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THE ENVIRONMENTAL AND HYDROGEOCHEMICAL PROPERTIES OF THE TUZLA-KESTANBOL-HIDIRLAR GEOTHERMAL SOURCES, TURKEY

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ABSTRACT

Tuzla, Kestanbol and Hıdırlar are located in Biga Peninsula, where is an important geothermal area, in northwest of Turkey. The surface temperatures of these three geothermal fluids are more than 65°C. According to drilling data, the reservoir temperature of Tuzla fluid is 173°C. The reservoir temperature of Kestanbol and Hıdırlar are calculated by geothermometers. Results show that the reservoir temperatures of Kestanbol and Hıdırlar are in between 120 and 150°C.

Except Hidirlar geothermal fluid, the other geothermal waters have acidic character, and its high EC value indicates that it has interacted with the host rock for a long time. Isotopic composition shows that these three geothermal fields have different origins. Isotope results signified that the hot saline waters in the Tuzla geothermal field originate from connate water along faults. Kestanbol fluid shows a mixing type of meteoric or cold water and sea water. Hıdırlar geothermal fluid has the same recharge area, shallow circulation and meteoric in origin as depicted by their $\delta^{18}O$ (‰) and $\delta^{2}H$ (‰) contents. Tritium (^{3}H) isotope analysis showed that geothermal fluids are older than 50 years. These studies also points out, with the exception of Hıdırlar geothermal fluid, possible impacts of geothermal fluid effecting quality of cold water and soil because of its high concentrations of As, Sr and B.

1. INTRODUCTION

Turkey is one of the most seismically active regions in the world. Its geological and tectonic evolution has been dominated by the repeated opening and closing of the Paleozoic and Mesozoic oceans (Dewey and Sengör, 1979; Jackson and McKenzie, 1984). It is located within the Mediterranean Earthquake Belt whose complex deformation results from the continental collision between the African and Eurasian plates (Bozkurt, 2001) (Figure 1).

The border of these plates constitutes seismic belts marked by young volcanics and active faults, the latter allowing circulation of water as well as heat. The distribution of hot springs in Turkey roughly parallels the distribution of the fault systems, young volcanism and hydrothermally altered areas (Simsek, 1997). There are a total of about a thousand thermal and mineral water spring groups in the Turkey (MTA, 1980; Simsek, 1985; 1988 and 1997) (Figure 2).

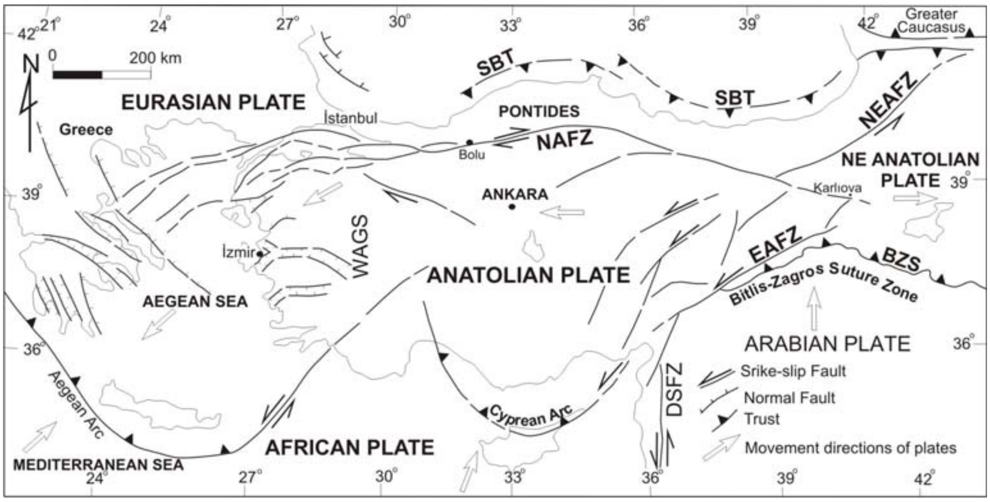


FIGURE 1: Simplified tectonic map of Turkey showing major neotectonic structures and neotectonic provinces (modified from Yiğitbaş et al., 2004)

