ovome radu izučena je geneza termalnih voda na temelju geološke građe, strukturno-tektonskih i hidrogeoloških karakteristika terena te fizičko-kemijskoga i izotopskoga sastava voda. Dobiveni rezultati novi su prilog razmatranju strukturne građe ovoga dijela Zeničko-sarajevskoga bazena, ali i stvaranju primjerenjih postavki za buduća istraživanja ležišta termalnih voda u tomu prostoru.

Ključne riječi:
Zeničko-sarajevski bazen, termalne vode, geneza, hidrokemija

Author(s) contribution

Ferid Skopljak led the researching and selected results for publishing. **Ćazim Šarić** helped in the article and field's data preparing. **Vedran Pobrić** collected data during his master thesis researching and also analysed them for selection in this publication.