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Some experiences in tapping deep thermal waters of the Triassic karstic aquifer in the Pannonian Basin of Serbia

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The Triassic karstic aquifer is the system with the greatest potential for the utilization of thermal waters in Serbia. As an integral part of the Dinaric tectonic unit, the Triassic aquifer extends widely over the western part of the Serbian territory and is characterized by cold waters. In contrast, the same but confined type of aquifer overlain by thick Tertiary sediments in the Pannonian Basin has significant geothermal potential. The major potential for tapping geothermal flow is in the southern and south-western parts of the Pannonian Basin (Srem) and in the adjacent areas of Mačva and Semberija in the Sava tectonic graben. In these areas the Triassic karstic aquifer has been tapped by several boreholes with depths ranging from 400 m to 2400 m. The temperature of the hottest water exceeds 75 °C, while maximal discharge is 40 l/s.

Although the prospect of wider utilization of geothermal energy undoubtedly exists, some Serbian national plans count on a limited contribution of geothermal energy in renewable energy sources of only 4%. This is probably due to the low level of current utilization, and the inefficient use of even some highly productive wells with a high water temperature, such as those drilled in the most prosperous Mačva region.

Keywords: geothermal energy, karst aquifer, Triassic, Panonnian Basin, Serbia

Introduction

In the Pannonian Basin (the Great Hungarian Basin) of the northern Serbian province of Vojvodina, four hydrogeologic (HG) systems were defined and described (Marinović 1982; Aksin et al. 1991). HG system I as the first from the top (Quaternary

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and Middle and Upper Pliocene) is the most prominent and is still exploited today, mostly for the supply of drinking water. HG system II is the next deepest (Pontian, Pannonian–Lower Pliocene and Upper Miocene sediments), while in HG system III (Miocene, Paleogene, Cretaceous) the presence of highly mineralized water has been confirmed during drilling of oil or geothermal wells. The deepest is HG system IV which contains the karstic and karstic-fissured aquifer of Triassic age in the basin's basement. Along with the hydrogeologically productive Triassic aquifer, a wide extent of the HG system IV also contains Proterozoic and Paleozoic impervious rocks. In some deep boreholes in the northeastern part of the basin (Banat) there are, for instance, irregular superpositions; beneath the Paleozoic metamorphic Tisza complex, Middle Triassic limestone and Jurassic ophiolites have recently been drilled (Dulić et al. 2013). Such vertical distribution is evidence of large tectonic movements which, during the Neogene and Quaternary, also resulted in several compressional geodynamic phases. In contrast, in the southwestern part of the Pannonian Basin and its extension into the Sava Graben, Triassic carbonate rocks are overlain by relatively thick, but stratigraphically synchronous Neogene sediments. The results of deep drilling for oil resources, especially in the 1970s and 1980s, provided many new data on the paleorelief of the basin and distribution of geothermal reservoirs. Effective utilization of the thermal waters and their heat is still low in Serbia, but the potential for tapping deep Triassic karstic aquifers exists and some new projects for its development are under implementation or preparation.

Analytical methods

The analysis of the distribution, permeability, and geothermal properties of Triassic carbonate rocks in the Pannonian Basin (Vojvodina) and adjacent areas (Mačva, Semberija) is based on results of drilling of more than hundred oil exploration boreholes as well as several wells drilled directly for the purpose of geothermal energy use.

Čanović and Kemenci (1988) collected and interpreted the results of the drilling of 190 deep boreholes in Vojvodina from 1950–1985 by the national oil company Naftagas, based in Novi Sad. Because the primary task was to develop petroleum projects, a large portion of cores from the drilled boreholes was not saved, which limited paleontological, lithostratigraphical and petrological analyses. However, Čanović and Kemenci (1988) proved that a complete Mesozoic system is developed in the pre-Tertiary basement, while tectonic relationships between individual units were found to be very complex.

Milivojević et al. (1995), Milivojević and Martinović (2000) and Martinović (2008) studied terrestrial geothermal flux and its potential along the southern and southwestern margins of the Pannonian Basin and the adjacent Mačva Basin, and designed several geothermal wells. Their results proved the high potential of the Triassic carbonate aquifer for wider utilization of geothermal energy in the investigated areas.

