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GEOTHERMAL ENERGY POSSIBILITIES, EXPLORATION AND FUTURE PROSPECTS IN SERBIA

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ABSTRACT

Geothermal investigations in Serbia began in 1974, after the first world oil crisis. A first assessment of geothermal resources has been made for all of Serbia. Detailed investigations in twenty localities are in progress. The territory of Serbia has favorable geothermal characteristics. There are four geothermal provinces. The most promising are the Pannonian and Neogen magmatic activation provinces. More than eighty low enthalphy hydrogeothermal systems are present in Serbia. The most important are located at the southern edge of the Pannonian Basin. The reservoirs of this systems are in karstified Mesozoic limestones with a thickness of more than 500 m. Geothermal energy in Serbia is being utilized for balneological purposes, in agriculture and for space heating with heat exchangers and heat pumps.

1. INTRODUCTION

Serbia is centrally situated in the Balkan peninsula (Fig. 1). It covers a relatively small surface area (about 88,000 km^2) but its geology is quite complex. The first descriptions of geothermal resources in Serbia were given at the end of 19th century by Radovanovic (1897) in the book "Ground Water". Radovanovic was one of the first Serbian hydrogeologists, and "the father" of Serbian hydrogeology and geothermology. Geothermal explorations in Serbia were initiated by hydrogeologists in 1974 and were carried out only for hydrothermal resources.

2. GEOLOGICAL OVERVIEW

Large geotectonic units (Fig. 2) present in Serbia belong to the Alpine Orogeny: Dinarides, Serbian-Macedonian Massif, Carpatho-Balkanides, and Pannonian Basin, and a small part of Mesian Platform (Grubic, 1980).

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 (Milivojevic, 1992). 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.

3. GEOTHERMAL BACKGROUND

The 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 (Dragasevic et al., 1990). 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 (Fig. 3) 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 (Milivojevic et al., 1992). The mentioned high heat flow densities indicate the presence of a geothermal anomaly (Milivojevic, 1992) which is certainly an extension of the geothermal anomaly of the Pannonian Basin (Bodri & Bodri, 1982). The thickness of the lithosphere, estimated by on a geothermal model (Milivojevic, 1993), is least thin in the Pannonian Basin, Serbian-Macedonian Massif, and its border zone on the Dinarides, only 40 km. In the Carpatho-Balkanides and the rest of the Dinarides, this thickness is up to 150 km. The lithosphere is the thickest in the Mesian Platform - from 160 to 180 km.

4. HYDROGEOTHERMAL RESOURCES

Within the territory of Serbia, excluding the Pannonian Basin, i.e. the terrain comprising solid rocks, there are 159 natural thermal springs with temperatures over 15 ^oC. The warmest springs (96 ^oC) are in Vranjska Banja, followed by Josanicka Banja (78 ^oC), Sijarinska Banja (72 ^oC) Kursumlijska Banja (68 ^oC), Novopazarska Banja (54 ^oC). The total flow of all natural springs is about 4000 l/s. The highest flows are from thermal springs draining Mesozoic karstified limestones, and the next highest are those from Tertiary granitoids and volcanic rocks. The greatest number of thermal springs are in the Dinarides, then the Carpatho-Balkanides, the Serbian-Macedonian Massif, and the lowest, only one in each, the Pannonian Basin and the Mesian Platform. As to their elevation, the greatest number of thermal springs are within the range 200-300 m. More than 90% of all thermal springs are at elevations below 600 m.

Considering the present state of our knowledge of the geological composition and hydrogeothermal properties of rocks to a depth of 3000 m, there are 60 convective hydrogeothermal systems in Serbia. Of this number, 25 are in the Dinarides, 20 in the Carpatho-Balkanides, 5 in the Serbian-Macedonian Massif, and 5 in the Pannonian Basin lower Tertiary sediments (Fig 4).

Conductive hydrogeothermal systems are developed in basins filled with Paleogene and Neogene sedimentary rocks. The majority of these are in the Pannonian Basin in Vojvodina, northern Serbia. The other 14 systems are less interrelated and less important (Fig. 5).

