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Hydrogeothermal Potentiality of Surdulica Granitoid Massif in Serbia

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ABSTRACT

This report is a compilation of the results of geological and geothermal surveys and investigations conducted in the territory of Surdulica granitoid massif for assessing its potential and possibilities for obtaining thermal water with temperature above 100°C. A wider zone of Surdulica granitoid massif belongs to the Serbian-Macedonian massif. The oldest lithological member is the complex of Paleozoic shale, mostly composed of mica schist, leptynolite, gneiss and chlorite schist rocks. Systematic exploration of the Surdulica granitoid massif, for possible use of thermal waters and geothermal energy, started in the mid 1960's. Two deep exploratory and production wells VG-2 and VG-3, were drilled for that purpose in Vranjska spa. The temperatures and quantities of thermal water, the hydrogeothermal system of Surdulica massif with Vranjska spa makes it the most perspective zone for obtaining and using, for multiple purposes, thermal water and geothermal energy. Two deep wells: VG-2 (1064 m) and VG-3 (1603 m) were drilled in Vranjska spa. Hydrogeochemical investigations covered groundwater analyses, determining that waters of Vranjska spa are: thermal, bicarbonate-sulphate-sodium, low alkaline, mineralized, with a low content of hydrogen sulfide, fluorosilic, with an elevated content of HBO_2 component and iron (Fe^{2+}). Temperature of thermal water in well VG-2 is 126°C, with self discharge of 26 l/s, and wellhead pressure of 9.5 bars. Temperature of thermal water in well VG-3 is 124°C, with self discharge of 21 l/s, and wellhead pressure of 8.5 bars. The silica geothermometer gives estimated values for temperatures of thermal water in Vranjska spa between 115 and 144°C. Possible production rate is about 80 l/s of thermal water with temperature of 120°C in area of Surdulica granitoid massif.

1. INTRODUCTION

Surdulica granitoid massif is located in the south east of the Republic of Serbia near the Bulgarian border, 325 km from Belgrade, Figure 1. They represent the largest intrusive rocks in Serbia, as well as the starting point of the igneous zone Surdulica-Osogovo-Thassos. The surface of the granitoid is around 250 km^2 (its length being 25 km and width around 11 km), but together with its rims it comprises the total area of around 480 km^2. Its orientation is between NW-SE and NNW-SSE. The abovementioned area has a mid-mountain type of relief (1000-2000 m). The formation of this indented relief was initiated by intensive and complex tectonic movements, water torrents, fluvial and slope processes. The highest parts are those in the center, northeast and southeast and they represent typical mountain areas (Besna Kobila-1923 m, Vardenik-1875 m, Čemernik-1638 m).Therefore, a large part of the research area is within the mountain climate zone, while west parts of the area belong to the moderate continental climate. The hydrographic network of the research area belongs to the Black Sea basin. The largest town is Surdulica (22 190 inh.) which is located in the north part of the area.

Figure 1: Geographic location of Surdulica granitoid massif.

2. GEOLOGICAL SETTING

A wider zone of Vranjska Spa fully belongs to the Serbian-Macedonian mass, its central (Vranje graben) and eastern (Vlasina complex) parts. The oldest lithological member is the complex of Paleozoic shale, mostly composed of mica schist, leptynolite, gneiss and chlorite schist rocks, Figure 2. Lenses of amphibolite and quartzite rocks appear occasionally within the complex.

The crystalline complex is intruded by granitoid rocks (the Cukljenik, Bujanovac and Surdulica granodiorite rock massifs), the age of which was defined as Paleozoic, Mesozoic and Cretaceous-Paleogene, respectively, with the Surdulica massif as the youngest. The central part of the area is formed of Paleogene tuffs and molasses (the south-east and north-west marginal parts of the Vranje graben). Volcanic activities in the Middle Miocene formed andesite-dacite rocks of the eastern and western marginal parts of the graben, Surdulica massif and protrusions in the south-east of it. These activities resulted in the creation of a package of volcanogenic-sedimentary formations at the turn from the Miocene to the Pliocene. The thickness of Paleogene and Neogene formations in the Vranje graben exceeds as much as 1,000 m.

The youngest lithological members are Quaternary sediments, the alluvion of the South Morava River and its tributaries, and diluvial-proluvial deposits.

