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GEOMORPHOLOGICAL, GEOLOGICAL, AND HYDROGEOLOGICAL FEATURES OF THE IMMEDIATE SURROUNDINGS OF SARAJEVO, BOSNIA AND HERZEGOVINA

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Abstract:

The Sarajevo depression and its surrounding area, from a hydrogeological perspective, represent an exceptionally complex system. In an area that was subjected to intense tectonic processes in geological history, due to the activity of specific climatic and hydrological conditions, a series of exogenous processes were activated, which, in morphological terms, reshaped this area and, consequently, influenced its hydrogeological properties. The area can be divided into two main units: the intensely folded and fractured mountainous region of the periphery and the Sarajevo field area, or the Sarajevo depression itself. The aim of this paper is to highlight the specific hydrogeological properties of the terrain, the particularities of individual blocks of the mountainous periphery, and the hydrogeological characteristics of the Sarajevo field area. The periphery of the Sarajevo depression is composed of powerful, predominantly limestone-dolomite deposits, which serve as hydrogeological conductors, and the underlying deposits of Lower Triassic age, known as the Sarajevo sands, which act as hydrogeological insulators. The key factors influencing the hydrogeological properties of the terrain include: hydrological conditions, terrain morphology, lithological composition, and structural characteristics. The aim of this paper is to present the most significant results of the mentioned research and to frame them into a unified whole, in order to provide a clear understanding of the hydrogeological properties of the terrain in the immediate surroundings of Sarajevo.

Key words: *Geomorphological, Geological and Hydrogeological properties, Sarajevo depression, Hydrogeological collectors, Hydrogeological insulators*

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1. INTRODUCTION

The environment of Sarajevo, specifically its mountainous part, is primarily composed of Mesozoic sediments, while younger Tertiary and Quaternary formations make up the lower periphery and the area of the Sarajevo-Zenica depression. Geological research initially began with informational prospecting, followed by regional geological surveys, and later detailed geological studies related to the implementation of specific projects. The first geological map of the wider Sarajevo area was created by E. von Mojssisovich, A. Bitner, and E. Tieze (1880). More detailed research was conducted by the Austrian geologist F. Katzer (1901–1918).

Between the two World Wars, more extensive research was carried out by B. Milojković (1929), Đ. Vasković (1931), and T. Jakšić (1931).

In the post-war period, notable works were done by I. Soklić, P. Stevanović, R. Milojević, P. Muftić, R. Jovanović, LJ. Rokić, E. Ramović, and others.

From a hydrogeological perspective, the oldest data dates back to the Ottoman period and is related to solving water supply issues. E. Ludwig and F. Katzer provided basic data on the occurrence of mineral and thermomineral waters in the Ilidža area [1].

Recent geomorphological, geological, hydrological, and hydrogeological research began in 1951 (Tilava) for the purpose of expanding the water supply network, while more extensive studies of the Sarajevo field and its outskirts aimed at defining the hydrogeological properties of this area started a bit later, and in some ways, continue to this day [5].

The goal of this paper was to present the most significant results of the aforementioned research and frame them into a cohesive whole in order to provide a clear understanding of the hydrogeological properties of the terrain in the immediate surroundings of Sarajevo.

2. RESEARCH METHODOLOGY

During the field research, for the purposes of constructing certain buildings, road infrastructure, as well as for the investigation and remediation of specific landslides, and during the supervision of the implementation of certain projects in the Sarajevo area and its surroundings, the authors collected all available documentation and used the results obtained from field research, as well as the results of laboratory tests. Based on these results, a synthesis was made, and this paper presents the basic geomorphological, geological, and hydrogeological properties of the terrain in the immediate surroundings of the city of Sarajevo.

Primarily, the results shown on the OGK SFRJ map of Sarajevo were used, as explained in the accompanying interpretation, along with available studies and works done in this field. A limitation is the absence of the OHGK Sarajevo map.

