Geothermal evaluation in the northern Serbia using interpretation of hydrocarbon well and seismic data

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ABSTRACT

The northern Serbian province Vojvodina is part of Pannonian basin and has very good prospects for utilization of geothermal energy. Previous hydrogeological explorations resulted in drilling several tens of water producing wells with temperatures in the range from 40 to 70 °C mainly used for space heating, balneology and recreation.

The extensive hydrocarbon explorations have been conducted in Vojvodina for more than 60 years and significant data of prospective reservoirs of groundwater are collected. According to this, the existence of water with temperatures higher than 100 °C can be expected and aim of this paper is to present area in central Vojvodina next to the Romanian border as one of potential locations.

The potential reservoirs are lithologically represented by limestones, sandstones, conglomerates and breccia of Badenian age. By the interpretation of the seismic exploration of the area it is possible to estimate the distribution of the reservoirs at depths from 2500 to 3400 m. On the basis of hydrodynamic measurements and logging measured layer temperatures are in the range of 120-160 °C. Water sampled during completion of hydrocarbon wells belong to the sodium-chloride type with the concentrations of total dissolved solids of 10-30 g/l.

1. INTRODUCTION

Company NIS has conducted explorations for exploitation of oil, gas and geothermal water in Vojvodina for more than 60 years. Its comprehensive documentation fund has geological and geophysical data gathered from over 2000 wells. These explorations did not focus on detection of reservoirs of high temperature waters that could be used for the production of electricity, but the present knowledge represents a solid base for the selection of potential sites on which further hydrogeological research could be focused.

Vojvodina in the south part of Pannonian basin is one of the most promising regions for discovering and utilization of geothermal energy due to favourable geologic characteristics (Fig. 1). The thin earth's crust and Neogene nonpermeable sediments of low thermal conductivity which have a significant share in the structure are the cause of the increased value of the geothermal gradient and heat flow density in relation to the average.

Based on existing data an area of about 200 km^2 in the eastern part of Vojvodina near the border with Romania is pointed out as one of the interesting locations for further exploration.

2. GEOLOGICAL AND GEOPHYSICAL DATA

The data of forty wells drilled for hydrocarbon exploration were analysed for over viewing the geological characteristics of the area. The drilling and exploration data collected include lithological descriptions of drill cuttings, laboratory analysis results of water and core samples, geophysical well logging measurements, testing and hydrodynamic measurements. The collected data gave us enough material to define lithostratigraphy of the borehole profiles and assess important characteristics that can indicate the ability of rocks to store and yield fluids. Based on known, the permeable Badenian sediments have been assessed as potential reservoirs of water.

The 2D seismic explorations and interpretation were the groundwork to estimate the distribution of the Badenian sediments in the area. The seismic profiles were recorded in an irregular network with different spacing. The average profile distance is around 1 km in the western part while the profile network with spacing of 4 to 5 km is less dense in the eastern part. The seismic data were recorded with different parameters of recording and processing in several times during the years.

2. INTERPRETATION OF DATA

The occurrence of the Badenian deposits is proven by drilling boreholes in the area. These sediments are discordantly deposited over rocks of the undefined stratigraphic series, Upper Cretaceous and Upper Triassic age and covered by sediments of the Pannonian, Sarmatian and rarely Lower Pontian age.

The upper boundaries of Badenian deposits are in the depths of 2837 to 3210 m. The deposits are presented by a variety of clastic sediments - sandstones, breccias, conglomerates, limestones, marls, siltstones and shales. The thickness of sediments is in the range of 7 to 160 m.

The time-structure map and map of thickness of the Badenian sediments (Fig. 2 and 3) were made on the basis of borehole data and interpretation of 2D seismic profiles. These maps allow more detailed analysis of the structural positions and thickness of sediments and point that occurrence of Badenian can be expected in the entire area. The thickest Badenian sediments (Well-1) are proven by drilling while maximum values up to 300 m are expected in the western part of the area. The increased values of thickness around the other drilled structures could be a good prospect for the detection of the high temperature water reservoir.

