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HYDROTERMAL PRODUCTS OF THE SPRECA FAULT ZONE

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SUMMARY

Complex endogenous geotectonic processes predisposed the Spreca fault zone with different geotectonic structures, within which an aquifer of thermomineral waters with CO_2 escalation was formed, in the Gracanica area, located in the lower Spreca depression, which makes contact with two different rock complexes: volcanogenic-sedimentary and ultramafic of the "central ophiolitic mélange" complex south of the Spreca fault zone and the Cretaceous-Tertiary complex of sediments "internal ophiolitic tectonized mélange" north of the fault zone.

Key words: Spreca fault, thermo-mineral water, borehole, temperature

INTRODUCTION

The origin of the thermomineral waters of this locality, the geotectonic and hydrogeological conditions that take place here, have attracted the attention of many researchers. Analyzing the results of previous research, it can be determined that the overgrown Triassic limestones are transit aquifers (released) of thermomineral waters, in which the water is under artesian pressure.

According to their hydrogeological functions, rock masses on this terrain can be divided into hydrogeological collectors and hydrogeological insulators.

Hydrogeological collectors can be divided into ordinary, thermomineral and mixed water collectors.

Collectors of ordinary water are formed in alluvial sediments, river terraces and siparis. These are collectors of intergranular porosity and are heavily influenced by the Spreča River.

In the Cretaceous (K) and Tertiary (Tc) carbonate rock masses, streams of ordinary water with a complex hydraulic mechanism were developed. These are low to medium permeable terrains. Within the alluvial sediments, mixed water releases were registered in different locations. Their occurrences have been registered at springs, dug wells and village "Norton" pumps.

Diabase-rose formation of Jurassic age is represented by metamorphosed sandstones, marls and other lithological members with insignificant porosity. It was raised by Neogene geotectonic activities, which is shown on the geotectonic-hydrogeological model and represents a roof barrier to the upward movement of thermal-mineral waters as well as a podina barrier to the descending movement of surface cold waters in a wider area than the Sprečan fault zone.

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Thanks to the existence of faults in the mentioned fault zone, there is a convective upward flow of thermomineral waters and CO_2 from already established aquifers (issued).

Analyzing the presented model with the fault structure and water movement mechanism based on previous research, the dilemma remains whether there are accumulations of the same in the limestone floor, as an aquifer of thermo-mineral waters, which slowly rise to the surface of the terrain.

1. GEOLOGICAL CHARACTERISTICS

Collectors of thermo-mineral waters and CO_2 in this area are carbonate rocks, probably of Triassic age. The Triassic age of these rocks has not been established paleontologically. The depth to the primary collector is different from locality to locality and is conditioned by tectonics.

The geotectonic-hydrogeological transverse profile of the thermal-mineral water locality in the Sočkovac-Gračanica locality is presented in Figure 1.

