JOURNAL OF THE BALKAN GEOPHYSICAL SOCIETY, Vol. 10, No. 1, February 2007, p. 8-15, 5 figs, 2 tables.

Temperature field study of fractured hydrothermal reservoirs in SE Bulgaria (Bourgas basin)

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(Received 16 January 2006; accepted 14 February 2007)

Abstract: *Fractured type hydrothermal reservoirs are not well studied in Bulgaria compared to porous ones in terms of their hydrogeological parameters and structure of the water permeable zones. This study compares three thermal water reservoirs located in the region of SE Bulgaria (Bourgas basin) – Poljanovo, Aitos and Sadievo. Geological and hydrogeological data for these reservoirs are present. The water temperature, the water flow rate, the temperature-depth profiles measured in the wells and the thermal capacity of the reservoirs are discussed. Maps of the temperature distribution at three depth levels (50m, 100m and 200m) exhibit three high temperature anomalies. These anomalies agree with the ones from the map of the water temperature measured at the wellhead and the map of the maximum reservoir temperature based on geochemical thermometers. The zones of high temperature anomalies are probably related to sub vertical water movement. The current thermal water use in these reservoirs is also discussed.*

Key words: *hydrothermal fractured reservoirs, temperature maps, chemical geothermometer*

INTRODUCTION

The Bourgas hydrothermal basin is located in a synclinorium, which belongs to the Eastern Sredna gora structural zone and is rich in mineral waters. Seven reservoirs and ten occurrences have been discovered there (Vlaskovski et al., 1997). Its geological exploration started in 19th century but more detailed study had been carried out after 1955 for copper ores, coal and water prospecting (Kulaksazov, 1974; Petrova et al., 1989).

The current study focuses on three reservoirs – Poljanovo, Aitos and Sadievo, located in the northern part of Bourgas basin (Karnobat-Aitos graben), along the Aitos fault (Fig. 1). The analysis is based on the existing information (geological, hydrogeological and geophysical) updated and summarized by Vlaskovski et al. (1997).

The aim of the paper is to present a more detailed interpretation of the temperature field distribution in depth using data from different sources – temperature logs, water temperature measurements, chemical geothermometers (chalcedony and Na-K-Ca). The outcome of this work will facilitate the magnetotelluric (MT) survey design.

HYDROGEOLOGICAL BACKGROUND OF BOURGAS BASIN

Bourgas hydrothermal basin is mainly built of Upper Cretaceous crystalline volcanic rocks (trachites and basaltoids) and volcano-sediments (alternation of tuffs, tuffites, limestones, sands and marls). According to the well data the top of this complex lies at a shallow depth (from 2 to 57 m below the surface, Vlaskovski et al., 1997). Quaternary and Pliocene-Quaternary sediments cover the Upper Cretaceous rocks.

Two major fault structures namely the Aitos fault and Peshterski upthrow are related to the basic drainage systems in the area. The reservoirs Poljanovo, Aitos and Sadievo are associated mainly with the Aitos fault system, which marks the northern and eastern borders of the Aitos graben. Aitos fault is of Late Alpine tectonic age (Neogene), which is still active during the Quaternary (Iliev-Brucev et al., 1994). The Peshterski upthrow is not well studied (Petrova et al., 1994). The graben area is also divided in segments by smaller fault zones associated with Aitos fault and Peshterski upthrow.

Groundwater recharge zone is located in the neighboring mountain massifs where the reservoir rocks (permeable Upper Cretaceous volcano-sediments and sedimentary rocks) outcrop. The water flow is probably directed from the highest part of the mountains to the east towards Black sea (Vlaskovski et al., 1997).

The underground water moves manly along a system of fractures. This results in a high hydrogeological and thermal heterogeneity of the basin and the formation of distinct reservoirs as well (Petrov et al., 1970).