4.1. Pannonian Basin

Within this geotectonic unit, which is also a geothermal province (Milivojevic, 1989) comprising a complex hydrogeothermal conductive system with a number of separate reservoirs, four groups of reservoirs are categorised by depth. The first group of reservoirs have a maximum thickness of 2000 m. The highest water temperature in the reservoirs is 120 ^oC. The average flowing well yields are 1-13 l/s. Total mineralization of thermal waters is 1-9 g/kg, mostly 3-5 g/kg. Chemically, thermal waters are of HCO_3-Na type. Water temperature at well-heads are 40-55 ^oC, maximum 82 ^oC (Tonic et al., 1989).

The second group of reservoirs are in Lower Pliocene and Pannonian sediments, composed of sandstones of a lower porosity than the aquifers of the first group. Thermal waters in this reservoir are of HCO3-Cl-Na type and of mineralization rate 4-20 g/kg, mostly 5-12 g/kg. The maximum expected water temperature in this reservoir group is up to 160 ^oC. Average yields of flowing wells are 2.5 to 5 l/s, and the well-head water temperatures are 50-65 ^oC on average.

The third group of reservoirs are those at the base of Neogene or Paleogene sediments. These are Miocene limestones, sandstones, basal conglomerates, and basal breccias. Thermal water contained in these rocks is highly mineralized (to 50 g/kg), and its chemical composition is of the HCO_3-Na type. Average well yields are 5-10 l/s and water temperature at well-heads are 40-50 ^oC.

The fourth group of reservoirs are in Mesozoic and Paleozoic rocks under Paleogene end Neogene sediments. The most important reservoirs of this group and of the entire Pannonian hydrogeothermal system in Serbia are Triassic karstified and fractured limestones and dolomites. Similar reservoirs extend beyond the Serbian border, in the Pannonian Basin, in Hungary and Slovakia. Far from the basin's margin, at depths exceeding 1500 m, thermal waters in Triassic limestones are of Cl-Na type. In the marginal zone of the basin, where Neogene sediments are 1000 m deep over Triassic limestones and where water-exchange is active, thermal waters are of HCO3-Na type and have mineral contents of up to 1 g/kg. Average well-yield is 12 l/s, or 40 l/s from reservoirs near the basin's margin. The water temperatures at well-heads are mostly 40-60 ^oC.

4.2. Dinarides

Hydrogeothermal systems in this geothermal province differ in their types, kinds of reservoirs and their extents, etc., as a result of varying geology. Rocks that have the widest distribution are Mesozoic in age: (1) karstified Triassic limestones and dolomites; (2) ophiolitic melange, including large Jurassic peridotite massifs whose origin is associated with the subduction of Dinaridic plate under the Pannonian and the Rhodopean plates; (3) Cretaceous flysch; (4) Paleozoic metamorphic rocks; (5) Paleogene and Neogene granitoid and volcanic rocks; and (6) isolated Neogene sedimentary basins.

Hydrogeothermal systems have formed in terrains of: (1) Neogene sedimentary basins with reservoirs of Triassic limestones under them; (2) peridotite massifs and ophiolitic melange with reservoirs in Triassic limestones; (3) granitoid intrusions and respective volcanic rocks with reservoirs in the same rocks; and (4) Paleozoic metamorphic rocks with reservoirs in marbles and quartzites. The best aquifers are Triassic limestones, as their thermal water have low mineral contents (<1 g/kg) of HCO_3-Na or HCO_3-Ca-Mg types. Spring flows are very high, up to 400 l/s, and well yields are up to 60 l/s. Maximum temperatures of waters at well-heads are 80 ^oC.

The second important reservoirs are those in granitoid intrusions and their marginal thermometamorphosed fracture zones. The contained thermal waters are also low in total mineralization (>1 g/kg), of HCO_3-Na type, and maximum yield to 15 l/s. The highest temperature of waters at well-heads are 78 ^oC. There are few occurrences of thermal water in Paleozoic metamorphic rocks. Such springs have low flows (<1 l/s), low water temperatures (<20 ^oC), mineralization rates 5-7 g/kg, HCO_3-Na in type, and high concentrations of free CO_2 gas.

