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THE HYDROGEOTHERMAL MODEL OF MACVA

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ABSTRACT

Macva is an agricultural region of about 800 square kilometers in surface area about 80 kilometers west of Belgrade. Geologically, it is on the southern margin of the Pannonian Basin. Geothermal anomalies in Neogene sediments and previous hydrogeothermal investigations indicate thermal water-bearing Triassic limestone beneath Neogene sediments throughout the whole Macva region. The highest measured temperature is 78 ^oC at a depth of 610 meters in Triassic limestone. The highest temperature expected in the aquifer on the basis of hydrochemical geothermometers, is about 100-110 ^oC. Natural conditions in Macva are favorable for intensive exploitation of geothermal energy. Based on the local geology, hydrogeological and hydrothermal characteristics, the calculated thermal power potential of the Macva region is approximately 150 MW_t.

1. INTRODUCTION

Macva is a large alluvial plain in Serbia, between the Drina and the Sava Rivers, some eighty kilometers west of Belgrade. Geotectonically, it lies on the southern margin of the Pannonian Basin where it joins the Dinarides (Fig. 1). The hydrothermal system of Macva was discovered in 1982, when a high conductive geothermal anomaly was detected in deposits at Dublje, central Macva (Milivojevic et al., 1982). Then hydrogeothermal investigations were started but have not yet been completed. The acquired data indicate that the low-temperature convective hydrogeothermal system of Macva is a part of a large regional system, extending under Macva Semberija and Srem - with a surface area of about two thousand square kilometers.

The present results are very interesting. Neogene sediments overlie a karst reservoir in Triassic limestones, which can be tapped at a high rate for house heating, food production and industrial uses. A conductive geothermal anomaly, the highest in the Pannonian Basin (thermal water of 75 ^oC found in the borehole BB-1 at the depth of 412 m), was detected above the reservoir in central Macva (Milivojevic and Peric, 1987). This makes Macva the Yugoslavian, and Serbian, "Red Spot", as the Pannonian Basin is for Europe (Horvath et al., 1979). Preliminary test results for boreholes, and all the available investigation data indicate a feasible extraction of geothermal energy near Bogatic of thermal power no less then 150 MW_t.

The hydrogeothermal resources of Macva have not yet been utilized, but there is an interest for it. A design was prepared for 25 hectares of green houses for production of vegetables, fruits and flowers. The project cost estimate is about 43 million USD. However, the project activities have been discontinued due to the economic blockade of Serbia and Yugoslavia.

2. GEOLOGICAL SETTING

The paleorelief of the Pannonian Basin has many shallow and deep depressions filled with Neogene and Quaternary sediments. Macva is situated over one of the depressions. Regional geophysical data indicate southern Macva as the deepest depression area. The greatest thickness of Neogene and Quaternary deposits in it is about 1500 meters, and the smallest about 200 meters in central Macva. Neogene and Quaternary sediments are alternating gravels, sands, and clays. The paleorelief of Neogene sediments in Macva was discovered only in 1981, when the first geothermal well BD-1 was drilled (Fig. 2). At the well site, the paleorelief is composed of karstified Middle Triassic limestones more than 200 meters thick. Karstified limestones of the Middle and Upper Triassic were found in boreholes BB-1 and BB-2 at Bogatic, and Triassic dolomite in BBe-1 at Belotic. Hole BMe-1 at Metkovic did not enter the paleorelief zone, but ended in Neogene sediments.