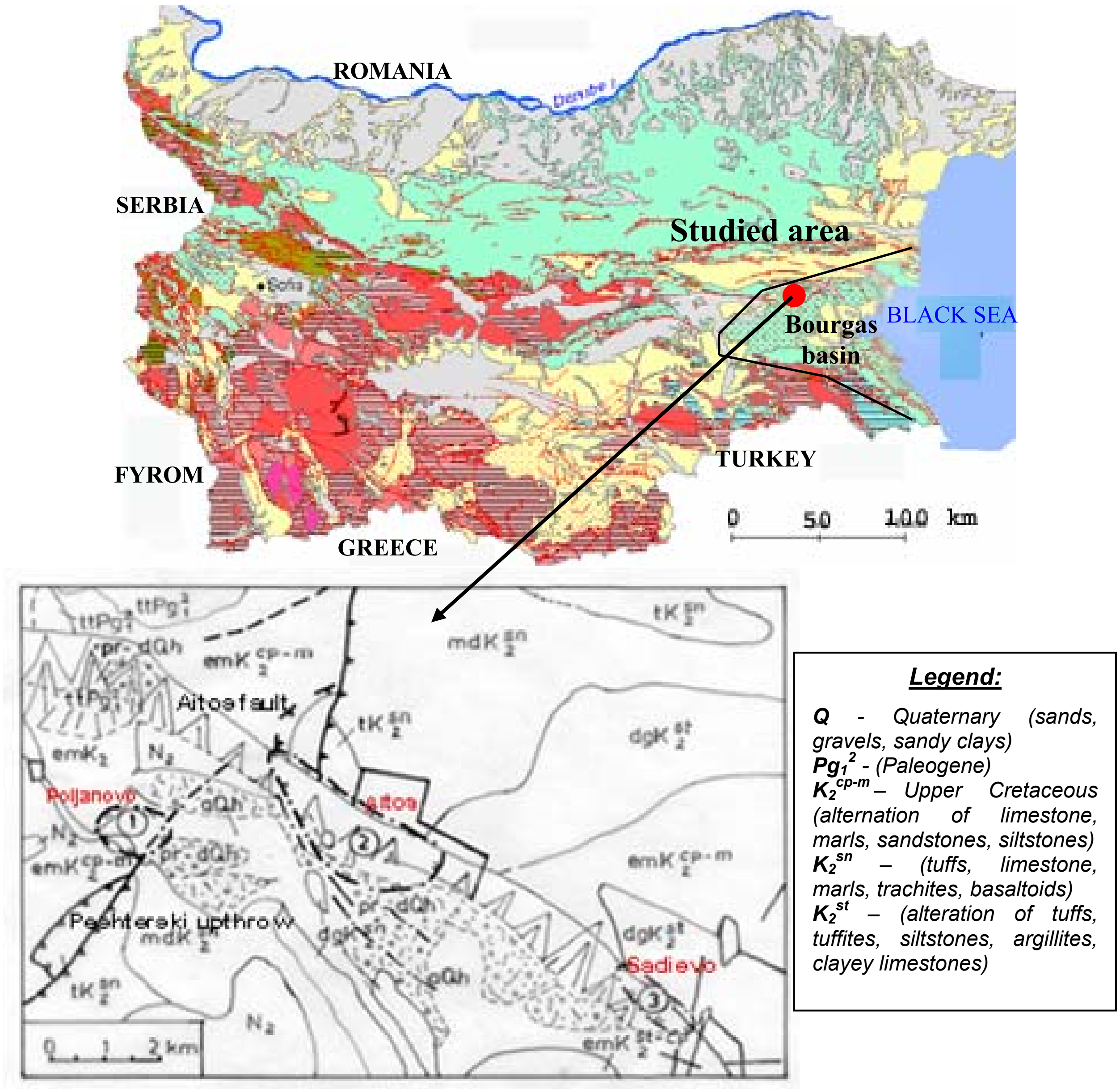


FIG. 1. Geological map of Bulgaria (Cheshitev et al., 1995) (top) and geological setting of the discussed region (bottom). Hydrothermal reservoirs: (1) Poljanovo, (2) Aitos, (3) Sadievo.

Table 1. Summarized data for the studied reservoirs.