4.3. Serbian-Macedonian Massif

There are two types of hydrogeothermal systems in this geothermal province. One is the type formed in the Proterozoic metamorphic complex, with their reservoir in marbles and quartzites up to 1500 m in thickness. Thermal waters in this reservoir have total mineral contents of 5-6 g/kg. Their chemical composition is HCO_3-Na-Cl type water with high concentrations of free CO_2. This gas is formed by thermolysis of marble at temperatures above 100 ^oC in the presence of water, as verified by isotopic studies (Milivojevic, 1990). Spring temperatures are 24-72 ^oC and spring flow is of gas-lift type due to the high CO_2 gas content. The second type of hydrogeothermal system was formed in contact with, and in the marginal zones of, the Neogene granitoid intrusions. The reservoir rocks are granitoids, metamorphic and contact-metamorphic rocks, heavily fractured as a result of heating and cooling. The thermal springs of Vranjska Banja belong to this system type and have the warmest water in Serbia, 80-96 ^oC. Its mineral content varies from 0.1 to 1.2 g/kg. The water type is HCO_3-Na-SO_4-Cl. Springflows are up to 80 l/s.

4.4. Carpatho-Balkanides

This geothermal province has many hydrogeothermal systems, most of them formed in regions of isolated Neogene sedimentary lake basins. Reservoir rocks are karstified Triassic, Jurassic or Cretaceous limestones. Thermal karst springs have flows of 60 l/s, with water temperatures to 38 ^oC. Total mineralization is 0.7 g/kg and the water type is HCO_3-Ca. Another type of hydrogeothermal systems in this geothermal province was formed in the Upper Cretaceous paleorift of Eastern Serbia, where Mesozoic limestones were penetrated and thickly covered with andesite lavas and pyroclastics. These waters contain are up to 0.8 g/kg and the water is of SO_4-Na-Cl type, or HCO_3-Na-SO_4-Cl type where it is in limestones. Water temperatures at thermal springs are up to 43 ^oC, and spring flows are up to 10 l/s.

5. EXPLORATION WORK

Geothermal exploration in Serbia began in 1974. A year later, the first preliminary assessment was made of the national geothermal potential (Milivojevic et al., 1975; Alimpic, 1975). Then a number of pilot studies were prepared for discrete areas (Peric & Milivojevic, 1976; Milivojevic, 1979). Another, more detailed regional exploration of geothermal resources began in 1981 and ended in 1988 (Milivojevic, 1989). This regional study was conducted in parallel with the exploration of some of the previously known hydrogeothermal systems. In the Serbian part of the Pannonian Basin, the first borehole, 1454 m deep, was drilled in 1969, the second was drilled 2509 m deep in 1974. From 1977 to 1988, 58 boreholes were drilled with a total drilled depth of about 50,000 m. The overall yield of all these wells is about 550 l/s, and the heat capacity about 48 MW (calculated for dT=T-25 ^oC) (Tonic et al., 1989). From 1988 to 1992, only four more boreholes were drilled. In other geothermal provinces, 45 test holes were drilled before 1992, with a total drilled depth of about 40,000 m. Only three of these as are deep as 1800 m, fourteen are 1000-1500 m deep, thirteen are 500-1000 m, and fifteen are 300-500 m deep. Most of these boreholes freeflow and are used as production wells. The total yield of these wells is about 500 l/s. Production wells have not been drilled anywhere else, because none of the hydrogeothermal systems have been well enough explored. For the same reason, the total geothermal energy reserve has not been assessed for any of the systems. The total heat capacity of all these wells is about 108 MW (thermal); the total heat capacity of all flowing wells drilled in Serbia is about 156 MW. The total heat capacity of all natural springs and wells is about 320 MW (calculated for dT=T-12 ^oC).

6. UTILIZATION OF GEOTHERMAL ENERGY

The commonest uses of geothermal energy in Serbia are the traditional ones: balneology and recreation. Certain archeological evidence indicates similar uses by the ancient Romans in the localities of the presently known spas: Vranjska Banja, Niska Banja, Vrnjacka Banja and Gamzigradska Banja. There are today in Serbia 59 thermal water spas used for balneology, sports and recreation and as tourist centers. Thermal waters are also bottled by nine mineral water bottling companies. The direct use of thermal energy for space heating or power generation is in its initial stage and very modest in relation to its potential capacity. In the hydrogeothermal system of the Pannonian Basin, thermal water is used from 23 wells. This direct use began in 1981. Water from two wells is used for heating green-houses, from three wells for heating pig farms, from two for industrial process in leather and textile factories, from three for space heating, and from thirteen wells for various uses in spas and for sport and recreation facilities. The total heat capacity of the wells presently in use is 24 MW (Tonic et al., 1989). Thermal waters outside of the Pannonian Basin region are used for heating in several localities. Space heating started in Vranjska Banja forty years ago. Thermal water is used there to heat flower green-houses, a poultry farm, a textile workshop, premises of a spa rehabilitation center and a hotel. A large hotel and rehabilitation center with a swimming pool is heated in Kursumlijska Banja. In Niska Banja, a heating system is installed for the hotel and rehabilitation center, including heat pumps of 6 MW, which directly uses thermal waters at 25 ^oC. Thermal direct use in the Sijarinska Banja is for heating the hotel and recreation center. A similar use is practiced in Ribarska Banja. Thermal water in Lukovska Banja is used in the carpet industry. A project has been completed for geothermal direct use at Debrc for drying wheat and other cereals. Another use at Debrc is for space heating.