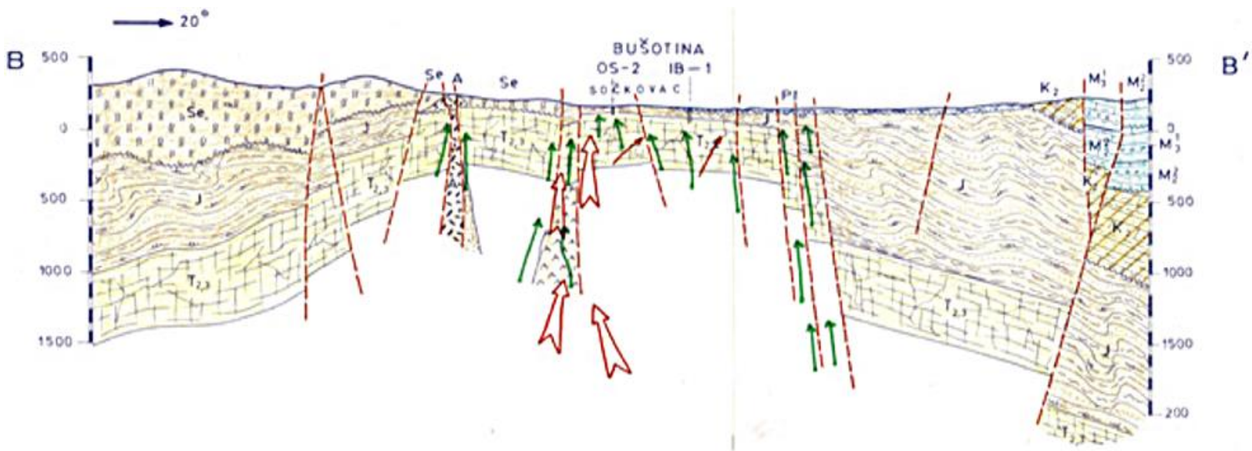

Figure 1. Geotectonic and hydrogeological transverse profile of the Gracanica locality

Analyzing the transverse profile (B-B), one can observe a large tectonic disturbance and outcropping of the lithological formations of both structural-facies units, including the formations of the Spreca depression, with the exception of the Quaternary (Q), which indicates an intense and complex Tertiary geotectonic activity, especially pronounced at the end of the Paleogene and the beginning of the Neogene, which puts it in the Oligomiocene.

The Spreca fault zone has been multiphase regenerated, and is currently active, which can be confirmed by frequent seismic earthquakes, as well as by the occurrence and analysis of the isotopic composition of CO_2 and the content of radon in thermo-mineral waters, which is shown in the analysis of topometric elements in the composition of thermo-mineral waters (table 1).

Analyzing the physical and chemical composition of thermal-mineral water from the locality, it can be concluded that it is hyperthermal, mineral, sodium-calcium hydrocarbonate, while CO_2 in this part of the Spreca fault zone is of dual origin.

From shallower zones, where it is formed by active chemical processes in Triassic limestones, and from deeper zones, where it is formed by thermometamorphic processes in outcropped serpentine-peridotite rocks, which form the Triassic limestone floor where temperatures are extremely high.

Table 1. Physical and chemical composition of thermal mineral waters of Gracanica

Cations (mg/l)	Anions (mg/l)	Gases (mg/l)	Microelements (mg/l)	Radioactivity	Physical characteristics
NH4 **0,1-3,**27	HCO3 **2322-2391**	CO2 **198-642**	Li **270-2100** Pb **1**	Ru **0,49-1,68**	**Mineraliz. 3538-4119 mg/l**
Fe2+ **4,2**	SO42 **-** **3,5-5,0**	O2 **11,86**	Rb **470** As **4**	Ra **0,19-0,39**	**Dry residue 2240-2343**
Na+ **277,2-606**	Cl - **187-198**	N2 **13,26**	Sr **2050** Ag **0,2**	U **0,1**	**Hardness 15,43-32 mg/l**
K + **35,5-40**	F - **0,76-1,11**	H2S **0,07**	Ba **1500** Cd **0,2**	**SiO2 38-40,1**	**pH 6,9-7,2**
Mg+ **63,6-134,2**	Br - **0,16-0,20**		Cr **3** Ti **2**	**HBO2 19-25**	**Eh +60 mV – 2,81 mS/em**
Ca+ **204,4-420**	J - **0,04-0,06**		Zn **2** Mo **0,5**		**Temperature 39°C**
	NO3 - **6,88**		Ni **1** Hg **0,2**		
	HPO42**-** **0,09-0,32**		Co **1** Se **1**		
	HS - **0,05**		Cu **1** Al **24-430**		

2. NATURAL MINERAL WATERS IN THE SPRECA DEPRESSION

The natural mineral waters of the Spreca depression have very complex geological and hydrogeological conditions in which they were formed and exist. It was found that the natural mineral waters on the edges of this depression have an increased content of Mg, Fe ions, and an increased content of CO_2.

The natural mineral water "Tuzlanski kiseljak Mg^{++}" contains a Mg concentration of 650 mg/l, which indicates specific hydrogeological conditions, and the increased mineralization of Mg originates from decomposed ultrabasic rocks with forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$).

