Bulletin d'Hydrogéologie No 17 (1999)
Centre d'Hydrogéologie, Universiti de Neuchâtel
EDITIONS PETER LANG

Geothermometry of Sofia field hydrothermal systems, Bulgaria

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ABSTRACT

The major reservoir rock **types** in Sofia geothermal field are Triassic limestone and sandstone, Jurassic limestone, Cretaceous sandstone and andesite. As secondary reservoirs, Pliocene sands accumulate the hot water and directly cover the bedrock. The chemical composition of 30 natural springs and geothermal wells in this field were taken into consideration. Several geothermometers (chalcedony, Na-K-Ca, K-Mg, Na-K and Na-Li) have been used to predict subsurface temperatures. It can be concluded that for Sofia field the chalcedony geothermometer is found to be the most reliable one of the studied geothermometers. According to it the highest predicted temperatures in the geothermal reservoir are above 90°C. Based on all geothermometer data it is possible that water with a relatively high temperature can be found in the northern part **of** the city of Sofia and in the towns of Mramor, Dobroslavtzi, Gniliane, Trebich and within an area east of Sofia, between the towns of Kazichene and Ravno pole where 81°C geothermal water has already been found. All these prospects areas **are** in the sedimentary rocks of the field. The maximum temperature **for** the accumulated water in the volcanic rocks of the southern parts of Sofia is not expected to be higher than 45°C. These results **are** in agreement with those of the authors obtained by the helium method and other methods of geothermal exploration that have been used in this field. Possibilities of application of the established correlation "trace elements abundance - T_{depth}" like new indicators, concerning the dynamics and the kinetics of the genetic processes and the migration in the thermal fluids - from the deep reservoir up to the emergence - are elucidated. Apparently, no geothermal water with significantly higher temperature than the measured temperature of existing waters is likely to be found.

KEYWORDS

Chemical geothermometer, trace element, migration, temperature, deep reservoir

Introduction

Initially, the geothermal water exploitation of Sofia field was limited to natural discharge from hot springs (Ovcha kupel, Sofia-centre, Pancharevo and Gorna bania) or to free flow from several shallow wells. The water was used for public baths and balneological purposes. The bedrock of the field is composed of different rocks. **The** major reservoir rock types are Triassic limestone and sandstone, Jurassic limestone, Cretaceous sandstone and andesite. **As** secondary reservoirs, Pliocene sands accumulate the hot water and directly cover the bedrock. However, geothermal water is mainly stored in the bedrock of the field. Drilling

for hot water and other purposes began in Sofia field in the early 1950s. Some of the deeper boreholes passed through Pliocene-Quaternary clays, sands and reached the bedrock of the field. The bedrock was found at different depths - from 52 m (Sofia-centre, W-3) to 1140 m (Elin Pelin, W-1). Today, a total of 139 deep wells have reached the bedrock (the main thermal water reservoir). More than 40 of them are producing wells. The deepest well reaches down to a depth of 1607 m. Flowrate from springs and wells generally lies in the range of about 1 l/s up to 10-15 l/s. The maximum temperature of the natural hot water is 81°C (Kazichene, W-1) (figure 1).

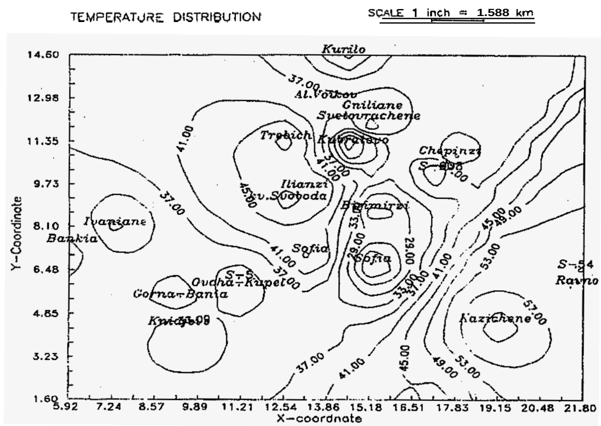


Figure 1: Water temperature of main geothermal springs and boreholes in Sofia field

Methodology

Various chemical geothermometers have developed to predict reservoir temperatures in geothermal systems. Both qualitative and quantitative chemical geothermometers are used in geothermal investigations. The quantitative techniques currently available require chemical analyses of thermal waters from springs **or** wells (PENTCHEVA et al. 1997). On the other hand, qualitative techniques may be used to look for anomalous concentrations of various "indicator" elements in the water (FOURNIER 1989; PENTCHEVA 1984).

