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The Possibilities for Electric Energy Production from Geothermal Energy in Serbia

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ABSTRACT

Geothermal investigations in Serbia began in 1974, after the first world oil crises. In 1990, a first assessment of geothermal resources has been made for all of Serbia. The territory of Serbia has favorable geothermal characteristics. There are four geothermal provinces. The most promising are the Pannonian and Neogene magmatic activation provinces. Age of certain granitoid rocks and their volcanic products is estimated using K/Ar method. Age of the examined rocks ranges from 30 to 10 million years. The analyses are made for an estimation of the energy potential in geothermal resources. For the granitoid plutons of Serbia, the age has been found dependent on hypsometric position of sampling sites. This may be explained by magma solidification inside the pluton 10 to 13 million years later than that of its upper portions. This is very important for the estimation of its present geothermal resources, or an estimate of its available HDR resources. Smith & Shaw, 1975 showed that granitoid massifs of Kopaonik, Cer and Golija are feasible for exploitation of HDR geothermal resources. This is expected to be corroborated by the next geothermal exploration and a new age estimation by K/Ar method.

1.INTRODUCTION

The assessment of the potential of Serbian geothermal energy resources and the latest world findings on geothermal energy indicate that this energy resource is capable of participating significantly in Serbia's energy supply and demand.

The available results show that with a comprehensive and effective development program, by 2015 the hydro-geothermal resources will be able to substitute the amount of energy provided by no less than 500.000 tons of oil on an annual basis. With the direct use of geothermal heat pumps it will be possible to reduce the consumption of electric power for at least 1.200 MW_e. These are generally the basic goals that should be achieved.

Apart from the already mentioned conventional geothermal resources, whose development has been brought practically to perfection, the use of hot and dry rock (HDR) geothermal resources, owing to the good results and the success achieved in Europe, is now becoming a reality regarding both energy and economic viability. Serbia is considered to be a country rich in geothermal resources that appear as heat originated from hot and dry rocks of large Neogene granitoid intrusions. Therefore, by applying the latest development results presently achieved in Europe in the field of HDR technology Serbia is capable of becoming a major producer and exporter of electric power. In Serbia the use of hydro-geothermal energy for the generation of electric power is possible at several localities applying "flash steam" technology and the "binary system" method. This paper presents the general features of prospective localities in Serbia that are to be used for the generation of electric power implementing the HDR and the previously mentioned technical know-how.

2. REGIONAL GEOTECTONICS

Large geotectonic units (Figure 1) present in Serbia belong to the Alpine Orogeny: Dinarides, Serbian-Macedonian Massif, Carpatho-Balkanides, and Pannonian Basin, and a small part of Mesian Platform [3].

The Dinarides occupy the largest part of Serbian territory and are mainly Mesozoic rocks, the most significant of which are thick deposits of karstified Triassic limestones and dolomites, Jurassic ophiolitic melange and Cretaceous flysch deposits.

The Rhodope Mountains, or the Serbian-Macedonian Massif (SMM), is composed of very thick Proterozoic metamorphic rocks: gneisses, micaceous shales, various schists, marbles, quartzites, granitoid rocks, magmatic rocks, etc. The Proterozoic complex of the Serbian-Macedonian Massif extends across eastern Macedonia and northern Greece into Turkey and farther eastward. The Serbian portion of the Serbian-Macedonian Massif is actually the upper part of the crustal "granite" layer. This Massif includes magmatic, or intrusive-granitoid and volcanic rocks of Tertiary age [9].

The Carpatho-Balkanides were formed in the Mesozoic as a carbonate platform separated from the Dinarides by the Serbian-Macedonian Massif. This unit is dominantly composed of Triassic, Jurassic, and Cretaceous limestones. The Pannonian Basin, or its southeastern part in Serbia, consists of Paleogene, Neogene and Quaternary sediments with a total maximum thickness of about 4000 meters.