The presence of CO_2 in the mineral waters of this depression can be linked to deep structural faults, as branches or parts of the Spreca fault zone, along which CO_2 reaches from greater depths, and is formed by the reaction $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$.

Thus, CO_2 is linked to metamorphic processes, caused by magmatic eruptions during the Cretaceous period.

At the "Ljubace" site (IEB-1), CO_2 can be bound to deeper magmatic processes, and its release to the surface in the form of acidic water is a consequence of tectonic disturbances.

This is also confirmed by the appearance of thermal and mineral waters, as well as acidic waters along the entire Spreca depression, from Toplice (24° C), through Ljubace, Stari kiseljak and thermal water (22 °C) in the village of Kiseljak (Shevar), all the way to acidic waters in Miricina and thermal waters of Sockovac (39 °C) near Gracanica.

3. RESULTS OF HYDROGEOLOGICAL RESEARCH

The thermal mineral waters of Gracanica, Sockovac and Kakmuz belong to the Spreca hydrothermal anomaly. Based on previous research and tests, it can be concluded that Triassic limestones are the basic aquifer of thermomineral waters and gas (CO_2).

Based on the results of drilling so far and the results of chemical analyzes of water and gases, as well as registered occurrences of gas escalations on the surface of the terrain, we can conclude that, in the investigation area, Triassic limestones are located at different depths from the surface of the terrain.

Wildcat wells GB-1 and GB-2 pierced Triassic limestones at depths of 45 m and 60 m, and wildcat wells GB-3 and GB-6 at depths of about 100 m.

Wilcat well GB -5, on the right bank of the Spreca river, was drilled to a depth of 621 m and did not pierce the Triassic limestones, that is, it remained in the sediments that make up the roof of the Triassic limestones on the left bank of the Spreča River. The consequence of this is that the northern wing of the fault zone is lowered compared to the southern one.

It is important to point out that in the area of Sockovac - Kakmuz, and the area of depression on the right side of the river Spreca, Gracanica area, where we have CO_2 gas escalation, there is an intense incrustation in the wells, which occurs due to pressure changes.

In this zone, thermo-mineral waters have a significantly higher temperature and a different chemistry compared to the waters in the Boljanic area, where the waters have a lower CO_2 content, are hyperalkaline (pH ≈ 11), lower temperatures, without incrustations, but with methane escalations.

3.1 SPATIAL LOCATION OF THERMO-MINERAL WATER AND GAS AQUIFERS

Figure 2 shows the spatial position of environments with different hemism of water, while the satellite image (Figure 3) shows the position of thermo-mineral waters in the localities of Sockovac – Kakmuz and Gracanica locality.

