Determination of the source and age of the geothermal fluid and its effects on groundwater resources in Kestanbol (Çanakkale-Turkey)

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Abstract Kestanbol located in Biga Peninsula is one of the important geothermal areas in Turkey. The surface temperatures of hot water samples are in the range of 66 and 76.2 °C. pH values and electrical conductivity (EC), between 5.9 and 6.4, 3450-3460 µS/cm, respectively. Geothermal water has acidic character, and its high EC shows that it has interacted with the host rock for a long time. Hot and cold waters are enriched with Na-Cl. Oxygen-18 (^{18}O) and deuterium (^{2}H) content of hot water samples are a mixing type of meteoric and sea water. Tritium (^{3}H) isotope analysis showed that geothermal water is older than 50 years. This study also points out possible environmental impacts of geothermal fluid effecting quality of cold water because of its high concentrations of Cl, Na, As, B, Se and EC.

Key words geothermal; hydrogeochemistry; isotope; Kestanbol; Turkey

INTRODUCTION

Geothermal energy is accepted as environmentally friendly and clean resource due to allowable environmental effects when compared with fossil energy resources. Usage of geothermal energy for domestic purposes goes back to ancient times. In modern era, different industries benefit from geothermal energy especially in energy sector.

Active tectonic zones around the world allow us to investigate geothermal resources. Biga Peninsula (Figure 1A), which is north western part of Turkey, also take place in one of these tectonic zones around the world. In terms of tectonic, southern and northern parts of Turkey are bordered with East Anatolian Fault Zone (EAFZ in Figure 1B) and North Anatolian Fault Zone (NAFZ in Figure 1B) respectively. Regionally, Biga Peninsula and vicinity of Çanakkale closely related to active tectonic zones of North Anatolian Fault Zone and West Anatolian Graben Systems (WAGS in Figure 1B). For this reason, geothermal systems manifest themselves with several hot water springs in Biga Peninsula (Figure 1C). Selected works from literature related to the field are Şamilgil (1966), Mützenberg (1997), Baba (2003), Baba & Ármannsson (2006), Şanlıyüksel & Baba (2007).

In this study, Kestanbol geothermal field, at the southwest of Biga Peninsula, was investigated in terms of determination of source and age of the geothermal fluid and also its effects to cold water. Kestanbol and its vicinity were known as the Alexandria Troas in historical times. The ancient city was built in the year 310 B.C. during the Hellenistic period. The emperor of Rome, public baths known as Kestanbol spa were constructed in the city with the help of Hadrian (Figure 1D; Mützenberg, 1997).