Numerous expert disputes related to this area refer to an undefined belonging of the granitoid apophysis in Vranjska spa (the Surdulica massif), and the relation of gneiss, mica schist and leptynolite rocks to chlorite schist rocks. According to the latest findings, granitoids in Vranjska spa are of the same age as the Surdulica massif. Moreover, the thesis of chlorite schist rocks as formations of the oceanic crust is becoming more widely accepted, and their syngenesis with mica schist, leptynolite and gneiss rocks, with a different hypsometric relation, is ascribed to the tectonic evolution of space.

Looking from the macro-structural aspect, the eastern edge of the Vranje graben, the monocline of Kocura and the Surdulica granitoid massif are distinguishable in the east of the South Morava River, and the zone of volcanic activities of Grot and Oblik spreads in the west thereof.

Marginal faults of the Vranje graben spread in the NE-SW direction, and the dominating direction in the monocline of Kocura is normal to them (NW-SE), Figure 3. Occasionally, mostly along the eastern margin of the graben, there are fractures spreading in the E-W direction, while fractures in the general N-S direction are only rarely present. Foliation routes and dacite and andesite intrusion zones (in the complex of schist rocks) have the same NW-SE direction.

The fault zone named Katalenec is in the system of peripheral faults of the Vranje graben from which it branches off in the N-E direction, ending in Vranjska spa. This fault zone is ascribed the role of the main drain of thermal waters. Literature also mentions a fault along the Banjska River, but it is not present on the Basic geological map (OGK), “Trgoviste” sheet, although geophysical surveys indicate its presence.

The Study (conducted in 1974) covered preparation of a neo-tectonic map of the Vranje graben (original scale 1:100.000) with separated areas of relative elevation and depression. The map shows the folding area in the zone of Vranjska spa, with the background block (to the south and south-west of Vranjska spa) relatively elevated, the same as the area of the Surdulica massif and the eastern marginal part of the Vranje graben, and with its central part in a relative depression.

3. GEOTHERMAL POTENTIALITY OF THE SURDULICA GRANITOID MASSIF

The territory of South Serbia is abundant in thermal waters discharging around Presevo, Bujanovac, in Vranjska spa and Sijarinska spa, Tular, Prolom spa and in the zone of Prokuplje. In the immediate vicinity of Surdulica, the tunneling work between Vrla II and Vrla III power plants revealed the inflow of thermal waters, after which BSG-1 well was drilled to the depth of 500 m (design depth 1500 m), the thermal logging of which recorded the temperature of 66°C at the depth of 470 m. Among the mentioned cases, Vranjska spa and Sijarinska spa show the closest resemblance regarding quantities, temperatures and hydrogeological conditions, but they differ substantially with respect to the content of free carbon dioxide. Waters in Vranjska spa and Bujanovacka spa, too, differ by the content of free carbon dioxide, but also by some other basic chemical components (e.g. Cl). Due to different physical and chemical properties and general hydrogeological conditions, the above-mentioned waters are classified into different hydrogeothermal systems without clearly defined boundaries.

Naturally occurring discharges in the zone of Vranjska spa, after the construction of a system of water intake shafts and drainage channels, gave the yield of 46 - 50 l/s of water the temperature of which was measured to be in the range of 80 - 85°C. Based on these data, thermometric testing to the depth of 30 m, logging of 100 - 300 m deep wells, and based on the estimated baseline temperature of 120 - 150°C and results of isotopic analyses, VG-2 and VG-3 wells were designed and drilled, giving positive results regarding both quantities adn obtained discharge temperatures.

4. VRANJSKA SPA

Vranjska spa is about 12 km to the north-east of Vranje, in south-east Serbia, at the foot of the Besna Kobila massif. The place is situated along the eastern edge of the Vranje valley, at the point where the Banjska River leaves its rugged valley and enters the valley of the South Morava River. It lies at the altitude of 380 - 400 m a.s.l. Thermal springs are known to date back from the Roman times. Over time the recreational spa center developed into a settlement with full infrastructure, now with about 4000 inhabitants.

Systematic exploration of the Vranje graben and Vranjska spa, for possible use of thermal waters and geothermal energy, started in the mid 1960’s. Two deep exploratory and production wells - VG-2 and VG-3, were drilled for that purpose. These were preceded by three shallow wells – from A group, and an array of B wells, 2 of which were included in the thermal water tapping system in Spa. Most of these wells are out of function. Previous natural points of discharge, i.e. thermal water springs, were tapped by a system of shafts and water collecting channels. Therefore, in a relatively small area, there is a high concentration of wells that tap thermal waters at different depths.