7. FUTURE PROSPECTS

Exploration to date has shown that geothermal energy use in Serbia for power generation can provide a significant component of the national energy balance. The prospective geothermal reserves in the reservoirs of the geothermal systems amounts to 400 x 10^6 tonnes of thermal-equivalent oil. The prospects for use of heat pumps on pumped ground water from alluvial deposits along major rivers are very good. For intensive use of thermal waters in agro- and aqua-cultures and in district heating systems, the most promising areas are west of Belgrade westward to the Drina, i.e. Posavina, Srem, and Macva. Reservoirs are Triassic limestones and dolomites >500 m thick, which lie under Neogene sediments. The priority region is Macva, where reservoir depths are 400-600 m, and water temperatures are 80 ^oC. The economic blockade of Serbia stopped a large project in Macva: space-heating for flower and vegetable green-houses over 25 ha (1st stage). The completed studies indicate that thermal water exploitation in Macva can provide district heating systems for Bogatic, Sabac, Sremska Mitrovica, and Loznica, with a population of 150,000. In addition to the favorable conditions for geothermal direct use from hydrogeothermal reservoirs in Serbia, geothermal use can also be made of hot dry rocks, as there are ten identified Neogene granitoid intrusions (Fig 6). Geothermal exploitation programmes have been prepared, but they have not been brought into operation.

REFERENCES

Alimpic, S., 1985. Geothermal potential and utilization of geothermal resources in Vojvodina. In: Procedings of Symposium of geothermal energy, Belgrade, p. 35-41, (in Serbian)

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.

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

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

Milivojevic, M., 1982. Palaeohydrogeothermal occurences of Avala. School of Mining and Geology, Belgrade, p. 203, (in Serbian).

Milivojevic, M., 1989. Assessment of Geothermal Resources of Serbia Excluding Autonomous Provinces (Doctoral 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 of 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., Ravnik, D., Kolbah, S., Jelic, K., Miosic, N. and Tonic, S., 1992. Yugoslavia. In: Geothermal Atlas of Europe. (Editors: E. Hurtig, V. Cermak, R. Haenel and V. Zui). GeoForschungsZentrum Potsdam, Publication No. 1, Potsdam, p. 102-105.

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.

Peric, J. and Milivojevic, M., 1981. Geothermal potential of Avala-Kosmaj-Bukulja-Rudnik region. Zbornik radova RGF, Vol. 6, Belgrade, p. 155, (in Serbian).

Radovanovic, S., 1897. Ground Waters: aquifers, springs, wells, thermal and mineral waters. Serbian Books Association 42, Belgrade, p. 152, (in Serbian).

Tonic, S., Milosavljevic, S., Vidovic, S. and Agatonovic, V., 1989. Results of exploration and utilization of geothermal water in Vojvodina. Journ. of YU Committ. of The World Petroleum Congr., Nafta (40), No. 10, Zagreb, p. 593-600, (in Serbian).