During the construction of certain buildings and the investigation and remediation of specific landslides, detailed engineering-geological mapping of the terrain was carried out at several locations for the needs of the project documentation, based on which numerous exploratory works were located, both in the design phase and additional exploratory works during the construction of the buildings themselves. A series of exploratory boreholes, excavation pits, and test trenches were made, certain geophysical investigations were applied, and a significant number of laboratory geomechanical, mineralogical, and petrological tests were conducted, as well as a number of engineering-geological and hydrogeological maps for specific parts of the terrain, depending on the construction issues of certain buildings, the remediation of landslides, or the resolution of stability conditions of certain slopes whose natural stability was disturbed either by the construction of new buildings or by some completely natural processes.

3. MORPHOLOGICAL PROPERTIES OF THE TERRAIN

Due to specific climatic and hydrological conditions, in an area previously subjected to strong tectonic processes, very active erosion-denudation processes have occurred, both before and during the glacial phase, as well as fluvioglacial processes that have acted over a long geological period and formed various and distinctive characteristic shapes in areas built by Mesozoic carbonate sediments, as well as Cenozoic carbonate-clastic and flysch sediments [1].

Basic structural forms, although transformed through various orogenic phases, have preserved elements of anticlinoria along the Romanija – Jahorina stretch and synclinoria along Bjelašnica – Igman. The morphogenetic forms resulted from the platy and radial movements, particularly affecting the rigid Triassic limestone-dolomitic plate, in relation to the plastic masses of the Verfens and partially towards the underlying Paleozoic rocks [3].

It is certain that in this area, where intense faulting processes took place, regional horsts and grabens were formed, which, through these basic structural forms, created special morphogenetic shapes. As a result, characteristic karst surfaces at various hypsometric positions were formed by the action of erosion-denudation processes, with periodic repetition of endodynamic movements, shaping primary morphological forms and giving them their present appearance.

Jovan Cvijić, regarding the relief development in central Bosnia, mentions that from the Sarajevo Field on the right side of the Bosna River, a series of long parallel valleys, tributaries of the Bosna River, are observed, which are inverse. It is believed that inverse valleys could not have originally been valleys of the present-day Bosna River, but rather belonged to another hydrological regime [9]. It is not excluded that the hydrological system developed several times and at different intensities in this area. Specific characteristics noted include preserved terraces at high altitudes, remnants of a lake basin that once filled the Sarajevo field. It is believed that the terraces of the Bosna River and other watercourses (Miljacka, Željeznica, Tilava) are up to 35 meters above their current beds [1].

Depression of the "Sarajevo-Zenica Basin" tends to sink unevenly towards the southwestern border compared to the northeastern. The river courses, Miljacka, Tilava, Željeznica, and Kasindolska River, have a Dinaric direction and are deeply incised into the Triassic sediments, which, in relation to the lake and Quaternary sediments, clearly indicate the oscillation of the depression. It is certain that the terraces of the upper courses correspond to lake development phases.

Glacial relief form, developed in the Bjelašnica area, and a large amount of glacial material was deposited and accumulated in the Veliko Polje area. A system of deep sinkholes with ponors formed in this area [1].

The sources of rivers below Bjelašnica and Treskavica developed intensively during the deposition of lake sediments, which caused a very deep erosional base to be reached in this area. The intensification of erosion-denudation processes resumed after the draining of the Oligocene lake in the Pliocene. It can be concluded that the surface of Igman was early karstified, but also that fluvioglacial deposits are found on its slopes.

The area of Trebević and Jahorina is not morphogenetically or hydrologically uniform, but represents a geomorphological form created by the high uplift of this part of the edge, as the Verfens sediments (T1) lie at high hypsometric levels, covered by relatively thin, variably oriented, radial and transverse faults, with fractured blocks of limestone-dolomitic plates. The parts of the limestone plates are relatively thin, so they do not allow for larger accumulations in the higher parts of Trebević, whose fragmented blocks gravitate towards the depression.

The narrower area of Paljanska and Mokranjska Miljacka, near the entrance to the Sarajevo basin, has specific morphogenetic forms. In this part, the Triassic limestone plates fractured, causing the limestone masses from the subsidized area to be the lowest and form the initial depression [12].

On the slopes towards Trebević and Hreša, an irregular slip of limestone blocks is evident, either towards the border of the internal depression or towards the initial depression in the Miljacka River valley. Notably, high terraces of the Miljacka River are preserved in this area, especially in the Bentbaša region.