Geological investigations of thermal waters in the area of Vranjska spa are related to a wider area of the Surdulica massif, while the area related to wells only, i.e. to the location of Spa, is 1000 x 1000 m in size, and is up to 1400 m deep. The extent of the entire water-bearing formation has not been clearly defined (there are numerous expert assumptions on that), but speaking of its potentiality, expressed through defined water quantity and temperature, it may be expected to extend over a dozen square kilometers within Paleozoic schist of the Surdulica granitoid massif and/or Tertiary vulcanites on marginal parts of the Vranje graben.

4.1. Shallow water Intake Structures

Natural places of discharge were tapped by a system of water collecting shafts and channels. Control hydrometric measurements recorded the quantity of 50 1/s, with the temperature from 70 to 90°C.

In Vranjska spa there is a larger number of exploratory wells concentrated on the site of natural discharge points. Until 1985, a number of exploratory and production wells were drilled, out of which B-1, B-lb, A-1, A-2, A-3 were included into a water production system.

B-l well was drilled in the park, to the depth of 120 m, Figure 4. It gave waters by self-flow, in the quantity of about 2 1/s and of the temperature of 82°C. B-1a was drilled to the depth of 30 m and it gave 2 1 of water per second by self-flow. B-1b well, 24 m deep, was drilled in the immediate vicinity of an old intake structure and gave, by self-flow, 1.5-2 l of water per second.

Based on these results, production wells were drilled with Ø 400 mm diameter and a built-in well structure of Ø 323 mm in diameter. A-l well was drilled to the depth of 26 m in silicified granodiorite. It gave, by self-flow, 3.5 - 4 l/s of 93°C water. A-2 well is 44 m deep and gave 1 1/s of 84°C water. In A -3 well, 26 m deep, water table is at about 3 m under the ground surface level.

The mentioned quantities and temperatures were recorded in the period just after the construction of wells, and later, reliable data on these values are not available for B-la, A-1, and A-2. B-1 borehole and A-1 well supply the medical center in Spa with hot water, whereas A-2 borehole is assumed to be connected to a drainage system. For the boreholes B-1, connected to a tap in the park, and B-1b, there are regime observation data showing no substantial drop in their yield.

Figure 4: Microlocations of boreholes and wells in Vranjska spa (www.maps.google.com).

4.2. Deep wells VG-2 and VG-3

VG-2 borehole was drilled to the depth of 1064 m with a lithological profile with a succession of granodiorite, schists and gneiss rocks. To the depth of 570 m granodiorites are dominant, while their representation in deeper parts is reduced to smaller intervals separated with gneisses. To the depth of 770 m several water-bearing horizons were identified with the quantity of above 50 l of water per second, by self-flow, with the temperature from 70 to 96°C. To that depth the borehole is cased, so as to prevent inflow from 6 identified horizons. The isolation of shallower parts of the borehole served to prevent its influence on natural outflow and thus enable tapping of a productive interval at the depth of 864-890 m, where the temperature was measured to be 126°C. From that segment, waters were tapped in the quantity of 26 1/s, with the outflow temperature of 111°C. At the borehole head, after closing, the pressure was measured to be 9.5 bars.

Based on these results VG-3 borehole was sited at the distance of 120 m to the west of the previous one, Figure 3. It was designed as an inclined borehole from the depth of 45 m and down, at the azimuth 120 and with the deviation from its orthocenter with 500 m from the borehole mouth, so that the vertical depth amounts to 1470 m for the total drilling length of 1604 m. The cross-section of this borehole shows a succession of schists and gneisses, whereas granodiorites are represented to the depth of 145 m in succession with gneisses and schists. Thermal logging determined that at the depth of 1500 - 1575 m temperature is 124 °C within porous gneiss, wherefrom self-flowing waters occur in the quantity of 21 1/s with the temperature of 100°C. After completed drilling, the pressure was measured to be 8.5 bars.

Chemical composition of waters from deep boreholes does not deviate a lot from the chemical composition of waters with natural outflow or that obtained in shallower boreholes.

