Journal of Geochemical Exploration 159 (2015) 101–114

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

journal homepage: www.elsevier.com/locate/jgeoexp

Hydrogeochemistry of thermal groundwaters in the Serbian crystalline core region

Tanja Petrović Pantić [a,*], Manfred Birke [b], Branislav Petrović [c], Jovana Nikolov [d], Veselin Dragišić [c], Vladimir Živanović [c]

[a] Geological Survey of Serbia, 12 Rovinjska Street, 11000 Belgrade, Serbia
[b] Federal Institute for Geoscience and Natural Resources, 2 Stilleweg, 20655 Hannover, Germany
[c] University of Belgrade, Faculty of Mining and Geology, 7 Djusina Street, 11000 Belgrade, Serbia
[d] University of Novi Sad, Faculty of Sciences, Department of Physics, 4 Dositej Obradovic Square, 21000 Novi Sad, Serbia

ARTICLE INFO

Article history:
Received 10 July 2014
Revised 5 August 2015
Accepted 21 August 2015
Available online 28 August 2015

Keywords:
Hydrogeochemistry
Thermal groundwater
Hydrogeology
Geothermometers
Serbian crystalline core
Serbia

ABSTRACT

Geochemical exploration has been applied for studying thermal groundwater characteristics in the Serbian crystalline core region. Within this hydrogeological region, thermal groundwater with temperature higher than 20 °C occurs at seven locations. The maximum discharge temperature of the thermal groundwater is 105 °C which is the highest groundwater temperature encountered in Serbia. Geothermal reservoirs are present within andesite, schist, grus (the fragmental products of in-situ granular disintegration granite), marl and sandstone.

Based on the concentrations of the major elements all of the water samples are of HCO_3–Na to SO_4–Na type. An elevated content of F, B, Ge and Rb is observed, while some samples also exhibit higher concentrations of As, Be, Cs, Ga, Ge, Li, V and W, and one has elevated concentrations of Nb, Zr and heavy rare earth elements (HREE). The groundwater is neutral to alkaline with TDS of 130–3822 mg/L.

Making use of various geothermometers, it was estimated that the temperatures in the selected aquifers of the Serbian crystalline core range from 45 to 146 °C.

Activity concentration of ^{222}Rn ranges from 10.4 ± 0.9 to 104 ± 15 Bq/L and is higher in groundwater that is in contact with schist and along faults, while ^{226}Ra has a smaller activity concentrations, within the range of 0.21 ± 0.09 to 0.48 ± 0.18 Bq/L.

1. Introduction

Previous research on thermal groundwater in the Serbian crystalline core region has been mostly focused on the characterization and study of the geothermal resources, with stable quality and temperature (Stanković, 1988; Stanković and i Zlokolica, 1993; Zlokolica et al., 1994; Zlokolica and Ilić, 1994; Milovanović, 2001; Špadijer et al., 2005; Tasić, 2006; Jovanović, 2008; Milanović, 2009). The characteristics of these groundwaters are also discussed in other studies (Milovanović, 1992; Protić, 1995; Milivojević and Perić, 1990; Filipović, 2003).

There are six hydrogeological regions in Serbia (Filipović et al., 2005): the Dacian basin region, the Carpatho-Balkan Mts. region, the Serbian crystalline core region, the Šumadija–Kopaonik–Kosovo region, the Internal Dinarides region of western Serbia and the Pannonian basin region.

The Pannonian basin extends in the northern part of Serbia, where 78 geothermal wells exist (Martinović et al., 2010); in other regions of Serbia there are a number of natural thermal springs. Most of the thermal springs and wells (temperature > 20 °C) are found in carbonate aquifers under deep layers of Neogene sediments (Pannonian basin and Internal Dinarides–Mačva). The highest groundwater temperatures are measured in samples extracted from igneous, metamorphic and contact-metamorphic rocks of the Serbian crystalline core.