Exploratory geothermal borehole BZ-2 is the deepest (1500 m) in Macva. Neogene and Quaternary deposits at its site have a thickness of 287 m. The paleorelief zone is composed of thermometamorphosed sandstones and siltstones of unknown age and Neogene plagiogranite. The age of the plagiogranite, determined by the K/Ar method is about 35 million years. These rocks verify their earlier assumed presence in the paleorelief of Neogene sediments in Macva (Milivojevic and Peric, 1984). Besides these magmatic rocks, drilling of BB-2 revealed a 50m thick series of ignimbrite. Its K/Ar age is about 30 million years. Triassic carbonate sedimentary rocks are of Alpine development type, thus their thickness can be up to a thousand meters, as in the Dinarides. This conclusion was verified by magnetotelluric and electromagnetic methods. Rocks in the paleorelief nearest to the surface are located in the Mt. Cer area and at the town of Sabac (Fig. 2). Rocks in the Mt. Cer area are Devonian-Carboniferous schists. All these rocks have a periclinal bed dip to the north, which is a consequence of intrusion and rising of the Cer granitoid pluton (Fig. 2). The pluton's extent on the surface is about 70 square kilometers. Magmatic activity in the Mt. Cer area evolved in several stages; thus the K/Ar age of the granitoid and its vein rocks is 7-17 million years (Milivojevic and Peric, 1986; Milivojevic, 1992). Near Sabac, rocks of the Neogene paleorelief are exposed in the small area. These are Lower Triassic limestones and sandstones.

3. REGIONAL GEOTHERMAL SETTING

The Earth's crust thickness in Macva is the smallest in the territory of both old and new Yugoslavia; it is 25-26 km. Similar values are in Semberia and Srem (Dragasevic et al., 1990). The thickest layer of the crust is a granite layer of about 15 km (Roksandic, 1974).

The terrestrial heat flow under the "sedimentary layer" in Macva is very high. In hole BS-1 at Sabac, it is 112 mW/m^2, and in BZ-2 at Bogatic it is 120 mW/m^2 (Milivojevic, 1989). The value of the heat flow from the upper mantle into the crust is 55-60 mW/m^2 for Macva, and the temperature at the Mohorovicic discontinuity is about 900 ^oC. The lithospheric thickness in Macva, determined by a geothermal model, is about 40 km (Milivojevic, 1993). Macva is situated in the domain of the geothermal anomaly of Serbia (Milivojevic, 1990), which is the southern part of the Pannonian Basin anomaly. The conductive and convective geothermal anomalies of Macva are consequently a result of very high regional values of the terrestrial heat flow in the crust of this Pannonian region.

4. RESERVOIR

Reservoir rocks in the hydrogeothermal system of Macva are highly karstified Triassic limestones, as established in holes BD-1, BB-1 and BB-2. Their thickness is not exactly determined; geological data indicate a minimum of about 500 m, and geophysical data a maximum of about 1000 m (Milivojevic and Peric, 1987). Caprock over the reservoir is Neogene sediments (Fig. 3). Temperature at the reservoir top is 35-78 ^oC. The highest temperature in the reservoir, according to hydrogeothermometers and models of mixing, is from 100 to 110 ^oC (Milivojevic 1989; Gorgieva, 1989). High temperatures at the reservoir top are responsible for the very high conductive heat flow and temperatures in the Neogene sediments.
The heat flow through them is 140-270 mW/m^2, and water temperature in alluvial sediments is anomalously high 14-20 ^oC. In other words, convection in the reservoir generates a high conductive geothermal anomaly in Neogene sediments of Macva, on one hand, and, in a reverse model, anomalously high temperatures in Neogene sediments are the main indication of the limestone reservoir and its high temperatures. For this reason, all holes drilled into the reservoir were located beside wells of artesian drinking water from Neogene sediments in which geothermal gradients were higher than gradients in Macva where the reservoir was not present. Geothermal gradient values higher than 0.07 $^oC/m$ are a positive indication of a limestone reservoir with high temperatures at its base (Milivojevic and Peric, 1984). Consequently, north of Bogatic toward Sremska Mitrovica, temperatures of about 90 ^oC (Fig. 4) should be expected at the top of the reservoir, according to indications.