This overview highlights some of the major findings of these previous studies, and discusses the shortcomings of some of recent statements which aim to generalize the high geothermal prospect of Triassic aquifer wherever drilled. Although found to be very promising for geothermal utilization in several locations, the confined aquifer is not equally permeable everywhere and its potential very much depends on the cover thickness and lithology as well as local tectonic conditions.

Results

The basement of the Pannonian Basin in Serbia represents an extension of the Alpine geostructural branches (Dinarides and Carpathians), including metamorphic, magmatic and sedimentary rocks of the Tiszia Mega-Unit, Serbian–Macedonian Massif and Vardar Zone. The basement of the Tertiary sedimentary complex consists of various lithostratigraphical units of Paleozoic and Mesozoic ages which lie at depths ranging from several hundred meters in the southern and southwestern parts to over 3000 m in the central and northeastern parts of the basin (Banat region).

Lower, Middle, and Upper Triassic calcareous–clayey siltstone, sandstone, sandy limestone, dolomitic limestone and reefal limestone were found in deep boreholes in eastern and northern parts of the basin (Fig. 1). The thickness of drilled Triassic sediments has been estimated to range between 11 m and 620 m, while the depth is in the range from 470 m to 2,890 m (near the Hungarian border).

Čanović and Kemenci (1988) stated that environmental conditions in the Lower Triassic were similar to those characteristic of the Alpine system: clastic and carbonate rocks were deposited along with evaporites in the hypersaline lagoons and sabkhas. Several deep wells along the northern part of the basin and near the Hungarian border confirmed the presence of Lower Triassic rocks. The Middle and Upper Triassic horizons are also present in the study area and consist predominantly of carbonate rocks.

Middle Triassic (Anisian) sediments were deposited on the carbonate shelf. The shallow water facies consist of organogenic, detrital and rather dolomitized limestone (Čanović and Kemenci, 1988). The basin exhibited a trend to subside during the Late Anisian, and hemipelagic sediments were deposited. This situation also extended into the Early Ladinian.

Čanović and Kemenci (1988) stated that shallow water with a predominantly reefal and perireefal depositional environment continued through the Late Triassic (Carnian, Norian and Rhaethian stages): the Upper Triassic carbonates contain typical reefal and perireefal biocenoses, while microfacial features can be fully correlated with the Triassic in the Alps, Dinarides and Carpathians. Similarity with the Triassic sediments in the Szeged–Békés area is also evidenced.

There is insufficient evidence to prove whether there was a break of sedimentation at the end of Late Triassic but various basinal and pelagic Jurassic and Cretaceous formations confirmed further deepening of the basin. Therefore a large part of older