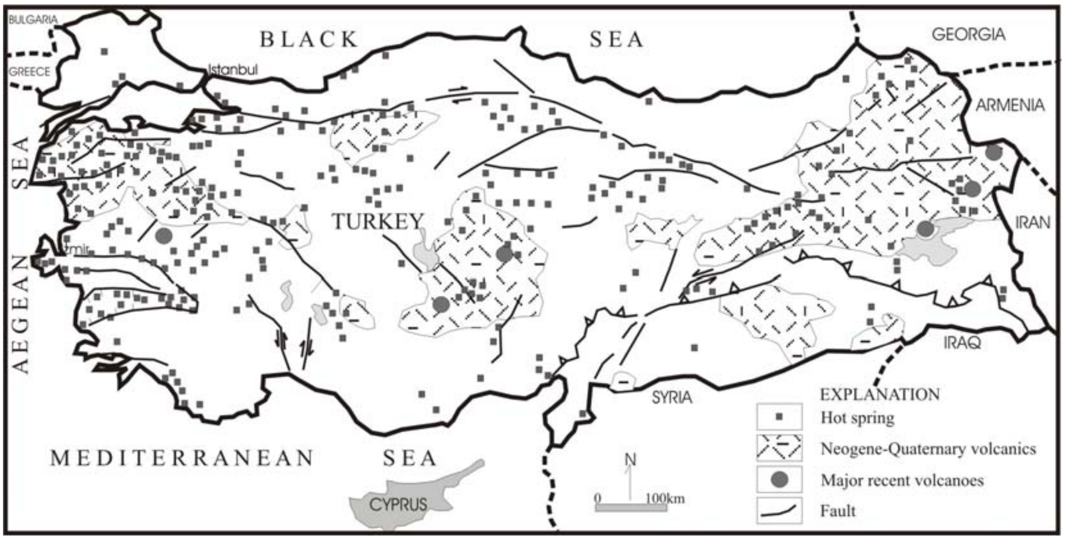


FIGURE 2: Simplified main neotectonic lines and hot spring distribution of Turkey (from Simsek, 1997)

Biga Peninsula (Figure 3A), which is in north western part of Turkey, is also in one of these tectonic zones around the world. In terms of tectonics, southern and northern parts of Turkey are bordered with the East Anatolian Fault Zone (EAFZ in Figure 3B) and the North Anatolian Fault Zone (NAFZ in Figure 3B), respectively. Regionally, Biga Peninsula is closely related to the active tectonic zones of North Anatolian Fault Zone and West Anatolian Graben Systems (WAGS in Figure 3B). For this reason, geothermal systems manifest themselves with several hot water springs in Biga Peninsula (Figure 3C). Selected works from literature related to the field are Şamilgil (1966), Mützenberg (1997), Baba (2003), Baba and Özcan (2005), Baba et al. (2005) Baba and Ármannsson (2006), Şanlıyüksel and Baba (2007), Baba and Ertekin, (2007).

Tuzla, Kestanbol and Hıdırlar geothermal fields were investigated in terms of hydrogeochemical properties of the geothermal fluid and also its effects on environment. These three geothermal fluid surface temperatures are above 65°C. The Tuzla and Kestanbol geothermal field is located south of Çanakkale city centre and 5 km away from the Aegean Sea (Figure 3D). Kestanbol geothermal site was known as the Alexandria Troas in historical times. Public bath known as Kestanbol spa has been used since classical times (Figure 3E). Hıdırlar geothermal site is located southeast 96 km of Çanakkale city centre and 86 km from the southwest of Balıkesir city (Figure 3F).