4.1 Reservoir recharge and origin of thermal water

The reservoir of the Macva hydrogeothermal system is recharged by direct percolation of rainwater on the northern Mt. Cer margin. Here Permian, Triassic and Cretaceous limestones are exposed, through a thin cover of sands and gravels where they are thinnest. The rainwater directly descends below the Drina River, near Loznica, into Triassic limestones in their beds. The thermal water then flows from deep parts of the system in Semberija and Srem (Fig. 3). These hypotheses are largely verified by isotopic tests. Thermal waters in BB-1 and BBe-1 do not contain tritium (^3H), are equal in deuterium (^2H), and differ only in oxygen (^{18}O) in conformity with their temperatures. Thermal water in BD-1 is much lower in its isotopic composition than waters in BB-1 and BBe-1; it contains 13.5 T.U. The same amount of tritium is contained in water of the fault zone in BZ-2, in metasiltstone at depths of 763-767 m. These data indicate that some of thermal waters in the southern part of the reservoir derive directly from infiltrated rainwater and is younger than thirty years. In the northern part of the reservoir, thermal water is older than fifty years and reached the Macva system from Semberija and Srem.

In other words, thermal water in the Macva hydrothermal system is a mixture of young and old waters from different recharge areas (Fig. 5). These and the chemical data indicate an active water flow through the reservoir.

4.2. Borehole Discharges

Karstification of the Triassic limestone aquifers is very high. Caverns in these rocks vary in size from 0.5 m to 17 m. Hence, preliminary hydrodynamic tests in small boreholes gave high transmissivity values of about 5.5 x 10^{-3} m^2/s (Martinovic, 1990).

Borehole yield and relevant data are given in Table 1. Intercepting intervals of drilled holes in the reservoir are open, without any screens. Therefore, thermal water flows in from caverns only through the hole bottom

4.3. Hydrogeochemistry

Total mineralization of the thermal water is low. Its quality approximates that of drinking water. The main chemical constituents of the water are given in Table 2. Thermal waters in all boreholes are of $Na\text{-}HCO_3$ type.

5. RECOVERY AND USE OF GEOTHERMAL ENERGY

The exploitable reserves of thermal water and geothermal energy recoverable from the reservoir of the Macva hydrogeothermal system have not been estimated completely. In our opinion, the recoverable amount of thermal water from limestone and dolomite reservoir in Macva is about 1500 kg/s of 75^oC water, or 150 MW_t of thermal power. This forecast is based on the surface area of the reservoir of about 800 km^2, its great thickness and its extraordinary hydrodynamic character. Large diameter wells can cause a pressure drawdown in the reservoir all of Macva. This will give rise to the geothermal energy rehabilitation in the reservoir. In other words, terrestrial heat flow contributes to the reservoir about 2500 x 10^{12} W of geothermal energy each year, and about 2300 x 10^{12} W of geothermal energy is extracted (without reinjection) for 150 MW_t during the heating season.

Macva is one of the best agricultural regions in Serbia, and Yugoslavia, which makes the geothermal resources in its convective hydrogeothermal system extremely important for food production, heating of homes and green-houses. The chemical composition of the thermal waters is suitable for direct use; for example, calcite scaling in BB-1 will be 900 g/day at a pumping rate of 37 kg/s and temperature of 75 ^oC (Papic, 1992).

6. FUTURE COURSE OF ACTION

Past investigations have not provided complete information on the reservoir extent and thickness. The full extent of the geothermal anomaly has not been determined. The main task for future investigators, therefore, will be to determine these parameters, to give a three-dimensional definition of the regional geothermal system. Also, another test well of a large diameter should be drilled to a depth of 1000 meters, and hydrodynamically tested. The test results should be used in developing a preliminary hydrogeothermal model for computation of necessary reservoir parameters and the best method and rate of thermal water and geothermal energy extraction. Only then can experimental extraction and development of the system be assessed to use the geothermal energy in the agricultural industries.

7. CONCLUSION

The conductive geothermal anomaly in Neogene sediments of central Macva, and the hydrogeothermal convective anomaly in highly karstified Triassic limestones, are the greatest anomalies of their kind in the Pannonian Basin. Present predictions indicate intensive production to be feasible and would use no less than 150 MW_t of geothermal energy in food and flowers production and also in agricultural industries and house heating.