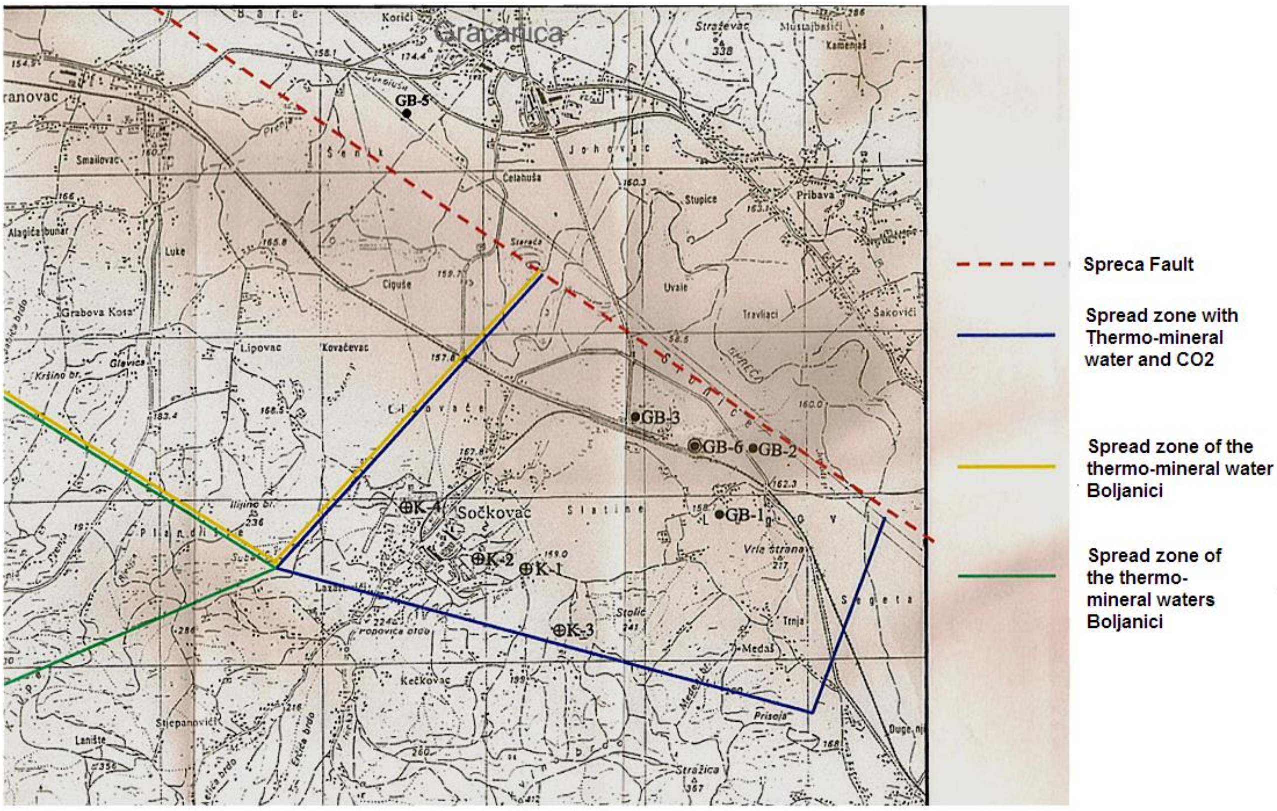

Figure 2. Spatial position of environments with different hemism of water (Scale 1 : 25000)

