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Extended Abstracts

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Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Origin of mineral water from Rogaška Slatina (Slovenia)**

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INTRODUCTION

Rogaška Slatina is famous by mineral water, which was discovered in this place in the time of Old Romans. The Bottling Company of Droga Kolinska d.d. is one of the powerful economic activities in Rogaška Slatina today. It produces natural mineral waters (Donat Mg, Tempel and Edina), spring water and soft drinks. Besides, aquifers with mineral water are exploited also for spa needs.

Numerous investigations of Rogaška groundwaters were subjects to balneology and to larger exploitation quantities (Nosan, 1975) that is why information are missing that are essential for definition of the Rogaška aquifer system and for its protection. Questions on the groundwater recharge area and dynamics, on connections between aquifers and on solute transport have remained open, which is closely connected with the field geology and structure. The latter is very complicated - three regional faults intersect in this area, which is folded to anticlinal and synclinal folds. The nature of geological structures, their mutual relations and extent haven't been explained at a satisfactory level in many parts.

With regard to results of previous hydro-geochemical investigations (Nosan, 1975; Pezdič, 1997) it was presumed that the Boč massif near Rogaška Slatina is a catchment area of Rogaška mineral waters, although geological data did not support this hypothesis (Aničić & Juriša, 1984). Hence, complex geological, hydrogeological, chemical, geochemical, isotopic and microbiological investigations were performed in this area during a period 2008-2010 to answer the discussed open questions.

STUDY AREA

The study area with its broader surroundings is geologically one of the most complex parts of Slovenia. It is the juncture of three major regional fault systems, separating three tectonic units (Figs.1 and 3). The Boč massif belongs to the Southern Karavanke unit. It borders to the south with Donat line on the narrow tectonic unit between the Donat line and Šoštanj fault close to which the town of Rogaška Slatina is situated. To the north, the Dravinja fault as part of the Periadriatic line separates the Southern Karavanke unit from the Upper Austro-Alpine unit. The ongoing dextral strike-slip motion along the Periadriatic line and the Šoštanj fault and associates eastward extrusion of the Eastern Alps as a result of the northward shift and counter-clockwise rotation of the Adria microplate that were recently observed using the GPS (Vrabec & Fodor, 2006; Weber et al., 2006). The complexity of the study area is reflected in lithological heterogeneity as a result of faulting into many small tectonic blocks, which are relatively displaced and folded (Figs. 1 and 3). Most of the area is composed of massive limestones and dolomites of Carnian age. They are capping the Boč mountain crest. Oligocene and Miocene beds, covering the northernmost part of the territory and the lower slopes north of Rogaška Slatina, are composed of alternating sandstones, sands, shaly claystones and marlstones and conglomerates in the lower parts. A wide belt of volcanic rocks (andesite, its tuffs and volcanic breccias) is also present in within these units. The upper part is almost entirely composed of hard and bituminous marlstones (Aničić, Juriša, 1984).

Mineral water is stored in fractured layers of the Oligocene tuff covered by the Upper Oligocene and Lower Miocene beds (Fig. 1). The disccused water belongs to a magnesium-sodium-hydrogen carbonate-sulphate facies. It could be exploited from five boreholes that are 24 to 600 m deep (Fig. 1). Donat Mg is the most famous among Rogaška mineral waters. It has the highest mineral content (Tab. 1) and contains more than 1000 mg/l of Mg.

Spring water and thermo mineral water are also exploited from the study area (Fig. 1). The former is stored in fractured Triassic carbonate rocks and Miocene sandstones of the Boč massif and the latter in a dolomitize keratophyre at depths between 1500 and 1700 m.