№	Reservoir	Number of wells	Depth of wells (m)	Water level (m)	Water temperature (^oC)	Flow rate (l/s)	Transmissivity coefficient (m^2/d)
1	Poljanovo	19	100 - 500	9.9 - (+44.9)	15 – 49	5 - 20.9	0.2 - 45
2	Aitos	5	310 - 1200	24.5 - (+10.6)	29 – 50	0.04 - 6	3.7 - 50
3	Sadievo	3	185 - 989	38.8 - (+50.3)	29 – 34	3.4 - 16.9	7.2 - 307

Note: (+) above the sea level surface

COMPARISON OF THE MAJOR RESERVOIRS CHARACTERISTICS

The geological environment of the reservoirs under investigation is similar. Namely, they belong to the South Bulgarian nitrogen hydrothermal mountainous system. On the other hand they exhibit different hydrogeological and hydrochemical characteristics as well as size and thermal potential (Vlaskovski et al., 1997).

Nineteen (19) wells exist in the reservoir of Poljanovo (Table 1). Several geophysical and well logging surveys have been performed there. Poljanovo reservoir exhibits the highest water flow rate (20.9 l/s) of the studied area. The highest water temperature values are registered in Aitos (50°C) and Poljanovo (49°C), while in Sadievo the temperature is about 34°C (Vlaskovski et al., 1997).

Although the reservoirs are located at a distance of about 10 km, a variation in water chemical content is observed. Water type varies from hydro carbonate – sodium (Sadievo) to hydro carbonate-sulfate-sodium (Poljanovo). In addition, the chlorine content in Poljanovo (up to 170 mg/l) is much higher than in Aitos (up to 59 mg/l) and is missing in Sadievo. The increased values of fluorine (up to 12 mg/l) and methasilisic acid (up to 150 mg/l) in the region are typical for this type of rocks. According to Vlaskovski et al. (1997) these reservoirs belong to the same tectonic system (Aitos fault), but they have no hydraulic connection. This is confirmed by the water chemical composition data. The value of Total Dissolved Solids (TDS) varies from 0.33 to 0.77 g/l, and pH does not differ considerably for the hydtrothermal reservoirs (7.8 –10).

GEOTHERMAL FIELD

Prior work

The number of temperature-depth profiles and their measured depth intervals are given on Table 1. In Poljanovo reservoir most of the 19 wells are located in a set of profile lines spaced at about 500 m apart. Temperature logs are available for 14 of them. Logs from wells P-111 and P-134 mark the temperature range variation within the site (Fig. 2). Most of the measurements in this reservoir do not reach 200 m and are not shown on Figure 2.

Although the wells in Aitos reservoir are only 7, temperature measurements probe much deeper and reach up to 800 m (A-63, Fig. 2). From the existing three wells in Sadievo, temperature data are available only for two of them. The measured depth is restricted to 300 m (S-88).

Heat flow data exist only for Aitos area (80 mW/m^2, Bojadgieva and Gasharov, 2001). This region is characterized by an increased thermal potential, compared to the average value for the country (71 mW/m^2).

The calculated geothermal gradient values are very high for Poljanovo and Aitos (up to 12.5 °C/100m) while for Sadievo they are much lower (4.4 °C/100m).

Results and analysis

Volcanic activity in the region as a source of thermal energy had stopped at the end of Upper Cretaceous. Thermal waters are considered as the main factor that currently controls the temperature field distribution (Vlaskovski et al., 1997).