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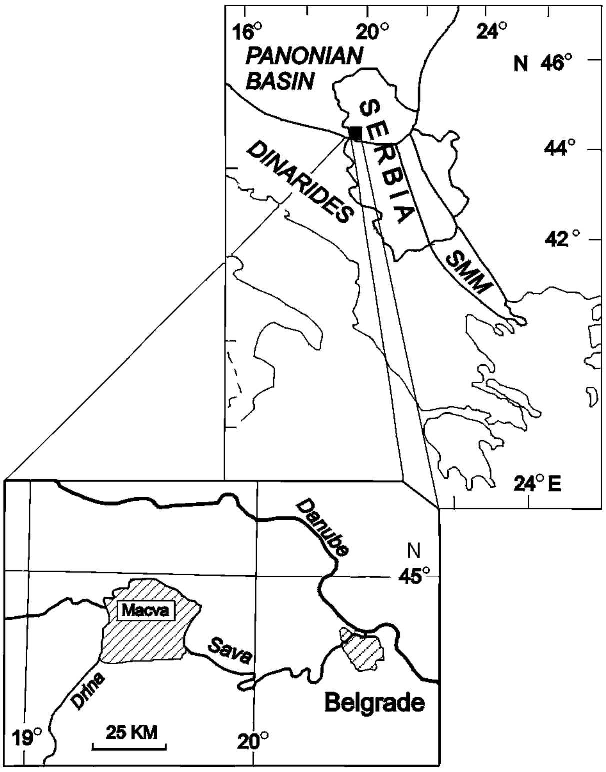

