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http://dr.rgf.bg.ac.rs/s/repo/item/0008169

9th International Conference
MINING AND ENVIRONMENTAL PROTECTION
May 2023, Serbia

SYNERGY BETWEEN THE MINERAL DEPOSIT EXPLORATION AND GEOTHERMAL RESOURCES ASSESSMENT ON THE EXAMPLE OF "VALJEVO" BORON AND LITHIUM DEPOSIT IN SERBIA

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Abstract: *Exploration of mineral deposits involves a collection of vast data sets on geological characteristics of the area. These data can largely contribute to the assessment of the geothermal potential, which can lead to an increase in the share of geothermal resources in the energy mix of the extractive industry and the local community. On the example of the "Valjevo" B-Li deposit, data on structural settings and previous hydrogeological investigations were combined with the results of resource drilling and geophysical survey to assess the geothermal potential of the basement of the Valjevo-Mionica Neogene basin. The study estimated the basin's depth and expected temperatures ranging from 40°C to 65°C for the Triassic limestone reservoir. The applied approach enabled the delineation of the perspective zones for further dedicated geothermal exploration drilling.*

Keywords: *Geothermal assessment, Mineral deposit exploration, Geothermal potential, Serbia*

1. INTRODUCTION

The research community and the mining industry are making efforts to improve the environmental performance of mining operations by shifting to renewable energy. Previous studies showed that mineral exploration data and the expertise from the mining industry could help identify and develop geothermal resources and potentially reduce the cost of geothermal energy utilization [1]. Geological settings where mineral deposits and geothermal resources are co-located create opportunities for developing more sustainable exploitation scenarios by substituting the fossil fuels energy systems in the industry and the local community [2].

The "Valjevo" boron and lithium prospect is among receantly discovered deposits in Serbia, with borax mineralization identified in 2019. The deposit is in the exploration stage as a greenfield boron and lithium project in Western Serbia, operated by Euro Lithium Balkan d.o.o. (ELB). The deposit is situated in the "Valjevo-Mionica" Miocene age basin, with mineral paragenesis typically comprised of probertite, ulexite, sirlezite, massive borax and Li-bearing smectite and silinaite minerals, deposited in three main zones: Borate zone, Borax zone and Lithium-borate zone.

The basin basement in the north part is dominated by lower Triassic clastic and Paleozoic metamorphic sediments, while to the south, the basement is composed of karstified middle Triassic limestones. In previous research, Simić, Milivojević and Martinović contributed significantly to the estimation and utilization of the geothermal resources of the wider area [3-5]. In relation to the aforementioned research, this study provides a more detailed estimation of the geothermal potential supported by new data collected on exploring the "Valjevo" deposit. The emphasis was made on understanding the structural style and depth of the Miocene cover, as well as the spatial distribution of the estimated temperatures in the Triassic reservoir. Still, uncertainty remains about the hydraulic properties and storativity of the limestone aquifer in the basement of the Miocene basin.

2. GENERAL SETTINGS

2.1. Study area

The presented research is focused on the western part of the "Valjevo-Mionica" Miocene age basin (Figure 1). The "Valjevo" deposit is situated in the Kolubara River valley. The boron-lithium mineralization is hosted within the fine-grained, lacustrine sediment sequence (siltstone, claystone, marls etc.), some 200-300 m below the alluvial plain. However, data from the wider area are used in the analysis to understand the structural pattern, including the basin margins, where Mesozoic and Paleozoic sediments outcrop on the surface.