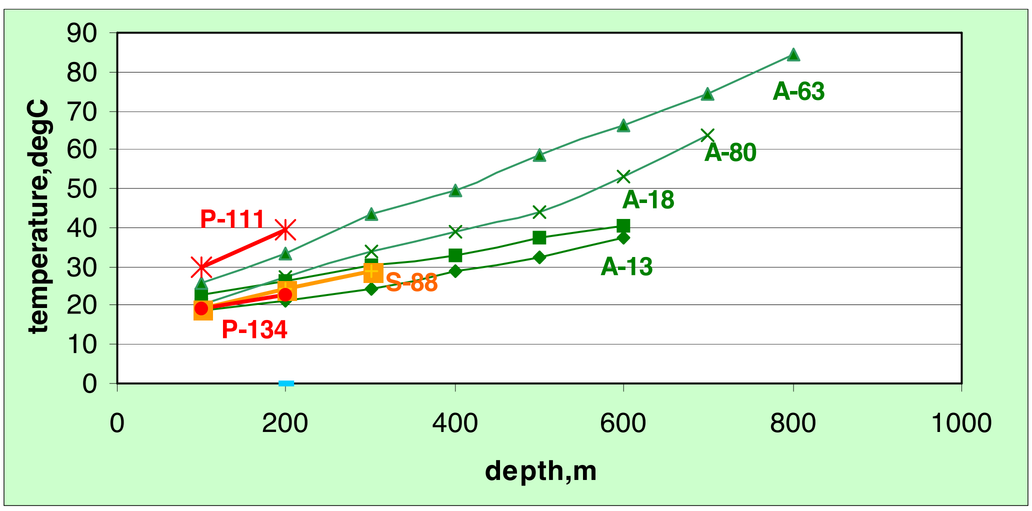


FIG 2. Temperature-depth profiles from the three reservoirs (P-Poljanovo, A-Aitos, S-Sadievo).

Figure 3 displays temperature maps at three depth levels (50m, 100m and 200m) based on the well data. They are analyzed together with the map of water temperature measured at the wellhead (Fig. 4) and the map of calculated maximum reservoir temperatures from chalcedony geothermometer (Fig. 5). Predicted temperatures from different types of chemical geothermometers are taken from Teneva (1994).

A general trend of increasing temperatures from Poljanovo to Sadievo is traced out on the 3D maps (Figs 3, 4 and 5). Two high temperature anomalies in Poljanovo and Aitos are outlined on all maps. Sadievo temperature anomaly is not well discribed due to lack of data. Namely the temperature data originate from two wells located very close to each other.

The temperature anomaly in Aitos exhibits two temperature peaks and occupies a larger area compared to Poljanovo (Figs 3, 4 and 5). It is probably related to a more complicated deep structure of Aitos reservoir, which is characterized by higher predicted temperatures compared to Poljanovo (Fig. 5). The distribution of expected maximum depth temperatures confirms the assumption that Aitos reservoir is of considerable geothermal but limited hydrothermal potential due to its low flow rate (Vlaskovski et al., 1997). The highest water temperature values predicted by chalcedony geothermometer in Aitos area are 99^oC (A-63) and 126^oC (A-83), while for Poljanovo it is 90^oC (P-111). Data calculated by using another chemical geothermomether (Na-K-Mg, Teneva, 1994) confirm these results.

According to Vlaskovski et al. (1997), well A-83 does not belong to Aitos reservoir as it exhibits different piezometric level and water chemical content. It probably, belongs to another fractured hydrothermal system.

Figure 4 shows the same trend of temperature distribution. Although these data characterize a mixture of different water flows into the wells, the role of thermal inflows is dominating.

The comparatively similar location of temperature anomalies illustrated in all maps is an indication of a sub-vertical water movement towards the surface along fractures. The underground structure is more complicated in Aitos compared to Poljanovo. It is expected that a future magnetotelluric (MT) survey will give more detailed information about the location of water conductive zones.