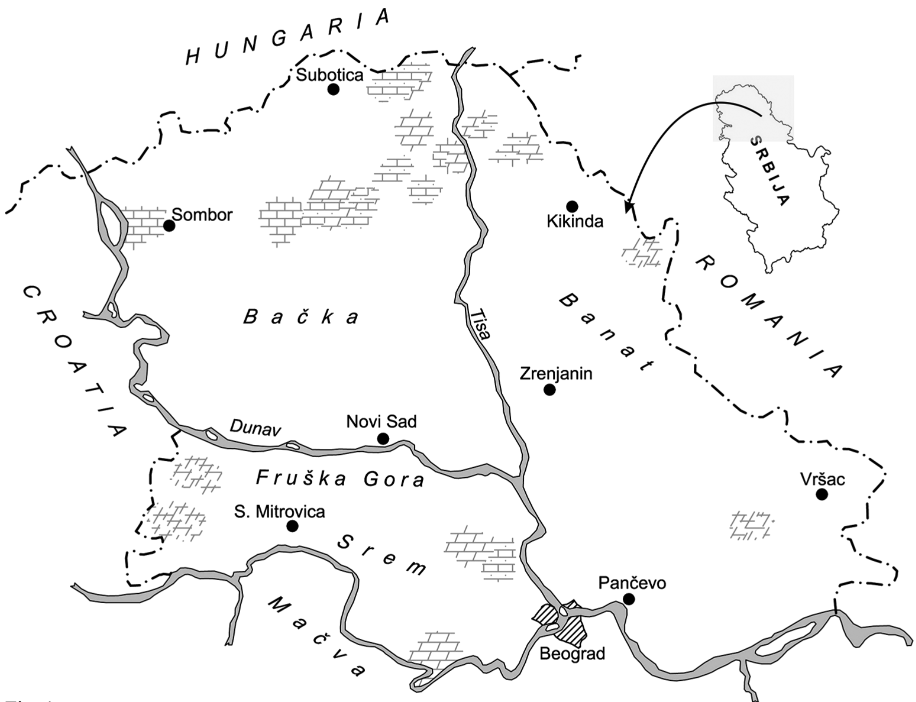

Fig. 1
Location map and distribution of Triassic carbonates in the basement of the Pannonian Basin in Serbia

Triassic rocks was submerged and covered by younger Mesozoic and Tertiary sediments.

The stratigraphic column of Triassic rocks in the Vojvodina area (after Čanović and Kemenci 1988) is shown in Fig. 2.

Similar lithology characterized Triassic formations in the southern part of the basin, and only very small facies variations were found. Further south, in the Sava Graben (Srem region) Triassic carbonate sediments were encountered at a minimal depth of 10 m from the horst structure of Fruška Gora where they crop out (Fig. 1). In adjacent localities of the Sava Graben (Mačva, Semberija) they are encountered at a depth of 1,192 m and 2,410 m, respectively. The thickness of the Triassic carbonate sediments ranges from 21 m to 400 m.

The Triassic karst aquifer is formed in lithologically relatively homogeneous structures of predominantly carbonate facies. The exception is the lowermost part where clastic, carbonate and evaporitic rocks of Seisian and Campilian stages prevail. The Middle and Upper Triassic horizons consist of well-bedded or partly massive limestone, dolomitized limestone, but rarely of marly limestone. Therefore a unique karstic and karstic-fissure type of aquifer exists, but there are large local vertical and lateral variations in dimensions of created voids, small channels and cavities, as privileged groundwater pathways. The Triassic aquifer is a typical non-homogeneous anisotropic medium with various degrees of effective porosity. Moreover, local tectonic conditions and above all compression of overlain sediments resulted in compaction as well as in secondary filling of created voids, by sediments which had been transferred by deep circulating flows. Unfortunately, as the primary task of the Naftagas survey primarily concentrated on the search for oil, little data concerning aquifer testing and obtained permeability parameters is available.

Most of the deep Naftagas boreholes were drilled in the northern part of the Pannonian Basin (Banat and Bačka regions), and very few exploration wells are located in the southern part (Srem). This is simply the result of previously conducted deep seismic surveys and the confirmed lesser depth to the pre-Tertiary basement in the south. In contrast, due to the great depth to the aquifer, complex tectonics and uncertain results, no deep wells aiming primarily to tap geothermal flux were drilled in the northern part. Figure 3 shows a cross-section over the northern part of Vojvodina and the position of the Triassic aquifer in five drilled wells along the W–E section. The depth to the Triassic rocks varies from 470 m to 1270 m, and in all of the wells the aquifer is directly overlain by Neogene sediments. Further to the east, Triassic rocks can be covered by Cretaceous flysch and Jurassic ophiolites or overthrusted by Proterozoic or Paleozoic crystalline rocks (Dulić et al. 2013).

Among several Naftagas oil wells drilled in the south (Srem) the shortest and most promising one is the Kup-1/H