Figure 1 Location of Macva

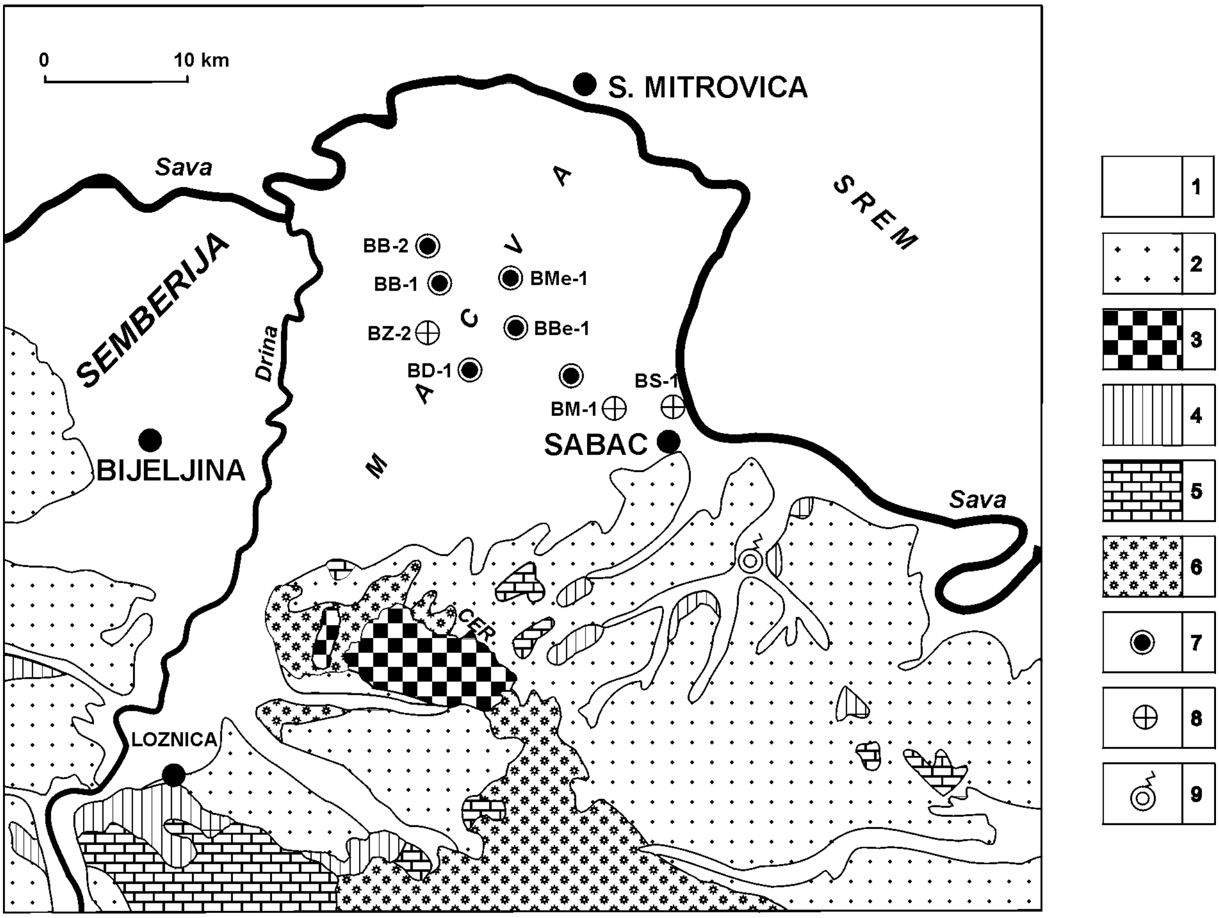

Figure 2. Geological map of Macva and surroundings (1-alluvial sediments; 2-Neogene sediments; 3-Neogene granitoid rocks; 4-Cretaceous limestone; 5-Triassic limestone; 6-Paleozoic schists; 7-geothermal borehole finished in limestone; 8-geothermal borehole not finished in limestone; 9-thermal spring)

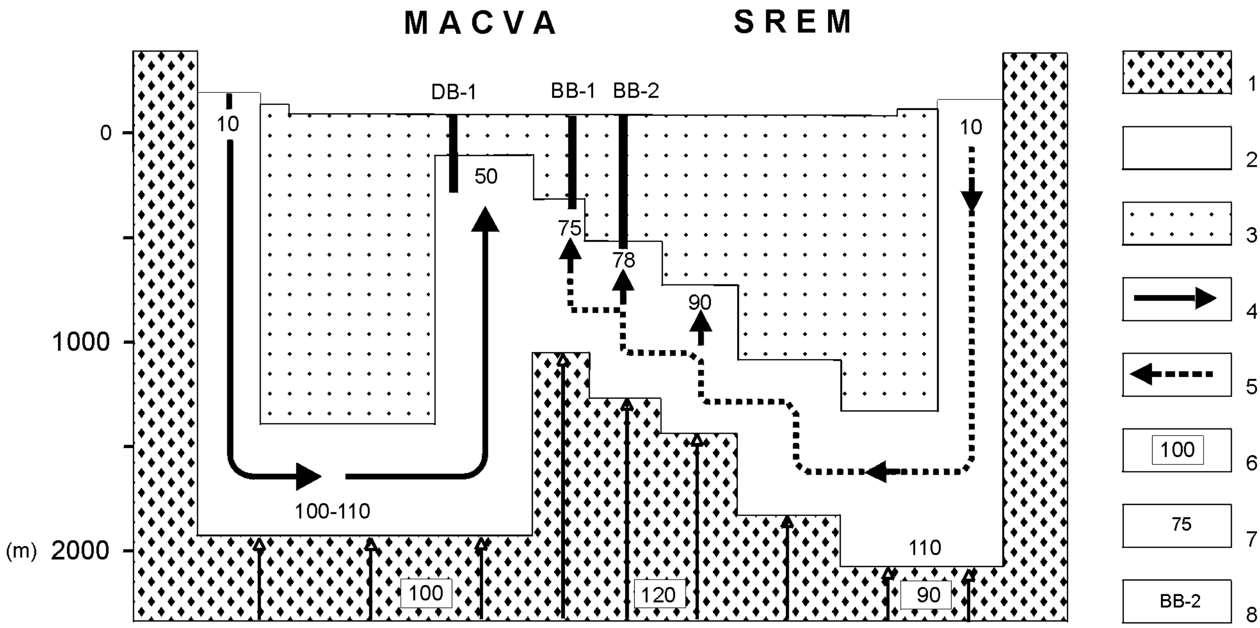

Figure 3. Schematic model of hydrogeothermal system of Macva *(1-caprocks Neogene sediments; 2-reservoir: Triassic and Cretaceous limestone; 3-bedrock:Paleozoic schists; 4-thermal water with tritium; 5-thermal water without tritium; 6-terrestrial heat flow density:* mW/m^2*; 7-temperature on the top of reservoir:* ^oC*; 8-exploratory geothermal borehole).*