The Romanija limestone surface actually represents the highest area in the southeastern surroundings of Sarajevo, in which the structure of the Middle Triassic (T2) limestone sediments lies over the Lower Triassic (Verfens) T1 clastic sediments.

4. HYDROLOGICAL PROPERTIES OF THE OBSERVED TERRAIN

The Bosna River, along with its larger and smaller tributaries in the wider Sarajevo area, covers a catchment area of nearly 1000 km^2. From the northeast to the southwest, the Vogošća, Koševski Potok, Mošćanica, and Mokranjska Miljacka flow as tributaries of the Miljacka River from its right side, while on the left side of the Miljacka, the tributaries include the Dobrinja River or Tilava, followed by the Kasindolska River, Željeznica with its tributaries, Presjenica, Bijela, and Crna rivers. The main hydrogeological collector is the outcrop from which the Bosna River originates. The source of the Bosna River is a typical karst spring, formed at the contact of Middle Triassic (T2) massive limestones as the hydrogeological collector and Verfens (T1) sandstones, known as the Sarajevo colored sandstones, which function as a hydrogeological isolator [2].

All the mentioned rivers are torrential in their upper parts, with varying intensities. Since the main valleys of these rivers are conditioned by structural morphological forms and pre-existing platy and particularly radial deformations, the valleys of these rivers are highly variable along their longitudinal profile, often alternating between wide sections and narrow gorges where these streams carve through blocks of Triassic limestone. Only upon entering the vast Sarajevo basin do they acquire the characteristics of lowland rivers.

The Bosna River is the main surface drainage collector of Sarajevo and its surrounding area. It springs at the foot of Igman, as a typical karst spring. The spring is a fragmented karst outcrop with a variable discharge regime, formed from a series of different springs along a stretch of about 550 meters.

The Večerica River is the first right tributary of the Bosna River. Its length is approximately 5 km. It is exclusively supplied by groundwater from the Igman-Bjelašnica block, as confirmed by hydrogeological studies [2].

The Željeznica River is a right tributary of the Bosna River, with the longest course (approximately 54 km). It springs beneath Treskavica and flows into the Bosna River at Osijek. The spring is located at an elevation of around 1200 m a.s.l., and the confluence is at an elevation of 491 m a.s.l., giving it an average gradient of 1.33%. The main tributaries of the Željeznica River are Crna River, Bijela River, and Presjenica. The average flow in the Krupaćki Rocks area is around 6 m³.

The Kasindolska River is the second right tributary of the Željeznica River. In its upper and middle parts, it is incised into a gorge in the carbonate rocks of the Middle Triassic T2. Its length is about 25 km.

The Dobrinja River, or its constituent rivers, springs beneath Trebević and its length is around 17 km. This river is actually made up of two smaller streams, Lukavica and Tilava.

The Miljacka River is one of the largest tributaries of the Bosna River, originating from the Paljanska and Mokranjska Miljacka, which meet 6 km southwest of entering the Sarajevo urban area. The elevation at the confluence is 595 m a.s.l. The total length of the Miljacka is 53 km. The main tributaries of the Miljacka are Lapišnica, Mošćanica, and Koševski Potok. All of these tributaries are torrential in their upper courses. The Paljanska Miljacka springs as a typical karst spring at an elevation of 1020 m a.s.l. on the northern slopes of Jahorina, flowing northeast into the area of Pale where it meets with the Repešnica River, which collects water from the wider Pale and Ravna Planina regions. From the Pale area, where it flows almost as a lowland river, slightly upstream from the confluence with the Bistrica River coming from the slopes of Jahorina, it cuts into a deep gorge of Triassic limestone, where the elevation differences are several hundred meters. The gradient in the gorge areas is close to 40°, while the average gradient is 2.81%. After the confluence with Bistrica, the flow direction is Dinaric.

The Mokranjska Miljacka springs on the western slopes of Romanija at an elevation of 1060 m a.s.l. The length of the course to the confluence is about 15 km. In the Mokro area, before entering the limestone gorge near Ljubogošte, it is a lowland river, receiving tributaries from Ratkovac and Tabakovačka rivers. From Ljubogošte to the confluence with the Paljanska Miljacka, there is a high gradient of 31.7. Below Bentbaša, the gradient of the Miljacka is 2.98.