According to the latest interpretations of the tectonics of Balkan Peninsula, which are the result of the applied "global tectonic" theory, the Earth's crust in the territory of former Yugoslavia consists of terranes. The terranes in the central and western parts of the Balkan Peninsula are the consequence of subduction that occurred during the Jurassic Period [4]. According to these authors the Earth's crust on the territory of Serbia consists of the following terranes: The Dinaric Ophiolite Belt terrane (DOBT), The Jadar Block terrane (JBT), The Drina-Ivanjica terrane (DIT); The Vardar Zone composite terrane (VZCT), The Serbian-Macedonian composite terrane (SMCT) and The composite terrane of Carptaho-Balkanides (ESCBCT). The distribution of the terranes is given in Figure 1.

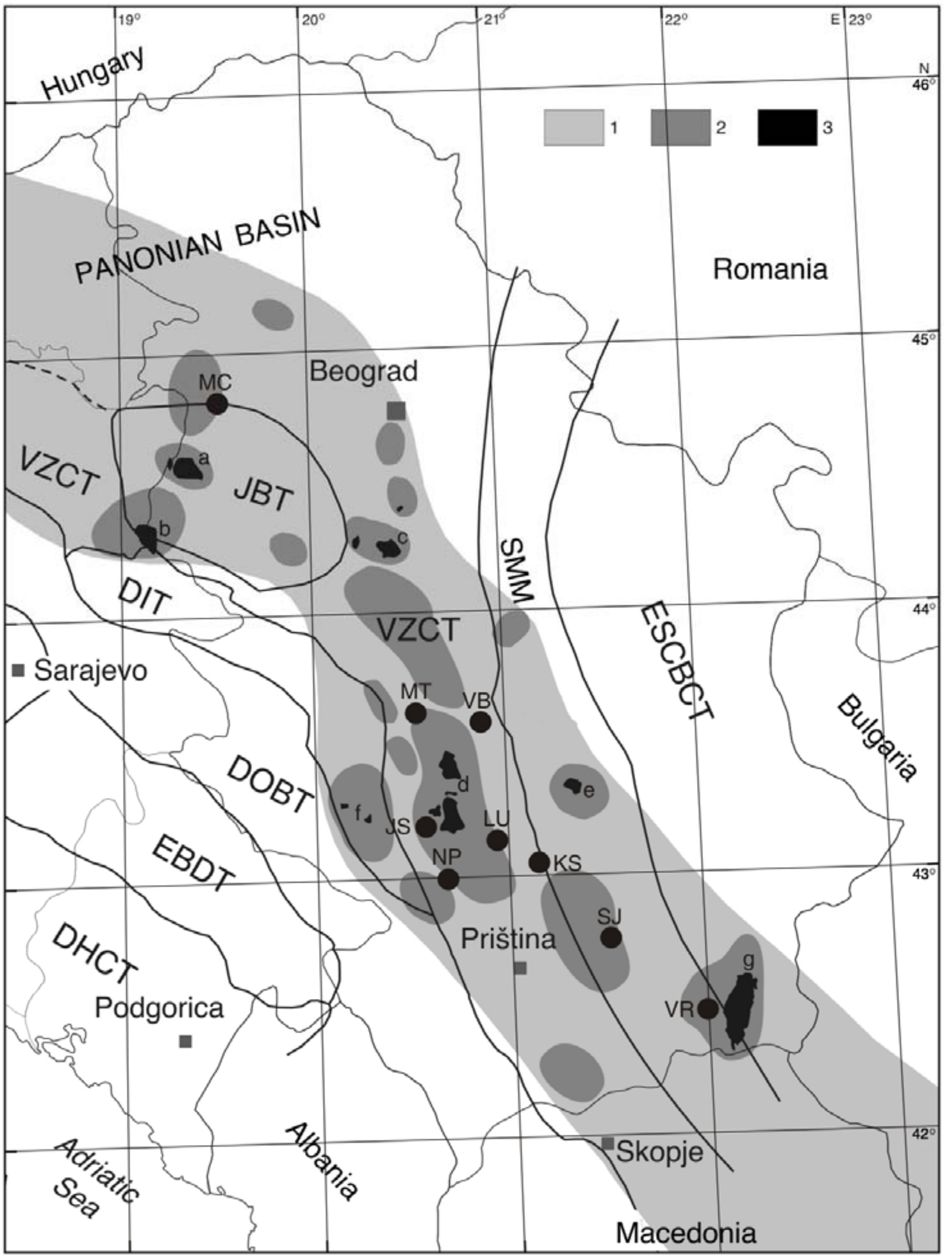

Figure 1. Locations of magmatic rocks occurances of neogene age at the territory of Serbia (explantion in text for geotectonic units-terranes),