POSSIBILITIES FOR THERMAL WATER APPLICATION

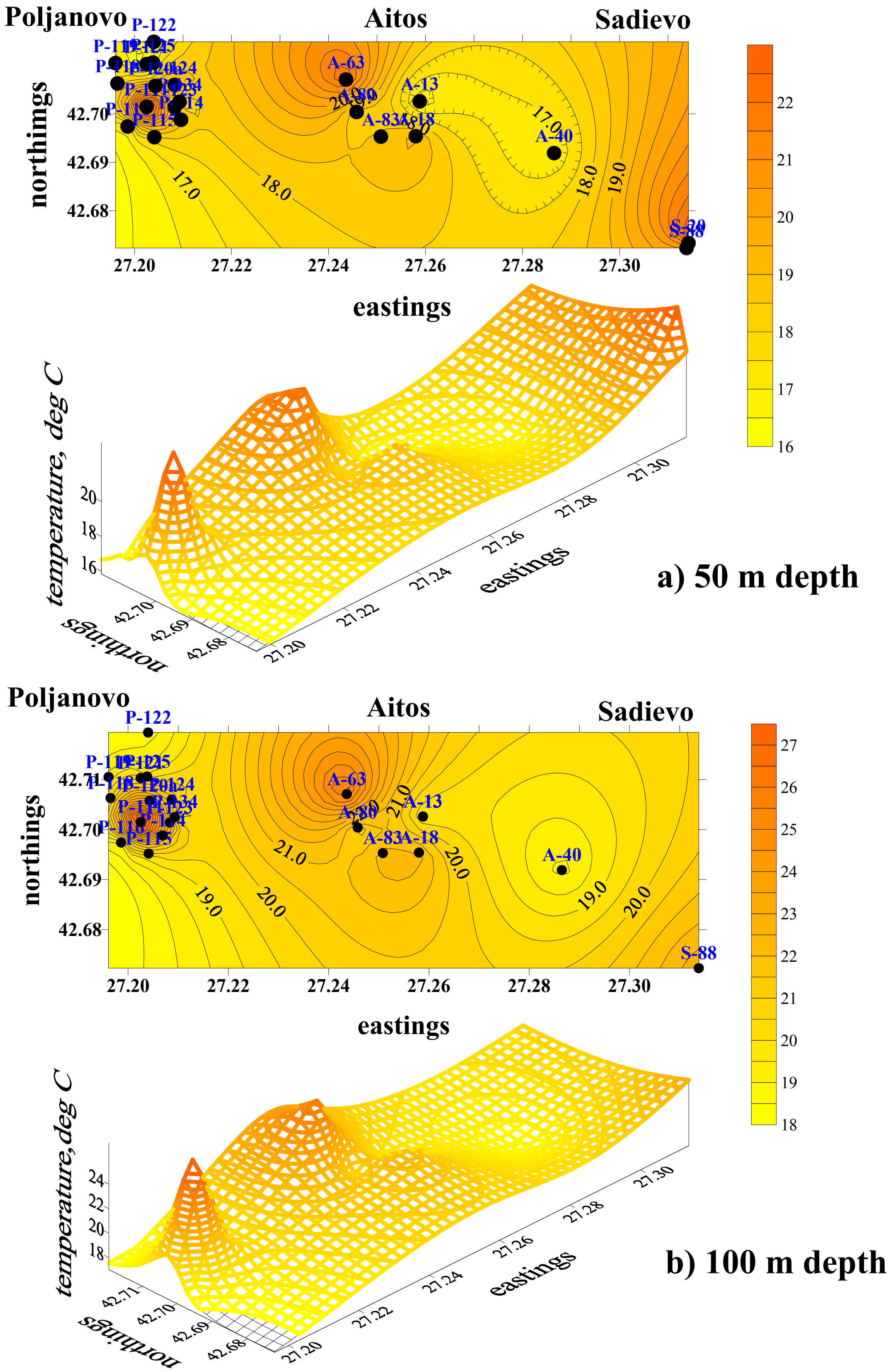
The hydrothermal reservoirs of Bourgas basin are of limited thermal capacity. The best conditions for exploitation at this stage of development belong to Poljanovo according to the thermal capacity data (Table 2, Vlaskovski et al., 1997). These values are estimated for water outflow of temperature 15^oC.

More information (structural and hydrogeological) on the water conductive zones will facilitate the reassessment of exploitation flow rate of these reservoirs. According to the preliminary assumptions (Vlaskovski et al., 1997) a significant flow rate increase is not expected in Aitos. Also, the surface conditions for carrying out an MT survey are unfavorable in Aitos reservoir due to its urban environment. Hence, the future exploration and exploitation should be focused on Poljanovo and Sadievo.