The lithology of core samples and values of porosity and permeability K obtained by laboratory analyses are shown in Table 1. Considering the purpose of research, the most of cored intervals are potential reservoirs of hydrocarbons while in terms of hydrogeological research are aquitards (marlstone, siltstone). The most interesting intervals are in Well-1 and Well-3 characterized by fair to good permeability according to the value of the K (interval in Well-3 confirmed in testing of self-flowing water).

The testing of potential hydrocarbon reservoirs of the Badenian age was carried out on thirteen intervals (Table 2). The intervals were opened by perforating the casing in length of 5 to 13 m. The results from ten intervals were inflow of thermal water (self-flow from six intervals) while the inflow of oil and water was registered twice. The pressure and outlet temperature were not measured during the testing so the conditions of exploitation of reservoirs can be only predicted on the results of hydrodynamic measurements under static conditions.

The measurements of pressure and temperature were carried out in wells 6 and 7 in the production intervals of the Panonian age (at depths just above Badenian sediments) and in well 8 in interval of Badenian age. The pressure and temperature are measured in the borehole after sufficient time for stabilization of conditions thus gathered data can be considered as representative ones (Fig. 4). The geothermal gradient Δ g calculated from the collected data has a uniform value of 4,69 (Well-6), 4,63 (Well-7) and 4,73 °C/100 m (Well-8) so the average value of 4,7 °C/100 m can be accepted in the considered area. At locations where such temperature measurements were not recorded the data from borehole logging give us information on expected temperatures. These measurements are performed after a short break in operation activity and generally register lower temperatures than actual values (in practice 10-15%) but also provide important data for characterization of the potential reservoirs of thermal water.

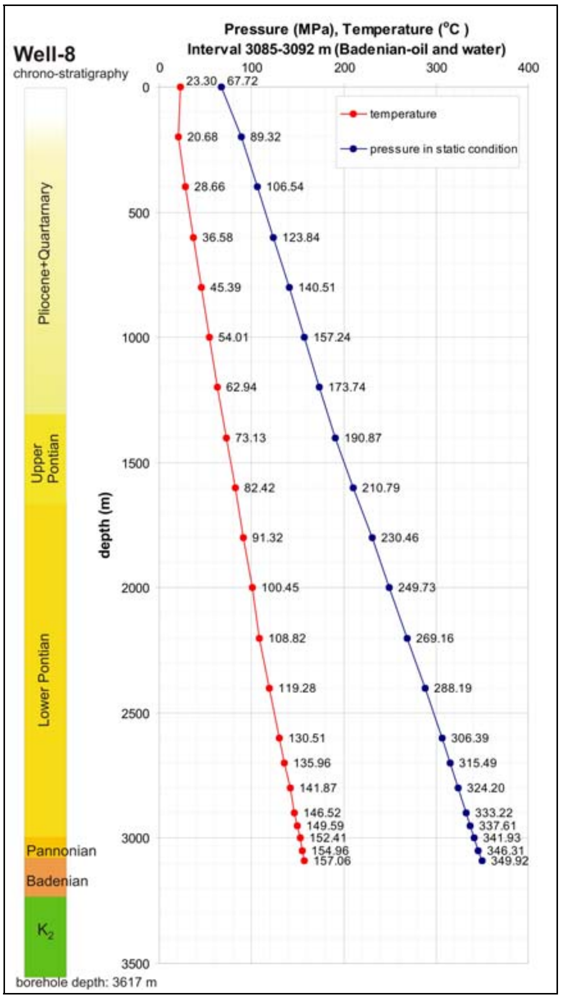

Figure 4: The static pressure and temperature in Well-8

The analysed water samples belong either to the bicarbonate-sodium or chloride-calcium types of waters that are widely found in oilfields. The content of total dissolved solids is between 11 and 27 g/l with very high concentration of NaCl (Table 3, Fig. 5). According to the Schoeller's classification concentrations of chloride are in range of very high to marine, sulphate are normal to average while the concentration of bicarbonate are high. The samples plotted in a Na-K-Mg triangular diagram show that they are close to equilibrium and the subsurface temperatures are between 120 to 160 °C (Fig. 6).