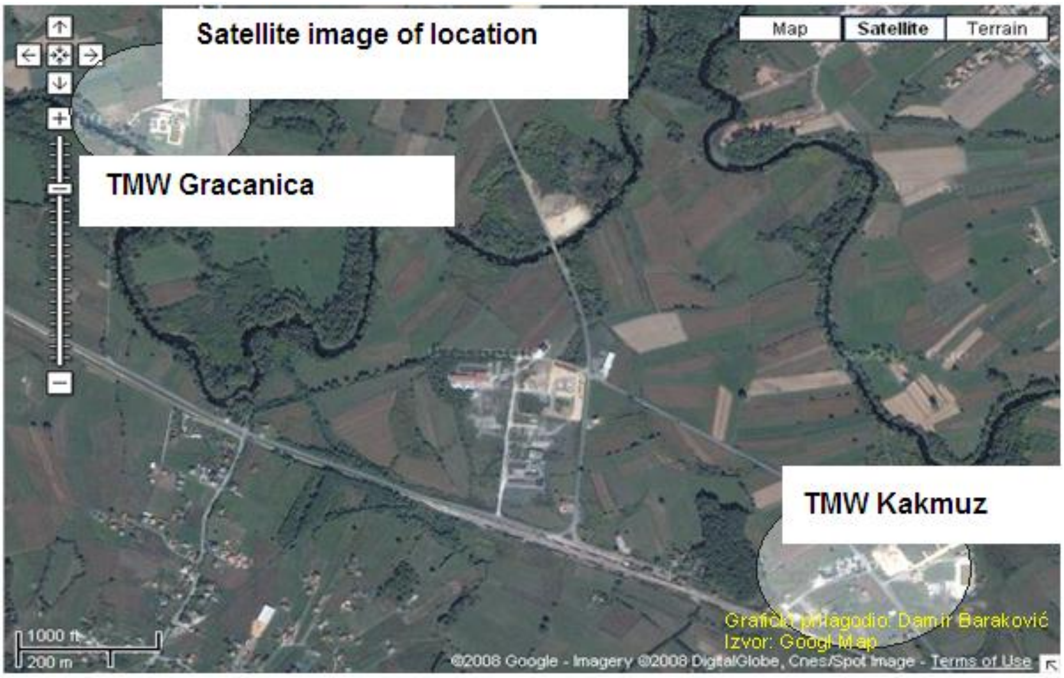

Figure 3. Satellite image of the central part of the Spreca depression with the positions of the occurrence of thermo-mineral waters

Water inflows in wells made in limestone are at various depths and in most cases hydraulically independent in the natural regime before drilling. This is proven by the different temperatures, pressures and physical-chemical characteristics of the water, determined during drilling.

It can be seen from this that there is also an interstratification horizontal to subhorizontal cavernous and cracked limestone at various depths, which is more pronounced than faulting and which provides ascending convection to vertical communication drains. This justifies conducting deeper drilling into the limestone collector, as this will yield larger amounts of water.

Exploratory drilling, carried out in 2003, obtained CO_2 escalations from the aquifer without the occurrence of thermo-mineral waters. This fact indicates that the formation of CO_2 takes place without the presence of water and at greater depths than the thermal-mineral water aquifer.

The thermo-mineral waters of the research area are old waters, pre-nuclear in terms of tritium, and according to some data they are 20.000-40.000 years old. Water exchange and circulation is slow, and they are fed from the hypsometrically higher parts of Ozren and the surrounding mountains.

The mineralization of these waters, as well as the enrichment with CO_2, takes place at greater depths and significantly higher temperatures. The origin of CO_2 and the place of its inflow is at greater depths than the depth of the appearance of thermo-mineral waters.

This is indicated by the fact that there are larger amounts of radon in gas than in thermal mineral waters.

At the depth of the formation of CO_2, high hydrostatic pressures and temperatures prevail, higher than in the aquifer of thermo-mineral waters, and thanks to this, there is an escalation or an eruption of thermo-mineral waters.

4. WILDCAT TGP-2

Based on the stated needs for new amounts of CO_2, i.e. the needs of companies engaged in the exploitation and processing of this mineral raw material in the researched area, a new well (TGP-2), 472 m deep, was drilled in 2007, at the position shown in Figure 4.