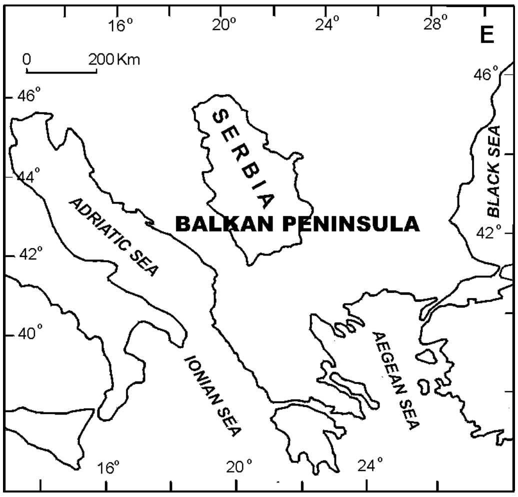

Figure 1. Geographical location of Serbia

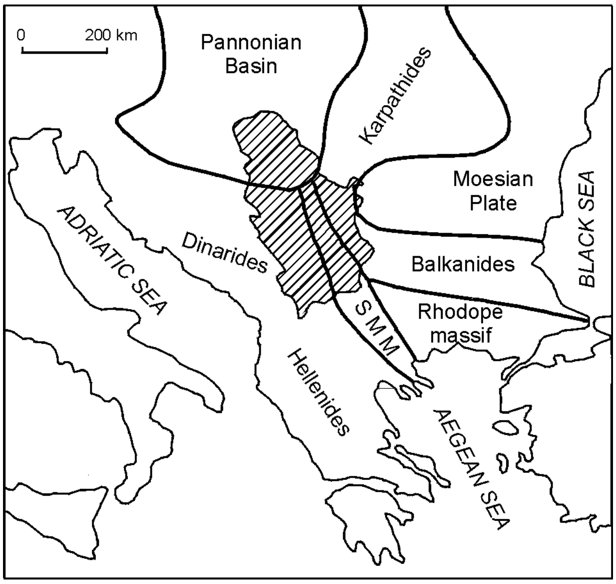

Figure 2. Tectonic map of the Balkan penninsula

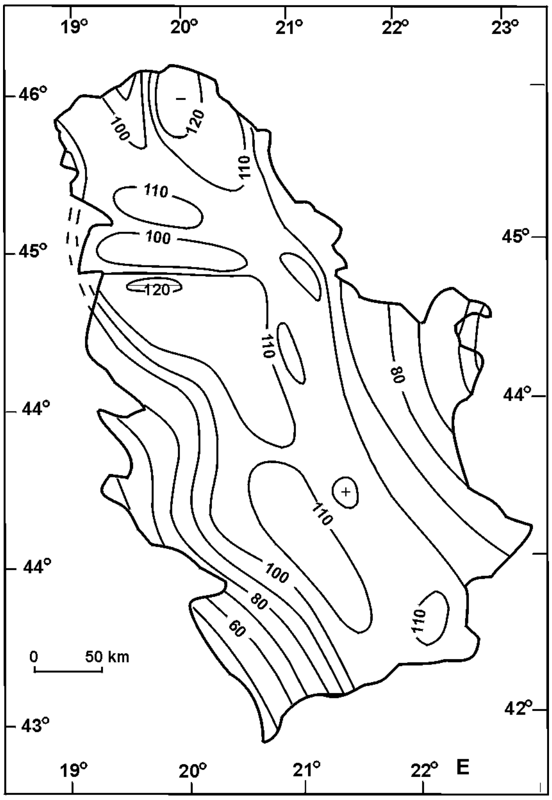

Figure 3 Heat flow map (mW/m$^{2)}$ of Serbia

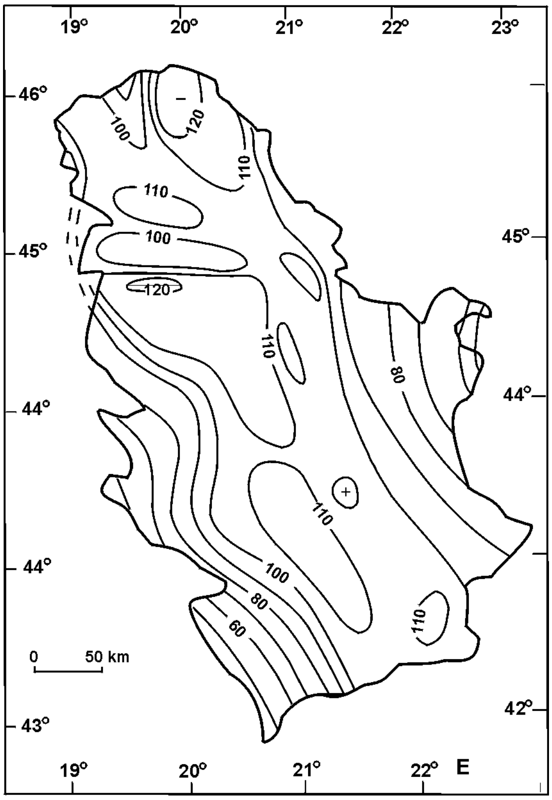

Figure 4. Locations of major thermal springs and wells of Serbia (1 - balneology, 2 - balneology, space heating, agriculture, 3 -not used)