Several geothermometers (chalcedony, Na-K-Ca, K-Mg, Na-K and Na-Li) have been used to predict subsurface temperatures in Sofia field. The Na-K and chalcedony geothermometer temperatures were computed by the programme CAT–TEMP (OLAFSSON 1993); and the Na-Li geothermometer temperatures were calculated using an empirical thermometric relationship (log Na/Li=1000/T-0.38), which was suggested by FOUILLAC & MICHARD (1981).

Results and discussion

The chemical composition of 30 natural springs and geothermal wells in this field were taken into consideration (Table 1). Results show correlation **of** the total dissolved solids (TDS) versus the measured temperature. The water chemistry from the andesite area is quite stable with TDS between 150mg/l (Kniajevo) and 300mg/l (Bankia). However, the waters from the limestone aquifers have a very variable composition, TDS ranging from 500 mg/l to 4500 mg/l.

Using the activities of aqueous components calculated for a series of temperatures, it is possible to compute the degree of saturation of the aqueous phase with respect to several minerals at each temperature. Figure 2b demonstrates such equilibrium calculations for one of the samples using a plot of log(Q/K) (Q is the activity product and K is the equilibrium constant) versus temperature for geothermal water in Sofia field. Six minerals were used, namely: anhydrite, calcite, fluorite, amorphous silica, chalcedony and quartz. Four of them (calcite, silica amorphous, chalcedony and quartz) are found in the reservoir **rock.** The curves for chalcedony and quartz intersect the log(Q/K)=0 at 40° and 70°C, respectively. The water is undersaturated with respect to amorphous silica, anhydrite and fluorite but supersaturated with respect to calcite. Thus, a calcite-scaling problem could occur in this case. The equilibrium temperature was not defined but if it exists it is likely to be in the range of 40°C to 90°C for Sofia geothermal field.

Table 1 Chemical geothermometer temperatures (°C) in Sofia field

No	Locality	T meas.	T chalced.	T K-Mg	T Na-K-Ca
1	Kostinbrod	25	28	64	86
2	Kostinbrod	35	24	35	18
3	Gniliane (W-588)	43	50	67	100
4	Al. Voikov (W-452)	38	57	66	102
5	Dobroslavtzi	23	33	59	105
6	Dobroslavtzi	40	70	67	108
7	Chepintzi (W-608)	51	60	46	61
8	Trebich (W-512)	51	52	79	133
9	Svetovrachene	47	41	66	101
10	Kv. Svoboda (W-4)	48	48	-	-
11	Ilientzi	47	58	87	143
12	Ilientzi	45	53	87	143
13	Ravno pole (W-49)	61	66	64	77
14	Ravno pole (W-47)	56	68	66	76
15	Ravno pole (W-45)	56	66	67	77
16	Ravno pole (W-44)	51	66	67	78
17	Ravno pole (W-11)	53	65	74	91
18	Ravno pole (W-46)	59	66	67	75
19	Ravno pole (W-54)	50	60	76	113
20	Birimirtzi	17	65	48	92
21	Mramor	42	85	68	129
22	Mramor (W-504)	40	91	69	123
23	Bankia (W-3)	36	36	-	-
24	Bankia (W-2)	38	36	-	-
25	Gorna bania (W-3)	31	37	-	-
26	Kniajevo	31	40	-	-
27	Ovcha kupel (W-1)	31	29	57	62
28	Pancharevo	46	31	32	23
29	Ivaniane (W-1)	28	37	-	-
30	Sofia 4 km	23	28	-	-

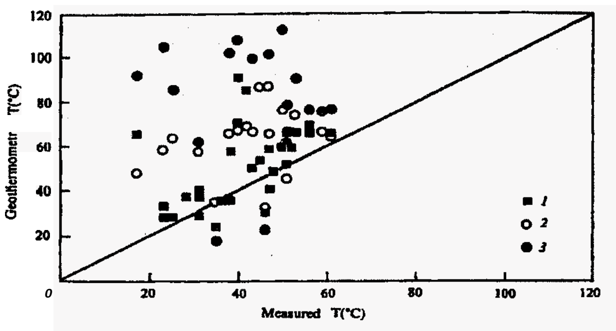


Figure 2a: Juxtaposition of the measured and the geothermometer temperatures 1: chalcedony; 2: K/Mg; 3: Na-K-Ca.