Zujevina is the most significant left tributary of the Bosna River in the Sarajevo basin. Its spring is located on the Quaternary watershed of Osenik. It receives the right tributary Krupa and the left tributary Rakovica. The length of the stream is around 20 km with a minimum flow of 0.2 m³/sec. In addition to the mentioned karst springs of Krupa, the right tributaries represent smaller karst springs in the area between Pazarić and Hadžići. The waters of this river are connected to the depressed parts of the limestone-dolomitic block of Bjelašnica-Igman but are more directly related to the narrower area of the Osenik watershed, particularly to the karst springs around Zovik and Hadžići.

At the hydrometric station Plandište, from 1961 to 2016, the average flow rate of the Bosna River was 5.51 m³/sec, with a maximum flow rate of 8.818 m³/sec and a minimum flow rate of 2.45 m³/sec. At the hydrometric station Reljevo Reservoir, where the Bosna River receives all its tributaries in this area, the average flow rate is 28.8 m³/sec, the maximum flow rate is 44.2 m³/sec, and the minimum flow rate is 17.9 m³/sec, according to data from the Agency for the Watershed of the Sava River [13].

From the above, we can conclude that most of the right tributaries of the Bosna River generally follow a Dinaric direction, while only certain sections are conditioned by radial tectonics, influencing such flow directions.

5. GEOLOGICAL COMPOSITION OF THE TERRAIN

The geological composition of the terrain of the city of Sarajevo and its wider surroundings can be classified into four geological units as follows [4]:

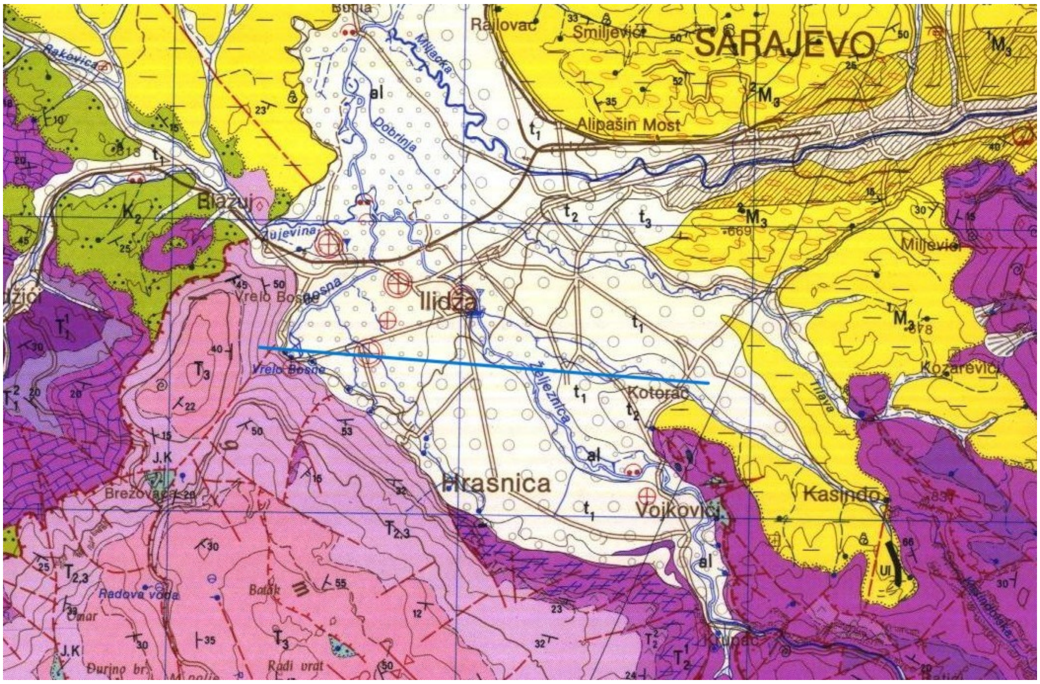

Fig. 1. Geological map of the studied area

- Lower Triassic or Verfenian sediments (T1), which can be subdivided into three lithological units:
    - A complex of sandstones, marls, and clays, which from a geotechnical perspective represents an unfavorable working environment, especially if the structural position is unfavorable relative to the slope. In terms of hydrogeological function, this lithological series acts as a hydrogeological isolator. In the geological past, it was exposed to strong tectonic processes and significant influences from exogenous factors, particularly denudation processes such as Sedrenik, northern slopes of Trebević, Pale, and Mošćanica. From an engineering geological aspect, it can be classified as rocks with unfavorable properties, where the terrain on gently inclined slopes is conditionally stable, while on steep slopes it is conditionally stable to unstable [7];