Currently, thermal water from the most productive well P-111 in Poljanovo is self-flowing (currently not in use) while well P-135 is closed. The water is partially used for bathing in Aitos (A-18 and A-75) and for washing and drinking in Sadievo (S-20 and S-88).

CONCLUSIONS

1. The hydrogeological data of the reservoirs (water temperature and chemical content, flow rate, thermal capacity, etc) are summarized and discussed.
2. Temperature field distribution is analyzed based on five maps – rock temperature distribution at three depth levels (50m, 100m and 200m), water temperature, measured at the wellhead and reservoir water temperature from chalcedony geothermometer. Sub-vertical water movement through fractured zones, probably forms the outlined temperature anomalies on all maps for the regions of Poljanovo and Aitos. These zones are more complicated for Aitos reservoir.
3. The most promising areas for carrying out magnetotelluric survey are Poljanovo and Sadievo due to the favorable surface conditions. Also, they are characterized by higher flow rates compared to Aitos. Sadievo reservoir is not well studied and detailed structural information will provide better location for drilling a new well.


Poljanovo
Aitos
Sadievo
P-122
A-63
A-13
A-40
A-83
A-18
S-88
northimgs
eastings
temperature, deg C
a) 50 m depth
Poljanovo
Aitos
Sadievo
P-122
A-63
A-13
A-40
A-83A-18
S-88
northings
eastings
temperature,deg C
b) 100 m depth