4.3. Hydrodynamic Testing of Deep Boreholes VG-2 and VG-3

A hydrodynamic test on the deep boreholes VG-2 and VG-3 was conducted in the total duration of 35 days. In the period before running the hydrodynamic test, in order to take stock of the situation, the existing structures were subjected to a continuous regime monitoring, both deep boreholes and all other existing structures. Three self-flow tests were conducted in total:

1. hydrodynamic test by a controlled self-flow on the deep borehole VG-2;
2. hydrodynamic test by a controlled self-flow on the deep borehole VG-3;
3. hydrodynamic test by a simultaneous self-flow on the deep boreholes VG-2 and VG-3.

Based on measurements right before the start-up of the test on VG-2 borehole, the wellhead pressure was determined to be 8.80 bars, and in VG-3 - 8.35 bars. Observations of VG-3 showed that the impact of pumping VG-2 was felt as soon as 20 minutes after the beginning of the test. After 48 hours, the water discharge capacity was increased to about 26 1/s. Just after increasing the capacity, water temperature raised to 106°C.

Seven hours after starting the testing of VG-3, the thermometer indicated the temperature of water of 100°C, which maintained at that level throughout the test with the self-flow capacity of 9.57 1/s. At the same time, in the period of continual rise of water temperature, an interesting effect of a change in pressure was obtained. Namely, after a drop by 0.9 bars immediately after opening the valve, it started "rising" (t = 10 min, T = 60°C) and stabilized at 0.2 bars (t = 2 hours, T = 90°C), and then after 5 hours of pumping, at water temperature of 98.5°C it went to 8.15 bars. This pressure was monitored until the end of the test with this capacity of self-flow, with minor changes. When a stable temperature regime was set up, water started flowing more and more vigorously into the intake tank, and the incrustation process started.

After 24 hours, the flow rate from the borehole increased by additional opening of the valve (to about 23 1/s). 45 minutes after opening the valve and increasing the capacity, the temperature raised to 106°C. This temperature regime maintained until the end of pumping at the rate of 23.1 1/s.

4.3.1. Hydrodynamic Calculations

In the course of the graphoanalytical processing of the results obtained from the hydrodynamic tests, by forming a diagram S=f(log t), i.e. S = f(log t/t') for the part of the test related to the monitoring of pressure recovery after completed pumping in certain structures, the following hydrogeological parameters were determined:

Transmissibility:

$T = 6.3 \times 10^{-4}$ m^2/s determined based on the data of measurements taken on VG-2.

$T = 4.7 \times 10^{-4}$ m^2/s determined based on the data of measurements taken on VG-3.

At the same time, based on the obtained value to = 4000 sec, the calculation defined the value of the storage coefficient of the following order of magnitude:

Storage coefficient:

$S = 1.7 \times 10^{-5}$

After the graphoanalytical processing, the entire self-flow test was simulated on a PC, with the hydrogeological parameters obtained by the graphoanalytical processing serving as the simulation input. The representative data for the identification of hydrogeological parameters through the hydrodynamic test simulation process were adopted to be those obtained by measurements taken on VG-3 borehole which was treated as an observation well during hte pumping of VG-2 borehole.

The simulation of the entire hydrodynamic pumping test gave the following hydrogeological parameters:

$T = 4.9 \times 10^{-4}\ m^2/s$

$S = 2.0 \times 10^{-5}$

Besides the fact that geological conditions indicate the existence of relatively close water impermeable limits, the model tests showed the best possible concordance between the calculation and observation values for the conditions of a homogenous, unlimited environment. The hydrogeological parameters obtained by the hydrodynamic test simulation process may be considered as representative.

4.4. Hydrochemical Composition of Thermal Waters in Vranjska Spa

The hydrochemical tests encompassed two deep boreholes VG-2 and VG-3, Shaft no. 5, Peraljiste, and the Geyser.

- Temperatures of tested waters range from 66°C to 107°C.
- Mineralization of waters is within the limits of 1 g/1 - 1.5 g/1.
- pH index values are within the limits 6.85 - 7.34.
- Based on the redox potential, the waters are poorly reducing (Eh from -20 mV to -145 mV).
- In the gaseous composition it is characteristic that the content of carbon dioxide is elevated (up to 88 mg/l), with the presence of hydrogen sulfides (0.135 - 5.78 mg/1), and the complete absence of oxygen in thermomineral waters from deep boreholes. This is in compliance with the measured redox potential values.
- In anionic composition, the prevailing ions are hydrocarbonate and sulfate ions. Their ratio varies and a higher presence of hydrocarbonates is noticeable in thermomineral waters from deep boreholes comparing to elevated contents of sulfates in shallower boreholes.
- In cationic composition, the dominant place is taken by the ions of sodium. The content of ions of calcium is much lower in thermomineral waters from deep boreholes.