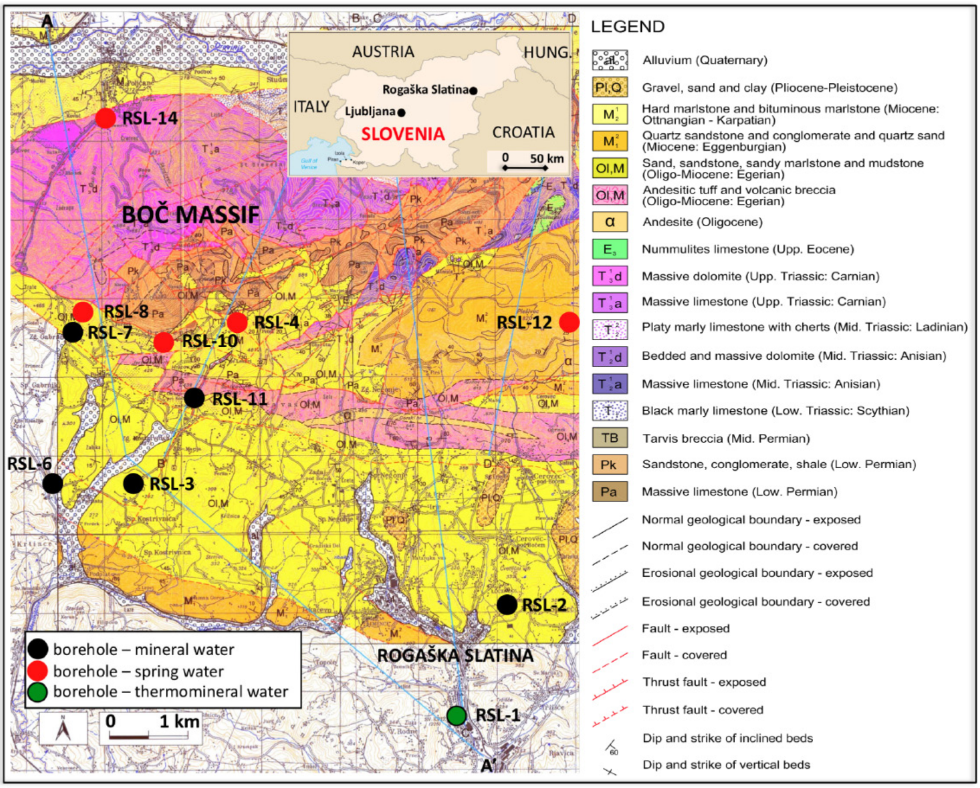

Figure 1. Geological map of the study area with locations of boreholes with mineral, thermo mineral and spring water.

THE RESEARCH METHODOLOGY

Detailed geological, hydrogeological, chemical, biological and isotopic investigations were performed in the study area with the aim to construct a local hydrological model that will provide the ability to predict flow and solute transport in the observed aquifer system and to asses the optimal balance between environmental protection and economic use of Rogaška groundwaters. However, only geological, hydrogeological and isotopic investigations are the topic of this paper.

A detailed structural-geological mapping was performed in the study area. Mutual relations of geological structures and lithological units were shown and also the type and extent of fractured zones that are main factors controlling the development of a hydrological network.

Hydrogeological investigations based on a so-called quantity monitoring, performed during a period of two years at important springs and boreholes of the study area. Besides, precipitation was monitored at four locations. The hydrological balance of the Boč massif will be calculated in 2010. It has not been made up to now, but it is a relevant method for definition of the fractured aquifer system with mineral and drinking water and for validation of the hypothesis that the Boč massif is the catchment area of Rogaška mineral waters.

Isotopic, chemical and microbiological investigations were fundamental for studies of groundwater dynamics and solute transport in aquifers with mineral and spring water and among them. They based on a so-called quality monitoring that run parallel with the quantity monitoring. The monitoring was performed in 5 boreholes with mineral water (RSL-2, RSL-3, RSL-6, RSL-7 and RSL-11) and 1 borehole with thermo mineral water – RSL-1 (Fig. 1 and Tab. 1). Additionally spring water from limestone (RSL-4, RSL-10), dolomite (RSL-8, RSl-14) and sandstone (RSL-12) was monitored (Fig. 1, Tab. 1). The quality monitoring included in-situ measurements of groundwater temperature, specific electroconductivity and pH and the water sampling for laboratorial analysis that was performed monthly as a rule. The geochemical laboratory of Joanneum Research, Institute of Water Resources Management (WRM) was responsible for isotopic investigations that based on analyses of groundwater ^{3}H, ^{13}C-DIC and ^{14}C composition.

Table 1. Average values of sampled water discharges (Q), specific electroconductivity (SEC), mineralisation (M), temperature (T) and pH in the period 2008–2010.