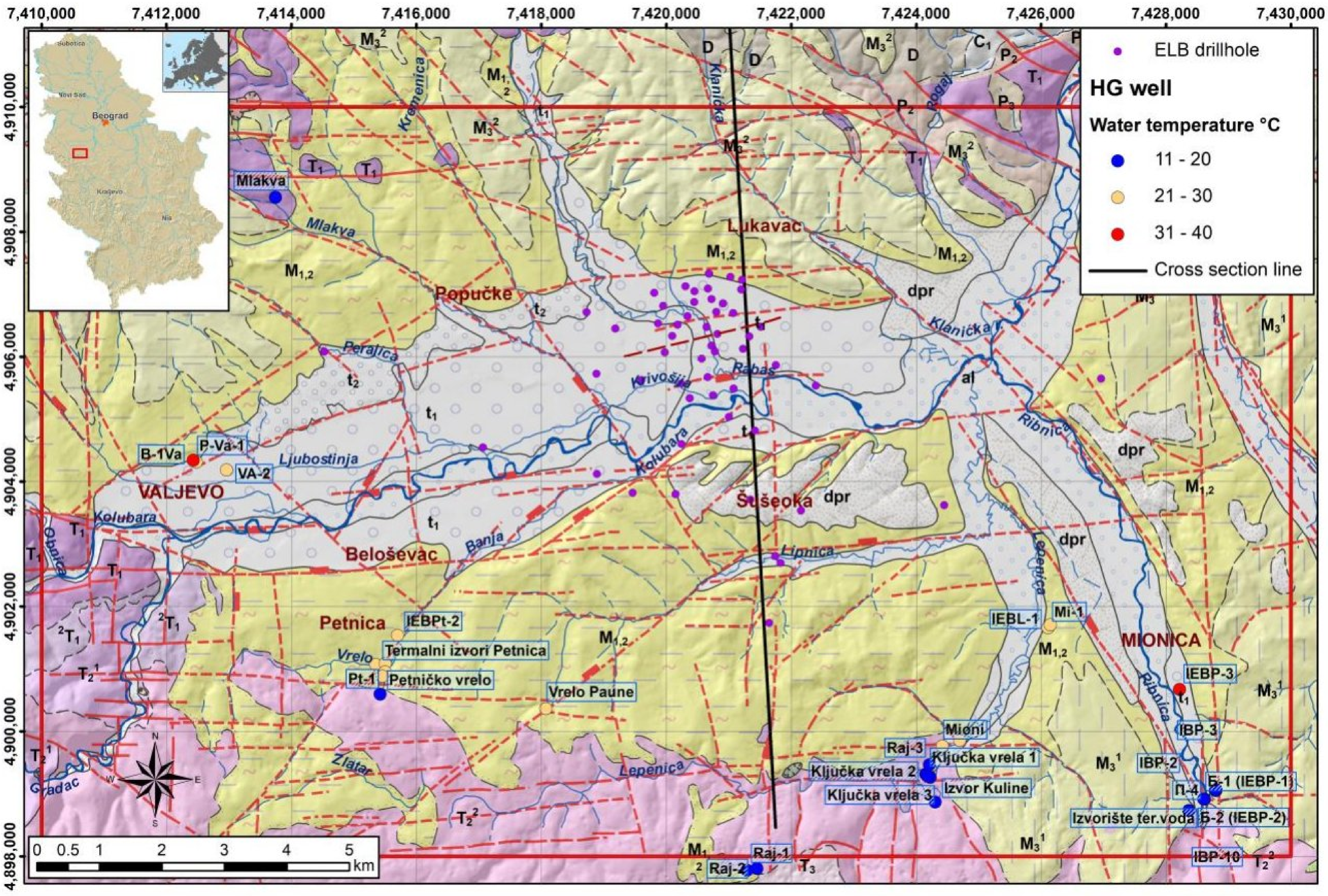

Figure 1. Location of the investigated area, basemap: OGK 1:100 000 sheets L-34-136 Valjevo i L-34-137 Gornji Milanovac [6, 7]

The basins spread in E-W direction with a maximal thickness around 900 m in central parts. The tectonic framework comprises older NE-SW and NW-SE faults, later overprinted with major E-W normal faults. Although the tectonic setting of the basin is complex, the ore body zone is situated in a relatively undisturbed area with gentle horizontal layering. The basin basement in the north part is dominated by lower Triassic clastic and Palaeozoic metamorphic sediments, while to the south, the basement is composed of karstified middle Triassic limestones. Outcrops of Miocene-age volcanic rocks are also identified in the wider project area.