When speaking of micro-components, what is typical for thermomineral waters of Vranjska spa is an extremely low content of the following components (Cu, Ni, Pb, Zn, Fe, Mg), which results from an elevated content of hydrogen sulfides (redox environment), and hydrocarbonate anions (poorly alkaline environment). Such environment is not favorable for the migration of the mentioned elements in thermomineral waters.

4.5. Prediction Temperatures of Thermal Waters in the Primary Reservoir According to the Hydrogeothermometers

The following hydrogeothermometers were used to determine temperature of thermal waters in the primary collector of Vranjska spa: *Silica hydrogeothermometer* (Fournier, 1983; Arnorsson, 1983; Fournier and Potter, 1982), *Calcedone hydrogeothermometar* (Fournier, 1983), *Na-K hydrogeothermometer* (Truesdell, 1976; Tonani, 1980; Arnorrson, 1983), *K-Mg hydrogeothermometer* (Giggenbach, 1988), *Na-Ca hydrogeothermometer* (Tonani, 1980), *K-Ca hydrogeothermometer* (Tonani, 1980).

The silica hydrogeothermometer gives estimated values for temperatures of thermal waters in Vranjska spa between 115 and 144°C (Martinovic et al., 2008). The average temperature of thermal water in the reservoir would be somewhere around 130°C, Table 1. Having in mind that the temperature recorded at the bottom of VG-2 borehole was 126°C, in non-stationary temperature conditions, i.e. just after completed drilling, it is realistic to assume that the temperature in primary reservoir is over 130°C.

Na-K hydrogeothermometers give lower temperature values in the primary reservoir than possible, Table 2, except for Eq. 10, probably because the chemical balance was disturbed by mixing with thermal water from shallower horizons.

Based on forecast temperatures obtained based on Na-K, Na-Ca, K-Mg and K-Ca hydrogeothermometers, we may conclude that these hydrogeothermometers are not adequate for the chemical balance of thermal waters of the Vranjska, since they give unrealistically low estimated values for temperature of thermal waters, except with Eq. 10.

4.6. Proven Reserves of Thermomineral Water of Vranjska Spa

Thermomineral waters of Vranjska spa, according to the degree of conducted research, may be classified into B group (proven reserves) in compliance with “Rules on classification of and maintaining records on groundwater reserves”. Thermomineral waters classified into B group reserves are those that discharge from objects:

- Deep boreholes: VG-2 and VG-3 (deep boreholes),

- Springs: Shaft no. 5 and Peraljiste (summary), Old water intake structure, B-l borehole, and the tap in the park.

The quantities were determined applying different methodologies. For VG-2 and VG-3 wells, based on the hydrodynamic test and the mathematical simulation model from structures for obtained parameters for the environment. For other wells, the reserves were determined based on the data obtained from regime observations, from previous periods, checking them in the course of the hydrodynamic tests.

A hydrodynamic test by a controlled self-flow was performed in order to determine “B” reserves of a part of thermomineral waters discharging from VG-2 and VG-3 wells. Both wells tap water-bearing horizons at the depths of 867 m (VG-2) and 1467 m (VG-3), which showed hydrodynamic interconnectedness during the test, and may be thus considered as a single water-bearing horizon. In particular pumping sessions at the maximum capacity (for the given technical conditions of the boreholes and their heads), the structures gave 25 1/s -VG-2 and 23 1/s VG-3 (Zlokolica, 1994).

The obtained data, once processed, served to determine the parameters of the environment and structures. By applying the mathematical model simulating simultaneous pumping, the quantities of 48 1/s were obtained for both structures together, which was confirmed during a 10-day simultaneous operation of the wells. This capacity was realized for pressures of 2.1 bars (VG-2) and 2.5 bars (VG-3), which virtually stabilized at these levels. The measured temperatures of waters were 102°C (VG-2) and 105°C (VG-3). Waters from both boreholes belong, by their determined composition, to hydrocarbonate, sulfate, sodium type, of a stable hydrochemical regime, and are thus shown together in Table 3.