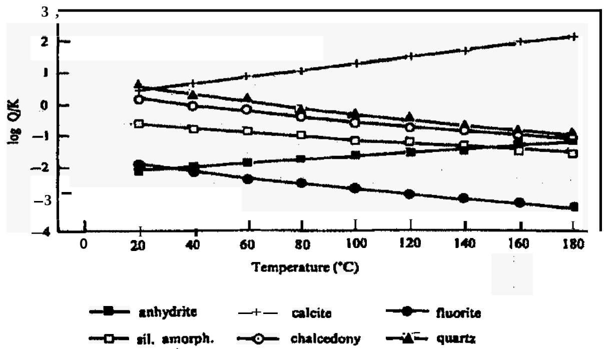
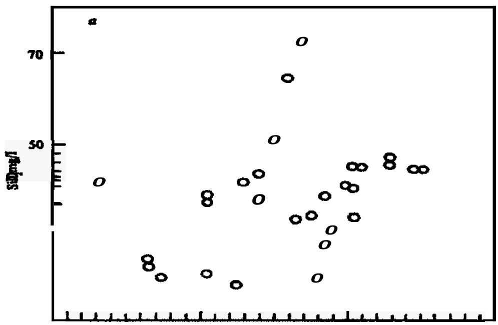


Figure 2b: Dependence of log Q/K on the temperature of geothermal waters

The results on figure 3a prove that there is a slight correlation between the silica concentration of the water and the measured temperature, indicating increased solubility of silica with increased temperature of the geothermal field. The chalcedony and Na/K geothennometer temperatures were computed using the computer programme WATCH (BJARNASON 1993). The chalcedony temperature has been plotted versus the measured temperatures (figure 3b). It can be seen that there is a relatively good correlation between the chalcedony temperatures and the measured temperatures. An exception is the water from the quarter of Birimirtzi, which measured temperature (17°C) is exceptionally low compared to the calculated chalcedony temperature (65°C). This discrepancy can best be explained by cooling of the geothermal water due to accumulation in a secondary reservoir (Pliocene sand). It is likely that water with a higher temperature can be found at a greater depth in the area. **A** drillhole has to reach the bedrock, which is the main reservoir **fa** the geothermal water. The **data** for Na/K geothermometer versus measured temperatures did not show any correlation. The Na/Li geothermometer temperatures were calculated but most of the results indicated temperatures higher than **200°C.** For this reason they **were** excluded fiom this work.



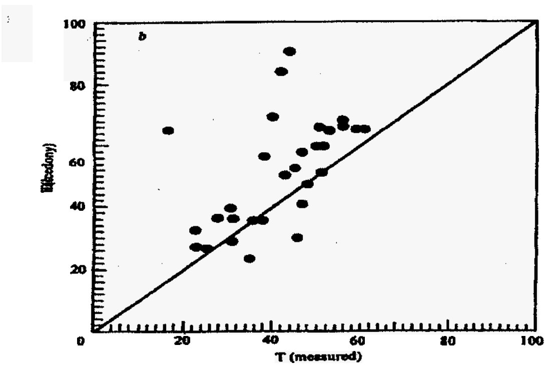


Figure 3b: Correlation of the measured temperature with chalcedony temperature.

The K/Mg and Na-K-Ca geothermometer temperatures were calculated using the CAT–TEMP computer program (OLAFSSON 1993). The data for K/Mg, Na-K-Ca and chalcedony geothermometer temperatures are plotted versus measured temperatures in Fig.-2a. The results show poor correlation between these three geothermometers and the real surface temperatures but the chalcedony geothermometer showed the best one as well as according to PENTCHEVA et al. (1996).

The most part of the specific and indicative for the alkaline N_2-thermal waters trace elements (PENTCHEVA 1984) are accumulated in the aqueous phase in direct proportional dependence with T_{depth} (Li, Rb, Cs, Ge, W, B, As, Sr) (figure 4a). This correlation is not so clear with the less typical trace elements in the specific association: Ga, Mo and V. Finally, the absence of geochemical relation with the heavy metals (with monotonous distribution in the underground waters) is to be underlined. These relations are established also for the model solutions of the hydrotherms - the aqueous phase of the respective interaction "water-silicate rock" at 100°C (see the methods of experimental simulation of PENTCHEVA 1984) - but with a different character and degrees.