- A complex of layered white and red sandstones (Sarajevo's colorful sandstones), which are more favorable from an engineering geological aspect compared to the previous lithostratigraphic unit, and the slopes composed of these sediments are stable to conditionally stable (Trebević, Sedrenik, Hreša, Pale, Mokro);
- A complex of marls and thinly layered marl-limestone rocks which have a limited distribution and are found in the area of Kijevo, as well as sporadically on the northern slopes of Trebević. In terms of engineering geological properties, they are similar to pure limestone rocks;

➢ A complex of limestones and dolomitic limestones from the middle Triassic (T21,2):

- Massive limestones of the Anisian stage of the middle Triassic (T21) form the lowest parts of the Sarajevo depression's boundary, characterized by a high degree of fracturing, with large systems of fissures along which significant block movements and displacements have occurred. As a working environment, these rocks are very favorable. These rocks can be used as quality construction materials, while the natural slopes are stable [12];
- Banked to layered limestones of the Anisian and Ladinian stages of the middle Triassic are characterized by a high degree of karstification, with significant presence of fractures and larger fissures. At the base of these rock layers, screes have formed, and natural slopes are stable. As construction materials, these rocks are less commonly used due to the presence of dolomites;
- Layered thin-bedded limestones and marls of the Ladinian stage are significantly folded and thrust. Natural slopes are conditionally stable to unstable. These rocks are rarely used as construction materials.
- Volcanic sedimentary complex of the Ladinian stage, which, in addition to thin-bedded limestones with dolomites and marls, includes volcanic rocks such as tuffs and spilites. Depending on whether they are exposed or not, and the structure of the rock mass, they behave differently regarding erosion-denudation processes [4];
- The first three formations function as conductors in hydrogeological terms, while the last formation acts as an isolator.

➢ Jurassic-Cretaceous J,K (Tithonian-Valanginian) flysch
This lithostratigraphic unit is represented by breccias, brecciated limestones, marls, and clays that alternately change in the geological column, and each of the facies of this complex has its engineering geological and hydrogeological properties. In general, we cannot view them individually, but rather as a complex, concluding that this complex has different engineering geological, geotechnical, and hydrogeological characteristics that depend on the individual facies of this flysch complex. Locally, this lithological formation functions as a hydrogeological collector, and in some areas as an isolator. It is widespread along the perimeter of the Sarajevo depression and is found in localities such as Hreša, Ljubna, Koševski potok, Zujevina, Rakovica, and others.

➢ Tertiary complex of multifacial freshwater sediments

This complex of freshwater sediments is very diverse in hydrogeological terms, depending on which facies is dominant. In the area of the Sarajevo depression and its perimeter, three series are distinguished:

- A series of conglomerates, sandstones with thin layers of marls appears in the areas of Sedrenik, Vraca, Lukavica, and Kasindol. This series is characterized by a general dip towards Sarajevo field (west-southwest), so the stability of the slopes primarily depends on the orientation of the interlayer surfaces and the fissures that intersect them;
- A facies of loosely bound sandstones developed along the stretch from Podhrastovi - Veliki park - Mejtaš - Hambina carina. It has a pronounced collector function, which is crucial for the stability of slopes;
- A series of thin-layered marls, sandstones, and clays (Koševska series) forms the area of Koševski potok, Čengić Vila, Lukavica, and Kobilje Glave. The process of lithification is not completed, meaning these rocks occasionally transition to their unbound equivalents, so this series can be characterized as unfavorable from an engineering geological standpoint. In hydrogeological terms, different types of springs have formed in this formation.

➢ Quaternary cover is represented on the slopes mostly by thin, and less frequently by thicker deluvial cover, as well as by screes and alluvial sediments along the riverbeds.