Table 3:“B” category reserves (proven reserves)

Object	Temp. (^oC)	Quant. (l/s)	Water type	Total (l/s)
VG-2 and VG-3	102-105	48.00	HCO_3-SO_4-Na	48.00
Shaft no. 5 and Peraljiste	63.5-76	46.25	SO_4-HCO_3-Na	50.15
B-1 and TAP	76-81	2.40	SO_4-HCO_3-Na	
Old water intake structure	76-81	1.50	SO_4-HCO_3-Na	
			TOTAL	**98.15**

“B” reserves of thermomineral waters for Shaft no. 5 and “Peraljiste” are given based on the adjusted value of regime observations for the period of 3 years. The relevant quantity was adopted to be 39.22 1/s (Zlokolica, 1994), which was measured immediately (10 days) before the beginning and during the hydrodynamic test and before the beginning of the heating season in Spa. For structures: Geyser (B-1) and Tap, summary values are given as well. The difference in temperature results from the cooling due to free and uncontrolled discharge from (B-l) borehole. For the Old water intake structure, too, the values given are those obtained by regime observations. These waters, in the total quantity of 41.12 l/s are of a sulfate, hydrocarbonate, sodium type with free discharge.

5. CONCLUSION

First of all, as for temperatures and quantities of thermal waters, the hydrogeothermal system of Surdulica with Vranjska spa makes the most perspective zone for obtaining and using, for multiple purposes, thermal waters and geothermal energy in Serbia.

Contours of the water-bearing formation cannot be defined with sufficient accuracy, but based on collected data and results obtained by hydrochemical tests we may speak of a zone of replenishment of thermal waters from the area of about 200 km^2.

The zone of replenishment of thermal waters was formed to the east and south-east of Vranjska spa, in the zone of the Surdulica granitoid massif (its southern part) and the monocline of Kocura, formed from Paleozoic schists with dominating gneiss rocks. The thermal water aquifer is over 1500 m deep (determined by drilling), while the thermal water circulation depth is over 2000 m.

Isotopic analyses determined the water replacement time of about 8,000 years.

Exploratory drilling and hydrodynamic tests determined the existence of thermal waters from the ground surface to the depth of 1470 m. These waters can be considered as hydraulically interconnected parts of the same aquifer where the vertical zones are present regarding the chemical composition, whereas regarding temperature there is a continuous geothermal gradient of the rock mass.

By the chemical type of waters, SO_4-HCO_3-Na waters are present in shallower parts of the aquifer and HCO_3-SO_4-Na in deeper parts of the aquifer.

The hydrodynamic test of deep wells determined the quantity of 48 l/s of waters of hydrocarbonate-sulfate-sodium type, of temperature 102 - 105°C (at the wellhead, freeflow) at pressure of 2-2.5 bars. These waters have a stable hydrochemical regime. They were determined to have an intensive decrease in calcium carbonate (97 % of the sediment) with the transition in atmospheric conditions, by spontaneous degasation.

With respect to corrosion they show a moderate corrosive effect on copper alloys and carbon steel. Waters were stated to contain micro-elements in elevated concentrations, namely those of: zinc, barium, strontium, vanadium, chromium and fluorine. Micro-components of the chemical composition are also the same for waters of the basic sulfate-hydrocarbonate-sodium type, of temperatures 75 - 94°C.

Based on hydrogeothermometers, the temperature of thermal water in the primary reservoir is between 130 to 140°C.