2.2. Hydrogeology

Based on existing data in the Valjevo-Mionica basin and the surroundings, the following aquifer types are identified:

- Intergranular, phreatic alluvial and terrace aquifers

- Fractured, semi-confined and confined aquifers within Miocene sedimentary basin
- Karst aquifer within Upper and Middle Triassic limestones
- Fractured aquifer within the Lower Triassic limestones

From the perspective of geothermal resources, Triassic aquifers are interpreted as the main reservoirs. A significant karst aquifer is formed on the basin's southern margin, with groundwater from the middle Triassic limestone being utilized for the public water supply of Valjevo, Mionica and surrounding settlements. Karst groundwater under artesian pressure and elevated temperatures (17-37 °C) are taped with wells drilled below the Miocene cover in the surrounding settlements of Paštrić, Sanković and Petnica.

3. MATERIALS AND METHODS

Considering the available data and the objective to assess the geothermal potential of the part of the basin, an approach was applied with three main steps:

- Analysis and interpretation of existing data (including results of exploration drilling and geophysical logging);
- Analysis of the spatial distribution of geothermal gradients and the thickness of Miocene sediments;
- Calculation of the expected temperatures in the Triassic reservoir.

A review of existing documentation was conducted, and relevant data were stored in a dedicated database. Three main groups of base data were compiled: geological, hydrogeological data and geothermal indicators. Data (point, line, polygon, raster) were spatially analyzed in a GIS environment. Vranješ et al. [8] provide more details on applied methodology.

4. RESULTS AND DISCUSSION

4.1. Basin basement geology

Modelling of the lithostratigraphy, structural settings and morphology of the basement of the Miocene sediments were conducted based on tectonic analyses of the basin periphery, interpretations of gravimetric and magnetotelluric geophysical research data, drilling core logging and creation of a series of auxiliary geological profiles. Results are interpreted in the form of a geological and structural map of the Neogene basement, containing isolines of the interpreted depth of the Neogene sediment cover (Figure 2).

The map shows that the basement is mainly composed of Triassic-age lithological units. Available data suggest that North of the Kolubara River, Lower Triassic carbonate-clastic sediments dominate, with rare Middle Triassic limestones preserved in the cores of synclinal structures . South of the Kolubara River, the base of the Neogene basin is mainly made up of Middle Triassic limestones. Locally, there are minor occurrences of Lower Triassic sediments in the cores of the anticlinal folds.

From the periphery of the basin, the Neogene's basal part descends deeper towards the axial part of the basin structure. The central part of the depression extends in the general direction ENE-WSW, whereby the basin is divided into several smaller spatially distant sub-depressions. The morphology of the sub-depressions is correlative with gravimetric depocenters and morphology of sub-depressions recognizable on geophysical maps developed for deposit exploration.