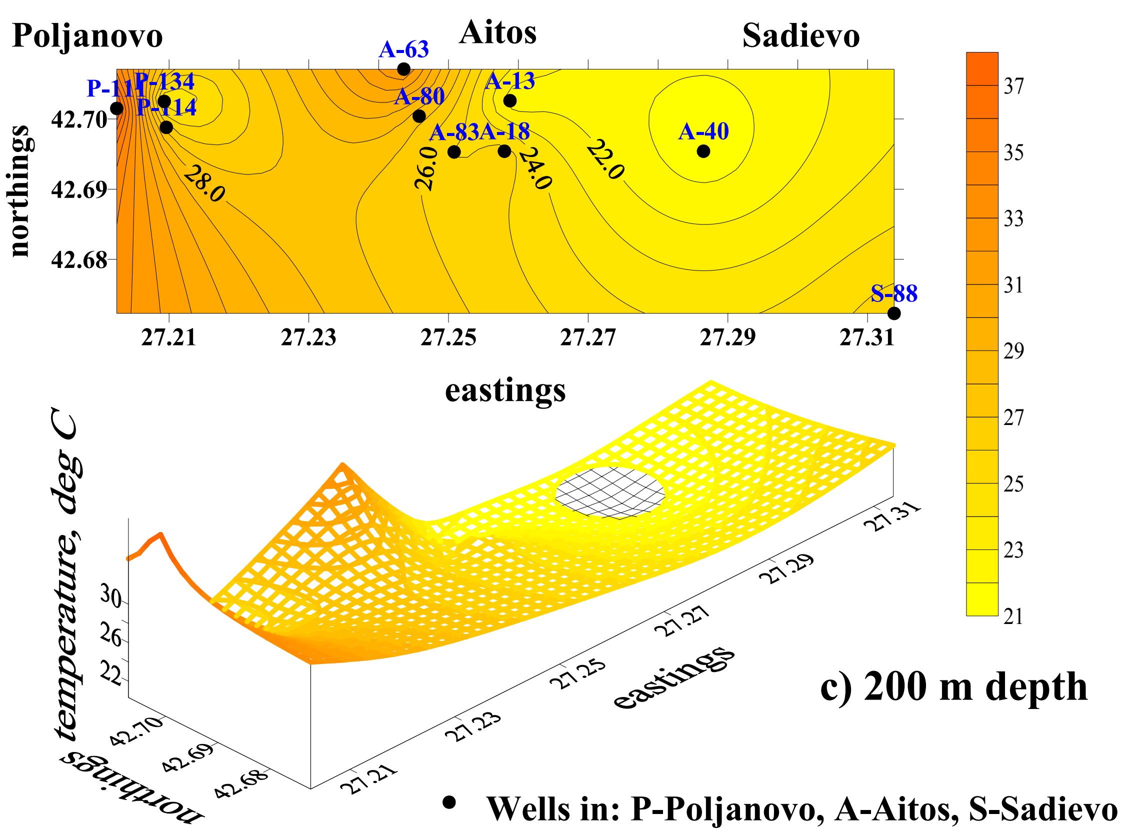


FIG 3. Rock temperature distribution maps at different depth levels below the surface (2D and 3D presentation) a) 50m b) 100 m c) 200m.

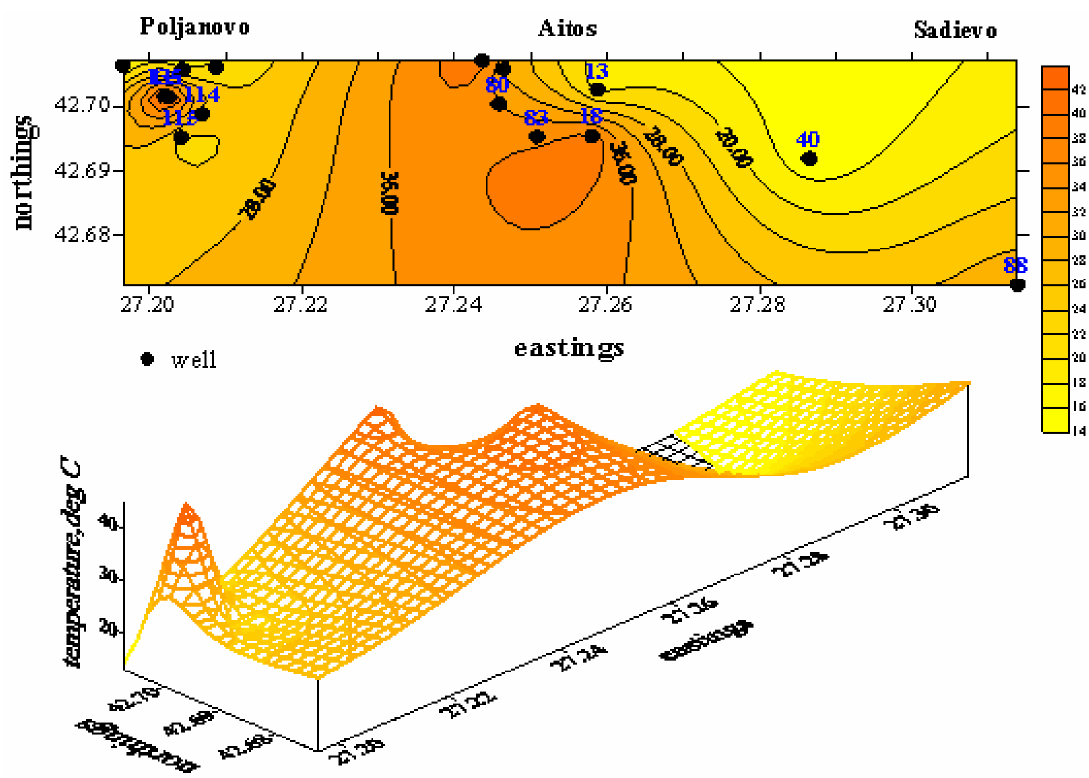


FIG 4. Distribution of water temperature measured at wellhead (2D and 3D presentation).