Thermal groundwater in the Serbian crystalline core (henceforth referred to as the SCC) region has been encountered so far at seven locations namely Ribarska Banja, Prolom Banja, Sijarinska Banja, Viča, Tulare, Vranjska Banja and Bujanovačka Banja (Fig. 1). Five locations have spa status, while at two locations (Viča and Tulare), groundwater with temperatures ranging from 23 to 26 °C, is used by the local population. Water in spas is mostly used for balneotherapy and for recreation, while in some cases thermal water is either bottled (wells: P2, B4 and B5), or used for other beneficial uses such as for water supply (Prolom Banja), for heating of spa buildings (at Ribarska Banja, Sijarinska Banja and Vranjska Banja) or for heating greenhouses (Vranjska Banja).

Prolom Banja is located on the northern slopes of Mt. Radan at an elevation of 630 m and is the spa with the highest elevation in Serbia. The geothermal reservoir of Prolom Banja is within the Lece andesite massif, with an area of 700 km^2 and volcanic activity during the Tertiary (Malešević et al., 1974). Thermal water (temperature from 30 to 33 °C) is taken from two wells (depths of 160 and 500 m) drilled into the andesite aquifer.

* Corresponding author.
E-mail address: tanjapetrovic.hg@gmail.com (T.P. Pantić).