(1-zone with occurrences of volcanic rocks; 2-granitoide pluton; 3-granitoide at the surface: a-Cer; b-Boranja; c-Bukulja; d-Kopaonik; e-Jastrebac; f-Golija; g-Surdulica)

3. GEOTHERMAL BACKGROUND

Geothermal characteristics of Serbia are very interesting. The Earth's crust varies in thickness, increasing to the south. This thickness is uniform, about 25-29 km, in the Pannonian Basin area [1]. South of it, in the Dinarides, the thickness increases to about 40 km in extreme southwest Serbia. In the Serbian-Macedonian Massif, the crustal thickness is about 32 km, and in the Carpatho-Balkanides from 33 to 38 km.

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, Serbian-Macedonian Massif, and in the border zone of the Dinarides and the Serbian-Macedonian Massif, or the terrain of Neogene magmatic activation. These values are the lowest in the Mesian Platform [6]. The mentioned high heat flow densities indicate the presence of a geothermal anomaly [9] which is certainly an extension of the geothermal anomaly of the Pannonian Basin [5]. The thickness of the lithosphere, estimated on a geothermal model [10], is least in the Pannonian Basin, Serbian-Macedonian Massif, and its border zone on the Dinarides, only 60 km. In the Carpatho-Balkanides and the rest of the Dinarides, this thickness is up to 150 km. The lithosphere is the thickest in Mesian Platform - from 160 to 180 km.

4. GEOTHERMAL RESOURCES POTENTIALLY VIABLE FOR THE GENERATION OF ELECTRIC ENERGY

As determined by currently developed technologies Neogene and Quaternary granitoid intrusions are the most suitable environment for the generation of electric energy based on the use of geothermal heat from dry rocks. The territory of Serbia is rich in Neogene granitoid intrusions. During the Neogene period a very strong acid magmatic activity took place in the territory of Serbia. This activity started by the end of the Paleogene period and lasted until the Quaternary period. In the course of this long-lasting process large bodies of volcanic rock were formed along with large granitoid rock intrusions. Granitoid rocks are in fact magmas that were formed through partial melting of continental crust under the effect of thermal domes in the upper crust during and after the subduction of the Dinaric plate from the west under the continental crust of the Serbian-Macedonian massif (SMCT) and the Pannonia Basin. The magmas formed in this way while moving upwards enter into differentiation processes creating magmatic materials of different viscosity.

Chronologically speaking, during the Neogene period, the first rocks bodies that were created in the territory of Serbia were the volcanic rocks and the intrsive rocks were formed subsequently. The volcanic rocks were formed in the following series: andesites and dacites followed by latites and quartzites and associated with large amounts of pyroclastic material. Intruded rocks were formed in the following series: quartz diorites - granodiorites - quartz monzonites. Intruded magmatic rock bodies due to their superior density and longer cooling period always solidify after the volcanic rocks.

In the territory of Serbia, the volcanic rocks were formed during clearly differentiated stages, which coincided with the periods of dilatation and cracking of earth's crust making way for magmas to reach the upper layers of the earth's crust and even the surface. Contrary to volcanic rocks, the formation of intruded rocks was continuous. That is, over a long period the inner layers of earth's crust melted forming magmas. These molten rocks continuously moved, throughout a long period of over 30 million years, towards the earth's surface, or pushed upwards the previously formed magmas.

In the territory of Serbia the granitoid and volcanic rocks occupy a wide area extending from north-west towards south-east. This area also occupies the territory of eastern Macedonia and from there it extends over northern Greece reaching Turkey and continues further to the east. A general feature characteristic for magmatic formations in this area is that the age of magmatic rocks decreases towards the south or towards the east.