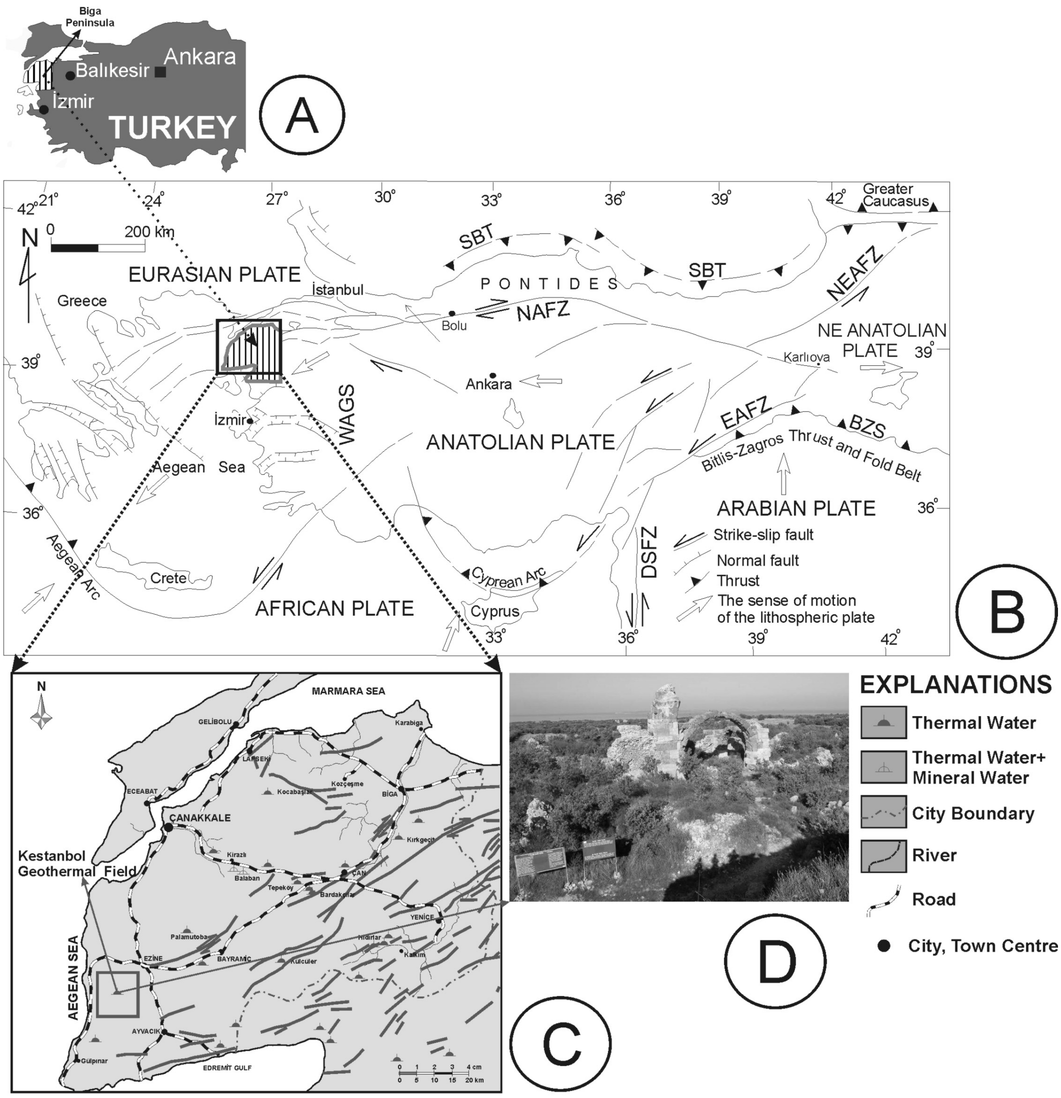

Fig. 1 (A) Location of Biga Peninsula. (B) Tectonic Scheme of Turkey (modified Yiğitbaş *et al*., 2004). (C) Tectonic Scheme of Biga Peninsula and Kestanbol geothermal field. (D) Ruins of the Alexandria Troas city.

GEOLOGY AND HYDROGEOLOGY

The basement of Kestanbol geothermal field consists of Kazdağı metamorphic rocks including calc-schist and quartzite. The metamorphic basement is intruded by Kestanbol intrusive body consisting of granite, syenite and quartzite (Figure 2). The intrusion produced a very narrow thermal aureole mainly with metasomatic reactions such as the formation of scapolite and garnet in metamorphic diopside-plagioclase schists at the development of skarns at the contact of the intrusion and adjacent Permian limestone (Mützenberg, 1997). The basement rock is overlain by Miocene conglomerate. The alluvium, which consists of sand-clay-gravel and blocks, is the youngest rock in the study area.

Permeable unit for deep circulating groundwater is presented by carbonate of the Kazdağı metamorphic rocks. Fault and fracture zones are important for movement and storage of hot water. Structural pattern is aligned along NE-SW and NW-SE strikes. Geothermal springs and geothermal drilling are related to normal fault extending through NE-SW (Figure 2). Additionally, sea water feeds geothermal water directly. However, cold groundwater is related to Permian limestone. Isotopic signature of hot water indicates mixing with sea and meteoric water.

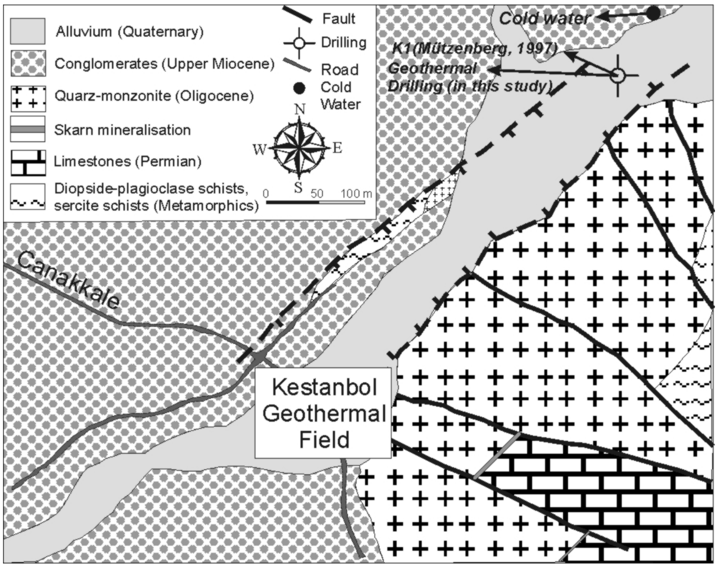

Fig. 2 Geological map of the study area (modified after Mützenberg, 1997).