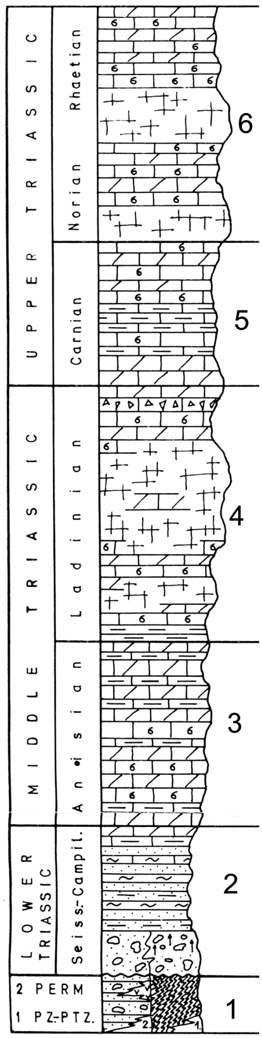

Fig. 2
Lithostratographic column section of Triassic sediments in Vojvodina (after Čanović and Kemenci 1988). Legend: 1. Permian or Paleozoic / Proterozoic basement; 2. Lower Triassic clastic carbonates and evaporitic (anhydrite) rocks; 3. Anisian organogenic detrital limestones and dolomitic limestones, sporadically impure marly limestones; 4. Ladinian bedded or massive reefal limestones, marley limestones in lower part, and carbonate breccia in upper part; 5. Carnian basinal and pelagic dolomitic and marly limestones; 6. Norian and Rhaetian dolomitic and brecciated limestones.

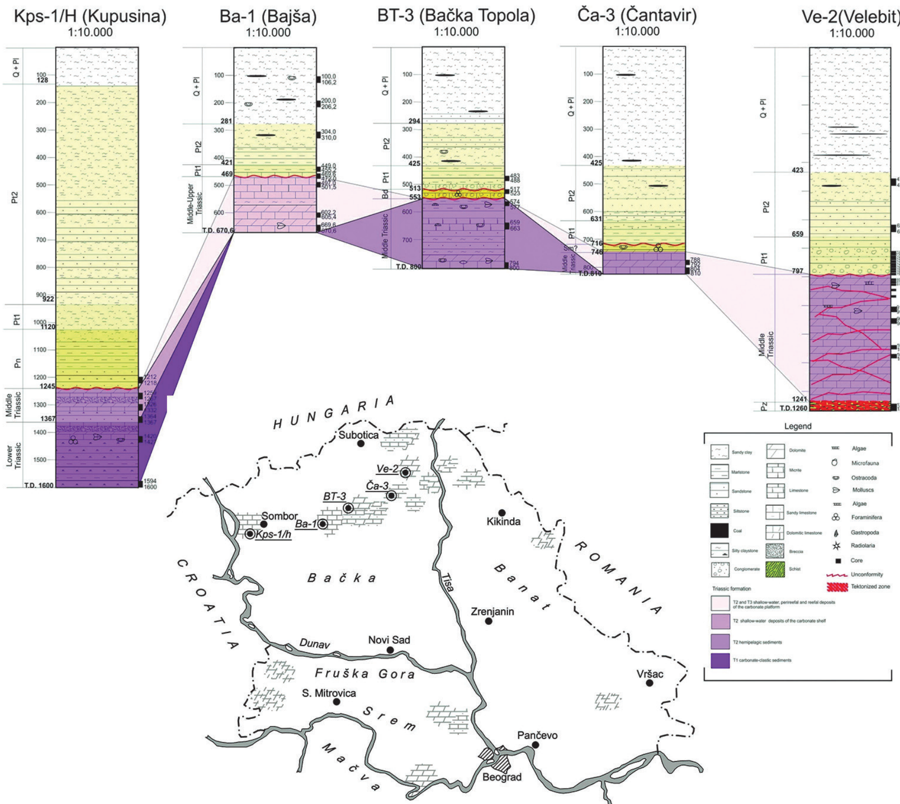

Fig. 3
Correlative W–E cross-section of the Nafta-Gas wells penetrating Triassic carbonate rocks in Bačka region (northern part of Vojvodina)

well in the village of Kupinovo along the Sava River bank (350 m deep). The initial artesian discharge of that well was 30 l/s, while the temperature of low mineralized waters (TDS: 674 mg/l) was around 40 °C.

The basin with most potential for utilization of geothermal energy is the southern rim of the Pannonian Basin and the transitional part toward the Dinarides represented by the Sava Graben in the Mačva region, where several highly productive deep boreholes were drilled into the Middle and Upper Triassic aquifer (Table 1). Hydrothermal investigations in Mačva started in 1981 by exploratory drilling of DB-1 in the village of Dublje. An artesian discharge of thermal water of 15 l/s with a temperature of 50 °C was obtained after Triassic limestone was reached beneath Neogene sediments at the depth of 207.5 m.

The most productive wells are those drilled in the village of Bogatić (Fig. 4). Their depths are in the range of 418–670 m, yields are about 40 l/s and water temperatures 75–80 °C (Martinović and Milivojević 1998).