The parallel interpretation of the results for the hydrotherms, from one side, and the Na^+-HCO_3^- (alkaline) and H_2O (neutral) model solutions, on the other, is resulting in significant conclusions for the different genetic stages of the thermal waters: from the rock lixiviation at depth by the high T_{depth} - up to the final metamorphism in the aeration zone. The data do not show very pronounced metamorphism processes - and so the deep water is reflecting at the emergence his primary composition. The abundance of Rb and Cs, Ge and W is the most dependent with the thermal conditions in depth, and their passage in the aqueous phase is very well related to the T_{depth} (figure 4a). For the genetic processes of the V, As and the heavy metals concentrations the case is not the same: the secondary deformation processes have an important role for the formation of the water microcomposition. That is why the results elucidate the possibility of application of the established trace elements correlation with the T_{depth} like new indicators, concerning the dynamics and the kinetics of the genetic processes and the migration in the thermal fluids - from the deep reservoir to the emergence.

Other kind of results are obtained with the intermediary of the SiO_2 concentration of the thermal fluid, directly dependent from T_{depth}. The same is concerning the correlation with the conductivity (figure 4b). These dependencies are discovered only for the specific trace elements cited.

The results ftom the correspondence factor analysis of the multielement data show the following aspects.

The trace elements (like W, Rb, Cs, and Li), reflect the reservoir reactions at high temperatures.

The trace elements controlled by secondary reactions near the surface and fast reequilibrated by lowest temperature (Mg, Al, e.g.). The data demonstrate two different behaviours of the variables (the elements) and the individuals (the hydrotherms), corresponding to the factors ($F_1 \rightarrow T_{emergence}$; $F_2 \rightarrow T_{depth}$).

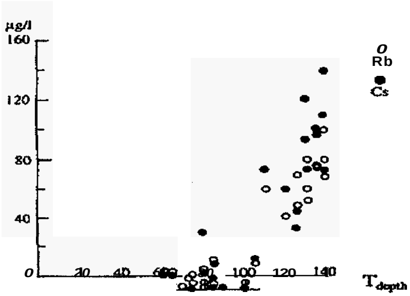


Figure 4a: Correlation of Rb and Cs with T_{depth}.

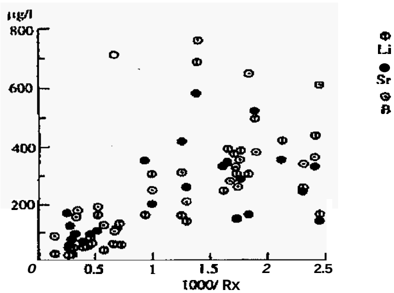


Figure 4b: Correlation of Li, Sr and B with the conductivity of the thermal waters.

Some conclusions can be made from the saturation index results (at T_{em}): for the thermal waters, more or less saturated in respect to the quartz, the T_{em} is not so different in comparison to T_{depth}; the oversaturation in respect to the quartz and in some cases - the undersaturation to the chalcedony for other hydrotherms show **(figure *5)*** that the equilibrium with quartz exists in depth, but the water becomes oversaturated during the ascent to the **surface,** because of the cooling; for the equilibrium with the calcite: in difference from the cold waters (always undersaturated) the Ca migration in solution in the most part **of** hydrotherms is controlled by the solubility just of the calcite (as well as F by the fluorapatite). The importance of these results is evident, because the repatriation of the trace elements in the hydrotherms is exclusively depended by the both parameters F and Ca.

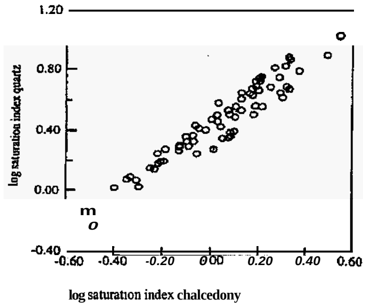


Figure 5: Saturation indexes in respect to quartz and chalcedony

Conclusions

It can be concluded that for Sofia field the chalcedony geothermometer is found to be the most reliable one of the geothermometers that were studied. According to chalcedony geothennometer the highest predicted temperatures in the geothermal reservoir are above 90°C. Based on all geothermometer data it is possible that water with a relatively high temperature can be found in the northern part of the city of Sofia and in the towns of Mramor, Dobroslavtzi, Gniliane, Trebich; and within an area east of Sofia, between the towns of Kazichene and Ravno pole where 81"C geothermal water has already been found. All these prospect areas are in the sedimentary rocks of the field. The maximum temperature for the accumulated water in the volcanic rocks, of the southern parts of Sofia, is not expected to be higher than 45°C. These results are in agreement with those of the authors (PENTCHEVA et al. 1997), obtained by the helium method and other methods of geothermal exploration that have been used in this field.

New potential indicators of the correlation between trace element abundance and T_{depth}, elucidating the genetic processes and the water migration evolution, are suggested. Apparently, no geothermal water with significantly higher temperature than the measured one are likely to be found.

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