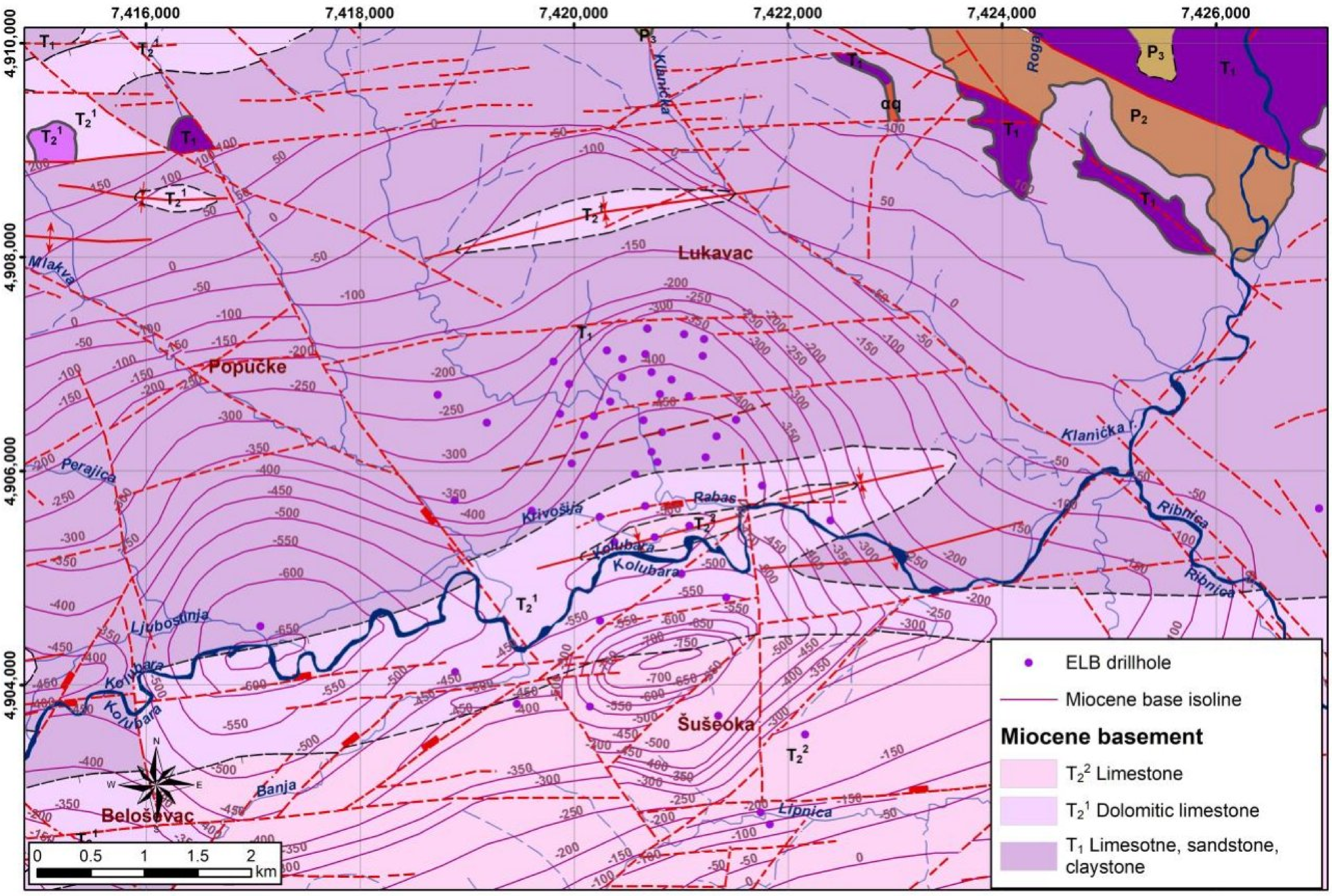

Figure 2. *Structural and geological interpretation of the basement of the part of "Valjevo-Mionica" Neogene basin*

4.2. Geothermal system

According to the geological settings of the terrain and the results of the analyzed parameters, the geothermal system of the Valjevo-Mionica basin belongs to the conductive type within the sedimentation basin (foreland basin/orogenic belt). The geothermal system consists of a carbonate