In the territory of Serbia there are nine granitoid plutons exposed by erosion: Cer, Boranja, Kosmaj, Bukulja, Zeljin, Kopaonik, Golija, Jastrebac and Surdulica. Figure 1 shows the position of these plutons. According to the position of volcanic rocks that follow the granitoid plutons or are situated in separate areas it is possible to determine that their underground spreading is larger than their surface spreading. It may also be concluded that in the deeper parts of earth's crust these plutons are probably connected and that, most likely, there are more hidden, yet undiscovered granitoid plutons. One of such hidden granitoid plutons, was discovered during geothermal explorations that took place in Macva [11].

In order to evaluate accurately the geothermal potentiality of granitoid plutons it was necessary to carry out geo-chronological investigations applying the K/Ar method [6]. Since these investigations were not detailed they may be considered as preliminary, but nevertheless they were very useful indicating favourable HDR geothermal resources. These investigations determined that the earliest part of the pluton are the ones that had solidified primarily, that is, the ones that are presently situated near the contact zone (boundaries) with adjacent non-magmatic rocks, which were during the initial solidification stage the closest to former surface. In the majority of plutons the age of such part is about 27×10^6 years. The cooling of inner and deeper (>1,5 km) part of plutons was much slower and therefore their age is estimated to approximately $17\text{-}9\times10^6$ years.

With a view of evaluating the present geothermal potentiality of granitoid plutons in Serbia it is possible to make use of the complex and detailed explorations of presently magmatic and geo-thermally active granitoid plutons in the area of Monte Amiata and Larderello in Italy [2]. According to this author, the previously mentioned plutons had been formed over $4\text{x}10^6$ years ago. Presently they are situated at depths ranging from 5 to 7 km and they spread over the area of about 1300 km^2. Their cooling rate ranges from 15 to 20 ^{o}C/10^6 years. Considering their vast underground spreading and the underground spreading of the majority of granitoid plutons in Serbia, which are larger than 1000 km^2 and taking into account the geological composition and the thermo-physical properties of the terrain in which they had been consolidated it is most likely to expect that in Serbia the cooling rate of large Neogene granitoid plutons will range from 20 to 30 ^{o}C/10^6 years. This may be adopted with considerable certainty, for example, for the granitoid pluton of Kopaonik, which spreads over 2000 km^2 and occupies the volume of at least 10,000 km^3 [6]. Using volumetric methods it was possible to calculate the expected geothermal resource potential of geothermal energy in the granitoid pluton of Kopaonik. Reaching the depth of 7 km (30 years of exploitation with the utilize factor of 1%) these reserves were estimated to 8,000 MWe [6]. Favourable preliminary indicators for large plutons were based on Smith & Shaw diagrams (1975).

Apart from previously mentioned granitoid intrusions, favourable prospects for the generation of electric energy also exist in the Pannonia Basin bedrock owing to high temperatures and hard schistose rocks. The area of western Srem is particularly outstanding in this respect. In this area in the oil well, at the depth of 3,500 m, the temperature of 196 ^{o}C was measured immediately after drilling.

With the use of "flash steam" technology (T>130 ^{o}C) and "binary system" technology (T>80 ^{o}C) it is possible to generate electric energy from geothermal fluids that have considerably low temperatures. In the territory of Serbia there are several convective hydrogeothermal systems in which the highest temperature of hydrogeothermal fluids may reach 150 ^{o}C. Owing to this fact it may be stated that the generation of electric energy is possible in this region.

Convective systems with reservoirs of hydro-geothermal fluids that enable the production of electric energy are situated in the area of Neogene acid magmatic formations. The localities favourable for such purposes are: Vranjska spa (VR), Josanicka spa (JS), Sijarinska spa (SJ), Mataruska spa (MT), Vrnjacka spa (VB), Lukovska spa (LU), Kursumlijska spa (KS), Novopazarska spa (NP), Macva (MC), (Figure 1). The results obtained from the hydro-geo-thermometers installed in all these localities were used to calculate the highest temperatures that may be expected in the reservoirs of hydro-geothermal fluids. The values obtained amounted to over 100 °C [6]. The highest temperatures, ranging from 130 to 150 °C are expected in the area of Vranjska, Josanicka and Kursumlijska banja. All the localities previously mentioned are situated in the peripheral sections of the Neogene granitoid plutons. The highest temperature of geothermal water was measured in the well VG-2 in Vranjska banja at the depth of 1500 m and it reached 127 °C. The temperature of the fluid reached 111 °C in the vicinity of the well head. Taking into account the resources that were determined in this well it is possible to launch the construction of the first binary system for the generation of electric energy in Serbia.