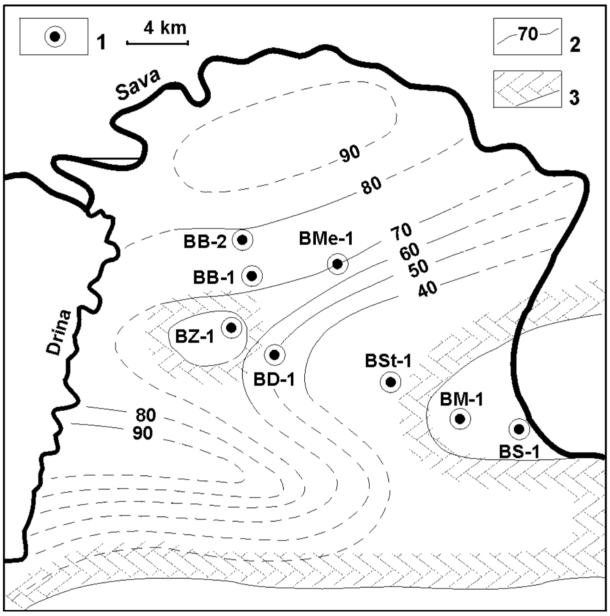

Figure 4. Temperatures at the top of the reservoir (1-exploratory geothermal borehole; 2-isotherm (^{o}C); 3-boundary of reservoir)

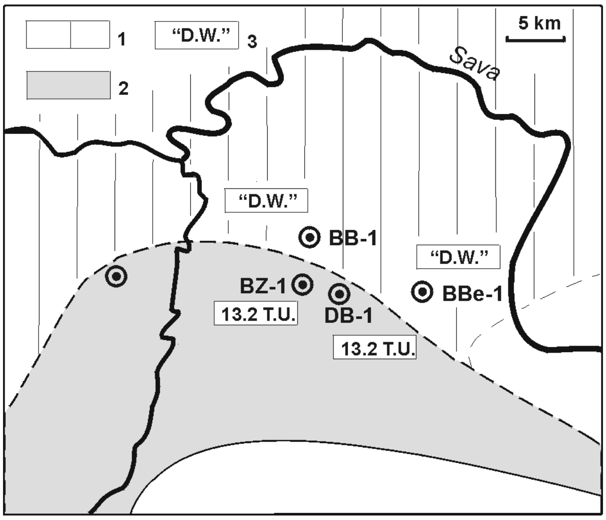

Figure 5. Origin of geothermal water in Triassic and Cretaceous limestones (1-part of the reservoir which contains geothermal water older then 15.000 years; 2-part of the reservoir which contains a mixture of old thermal water and thermal water with tritium; 3-thermal water without tritium).

Table 1. Borehole summary

Borehole	Location	Depth (m)	Borehole interval in reservoir of limestones (m)	Borehole diameter in reservoir of limestones (mm)	Yield (kg/s)	Temperature (°C)	Pressure (bar)
BB-2	Bogatis	618	16	150	61	80	2.7
BB-1	Bogatic	470	58	86	37	75	2.3
BD-1	Dublje	400	193	86	15	50	1.5
BBe-1	Belotic	450	138	118	25	34	1.0
BMe-1[1)]	Metkovic	627	-	-	7	63	-

1) Drilling ended in the Neogene sediment basal series above the limestone reservoir

Table 2. Chemical composition of waters from Triassic limestones and dolomite in Macva

Borehole	T	pH/T	Na	K	Ca	Mg	HCO_3	SO_4	Cl	F	SiO_2	TDS
	(°C)	/(°C)	mg/l									
BB-1	75	7.1/22	155	11	40	10	409	4	107	1.7	64	807
BB-2	80	7.2/25	149	10	47	9	408	2	113	1.9	66	806
BD-1	50	7.2/22	174	13	50	7	450	5	55	3.7	34	884
BBe-1	34	7.1/25	210	9	40	12	555	6	114	1.7	23	980
BMe-1	63	7.1/22	268	17	28	8	898	1	142	2.4	37	1082