reservoir within a basement Triassic limestone and the insulator of the Paleozoic and Neogene ages (Figure 3).

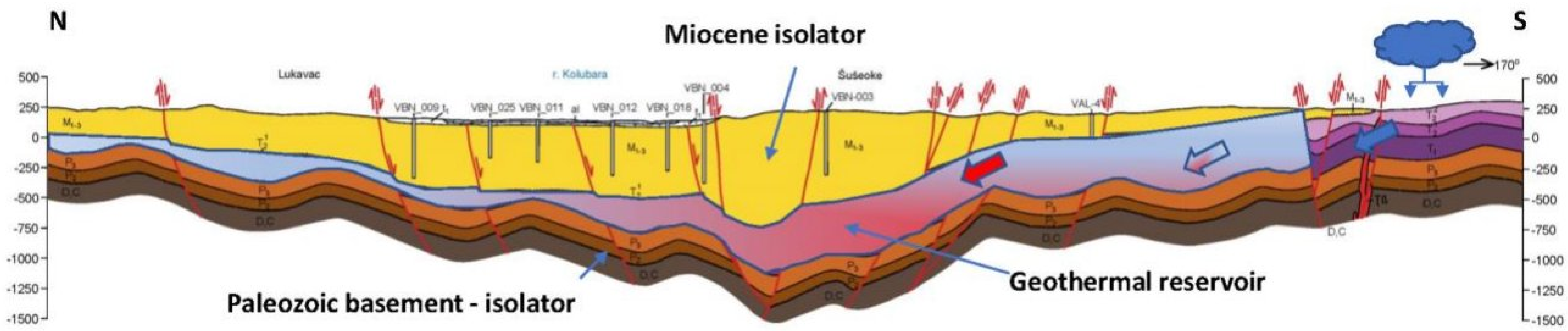

Figure 3. *Generalized cross section N-S of the geothermal system in the Triassic limestone of the western part of the "Valjevo-Mionica" basin – Legend: Yellow – Neogene sediments; Puprule shades – Triassic rocks; Brown to gray – Paleozoic; Red lines – faults; Arrows – estimated groundwater flow direction*