3. CONCLUSIONS

The requirements for increasing the share of renewable energy sources in total consumption and the reducing emission of greenhouse gases impose the need of assessment of the unused available potential. The geological explorations point out the presence of rocks in geological structure of Vojvodina that could have the good reservoir properties. The existence of high temperature reservoirs with high water pressure are already proven on some locations.

The existing results are a solid basis for the allocation the most promising areas for further explorations that should include detailed geophysical surveys to define the location for the drilling of new geothermal wells.

The wells should be adequately designed to enable the collecting of representative information about hydraulic conductivity, specific storage and transmisivity of reservoirs as well as pressure and temperature that exist in there. In case of positive results, this will be relevant input data for feasibility studies of projects of producing electricity from geothermal energy.

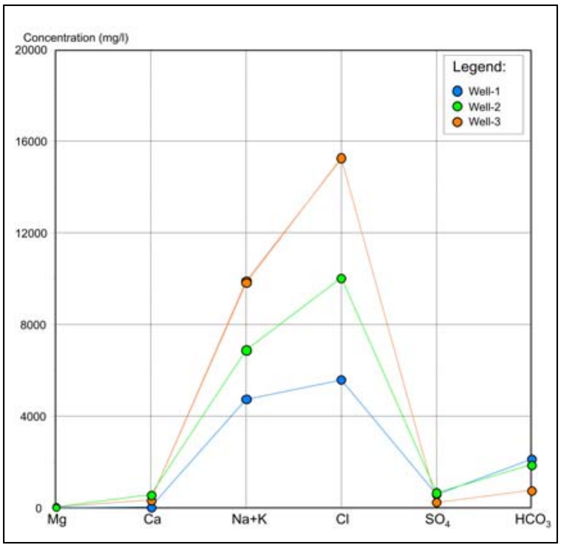

Figure 5. Schoeller's diagram of water samples from Badenian reservoirs

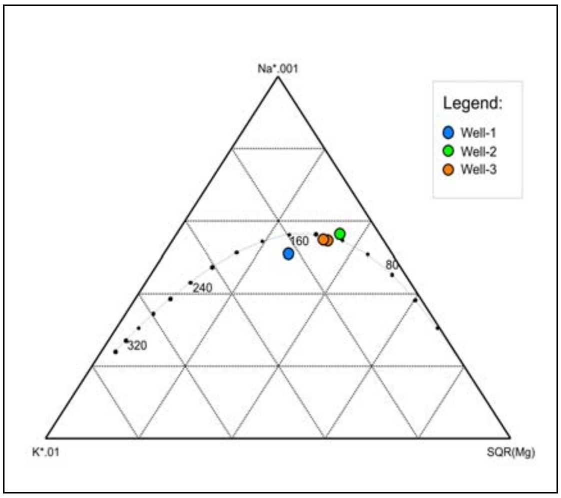

Figure 6. Na-K-Mg triangular diagram of samples from Badenian reservoirs

Table 3. Analyses results of water samples in Badenian reservoirs

Location	Well-1	Well-2	Well-3	Well-3
Interval (m)	3099-3112	2927,94-2947	3060-3067	3075-3080
pH	7,2	7	6,5	7,6
Hardness (dH)	4,28	82,69	51,97	52,66
Salinity (g/l)	8,93	16,41	24,42	24,66
TDS (g/l)	10,96	18,84	26,32	26,63
Na (mg/l)	4544,34	6784,8	9595,4	9691,3
K (mg/l)	198,6	102,0	225,0	216,25
Mg (mg/l)	5,55	17,5	31,5	34,5
Ca (mg/l)	21,46	563,0	320,0	320,0
Fe (mg/l)	0,63	52,5	0,08	0,22
Cl (mg/l)	5591,25	10035,18	15283,2	15247,8
HCO_3 (mg/l)	2122,8	1860,5	756,4	780,8
SO_4 (mg/l)	580,91	645,82	0,0	227,4