Table 1. Geothermal wells of Mačva region (after Milivojević and Martinović 2000)

Well (location)	Discharge (l/s)	Temperature (°C)	Potential thermal power (MWt)
BB-1 Bogatić	37	75	8.5
BB-2 Bogatić	60	80	15.1
DB-1 Dublje	15	50	1.9
DB-2 Dublje	10	30	0.4
BBe-1 Belotić	12	35	0.8
BMe-1 Metković	15	67	2.9

Several other wells have also been drilled in the wider area. Their depth ranges from 400 m to 2,400 m. The most recent is the deep borehole GD in the village of Slobomir in Semberija, on the border between Serbia and Bosnia and Herzegovina. The water has a temperature of 75 °C, while optimal discharge is 40 l/s for a draw-down of 8.3 m.

The GD well was drilled for commercial purposes, for the existing spa center and the Olympic swimming pool. The wells in Mačva, although primarily drilled for greenhouse heating and recreational purposes, have not been properly utilized for

Fig. 4
Borehole BB-2 in Bogatić (photo M. Martinović)

more than 20 years. The uncontrolled thermal overflow from some of the wells even polluted the surrounding cultivated land. Finally, some recent development projects have started to put the geothermal flow under control and create a basis for its wider multi-purpose utilization.

Discussions

The Triassic karstic aquifer in the Pannonian Basin and adjacent area is a typical confined aquifer system. Triassic outcrops are present, but to a limited extent in the Dinaric karst of NW Serbia (Pocerina, Lelić karst) and SW Romania (Carpathians chain – Apuseni, Bihor Mts.), as well as in horst structures located in Serbia (Fruška Gora) and in Hungary (Mecsek, Bükk). Therefore aquifer recharge from the unconfined aquifer part is very slow and limited. Some recharge is effectuated by waters percolating from overlying Tertiary sediments, but due to their great thickness the aquifer can probably only be replenished by a very limited amount of water, roughly assessed by some previous studies not to exceed 2–3% of the rainfall. The fact that discharge is much higher than recharge is evidenced by the depressurization of artesian wells which has been noticed at several drilled locations throughout the region. However, the tapped amount and the free overflow of thermal waters are still relatively small and stored reserves still enable artesian flow. Greater recharge is taking place in marginal parts of the Pannonian Basin such as in the Mačva or Srem region where the most productive aquifer layers were found. In this area, the aquifer is shallower and is covered by thinner Neogene deposits which enable more intense percolation and higher effective recharge.

The cross-section from the southern marginal part and Mačva to the northern part of the Pannonian Basin in Serbia and the border with Hungary (after Martinović

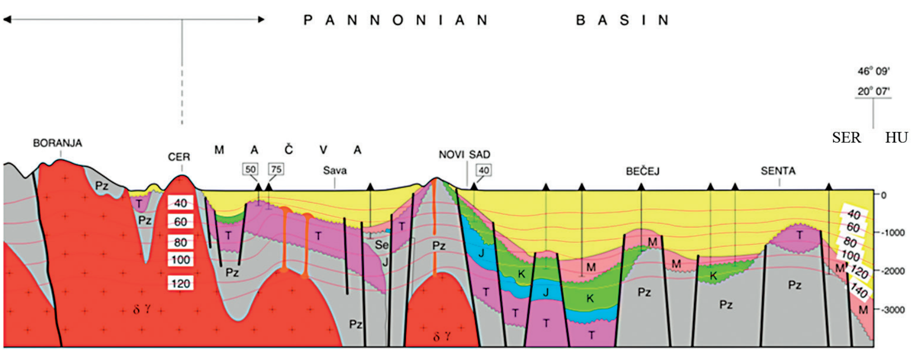

Fig. 5
S−N cross-section of the Pannonian Basin from Mačva (S) to the Hungarian border (N) (after Martinović 2008). Legend: Pz – Paleozoic basement, T – Triassic karstic aquifer, J – Jurassic pelagic sediments, Se – Jurassic ophiolites (serpentinites), K – Crecatacous rocks, δγ – Tertiary granodiorites, M – Miocene sediments, 50 – estimated water temperatures at certain depths

2008) is presented in Fig. 5. The section crosses the horst structure of Fruška Gora and shows the depth and thickness of the Triassic aquifer as well as estimated water temperatures. The geothermal gradient is generally in the range of 1 °C / 20 m.