METHODS

The sampling campaigns covered the period from 2005 to 2006. Three type water samples were taken from cold groundwater, geothermal well and sea water. The concentrations of major ions, trace elements, oxygen-18 (^{18}O), deuterium (^{2}H) were determined on water samples. One-litre double-tapped hard plastic bottles were used in the sampling. In order to prevent the complex formation of heavy metals with oxygen, pH< 2 conditions were maintained. Acidified and natural samples were analyzed for major and trace elements at ACME Labs., (Canada) by inductively coupled plasma mass spectrometer (ICP-MS). Electrical Conductivity (EC), temperature (°C) and pH values were measured in-situ with a WTW Multi340i/SET. The pH-meter was calibrated with buffer solutions, pH 4, 7 and 10 before field work. The deuterium and oxygen-18 isotopes in the samples were determined in the laboratories of the Technical Research and Quality Control Department of DSİ (State Hydraulic Works) in Ankara. For this purpose, mass spectrometry was used with an overall precision of 1‰ and 0.1‰ for deuterium and oxygen-18, respectively. These values are expressed conventionally in delta notation as per mil deviation from the V-SMOW (Vienna Standard Mean Ocean Water). The tritium (^{3}H), analyses were carried out by the

Hacettepe University using Liquid Scintillation Counting Method of IAEA (International Atomic Energy Agency).

GENERAL INFORMATION OF FLUID CHEMISTRY

The average discharge of the thermal water is variable 1-6 L/sec. The surface temperature of thermal water changes 66.0 to 76.2 °C, pH values are in the range of 5.9-6.4 and electrical conductivity (EC) values, 3450-3460 µS/cm. The surface temperatures of the cold water were measured 13 and 19 °C. pH values are in the range of 7.07-7.10 and electrical conductivity values, 1007-1010 µS/cm (Table 1).

Hot water has acidic character, and its high electrical conductivity shows that it has interacted with the host rock for a long time. Due to high electrical conductivity and acidic character, production of geothermal fluid can affect the quality and quantity of cold water. Hence, undesirable effects change cold water quality. In other words, production of geothermal fluid can cause exceeding groundwater quality for domestic purposes. High ratios of Na, Cl, As, B and Se ions can be expected in cold water resource.

When results are plotted on Piper and Schoeller diagrams, it was seen that geothermal water is enriched with Na-Cl (Figure 3). According to the Piper diagram, the hot water samples are in Na-Cl facies (in the same facies with sea water samples). Types of cold water are Ca-SO_4-Cl or Ca-Na-SO_4-Cl. Cold water source of the study area is affected by geothermal fluid containing high concentrations of Cl, Na and EC. Isotopic composition of water samples easily depict by $\delta^{18}O$-$\delta^{2}H$ diagram (Figure 4) and show a mixing type of meteoric or cold water and sea water. Kestanbol geothermal water is aged by tritium more than 50 years.