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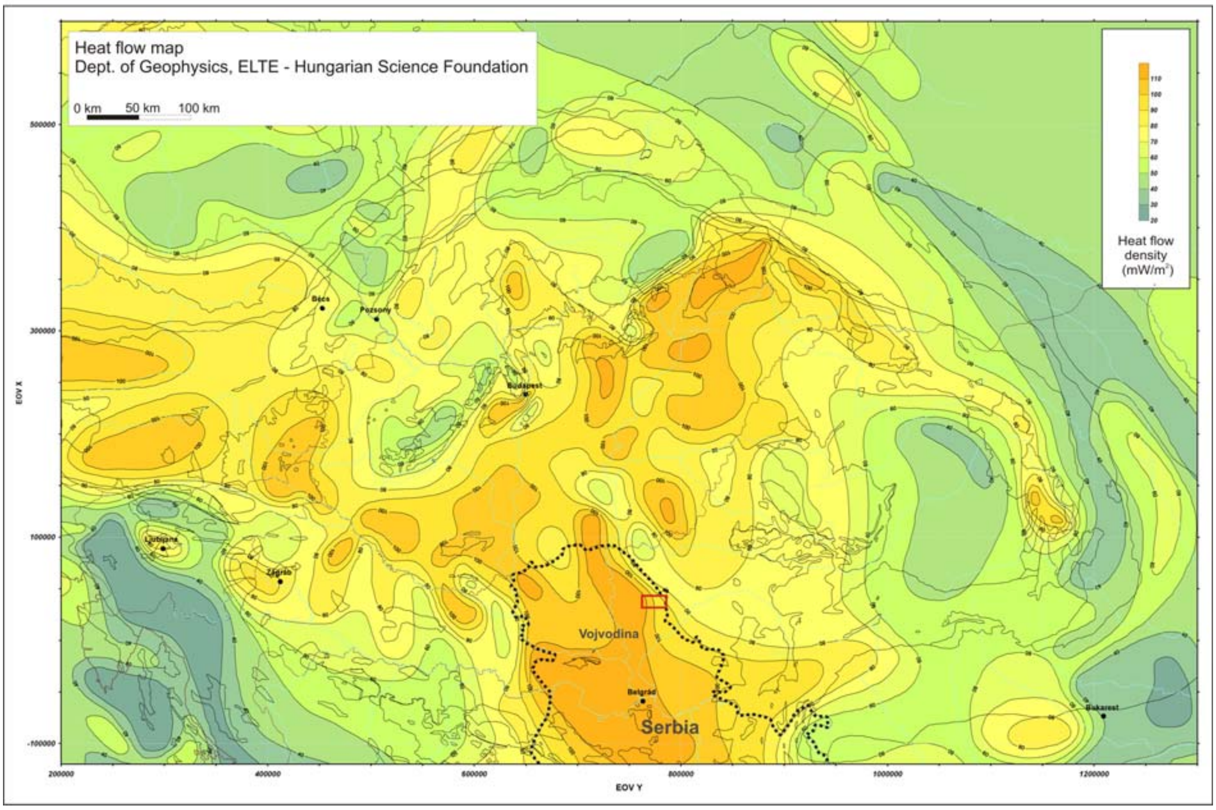

Figure 1. Heat flow map of the Pannonian Basin (http://geophysics.elte.hu/atlas/geodin_atlas.htm)