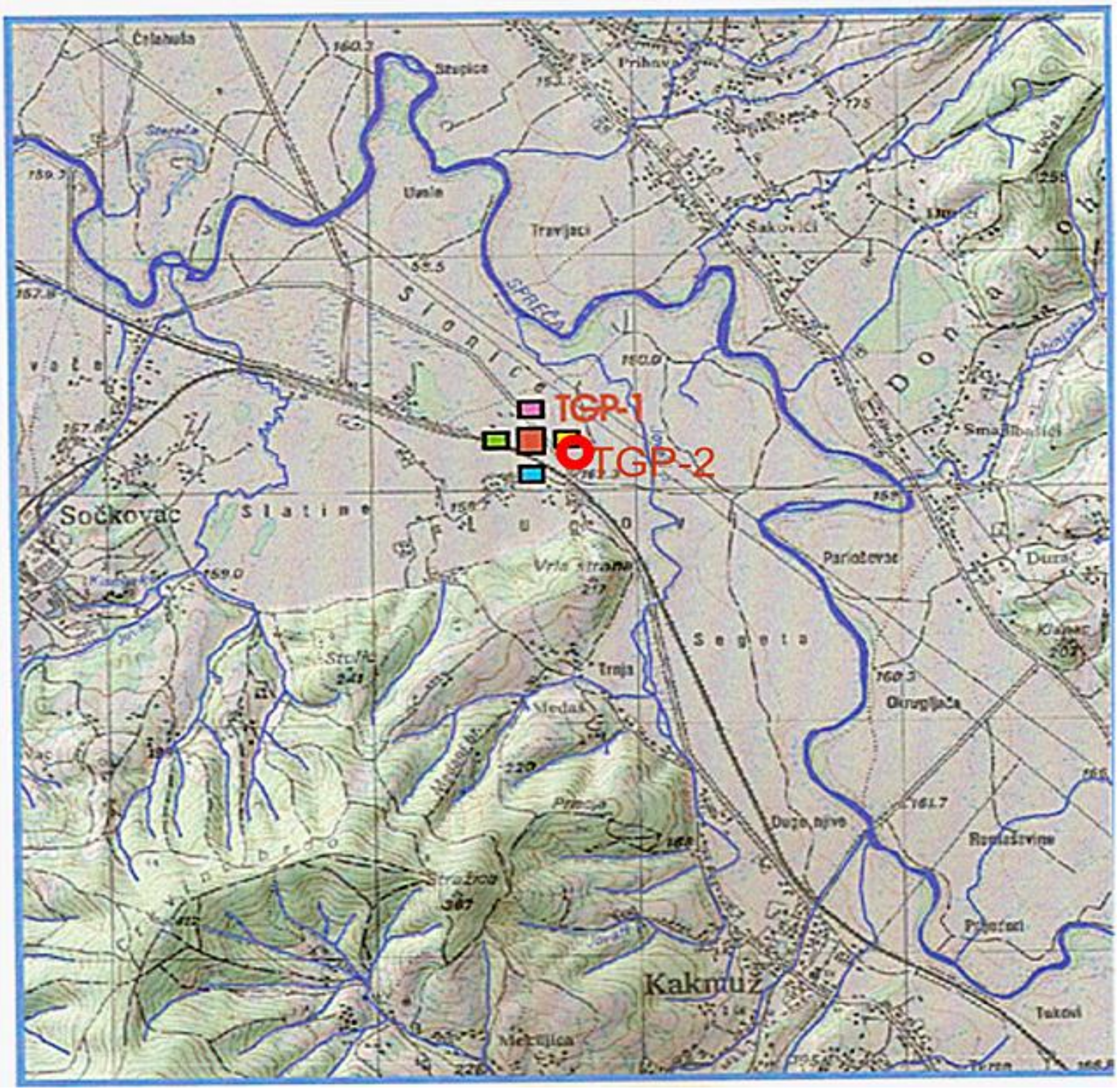

Figure 4. Spatial location of the well TGP-2

4.1. LITHOLOGICAL AND TECHNICAL PROFILE OF THE WELL TGP -2

The TGP-2 well was drilled on the basis of geophysical investigations and the results obtained on the basis of those tests. Figure 5 shows the lithological - technical profile of the well TGP-2.