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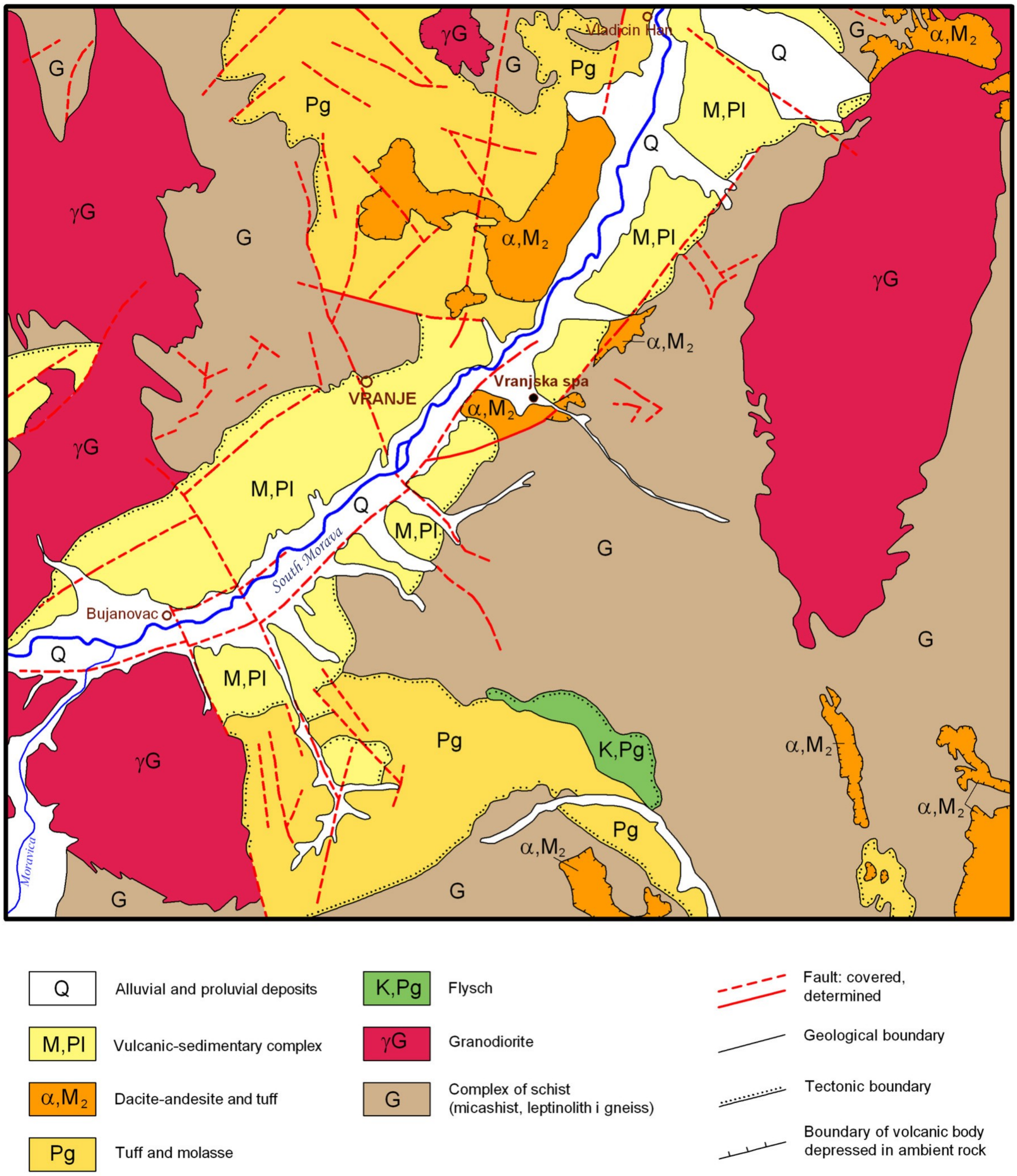

Figure 2: Geological map of wider vicinity of Surdulica granitoid massif, 1:300,000.