Table 1. The core samples of Badenian sediments and results of laboratory analyses

Loc.	**Badenian occurrence (m)**	**Core sample (m)**	**Lithology**	**Porosity n** (Average %)	**Permeability K** (μm^2)/(mD)
Well-1	2955-3115	3011-3019	sandstone	15,35	8,13E-02 / 82,35
		3019-3025	sandstone	non defined	non defined
Well-2	2930-2937	**2929-2938***	limestone	non defined	non defined
Well-3	3042-3085	**3068-3077***	limestone	13,56	6,12E-02 / 62,0
Well-4	2837-2918	2837-2839	marlstone	non defined	non defined
		2862-2866	sandy limestone	non defined	non defined
		2896-2900	breccias	non defined	non defined
Well-5	2893-2960	2899-2908	marlstone, limestone	6,89	1,64E-04 / 0,23
		2908-2917	marlstone, marly limestone	3,98	1,94E-05 / 0,02
		2930-2939	sandy limestone	18,99	3.85E-03 / 3,9
Well-6	2890-2913	2890-2893,5	marlstone, siltstone	0,84	non defined
		2893,5-2895	siltstone	3,82	non defined
Well-7	3210-3342	3213-3222	sandstone, siltstone	9,92	2,43E-04 / 0,25
		3222-3231	siltstone	4,09	1,90E-05 /0,02
		3269-3278	siltstone	1,65	8,39E-06 /0,01
Well-8	3075-3212	**3085-3094***	siltstone	4,75	6,56E-04 / 0,66
		3123-3131	sandstone, siltstone	12,34 (sandstone)	7,88E-03 / 7,98