6. HYDROGEOLOGICAL PROPERTIES OF THE TERRAIN

Hydrogeological Zoning of the Sarajevo Depression and Its Surroundings

The hydrogeological zoning of the Sarajevo Depression and its surroundings, based on major tectonic and structural units, can be divided into two completely separate parts [6]:

Intensively folded and eroded mountainous areas of the periphery, where several geomorphological and consequently hydrogeological units stand out:

- Bjelašnica-Igman
- Trebević-Jahorina
- Crepoljsko-Glog
- Narrow catchment area of the Miljacka River
- Kijevo-Ledići
- Zujevina area
- Sarajevo Basin as part of the unique "Sarajevo-Zenica coal basin."

In the area of the Sarajevo Field, completely different hydrogeological conditions prevail compared to its surrounding mountainous borders and previously listed regions. These structural-morphogenetic differences, along with the hydrogeological functions of the rocks in a lithofacial sense, directly affect all hydrological and hydrogeological phenomena, processes, dynamics, and groundwater regimes. Consequently, they influence the formation of springs, particularly large underground accumulations, their recharge, drainage, and hydraulic characteristics [8].

- Block Bjelašnica – Igman

This block is composed of limestone-dolomitic masses from the middle and upper Triassic, dominated by fissure porosity (T2,3), extending to cavernosity. The degree of karstification is very high. Below this formation, there are layers that serve as isolators, specifically Verfenian sandstones (T1), often referred to in literature as Sarajevo sandstones due to the unique development of this series. The length of the isolating layer is unknown, but it is spatially and morphologically clearly defined. The profile line in Figure 1. is marked in blue.

The mechanism of recharge and drainage of this block is conditioned by surface deposits and their drainage into the underground, mostly towards the Sarajevo Field.

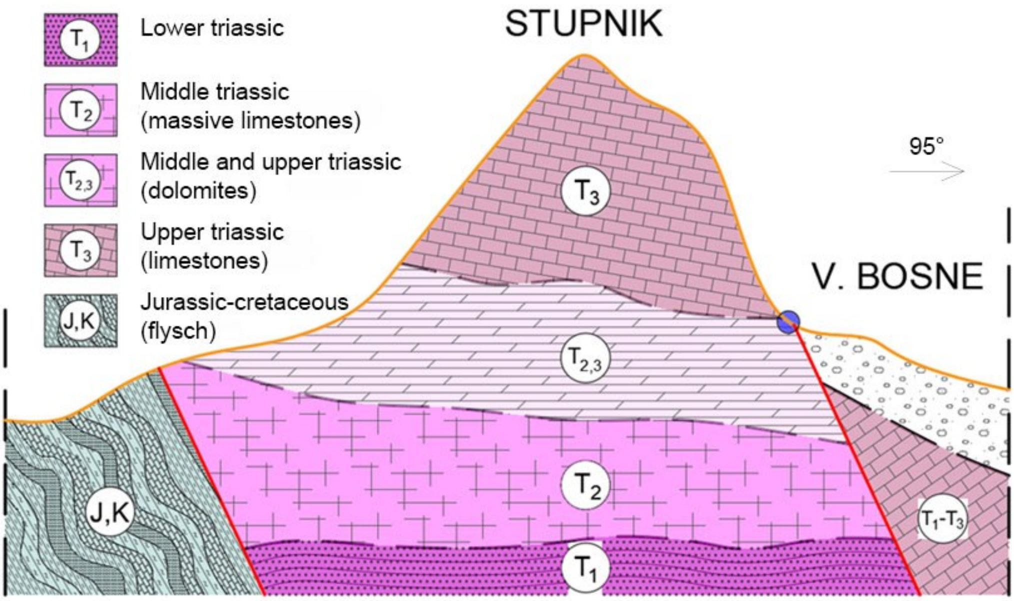

Figure 2. Geological Profiles in the Area of Vrelo Bosne

- Block Trebević - Jahorina

In the structure of the anticline Romanija – Jahorina, the southwestern part of the fractured wing that forms Trebević and Jahorina stands out, an area that contains several smaller hydrogeological units. This area morphologically represents the watershed between the Paljanska Miljacka river basin and the Crna River, Kasindolska River, and Tilava as tributaries of the Željeznica River. This area is divided structurally into several units (J. Josipović, 1969) [6], with most of the precipitation flowing over the surface or originating as springs of varying discharge in the tributaries of the Željeznica and Bistrica rivers. The underground water accumulation of Jahorina is fragmented, partially draining towards the source of the Prača River. The underground accumulations of Trebević partially drain towards the Miljacka River, or its basin, while part of the water drains towards Tilava and Lukavica.