With the deepening of the aquifer in the northern direction, pressure on the aquifer system also increases. In the S–N section the greater depth of the Triassic rocks is in the northern part. Similarly, the depth to the basement is shallower in the western part of the basin than in the eastern where a large depression exists (Fig. 3). Therefore, the maximal depth and largest pressure of the Triassic aquifer characterizes the NE part of the basin (Banat region). However, high pressure does not correspond with the large permeability, and in accordance with sporadically conducted tests of Naftagas wells, Triassic carbonates might be of very low permeability in certain horizons due to thick overlying sediments, including flysch.

Values of the terrestrial heat flow density under most of Serbia are higher than the average for continental Europe. The highest values (> 100 mW/m^2) are in the Pannonian Basin and in Mačva (NW Serbia), but also in the Serbian–Macedonian massif in the central part of Serbia (Milivojević et al. 1995). According to current knowledge, up to a depth of 3,000 m there are 60 convective hydrogeothermal systems in Serbia, while in the Pannonian Basin and in thick sedimentary complexes conductive systems prevail. This conclusion is based on observation of 81 deep boreholes drilled mainly for oil exploration and later adapted as geothermal wells. The majority of them, 58 boreholes in total, were drilled between 1977 and 1988 with a total drilled depth of about 50,000 m. The total potential yield of these wells is about 550 l/s (Milivojević et al. 1995), resulting in a heat capacity of about 48 MW (calculated as $\Delta T = T - 25$ °C), but not all of them are linked to the Triassic aquifer.

The most promising ones for further geothermal prospection and energy utilization is the Mačva region. Based on results obtained from tested wells listed in Table 1, Milivojević and Martinović (2000) and Martinović (2008) created a hydrogeologic model, presented in Fig. 6. This model shows that dominant recharge by "young" water which contains tritium, is taking place in the south, while the contribution in the north is from the "older" water without tritium. The model also estimates the maximal reservoir (inner) water temperature of around 100–110 °C in the deep pockets located at the depth of 2000 m.

Martinović (2008) also estimated the terrestrial heat flow in Mačva based on the data of direct temperature measurements in deep wells, or indirectly determined values of heat conductivity of the substrates that were detected at relevant geothermal wells. The level of terrestrial heat flow in Mačva is very high, in the range of 112 mW/m^2 to 120 mW/m^2. The depth of the lithosphere in Mačva is estimated at about 40 km, while the temperature at Mohorovičić discontinuities should be about 1,000 °C.

The total geothermal energetic potential of the waters from the Triassic limestone and dolomite in Mačva is the equivalent of about 200×10^6 tons of oil equivalent (toe; Martinović 2008). Forecasting total reserves of geothermal energy in the reservoir (substrate + water), a value of about 550×10^6 toe has been obtained.