http://dx.doi.org/10.1016/j.gexplo.2015.08.009
0375-6742/

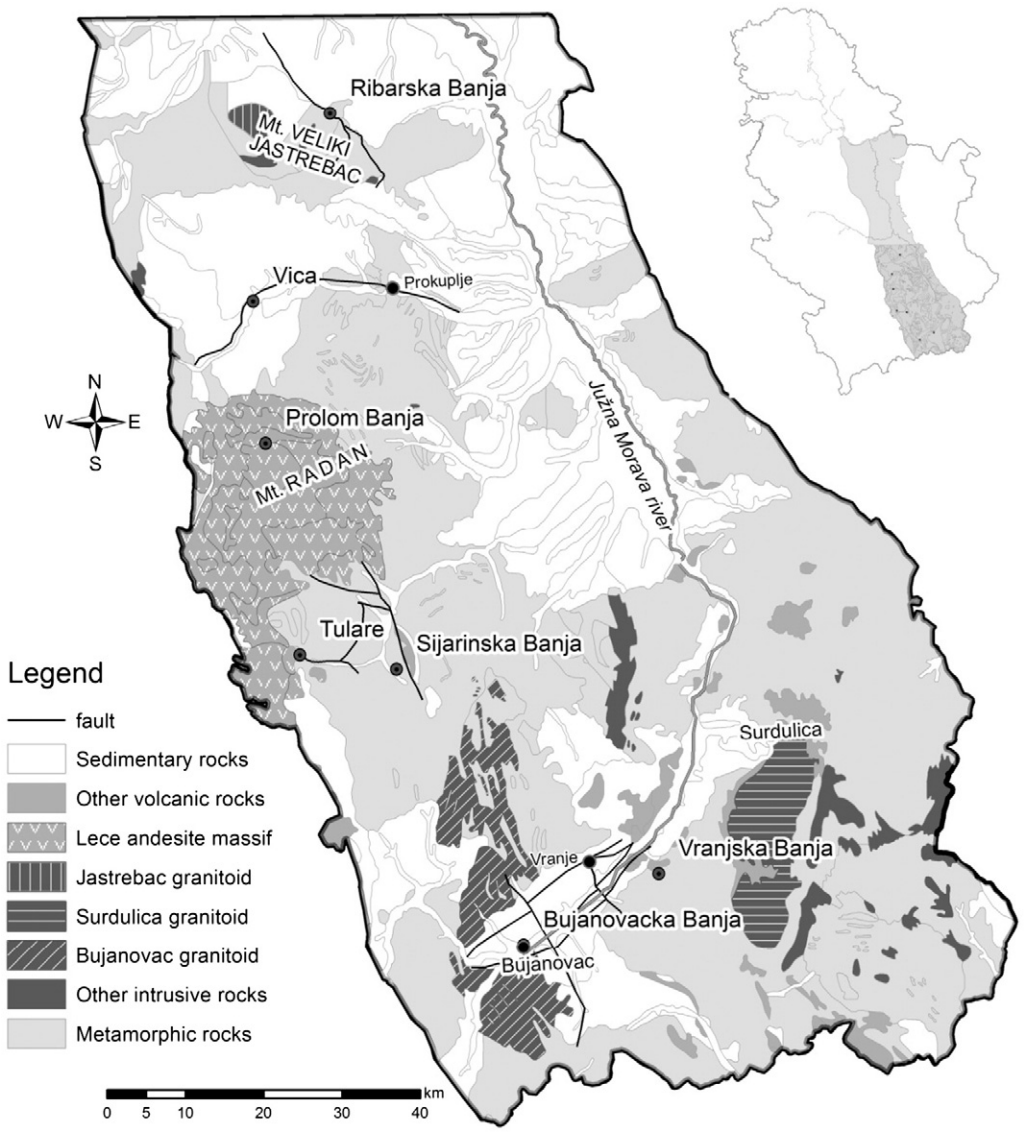

Fig. 1. Geological map of the lower part of Serbian crystalline core and the locations of thermal groundwater (only major faults in the study area are shown on the map). Sampling points are very close at each spa location, so it is impossible to be shown on map.

Ribarska Banja is located on the eastern hillsides slopes of Mt. Veliki Jastrebac, at an elevation of 540 m. This mountain was formed by the intrusion of a granitoid into Upper Cretaceous–Paleogene metamorphic rocks. These rocks (phylite, metasandstone, metasiltstone, conglomerate and contact-metamorphic rocks) are overthrusted by high-grade schists. Groundwater temperature ranges between 38 °C and 54 °C. Water is extracted from contact-metamorphic rocks of Jastrebac granitoid by wells with depths of 163 to 1543 m.

The thermal water at Sijarinska Banja is extracted from a shallow well with a depth of 8 m (71 °C, S2 in Table 2), as well as from a deep well with depth of 1232 m depth (76 °C, S3 in Table 2). The terrain mainly comprises crystalline rock, e.g., gneiss, leptinolite and mica–schist, with andesite outcrops. The most significant heat conductor is a large fault zone that connects the Sijarinska Banja and the Lece andesite massif.

The maximum recorded groundwater temperature at Vranjska Banja is 105 °C (in well VG-3). The Surdulica granodiorite, which contains numerous dykes of quartz latite and dacite, is present on the southeastern side of the spa, while andesite–dacite–volcanic necks are found on the western side — evidence for intense volcanic activity during the Tertiary. These activities resulted in the formation of a succession of volcanogenic-sedimentary rocks, of Miocene to the Pliocene age. The rocks underlying these magmatic rocks at Vranjska Banja are metamorphic (granite gneiss, gneiss and amphibolites). Based on a hydrodynamic test and a mathematical simulation model (Zlokolica et al., 1994; Martinović and Magazinović, 2010), about 100 L/s of the groundwater of Vranjska Banja can be sustainably utilized. This spa has the highest geothermal potential in Serbia.

Bujanovačka Banja is located in a valley that is surrounded by Bujanovac granitoid. The Bujanovac basin comprises of alluvial Neogene sediments on surface, underlain by Miocene sandstones, conglomerates and marls and the Hercynian granite and grus bedrock (Petrović et al., 2012). Temperatures of groundwater range from 29 °C (water extracted from marl and sandstone) to 46 °C (water extracted from grus).

The Tulare village is located 15 km west of Sijarinska Banja, on the southeastern part of the Lece andesite massif. The geological sequence comprises Tertiary rocks, volcaniclastic rocks composed of andesite, tuffs and pyroclastic breccia and subvolcanic diorite rocks that unconformably overlay the metamorphic base rocks. The metamorphic base rocks, especially the Fe-rich varieties, are hydrothermally altered and mineralized. Well T1, for instance, with a groundwater temperature of 26 °C, was drilled through hydrothermally altered rocks to the depth of 300 m.