- Block Romanija

The Romanija block is located at the far eastern limit of the Sarajevo Depression, marking the boundary of this geological unit. In this study, only the Kružlja spring can be mentioned, which feeds the Mokranjska Miljacka spring.

- Block Crepoljsko – Glog

This unit, both stratigraphically and structurally, morphogenetically, and hydrogeologically, represents the most complex part of the wider Sarajevo area. The composition of the morphological watershed mainly consists of relatively thin masses of Anisian and Ladinian limestones with roestones, beneath which Verfenian sediments appear in different facies. The limestone masses are separated by the discontinuous tectonic line Mrkovići-Faletići-Hreša, and intermittently where flysch zones occur, overlaid on the also fractured limestone masses of the Middle Triassic. Along this line, the springs of Mrkovići, Crnjilo, and Mošćanica appear.

- Block of the Middle Miljacka River

This area, which stretches deep into the limestone masses, is carved by the gorges of the Mokranjska and Paljanska Miljacka rivers, with tributaries such as Mošćanica and Lapišnica. In this area, a very small number of springs occur, with the most significant being the Sedrenik spring and the karst periodic spring in Ljubogošta.

- Block Sarajevo Field

The inner depression of Sarajevo Field can be considered a separate hydrogeological unit, particularly the part belonging to the open basin of Sarajevo Field, where the freshwater tertiary sedimentary complex is covered by Quaternary gravelly-sandy sediments of varying thickness. (Fig. 2)
It is believed that the thickness of the Quaternary sediments, especially in the depression area, is variable, with the upper gravelly horizons, from which groundwater is extracted, reaching depths of 40 meters, while the hydrogeological isolators reach depths of up to about 100 meters. Essentially, it can be concluded that in the upper parts of the depression, a compact aquifer has formed with a free level, while in the lower parts, the water is under pressure and appears as artesian aquifers [11].

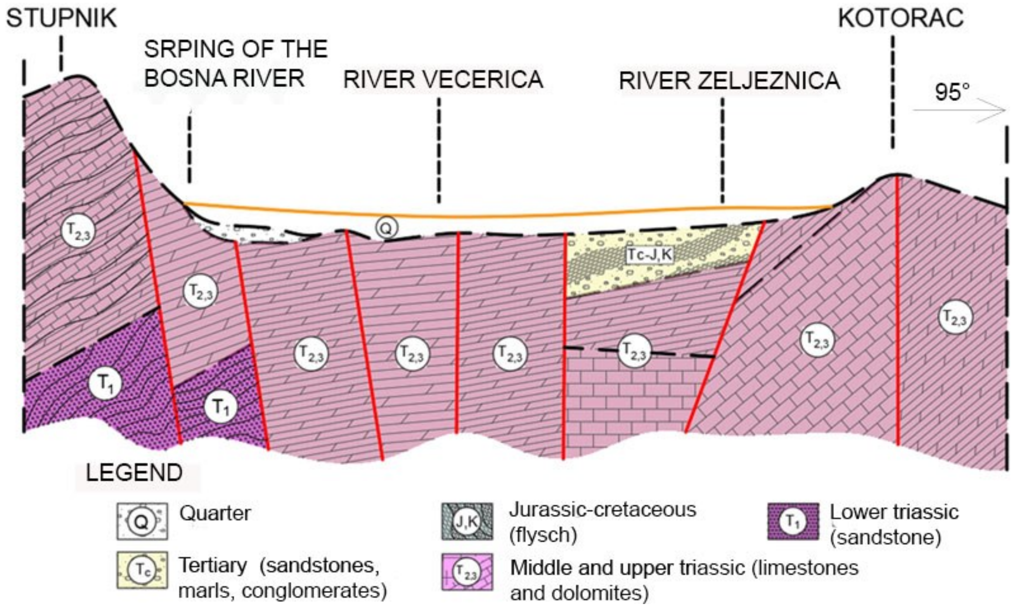

Figure 3. Projected Geological Cross-Section of the Stupnik – Kotorac Area

This arises from both structural-tectonic and morphological, as well as hydrogeological relationships. This area is composed of hydrogeological collectors – reservoirs with intergranular porosity and various hydraulic conditions present within them. A subsurface hydrogeological barrier along the Blažuj - Ilidža-Kotorac line separates this area from the Bosna river basin into a smaller, deeper part, while the higher part ends with the Tertiary "Reljevski threshold" in the Bosna valley.