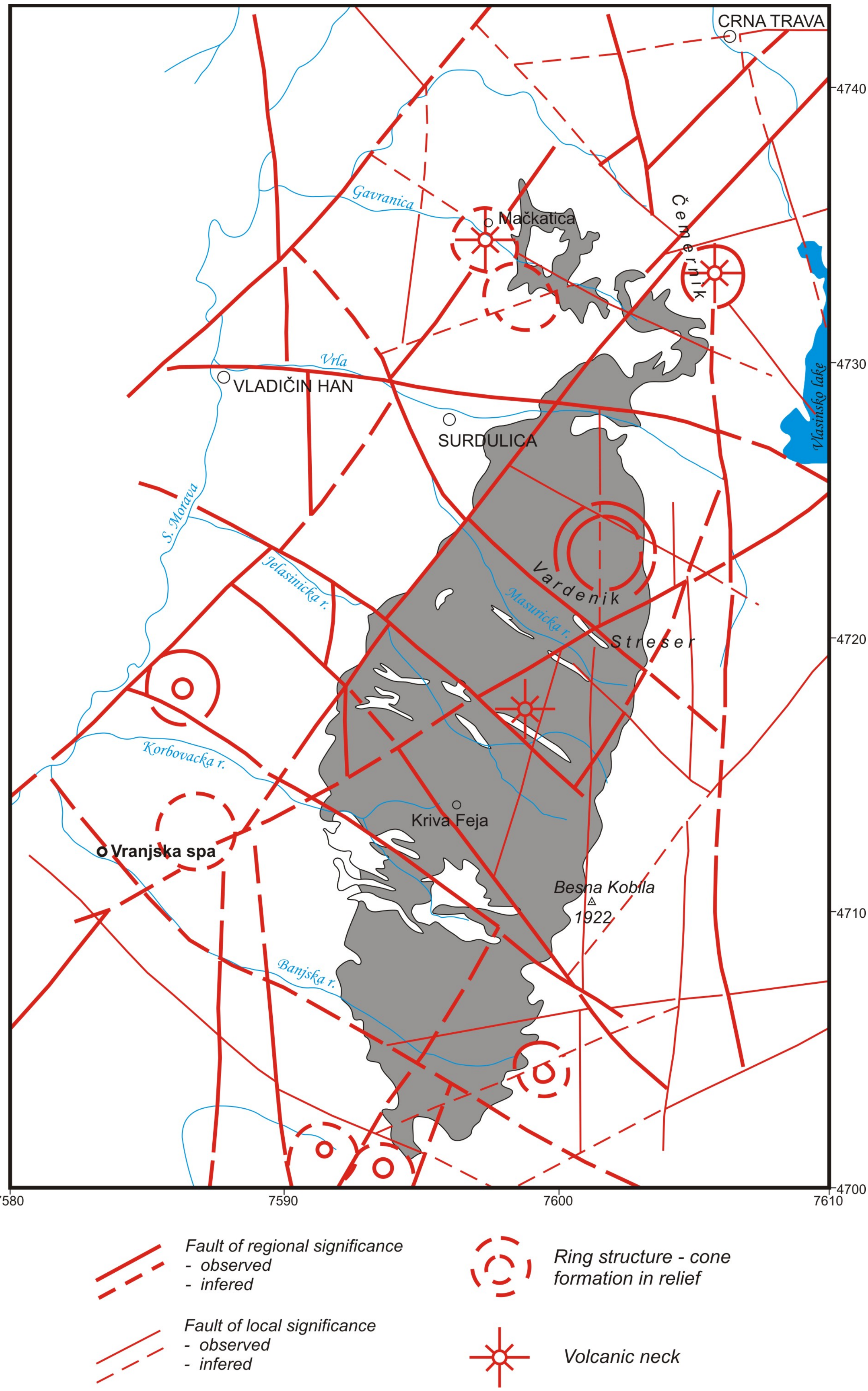

Figure 3: Regional tectonic map of near vicinity of Surdulica granitoid massif.

Table 1: Estimated temperatures of thermal waters in the primary reservoir based on a Silica hydrogeothermometer (1,2-Fournier, 1983; 3,4-Arnorsson, 1983; 5-Fournier and Potter, 1982), and Calcedone hydrogeothermometar (6,7-Fournier, 1983).

Borehole	Temp.	Content (SiO_2)	Estimated temperature values (by equations)						
			1	2	3	4	5	6	7
VG-2	102	111	143.1	137.7	134.6	136.7	142.8	117.1	115.1
VG-3	105	113.2	144.2	138.6	135.8	137.7	144.0	118.3	116.2
Shaft	50	113	144.1	138.5	135.7	137.6	143.9	118.2	116.1
Peljiste	50	108	141.5	136.4	132.9	135.4	141.3	115.3	113.6
Geyser	35	110	142.6	137.2	134.0	136.3	142.3	116.5	114.6

Table 2: Estimated temperatures of thermal waters in the primary reservoir based on Na-K (8-Truesdell, 1976; 9-Tonani, 1980; 10-Arnorrson, 1983), K-Mg (11-Giggenbach, 1988), Na-Ca (12-Tonani, 1980) and K-Ca (13-Tonani, 1980) hydrogeothermometers.

Borehole	Temp.	Content (mg/l)			Estimated temperature values (by equations)					
		Na	Ca	Mg	8	9	10	11	12	13
VG-2	102	378	13.2	1.2	123.9	127.6	**144.9**	109.6	758.8	341.0
VG-3	105	382	16.0	1.5	101.2	103.8	**121.7**	98.7	723.9	309.8
Shaft	94	375	27.4	6.1	109.4	112.3	**130.1**	82.5	622.2	296.7
Peljiste	50	374.9	21.5	6.1	110.3	113.3	**131.1**	82.8	662.4	306.7
Geyser	88	303.4	20.1	6.1	112.7	115.8	**133.5**	78.4	604.5	295.8