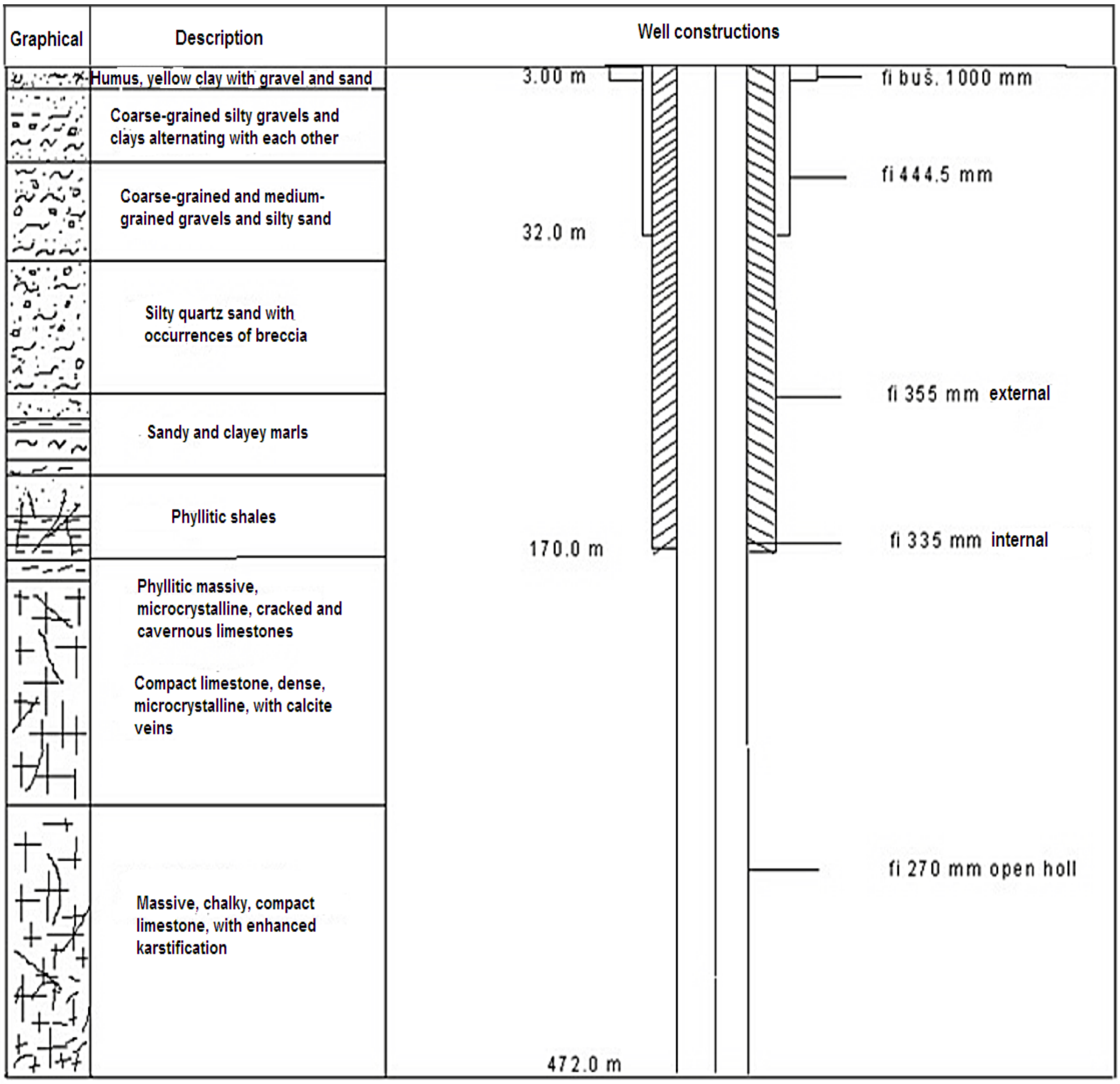

Figure 5. Lithological profile with the construction of well TGP-2

5. RESULTS OF EXPLORATION DRILLING

During drilling, in the limestone zone, three series of blocks, or aquifers, separated by fault planes, which are the main carriers of mineralized water, were identified. On that occasion, at a depth between 200 m and 250 m, the drilling tool failed and the mud was lost. It can be assumed that it is a larger "cavern", from which larger amounts of gas and water are escalating. The second aquifer is in the interval from 280 m to 340 m, and the third from 380 m to 450 m.

Within all the mentioned intervals, there is a drop in the value of the specific electrical resistance, which indicates the karstification of the limestone.

The measurement of the yield of the well was carried out for the first time on 18.12.2007. year, whereby the following results were obtained:

First measurement: 18.12.2007.

The measurement of the water outflow from the TGP-2 borehole was performed (airlift performed by releasing processed CO_2)

Observed characteristics:

- Water capacity:

In 6.5 sec. the container is filled (V=700 l)

Q_v = 385 m³/h respectively 107 l/s

- Gas capacity (ϕ150 mm),

Container (8 m³) filled for 53 sec.

Q_g = 550 m³/h, respectively 770 kg/h

Q_{fakt} = 1:1,4 – H_2O : CO_2

Second measurement: 14.02.2008.

Measurement performed with a compressor (p = 2.5-3 kW) max power. At a depth of 250 m, pumped air under a pressure of 23 bar.