* Intervals tested for hydrocarbons and resulted in thermal waters

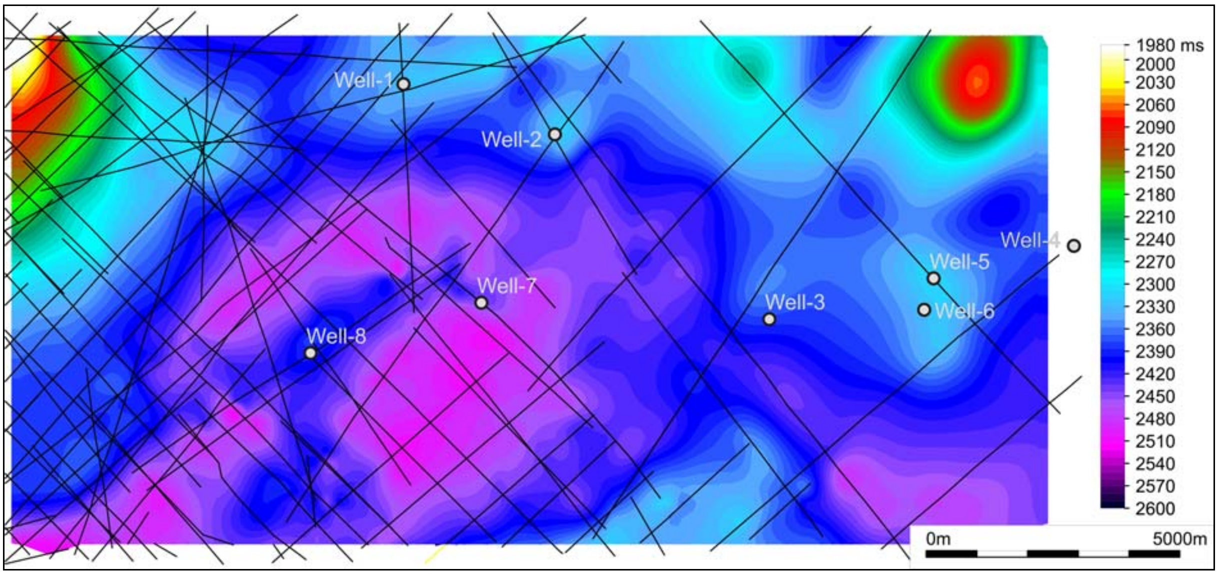

Figure 2. The time structure map on the top of the Badenian sediments

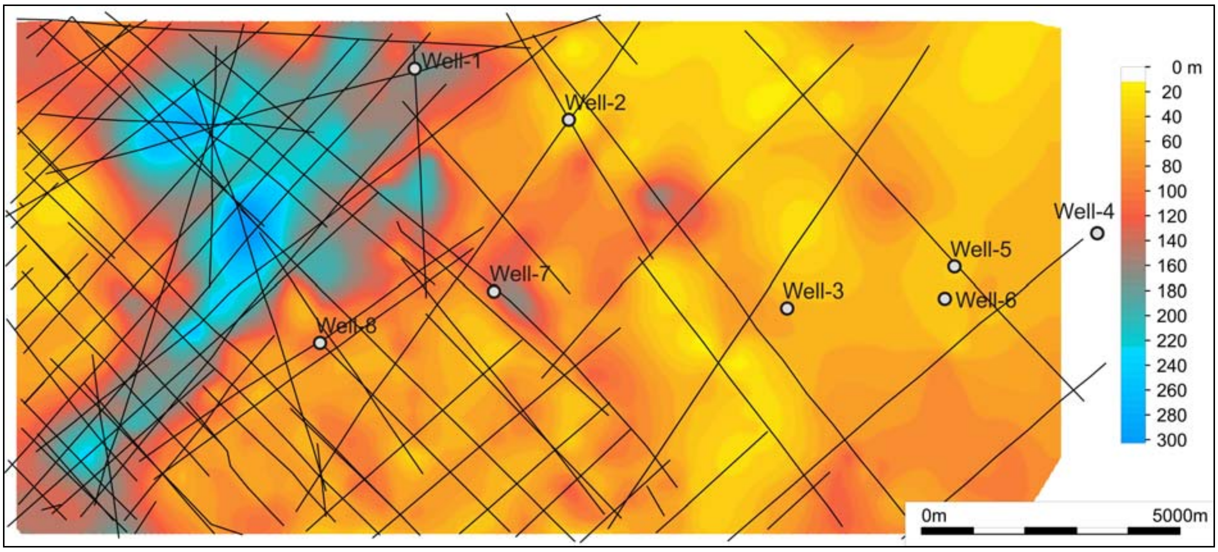

Figure 3. The map of thickness of the Badenian sediments

Table 2. The results of testing and temperature measurement

Loc.	**Interval in Badenian** (m)	**Testing result**	**Lithology**	**Temperature** T_{max}
Well-1	3099-3112	water, self-flow	sandstone, conglomerate	140 °C on 3207 m
Well-2	2927,94-2947	water, DST	limestone, breccias	162 °C on 3207,5 m
Well-3	3060-3067	water, self-flow	limestone	128 °C on 3250 m
	3075-3080	water, self-flow	limestone	
Well-4	2855-2860	water, swabbing	sandstone, marlstone	127 °C v 2996 m
	2868-2874	water, swabbing	sandstone	
	2881,5-2888	water, self-flow	sandstone	
Well-5	2923-2928	water, self-flow	shale, limestone	112 °C on 2932 m
Well-6	2905-2918	water, swabbing	siltstone, breccias	125 °C on 3023,5 m (145,3 °C on 2865 m)*
Well-7	3336-3345	water, self-flow	conglomerate, breccias, sandstone	143 °C on 3418 m (155,9 °C on 3130 m)*
	3216-3225	oil and water, swabbing	sandstone, siltstone	
Well-8	3085-3092	oil and water, swabbing	siltstone and sandstone,	138 °C on 3269 m (157,1 °C on 3088 m)*
	3159-3165	no inflow	shale and sandstone	

* Temperature in static conditions measured during hydrodynamic measurement