7. THE OCCURRENCE OF THERMAL AND ACIDIC WATERS

The first observations on the occurrence of acidic and thermal waters were made by Austrian geologists A. Bittner, E. Tieze, and E. von Mojssisovics (1880), while F. Katzer significantly expanded the findings of his predecessors (1903) [12]. After World War II, the most significant works were done by Professor R. Jovanović, as well as many other geologists. Thermal waters, or their occurrence, are associated with the Ilidža area, while acidic waters are linked to the Kiseljak area. Based on data obtained from research throughout the 20th century, the following conclusions can be made:

The thermal water in the upper parts of the quaternary is spread in a relatively narrow zone with a northeast-southwest direction and is closely associated with the Željeznica River bed [14]. The measured surface temperatures of the thermal water range from 36°C to 38°C.

The area of the thermal spring's outflow is clearly limited by the occurrence of pure bigrovitic masses or aragonitic conglomerates, which have been identified in numerous exploration wells. In the zone of the so-called "Busovački Fault," extending from Sarajevo to the northwest, acidic waters, or Kiseljaci, appear. The best-studied spring is in the town of Kiseljak, from which it got its name. The captured well, drilled in 1971, where a bottling plant was built, has an output of 30 liters per second and represents one of the most prolific cold mineral water wells (13°C) in the former Yugoslavia [10].

8. DISCUSSION OF THE RESEARCH RESULTS

This paper presents the most significant geomorphological, geological, and hydrogeological characteristics of the terrain in the immediate surroundings of Sarajevo. In geomorphological terms, morphological units were identified, formed by the interaction of endogenous and exogenous processes that led to the creation of the current relief. The key factor in shaping the primary landforms was the continuous and intermittent river flows, whose action has been ongoing.

Based on the existing OGK SFRJ map of Sarajevo, as well as data obtained through terrain mapping at certain locations and available literature, the geological composition of the immediate surroundings of Sarajevo (lithological composition and tectonic properties) was analyzed and presented.

By analyzing geomorphological, geological, and hydrological data, hydrogeological blocks (areas with different hydrogeological properties) were identified. Special attention was given to the hydrogeological block of Bjelašnica - Igman, where the largest springs were formed, including the largest spring (Vrelo

Bosne). Figure 2. and Figure 3. show the specifics of this spring in both a broader and narrower sense.

9. CONCLUSION

The area of the Sarajevo depression and its wider surroundings, from a hydrogeological perspective, is divided into several different blocks, which are essentially limited by large dislocations created during previous tectonic activities.

From the southwest to the far southeast, along the broader perimeter of the Sarajevo depression, high limestone mountains dominate, broken and karstified by intense tectonic processes. A common characteristic of all these previously separated blocks is that the limestone sediments, predominantly of Middle Triassic age, function as hydrogeological collector-conductors and represent areas for large underground accumulations. Below them, with the role of a hydrogeological isolator, extends a layer of Verfen sandstones (T1), referred to in the literature as "Sarajevo sandstones." It is precisely at these contacts that large springs of high discharge are formed, such as the Vrelo Bosne, Paljanske and Mokranjske Miljacke, Bistrica, Željeznica, Crna Rijeka, Presjenica, Zujevina, and Tilava springs. The discharge of these springs is substantial.

In the area of the Sarajevo depression itself, fluvial sediments dominate on the banks of the Željeznica, Miljacka, and Bosna rivers, with thicknesses ranging from a few meters to several dozen meters. In the alluvial sediments, which are characterized by intergranular porosity, aquifers with free levels have formed, as well as some artesian aquifers. In addition to the springs used for the city's and its surroundings' water supply, water from the alluvial aquifers, such as the Stojčevec region, is also used for this purpose.

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