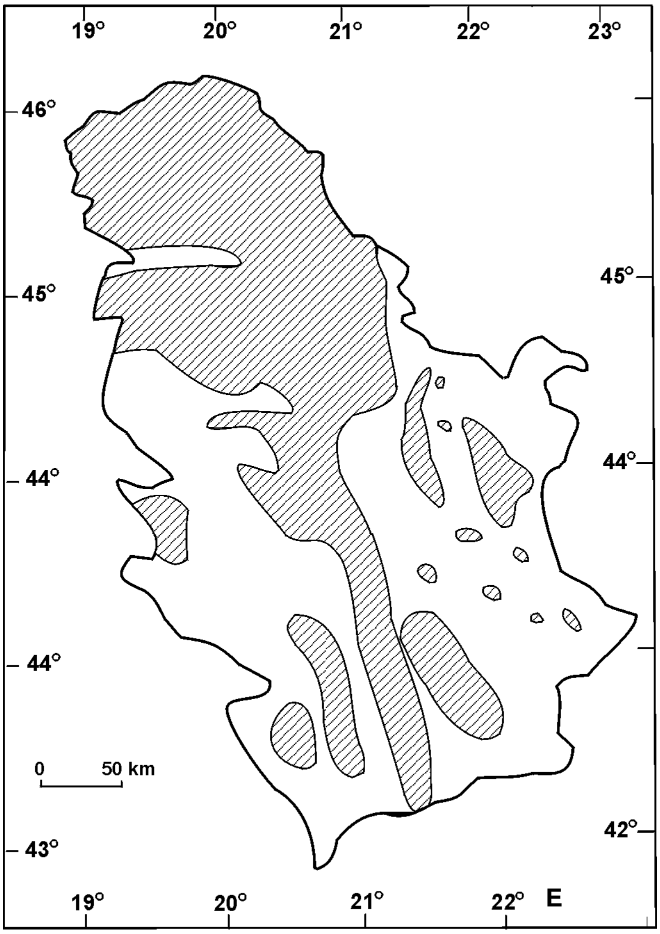

Figure 5 Distribution of major convective type geothermal systems in Serbia

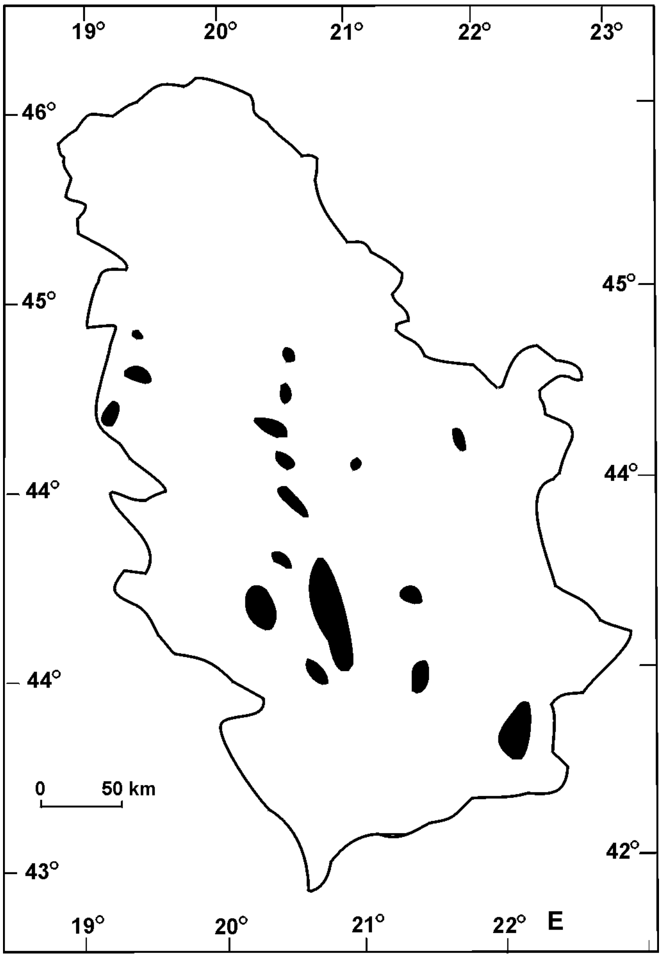

Figure 6. Distribution of granitoid intrusion potential of HDR locations