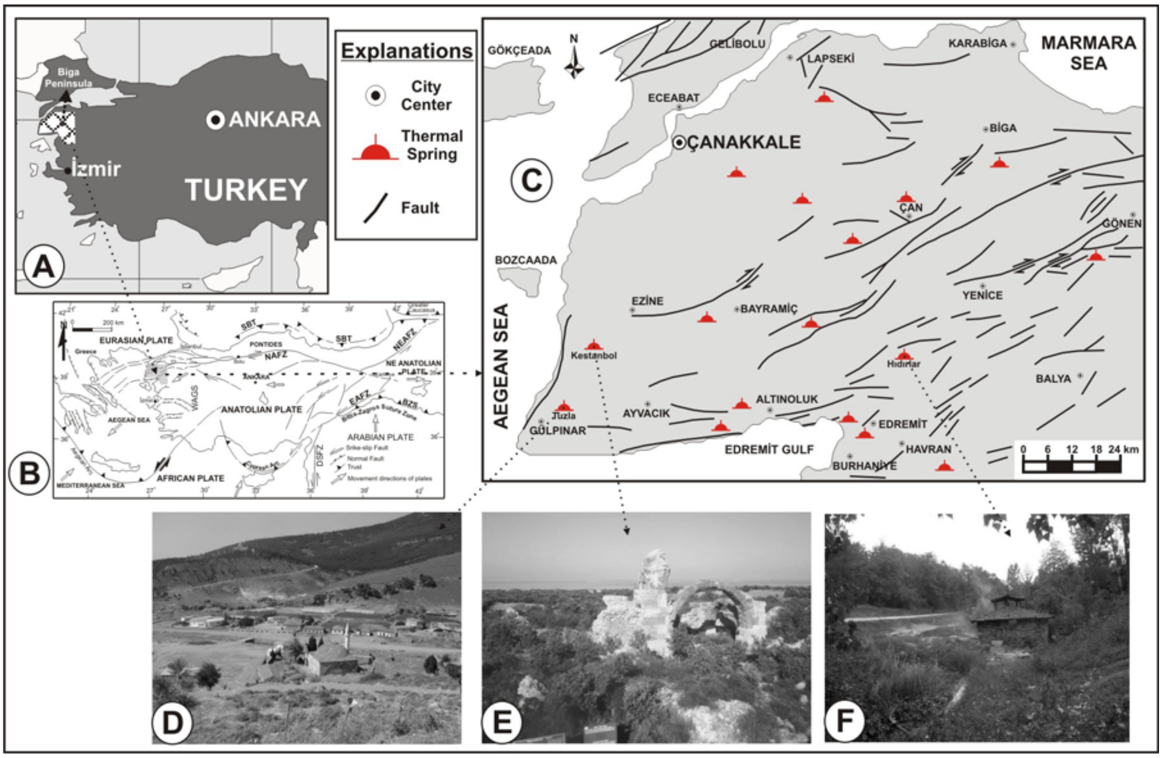


FIGURE 3: (A) Location of Biga Peninsula. (B) Tectonic scheme of Turkey (modified Yiğitbaş et al., 2004). (C) Tectonic scheme of Biga Peninsula and geothermal fields. (D) Tuzla geothermal area. (E) Ruins of the Alexandria Troas City. (F) Hıdırlar geothermal area

2. GEOLOGY OF THE STUDY AREA

The study area is located in the Biga peninsula which is an active region in point of tectonics. Basement rocks of the peninsula are composed of Paleozoic aged metamorphic rocks named as Kazdağ group. Rocks of the Karakaya complex were settled on this group with tectonic boundary. Volcanic and sedimentary rock series cover these rocks in the peninsula (Figure 4). Volcanic rocks are dominant rock types in the region but many types of volcanic, sedimentary and metamorphic rocks are observed. Most of these rocks had altered and fractured due to effects of active faults. The alluvium, which consists of sand-clay-gravel and blocks, is the youngest rock form in the study area. The currently active thermal regime is associated with tectonic and volcanic activity in the geothermal site (Figure 5). The hot resources of the geothermal area are granodiorite that is identified by outcrops in the study area. The reservoir rocks are volcanic and marbles which crop out in Kazdağı metamorphic rocks.

3. METHODS

The sampling campaigns covered the period from 2003 to 2007. The concentrations of major ions, Arsenic (As), Boron (B), Strontium (Sr), Oxygen-18 (^{18}O), Deuterium (^{2}H) and Tritium (^{3}H) were determined in water samples. First time used, 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 on site. Acidified and natural samples were analyzed for major and trace