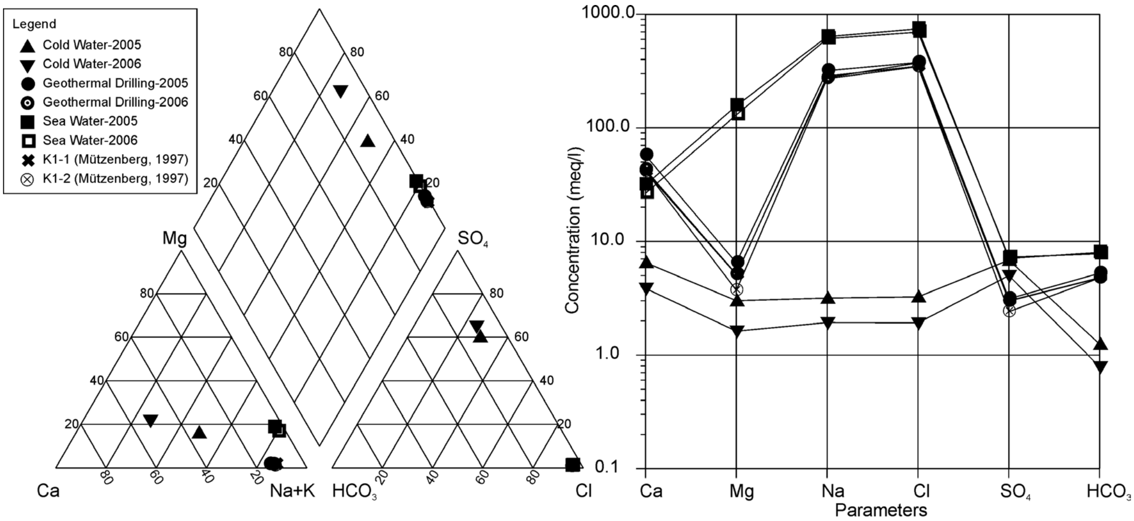

Fig. 3 Piper and Schoeller diagrams of water samples in Kestanbol geothermal field.

Table 1 Hydrochemical compositions of geothermal, cold and sea waters in Kestanbol.

Constituents	$^{\beta}$Cold Water	$^{\Delta}$Cold Water	$^{\beta}$Geothermal Drilling	$^{\Delta}$Geothermal Drilling	$^{\beta}$Sea Water	$^{\Delta}$Sea Water	$^{\tau}$K1-1	$^{\sigma}$K1-2
pH	7.07	7.10	6.20	6.40	8.30	8.30	5.90	-
T (^{0}C)	19.0	13.0	68.0	66.0	17.8	10.0	76.2	76.1
EC (μS/cm)	1007	1010	3460	3450	5560	5540	-	-
*Ca	130.4	77.1	1143.8	858.5	629.3	532.7	828.7	835.7
*Mg	36.50	19.7	78.7	62.42	1897.7	1576.3	61.8	45.0
*Na	72.8	44.3	7316.5	6343.0	14600.0	14000.0	6570.0	6220.0
*K	2.3	2.2	825.1	735.2	565.7	484.2	804.0	904.0
*SO_4	328.0	240	150.0	143.0	340.0	348.0	-	-
*HCO_3	76.0	48.0	320.0	291.0	488.0	475.0	292.2	291.0
*Cl	115.0	68.0	13321.0	13207.0	26326.0	24648.0	12319.0	12230.0
*Si	21.0	15.5	67.2	54.0	0.40	2.8	65.1	54.1
*As	0.015	0.012	0.101	0.087	-	-	-	-
*B	0.041	0.052	12.72	10.70	-	-	-	-
*Se	0.003	0.005	0.14	0.15	-	-	-	-
δ^2H	-33.2	-34.6	-33.38	-33.62	-	-	-37.5	-37.0
^{3}H	0.4	2.5	0.22	0.25	-	-	< 0.9	-
δ^{18}O	-6.36	-5.97	-5.65	-5.12	-	-	-5.18	-5.09

*: Unit of constituents is in ppm; β: 22/October/2005 dated samples; Δ: 05/March/2006 dated samples; τ :02/October/1987 dated samples (Mützenberg, 1997); σ: 27/March/1988 dated samples (Mützenberg, 1997).

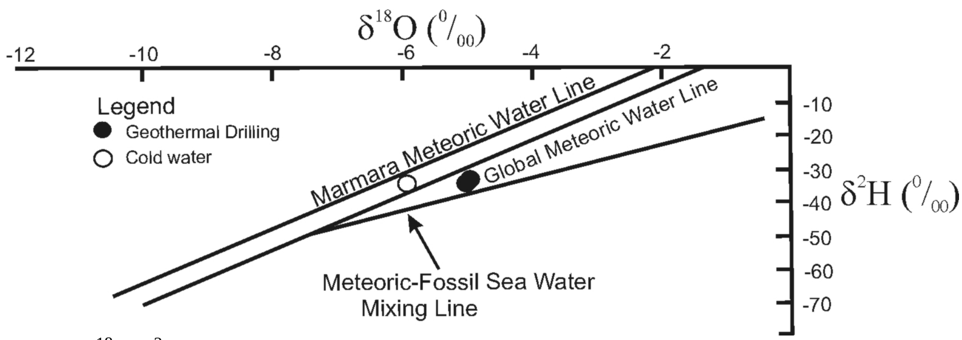

Fig. 4 δ^{18}O-δ^2H diagram of water samples in Kestanbol geothermal field.