The geothermal reservoir was formed in rocks of the Mesozoic age, predominantly in Triassic sediments. Existing data indicate that the limestones of the Middle Triassic are characterized by a significant degree of karstification and that they are more water-bearing than compared to the Lower Triassic. However, to consider the geothermal potential, the Triassic sediments are interpreted as a unique carbonate reservoir, with an estimated area of 200 km^2 and an average thickness of 300 m. Recharge of the geothermal reservoir takes place by infiltration of precipitation, dominantly on the southern margin of the basin where karst features are present on the surface.

4.3. Assessment of the reservoir temperatures

Groundwater temperatures of part of the Triassic carbonate reservoir were estimated at the base of the Neogene sediment sequence and as maximal expected temperatures. The temperatures at the contact of the Triassic reservoir with the Neogene cover are calculated as a product of the values of geothermal gradients of the Miocene sediments and their thickness. For this purpose, the geothermal gradients were calculated based on the results of the downhole survey of the resource drillholes and the results of previous research. These gradient values are interpolated in a GIS environment, resulting in Neogene geothermal gradient map (Figure 4).

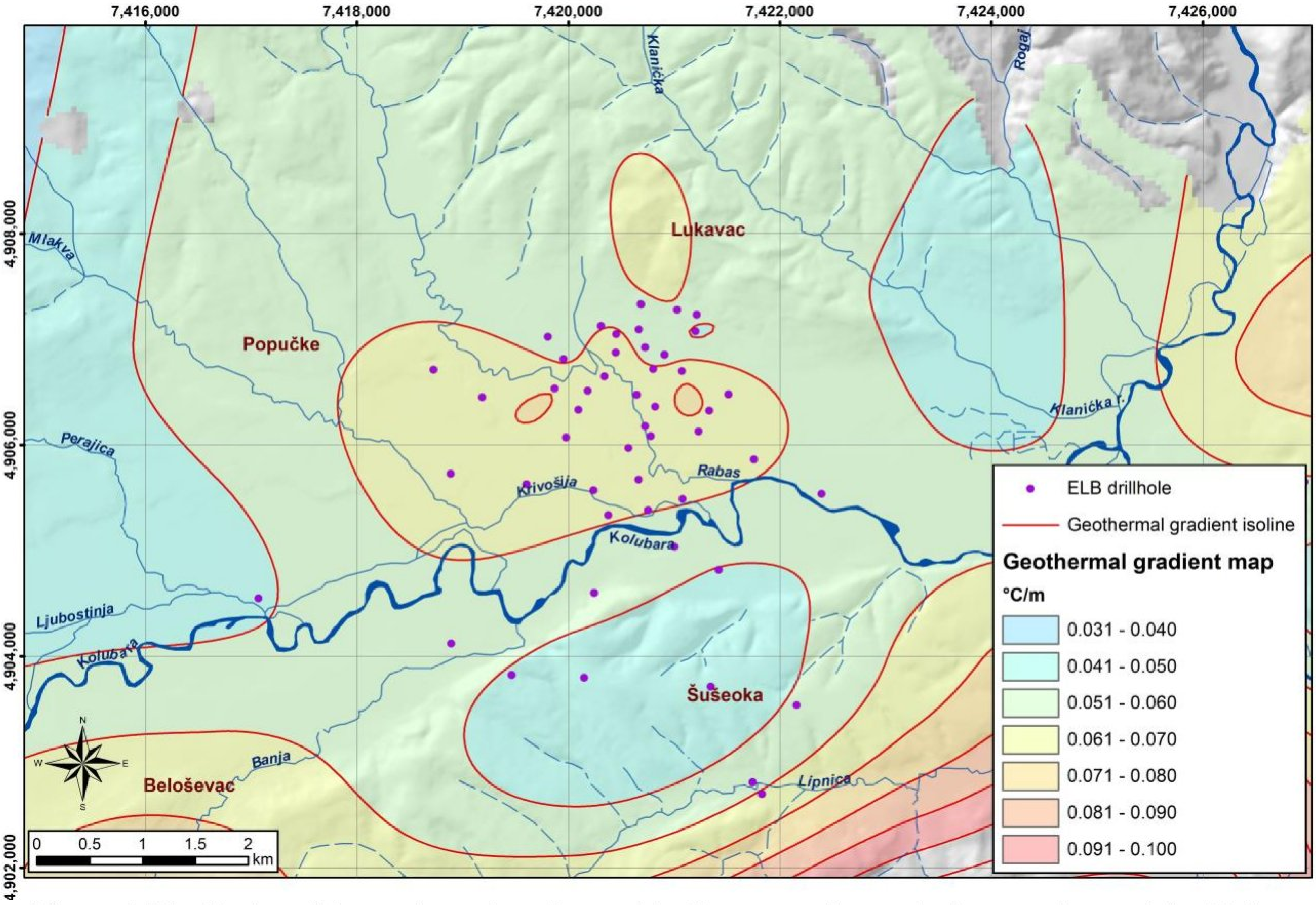

Figure 4. *Distribution of the geothermal gradients of the Neogene sediments in the central part of the "Valjevo-Mionica" basin*

The resulting gradients in the Neogene sediments, where conductive heat flow prevails, are 0.049 – 0.069 °C/m (assuming 12 °C average air temperature). These values are considered high compared to the 0.03 °C/m adopted as the average for this part of Europe [3]. The Neogene geothermal gradient map is combined with the map of the thickness of the Neogene sediment cover to estimate temperatures at the upper boundary of the reservoir.

Since limited data exist on the temperature increase with depth within the Triassic reservoir, a conservative assumption was made, supported with geothermometers derived from the available groundwater chemistry data. Considering that the reservoir is interpreted to facilitate convective heat flow, the gradients are significantly lower than in the conductive system. With this in mind, the geothermal gradients of the Triassic reservoir are estimated at 1-2 °C/100 m. Finally, depending on the estimated reservoir depth, these values are added to the previously calculated temperatures of the base of the Miocene. The applied approach resulted in the creation of the Triassic carbonates reservoir temperature map of the central part of the "Valjevo-Mionica" basin (Figure 5).