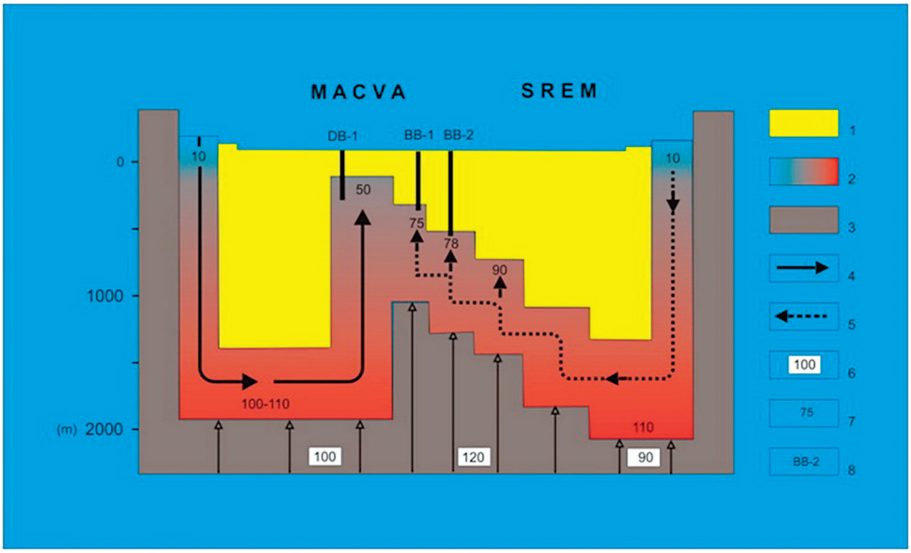

Fig. 6
Hydrogeological S–N conceptual model of Mačva (S) – Srem (N) region (after Martinović 2008). Legend: 1. Neogene sediments, 2. Main geothermal reservoir: Triassic and Cretaceous rocks, 3. Paleozoic basement, 4. “young” thermal waters (with tritium), 5. “older” thermal flux (no tritium), 6. thermal flux (mW/m^2), 7. maximal temperature in the reservoir (°C), 8. geothermal wells

Martinović (2008) suggested the optimal pumping rate of the wells in Mačva to be around 300 l/s resulting in 75.3 MWt. He also forecasted effects of an extraction of 300 l/s for a period of 30 years in the village of Bogatić (Table 1) on the created mathematical model. Local drawdown of 60 m (with point maximum of 80 m) when compared with an initial artesian pressure has been obtained. Taking into consideration current potentiometric pressure this corresponds with a water table 40 m below land surface (Martinović 2008). A large portion, or 80%, of the drawdown would be effectuated during the first five years, while further average annual drawdown would average 1.2 m/year. Finally, Martinović suggested the construction of a doublet system in Bogatić with three injection wells. By injecting an equivalent yield of 300 l/s, the estimated drawdown should be 15–20 m below land surface after 30 years of such a system operation.

The estimated geothermal energy in Triassic limestone and dolomites could be used to build heating systems for the nearby city of Bijeljina in Bosnia and Herzegovina (50–100 MW) or for the agro-industry in Mačva (up to 400 MW). Some preliminary estimates concerning the construction of geothermally-based heating systems (a few small cities with one connection system) or greenhouses (50 ha) revealed a required investment of roughly 70 million euro for each of these projects.

Implementation of this and several other projects in Serbia will improve the global situation of the utilization of geothermal energy. This will also enable the verification of the prospect for wider geothermic use as well as the revision of some Serbian national plans, which count on a limited contribution of geothermal energy in renewable energy sources of only 4%. The latter is a result of the currently still low level of use of previously drilled deep wells with thermal waters.

Conclusions

Because of their shallower depth and larger extension in paleorelief, the Triassic carbonate sediments in the southern and southwestern part of the Pannonian Basin (Srem) and in the adjacent area (Mačva, Semberija in the Sava tectonic graben) have the greatest potential for tapping geothermal flow. In these areas the Triassic karstic aquifer has been tapped by several boreholes at depths ranging from 400 m to 2400 m. The hottest water has a temperature of 75 °C, while maximal discharge is 40 l/s (Slobomir).

Although generally well fractured and karstified, not all Triassic horizons are promising for tapping and utilization. The Triassic carbonate aquifer is typically a non-homogeneous anisotropic medium with variable porosity degrees, both in the vertical and lateral directions. Marly and clayey sequences present in the sequence are additional limitations on the productivity of Triassic aquifer. And finally, when thick and compact impermeable rocks such as Cretaceous flysch overlie Triassic carbonates the latter are usually compressed and their porosity is further reduced.

Such a scenario has been proven by several boreholes in the Bačka and Banat regions of the Serbian province of Vojvodina. In some cases Triassic limestone is overthrusted and sandwiched between metamorphic rocks of the Tiszia Fm. and underlying Jurassic ophiolites. The permeability of Triassic rocks is then very low and the presence of geothermal flow is limited.

The most promising from a geothermal point of view are, therefore, limestone or dolomite covered exclusively by Tertiary sediments.

Acknowledgement

This article is dedicated to our colleague and friend Mića Martinović, Scientific researcher of the University of Belgrade, Faculty of Mining & Geology who passed away in 2011 while still working on his doctoral thesis concerning geothermal research and applications in Serbia. This paper also contains some of his findings regarding Mačva, geothermally the most promising region in all of Serbia.

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