ESTIMATION OF RESERVOIR TEMPERATURES AND MINERAL SATURATION

Chemical analyses of geothermal fluids can be used to estimate subsurface reservoir temperature. Chemical geothermometers depend on the water-mineral equilibria and give the last equilibration temperature for the reservoir (Nicholson, 1993). Several geothermometry techniques have been developed to predict reservoir temperatures in geothermal systems (Fournier & Truesdell, 1973; Truesdell, 1976; Fournier, 1977; Fournier, 1979; Tonani, 1980; Fournier, 1991; Arnórsson *et al.*, 1983; Nieva & Nieva, 1987; Giggenbach, 1988). All are based on the promise that temperature dependent water-mineral equilibrium is attained in the reservoir. In this part, solute geothermometry techniques were applied to hot water in the field. The results are presented in Table 2. Surface temperature of thermal water varies between 66 and 76.2 °C. According to silica geothermometers the temperature of the reservoir varies between 95 and 159 °C (similar with K1-1 and K1-2 results of Mützenberg, 1997 given Table 2).

The ternary plot of Na/1000-K/100-Mg^(1/2) of Giggenbach (1988) is a method to discriminate mature waters, which have attained equilibrium with relevant hydrothermal minerals from immature waters and waters affected by mixing and/or re-equilibration at low temperatures during their circulation. Only geothermal drilling samples plotted into partially equilibrated or mixed water zone in Figure 5. Reservoir temperature value estimated by this method is in the range of ~180 °C - ~200 °C, whereas Na-K geothermometers show unaccepted results for water samples plotted partially equilibrated or mixed water zone.

A different approach to geothermometry (Reed & Spycher, 1984) is shown in Figure 6, where the changes in saturation index (SI) of relevant minerals with temperature were investigated for hot water samples in Kestanbol area. Figure 6 shows SI with respect to selected hydrothermal minerals of versus temperature for thermal waters of the field. SI for each mineral was plotted versus temperature. SI with respect to chalcedony and quartz approaches zero at ~100 °C in all four cases. SI for anhydrite also approaches zero at ~150 °C in all four water samples. SI for dolomite approaches zero at ~150 °C for hot water samples of this study. SI for calcite also approaches at ~50 °C and ~ 150 °C. According to Figure 6, estimated reservoir temperature is variable ~100 °C to ~150 °C.

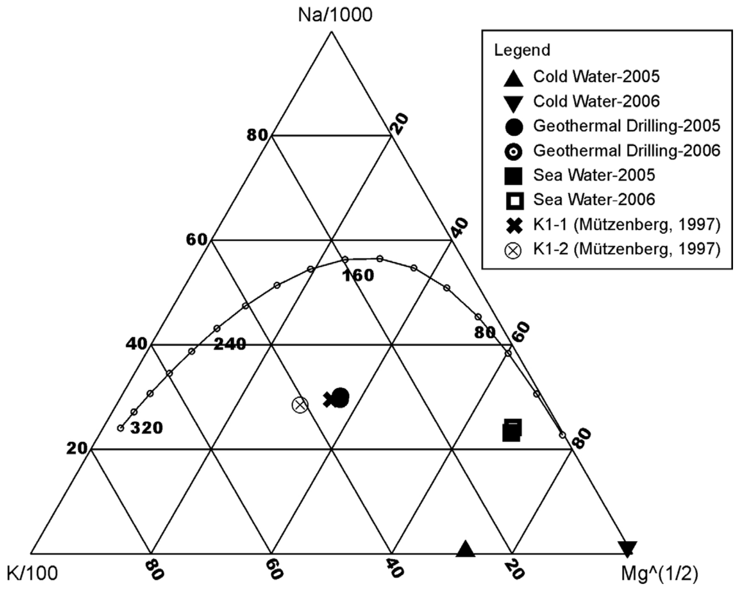

Fig. 5 Giggenbach (1988) diagram of water samples in Kestanbol geothermal field.

Table 2 Chemical geothermometer results of Kestanbol geothermal field.