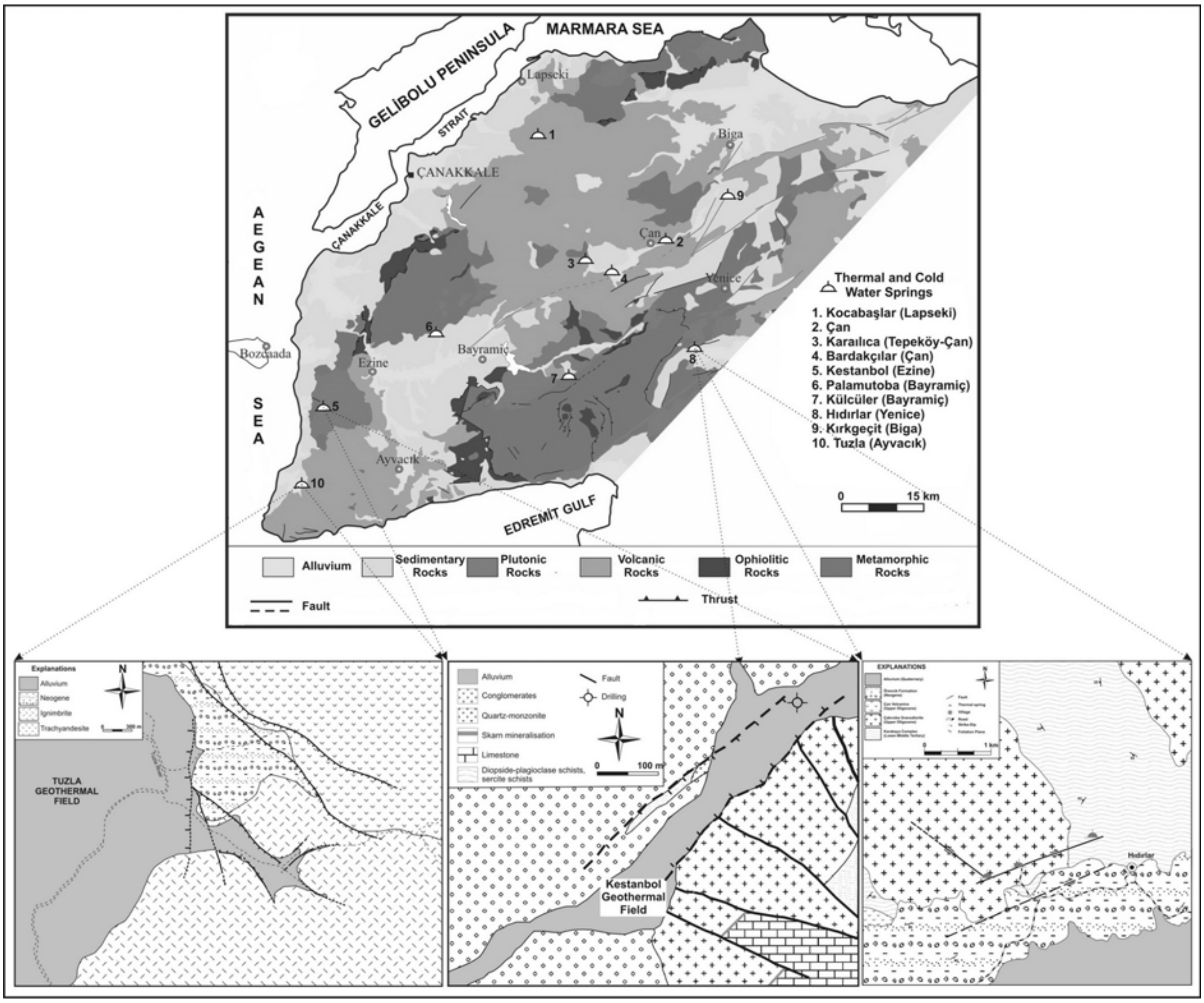


FIGURE 4: Geological maps of Biga Peninsula (modified after MTA 2002) and the study area

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. The tritium (^3H), analyses were carried out by the Hacettepe University using Liquid scintillation counting method of IAEA (International Atomic Energy Agency).

4. HYDROGEOCHEMICAL PROPERTIES OF GEOTHERMAL FLUID

The average discharge of the Tuzla, Kestanbol and Hıdırlar geothermal fluid are variable between 25 and 50 L/s, 1 and 6 L/s, and 1 and 3 L/s, respectively. The pH values are in the range of 5.7-6.5 and electrical conductivity (EC) values, 70900-80300 µS/cm in the Tuzla fluid (Table 1). The pH and EC values of Kestanbol geothermal fluid are in the range of 6-6.4 and 3002 and 3460 µS/cm, respectively, and the pH and EC values of Hıdırlar geothermal fluid in the range of 7.8-8.3 and 948-1087 µS/cm, respectively (Table 1). Except for the Hıdırlar geothermal fluid, the other geothermal waters have acidic character, and their high EC shows that it has interacted with the host rock for a long time. Hıdırlar geothermal fluid has alkaline character, and the low electrical conductivity shows that they are not reacted with aquifer for a long time.