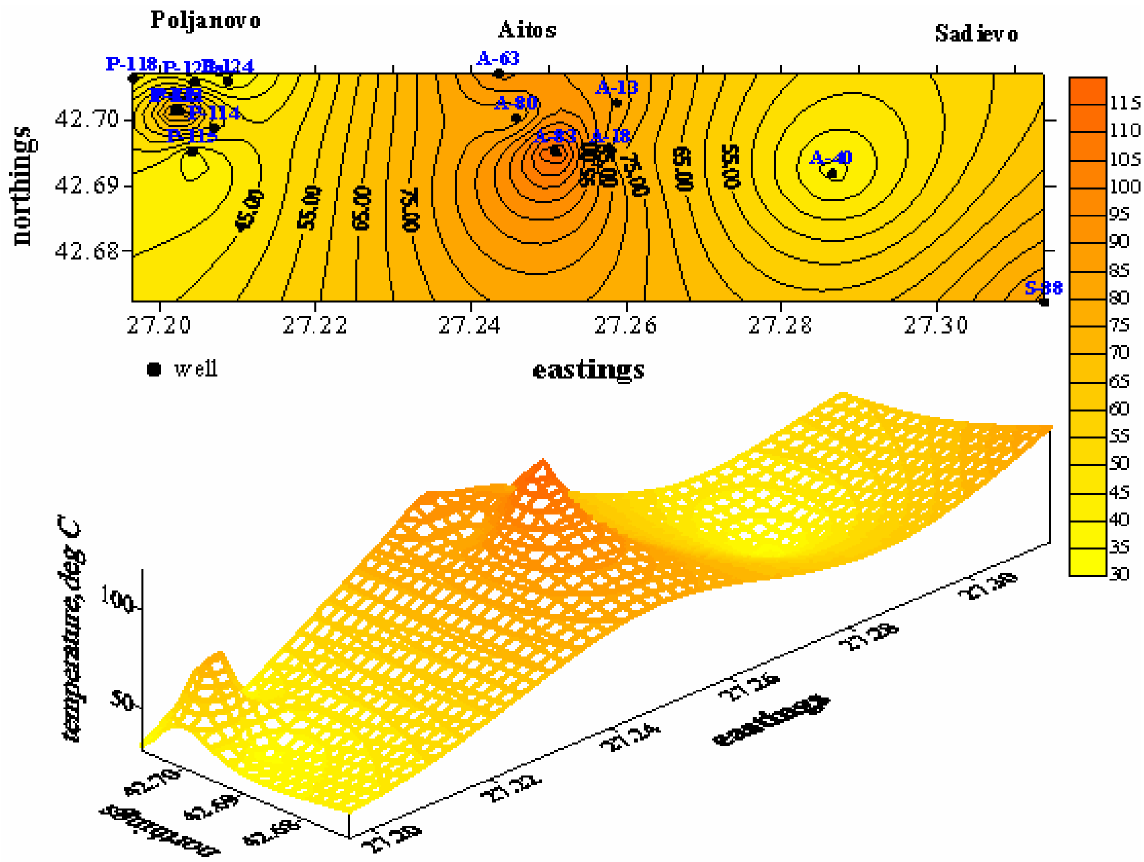


FIG 5. Distribution of predicted reservoir water temperature calculated by chalcedony geothermometer (2D and 3D presentation).

Table 2. Estimated thermal capacity of the studied reservoirs (Vlaskovski et al., 1997).

№	Reservoir	Wells	Exploitation flow rate (l/s)	Temperature (^{o}C)	Thermal capacity of the wells (Tout=15^{o}C) (10^6 kJ/24h)	Total thermal capacity (10^6 kJ/24h)
1	Poljanovo	P-111	5.4	49	66.3	224.6
		P-135	13.7	47	158.3	
2	Aitos	A-18	6.0	42	58.5	87.8
		A-75	4.5	33	29.3	
3	Sadievo	S-20	16.1	29	81.4	124.5
		S-88	7.7	30.5	43.1	

ACKNOWLEDGEMENTS

This research is related to a bilateral Indo-Bulgarian project: NZ 1411/04 "Mapping of subsurface geo-electric structure to assess geothermal potential of Bulgaria using magneto-telluric studies" (2004-2007) between Bulgarian Academy of Science, Sofia and National Geophysical Research Institute, Hyderabad, India with the financial support by the Ministry of Science and Education, Bulgaria and Bulgarian Academy of Sciences.

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