	Mineral water					**Thermo mineral water**	**Spring water fromlimestone**		**Spring water from dolomite**		**Spring water from sand-stone**
Borehole (depth)	RSL2 274 m	RSL3 24 m	RSL6 606 m	RSL7 603 m	RSL11 170 m	RSL1 1700 m	RSL4 215 m	RSL10 130 m	RSL8 170 m	RSL14 38 m	RSL12 100 m
Q (l/s)	0.5	0.2	1	0.4	0.1	6.0	2.2	2.1	1.4	40.0	2.0
M (g/l)	12.75	5.80	11.80	8.65	8.08	6.00			0.5		
SEC (μS/cm)	10999	5165	10539	8627	7102	6418	459	379	570	481	382
T (ºC)	14.6	11.9	28.4	15.1	12.0	55.4	12.6	11.	11.7	12.9	9.9
pH	6.8	6.4	6.9	6.5	6.5	7.1	7.1	7.5	7.3	7.5	7.7

RESULTS

A new structural-geological map of the study area was made. It serves as grounds for construction of a conceptual model of the discussed aquifer system and for evaluation of natural background of mineralization. Field maps include the following elements: lithological data (rock types, rock structures and their ages), structural data (bedding dips, faults, folds and fractured zones), hydrological and geomorphological data (springs, wets, vertical shafts, sinkholes and dolines). The data clearly indicate the dependence of a hydrological network on the geological factors. All springs, swallow holes, shafts and dolines are tied to lithological contacts and fault zones. However, the most important outcome of the structural-geological mapping is the better understanding of the Boč massif tectonic structure, which contradicts previous interpretations. According to our model, Upper Paleozoic to Lower Mesozoic carbonate complex of the Boč massif is not thrusted to the north over the Miocene clastic rocks as it is illustrated in the Basic Geological Map 1 : 100,000 (Aničić & Juriša, 1984). It was found out that the contact between the discussed rock units in the northern slope of the massif is inclined at about 75° to the N-NW direction. This finding is especially important to prove our research hypothesis that the Boč massif could be the recharge area of Rogaška mineral waters (Figs. 2 and 3). Previous models do not permit such an interpretation since the fractured carbonate aquifer system would be cut off with thrust fault in relativelly shallow depths and impermeable Miocene clastic rocks below the supposed contact would not allow a deep groundwater flow (Figs. 2 and 3).

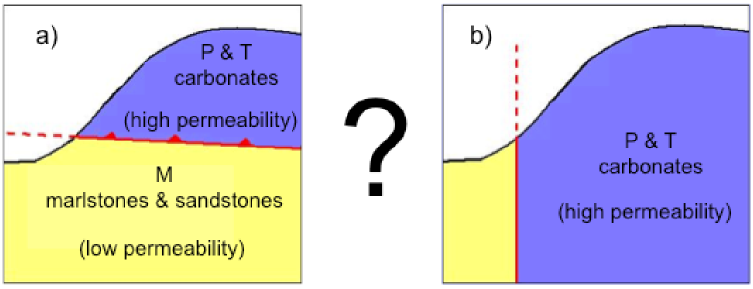

Figure 2. Open question one the contact between the P-T and M rocks in the northern side of the Boč massif.