Geothermometer Equations	[β]Geothermal Drilling	[Δ]Geothermal Drilling	[τ]K1-1	[σ]K1-2
t°C = [1309/(5.19-logSiO_2)]-273 (Fournier, 1977)	159 °C	145 °C	157 °C	146 °C
t°C = [1522/(5.75-logSiO_2)]-273 (Fournier, 1977)	151 °C	140 °C	149 °C	140 °C
[a]t°C = [1032/(4.69-logSiO_2)]-273 (Fournier, 1977)	134 °C	120 °C	132 °C	120 °C
[b]t°C = [1000/(4.78-logSiO_2)]-273 (Fournier, 1977)	108 °C	95 °C	106 °C	95 °C
[c]t°C = [781/(4.51-logSiO_2)]-273 (Fournier, 1991)	59 °C	46 °C	57 °C	46 °C
[d]t°C = [731/(4.52-logSiO_2)]-273 (Fournier, 1977)	36 °C	24 °C	35 °C	24 °C
t°C = 856/[log(Na/K)+0.857]-273 (Truesdell, 1976)	202 °C	204 °C	211 °C	232 °C
t°C = 883/[log(Na/K)+0.780]-273 (Tonani, 1980)	239 °C	242 °C	249 °C	273 °C
t°C = 933/[log(Na/K)+0.993]-273 (Arnórsson, 1983)	208 °C	211 °C	217 °C	237 °C
t°C = 1319/[log(Na/K)+1.699]-273 (Arnórsson, 1983)	226 °C	228 °C	232 °C	247 °C
t°C = 1217/[log(Na/K)+1.483]-273 (Fournier, 1979)	228 °C	230 °C	235 °C	251 °C
t°C = 1178/[log(Na/K)+1.470]-273 (Nieva & Nieva, 1987)	215 °C	217 °C	221 °C	237 °C
t°C = 1390/[log(Na/K)+1.750]-273 (Giggenbach, 1988)	243 °C	245 °C	249 °C	264 °C
t°C = 1647/{log(Na/K)+β[log($Ca^{1/2}$ / Na)+ 2.24]}-273 (Fournier & Truesdell, 1973)	-192 °C	-192 °C	-191 °C	-191 °C
t°C = 4410/[$\log(K/Mg)^{1/2}$+14.0]-273 (Giggenbach, 1988)	31 °C	30 °C	30 °C	28 °C

a: chalcedony; b: α-cristobalite; c: β-cristobalite; d: amorphous silica; β: 22/October/2005 dated samples; Δ: 05/March/2006 dated samples; τ: 02/October/1987 dated samples (Mützenberg, 1997); σ: 27/March/1988 dated samples (Mützenberg, 1997).

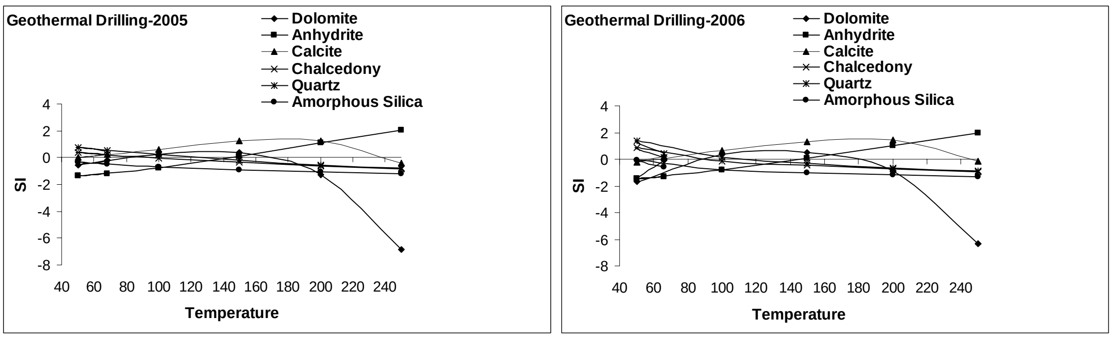

Fig. 6 SI-temperature diagram of hot water samples for selected minerals in Kestanbol geothermal field.

CONCLUSION

Thermal water in the Kestanbol area is from the deep reservoir filled seawater in the pores, but mixes with meteoric or cold water in various ratios. All waters in the area are of meteoric origin and consist of mixture of cold water. Acidic geothermal water, with extremely high salt content, discharges into cold water aquifer. Evaporation occurring particularly in dry periods increases the accumulation and concentration of salts and some heavy metals in cold water. Therefore, high contents of salt and heavy metals are observed in the cold water aquifer.

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