In the area of Macva the prospects for the generation of electric energy are also very favourable. The expected temperature of geothermal water reaches 110 °C and the quantity is estimated to 500 l/s. Besides, promising results are also expected in the area of Josanicka banja, where the highest temperatures of geothermal fluids are estimated to approximately 130 °C.

4. CONCLUSION

It may be stated that in the territory of Serbia there are excellent potentials for the generation of electric energy from geothermal resources that originate from hot and dry rocks of Neogene granitoid intrusions and from fluids in the reservoirs of convective hydro-geothermal systems, in which the temperature reaches the value of 150 °C. By implementing the HDR technology for the production of electric power, Serbia may become a major exporter of this commodity. Presently, in Serbia there are no conditions for a self-reliant development of geothermal energy exploitation from previously stated resources. However, it is possible to encourage research and development work that will enable the determination of the most favourable and prosperous localities in which it will be possible to implement newly developed HDR and binary system technologies.

REFERENCES

Dragasevic, T., Andric, B. & Joksovic, P., 1990. Structural map of Mohorovicic Discontinuity of Yugoslavia. Scale 1:500,000. Fed. Geol. Inst., Belgrade.

Gianelli, G. et al., 1988. Geological model of a young volcano-plutonic system: the geothermal region of Monte Amiata (Tuscany, Italy). *Geothermics*, Vol. 17, No. 5/6. Pergamon Press, London.

Grubic, A., 1980. An Outline of Geology of Yugoslavia. 26th Intern. Geological Congress, Paris, *Guide book*, p. 49.

Karamata, S. & Krstic, B., 1996. Terranes of Serbia and neighbouring areas. *In: terranes of Serbia* (Rds: Knezevic, V. & Krstic, B.), Fac. of Mining and Geology & Committee for Geodynamics of Serb. Sci and Art, Belgrade, p. 24-40.

Bodri, L., and Bodri, B., 1982. Geothermal model of the heat anomaly of the Pannonian basin. In: *Geothermics and geothermal energy* (Editor: V. Cermak and R. Haenel). E. Schweizerbart'sche Verlagsbuchhandlung, Stutgart, p. 37-43.

Milivojevic, M., 1989. Assessment of Geothermal Resources of Serbia Excluding Autonomous Provinces (Doctor thesis), University of Belgrade, Belgrade, p. 458 (in Serbian).

Milivojevic, M., 1990. Assessment of The Geothermal Resources of Serbia. Geothermal Resources Council Transactions, Vol. 14, Part II, p. 933-936.

Milivojevic, M., 1991. Geothermal Anomaly of the Pannonian Basin and its Association with the Geothermal Anomaly o Serbia. In: Geodynamic Evolution of The Pannonian Basin, (Editor: S. Karamata), Acad. of Sci of the Serbia, Acad. Conf., Vol. LXII, Belgrade, p. 355-365.

Milivojevic, M., 1992. Age of Tertiary Magmatism Rocks in the "Vardar Zone" on Serbian Territory using K/Ar Method and its Geothermal Importance. In: Abstracts, Vol. 3/3, 29th Intern. Geological Congress, Kyoto, Keirin Assoc., Kyoto, p. 844-845.

Milivojevic, M., 1993. Geothermal model of Earth's crust and lithosphere for the territory of Yugoslavia: some tectonic implications. Study geoph. et geod., Vol. 37, Acad. of Sci of the Szech Republic, Praha, p. 265-278.

Milivojevic, M. & Vukov, M., 1993. The first discovery of tonalite of tertiary ages in Macva. Geol. Ann. Of Balk. Pen., Vol.1, 57/1. Belgrade, 309-321.

Smith, R.L. & Shaw, H.R., 1975. Igneous-Related Geothermal Systems. Geol. Sur. Circ. 726.