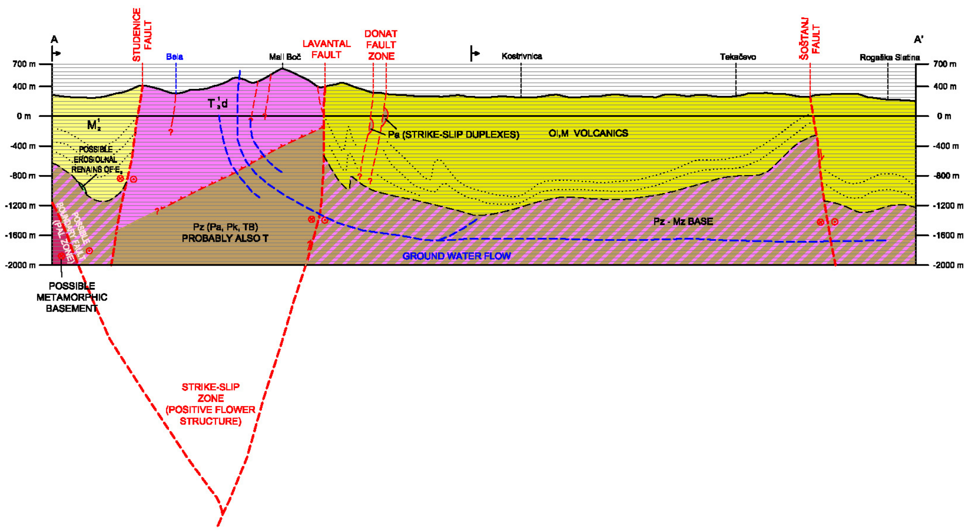

Figure 3. Geological cross section A-A’ of the Rogaška Slatina area (see Fig. 1).

The existing structural boreholes indicate that the Permian basement is present at very different depths in the study area. This reflects great displacements along nearly sub-vertical faults at relatively short distances as well as the presence of an important strike-slip zone trending ENE-WSW parallel to the Ljutomer fault. Our model is also in accordance with structural-geological models of a broader region in which an astomosing sub-vertical system of NW-SE and E-W trending dextral strike-slip faults are arranged in a positive flower structure in a trenspressional tectonic regime (Márton et al., 2002).

The Rogaška mineral waters discharge with a help of a gas lift, thermo mineral water discharges with a help of a thermo lift, while spring waters of boreholes RSL-4, RSL-8, RSL-10 and RSL-14 are artesian. Average values of sampled water discharges, specific electroconductivity, mineralisation, temperature and pH during a monitoring period are presented in Table1.

The results of tritium (^3H) analyses in sampled groundwater are illustrated in Figure 4. They indicate older and younger groundwaters (younger than 55 years) and reflect a mixing of groundwaters. Old groundwaters refer to RSL-1, RSL-2, RSL-6, RSL-7 and RSL-11 (Fig. 1, Tab. 1). These waters are thermo mineral and mineral waters, respectively. RSL-3 is also mineralized, but it should be mixed with young fresh water. Other groundwaters are younger than 55 years and are categorised as spring water.

The ^{13}C isotopic composition of the dissolved inorganic carbon in sampled groundwater is also presented in Figure 4. The figure points out groundwaters that are influenced by the volcanic CO_2: RSL-2, RSL-3, RSL-6, RSL-7 and RSL-11. These waters are highly mineralized, as it is evidenced in Table 1. The RSL-1 water has a lower mineralization, which is reflected in ^{13}C-DIC values.

DISSCUSION AND CONCLUSIONS

The presented results confirm the research hypothesis so far. They gave important information on the recharge area and on the groundwater origin, on mixing processes and groundwater residence times and with that on hydrodynamic connections among individual aquifers. They will be combined with the results of other investigations in a hydraulic model of the Rogaška Slatina area, developed with a help of computer tools MIKE SHE (DHI Water & Environment) during the next research phases. The model will provide the ability to determine the optimal balance between environmental protection and economic use of mineral and spring water resources in the Rogaška Slatina area and it will contribute to an efficient management of the discussed groundwater resources.

a) b)

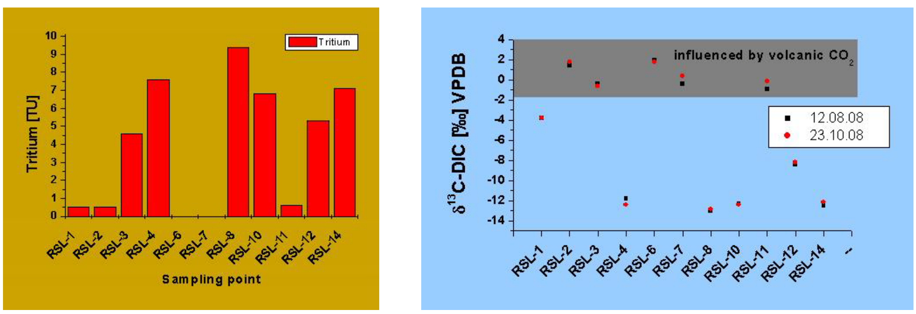

Figure 1. a) Tritium concentrations, b) ^{13}C isotopic composition of dissolved inorganic carbon in groundwater, sampled in the Rogaška Slatina area.

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