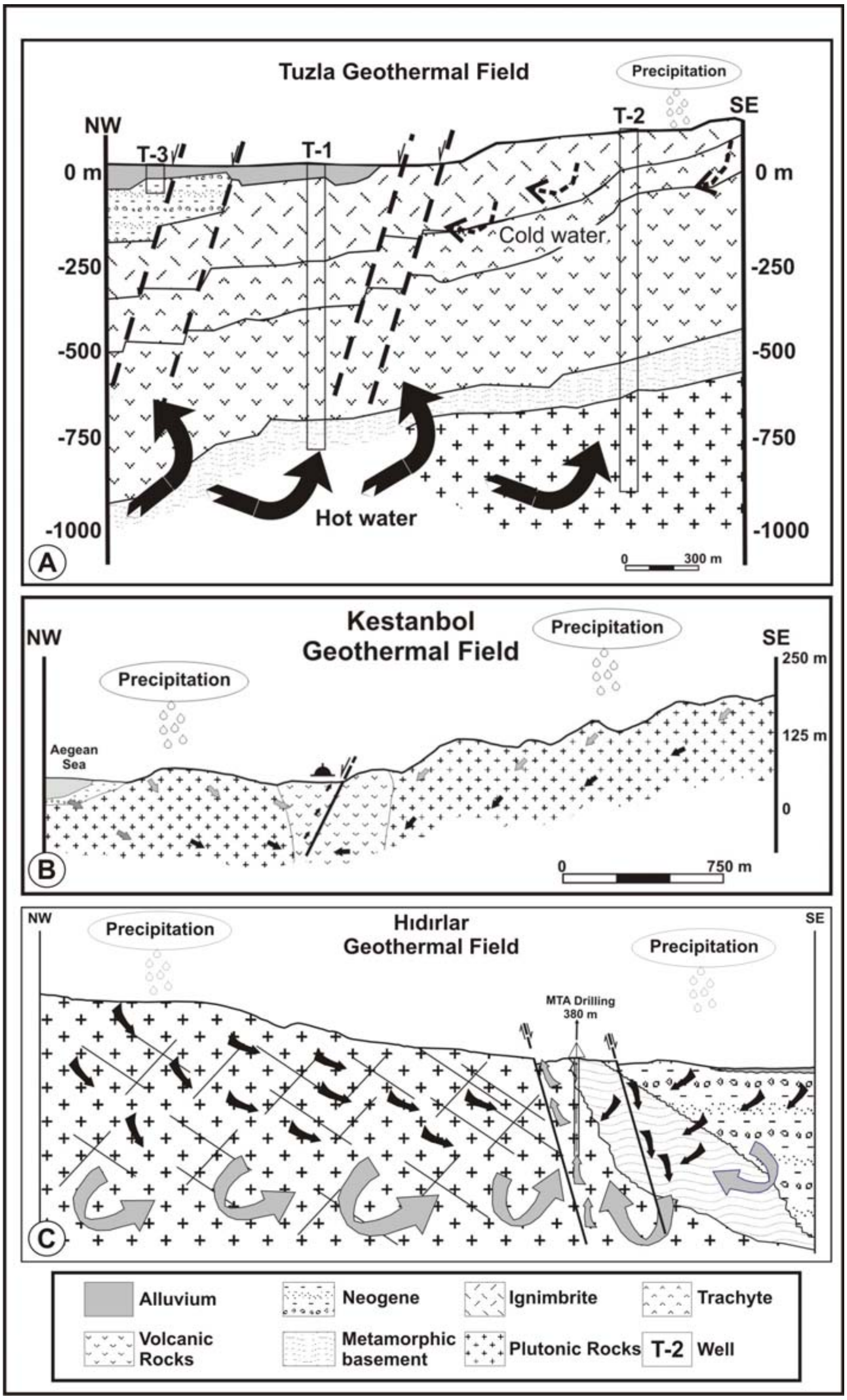


FIGURE 5: Schematic sections of the study area (A) Tuzla geothermal field (Baba et al., 2008), (B) Kestanbol geothermal field (Baba and Ertekin, 2007), (C) Hıdırlar geothermal field (Ates, 2007)

When results are plotted on Piper and Schoeller diagrams, it was seen that Tuzla and Kestanbol geothermal water is enriched with Na-Cl (Figure 6). Hıdırlar geothermal fluid is enriched with Na-SO_4.