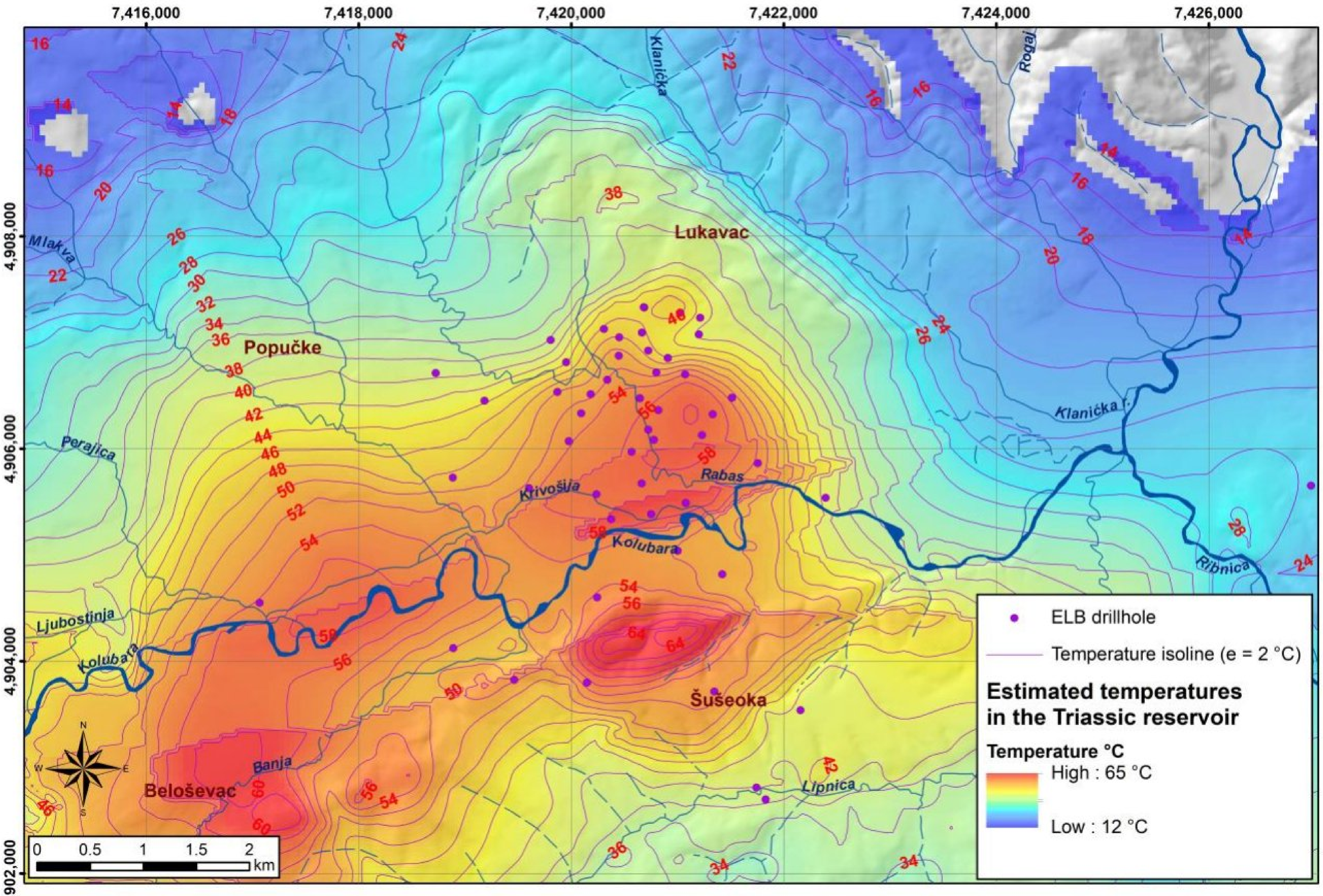

Figure 5. *Map of estimated temperatures in the Triassic reservoir in the central part of the "Valjevo-Mionica" basin*

Results suggests that biggest part of the studied area has reservoir temperatures of around 50 °C. Maximal estimated temperatures are up to 65 °C in the area of the Kolubara fault and correspond with the zone where the Neogene sediments cover is estimated to have the highest thickness (approximately 950 m). This temperature correlates well with the temperatures derived from the quartz geothermometers, which are in the range of 40-60 °C [8].

5. CONCLUSION

Geological data collected to investigate boron and lithium mineralization in the "Valjevo-Mionica" basin are combined with results of previous research to estimate the geothermal potential of the area. Within the applied framework, gravimetric and magnetotelluric survey data, along with the downhole geophysical logging and groundwater quality analyses, are shown to be highly relevant in assessing geothermal characteristics. Elevated geothermal gradients (average about 6 °C/100 m), structural assembly, especially Kolubara and Banjska faults, as well as existing occurrences of thermal waters are identified as the most significant indicators of the geothermal potential. Magmatism has been assessed as a factor of less importance, while the source of heat is in connection with the density of the heat flow and the depth of the Triassic reservoir. The geothermal system in the researched area consists of Triassic limestone as reservoirs and Neogene sediments acting as heat insulators and a barrier to groundwater flow. The highest expected groundwater temperatures in the analysed reservoir domain are up to 65 °C, while the average temperature is estimated at 50 °C. The applied methodology allows spatial identification of the perspective zones for further research. The demonstrated approach highlights the importance of consideration of geothermal potential in the early stages of deposit exploration as a significant opportunity for more sustainable mine project development.

Acknowledgment: Research of the geothermal potential of the Valjevo-Mionica basin was carried out as part of the "Study of the Geothermal Potential of the City of Valjevo", funded by the company Euro Lithium Balkan d.o.o**.**

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