Observed characteristics:

- Gas capacity (ϕ 250 mm)

Container (8m³) filled for 40 sec.

Q_g = 720 m³/h, respectively 1008 kg/h

For the calculation, we take a coefficient of 1.4 from the production of 1m³ of gas, i.e. 1.4 kg, which gives the result:

Qv = 385-396 m³/h, respectively 107-110 l/s

The pressure value of the compressor in free operation without load was also measured.

The 8 m³ balloon (container) fills in 6.5 minutes.

Pcomp. ≈ 1.5 m³/min.

Based on the well testing, the hydrogeological parameters of the aquifer environment were calculated. It is located near the borehole of TGP-1 (approx. 70 m), and these parameters can also be used for the aquifer drilled with the TGP-2 borehole.

Transmissibility coefficient:

$$T = 1.05 \times 10^{-2}\ m^2/s$$

Filtration coefficient:

$$k = 1.05 \times 10^{-9}\ m/s$$

From the given values of the parameters of the water environment, it can be seen that the Triassic aquifer belongs to water-abundant environments, which has been confirmed by previous research.

6. PHYSICAL - CHEMICAL CHARACTERISTICS OF WATER AND GAS

Thermo-mineral, carbonic acid waters of the investigated area are hyperthermal, mineral HCO_3-Ca-Na-Mg type, acidic, with a content of dissolved CO_2 in the amount of 200-620 mg/l, with free CO_2 of 2 dm/l of water, with increased content of SiO_2 and HBO_2, and are made of iron with a rich content of effective microelements with a mineralization of 3.5 g/l, slightly radioactive. Water temperatures are 37-39 ºC. The content of dissolved and free CO_2 is 98 – 99 %.

During the research, complete chemical water analyzes and radioactivity analyzes were performed for the research area on the left side of the Spreca river bank.

Comparison of chemical analyzes of water that were carried out in previous research (1989) by the Geoinstitut (Belgrade) and the Institute Jozef Stefan (Ljubljana), and the results carried out in 2003 at the Institute of Health in Banja Luka, indicates that the thermo - mineral waters of this area are hydrocarbonate-chloride-sodium-calcium waters. The mineralization of these waters ranges from 3,700 - 4,500 mg/l, with a dry residue of 1,400 - 2,500 mg/l. The water temperature is 312 K (39 °C).

In this time interval, it can be observed that there was no change in the hemism of the water, that is, that the differences are within the permissible limits.

These waters contain an increased concentration of iron, ranging from 2.78 to 3.12 mg/l.

Of the other metals, aluminum (0.25), copper (0.18), zinc (0.97) are present, while arsenic, lead, mercury, selenium and chromium occur in concentrations below 0.05 mg/l. Also, these waters are low radioactive with a radon content of 0.57 Bq/l.

The content of dissolved gases in water is:

CO_2 – 488.56 mg/l, O_2 – 7.11, N_2 – 9.88 and H_2S – 0.09 mg/l

CONCLUSION

The geological picture of the terrain of the Spreca fault is very complex. The appearance of thermal-mineral waters is a real result of complex geotectonic activities in this area. The results of the conducted research indicate that the waters of the Spreca fault are of thermo-mineral character, originating from Triassic fractured sediments.

Triassic aquifer belongs to water-abundant environments, which has been confirmed by previous research, but its thermal characteristics need to be determined by additional tests.

The thermal mineral waters of this area are hydrocarbonate-chloride-sodium-calcium waters. The mineralization of these waters ranges from 3,700 - 4,500 mg/l, with a dry residue of 1,400 - 2,500 mg/l. The water temperature is around 39 °C.

The increased CO_2 content is probably a product of the influence of high hydrostatic pressures and temperatures, which are much higher than in the thermo-mineral water aquifer.

Because of this, there is an eruption of thermo-mineral waters.

The capacities of water and gas were determined, measured at the TGP-2 well, which, in addition to confirming the formation of thermo-mineral water, also indicate the existence of other elements, some of which are radioactive, which must be a sufficient indicator of the future possibility of using this thermo-mineral water.

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