TABLE 1: Hydrochemical compositions of thermal waters in Tuzla, Kestanbol and Hıdırlar

Constituents	Tuzla			Kestanbol			Hıdırlar		
	December 2003	**April 2003**	**June 2004**	**October 2005**	**March 2006**	**March 2007**	**October 2005**	**February 2006**	**August 2006**
T ^{0}C	87	87	86.4	68	66	74	76.7	75.5	77.5
EC (µS/cm)	70900	80300	75900	3460	3450	3002	948	968	1087
pH	6.1	6.5	5.7	6.2	6.4	6	7.8	7.9	8.3
Na (ppm)	5838	5893	13721	7316.5	6342.99	6529.57	195.57	200.13	199.78
Ca (ppm)	2526	2636	1532	1143.8	858..52	902.3	19.19	18.89	18.28
K (ppm)	1985.3	1979.2	1398	828.07	735.16	759.21	6.01	7.33	5.47
Mg (ppm)	71.9	75.2	27.6	78.7	62.42	65.63	0.1	0.13	0.12
Cl (ppm)	31240	58220	28476	13321	13207	12929	13	15	13
SO_4 (ppm)	554	201	241.4	150	143	112.5	280	277.65	352.19
HCO_3 (ppm)	151	134	67	320	291	334.2	146.4	162	92
As (ppm)	0.006	0.089	0.058	0.101	0.087	0.184	0	0.002	0
B (ppm)	25.95	22.11	32	12.72	10.71	7.79	0.196	0.252	0.196
Sr (ppm)	122.3	122.1	130.5	51.05	45.5	50.23	0.499	0.505	0.488
δ^{18}O (‰)	-	-0.88	-1.29	-5.65	-5.12	-	-8.59	-8.33	-
δ^2H (‰)	-	-21.37	-21.19	-33.38	-33.62	-	-46.06	-52.28	-
^{3}H	-	0	-0.32	0.22	0.25	-	0.32	-0.19	-

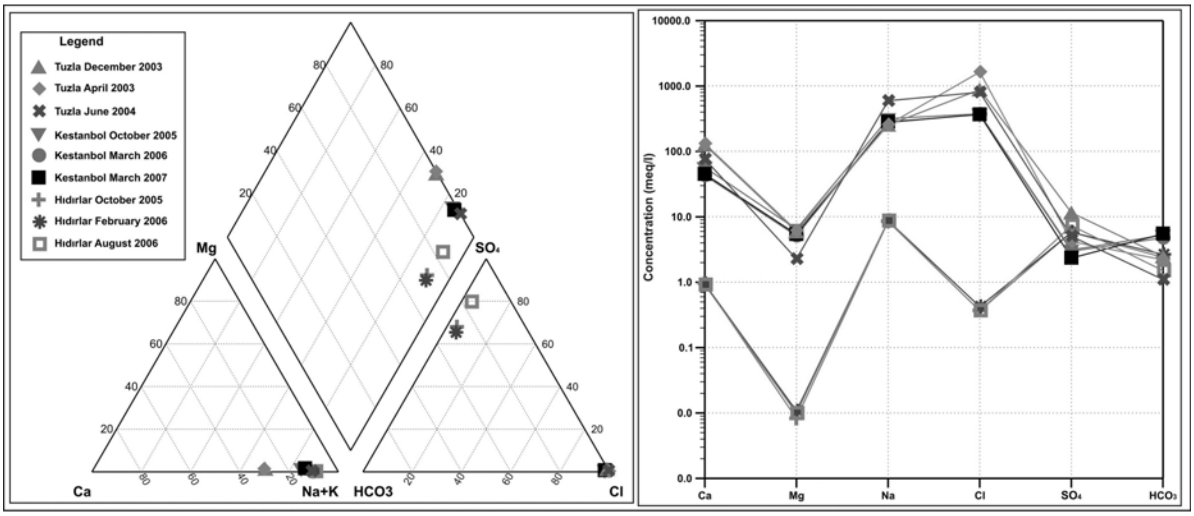
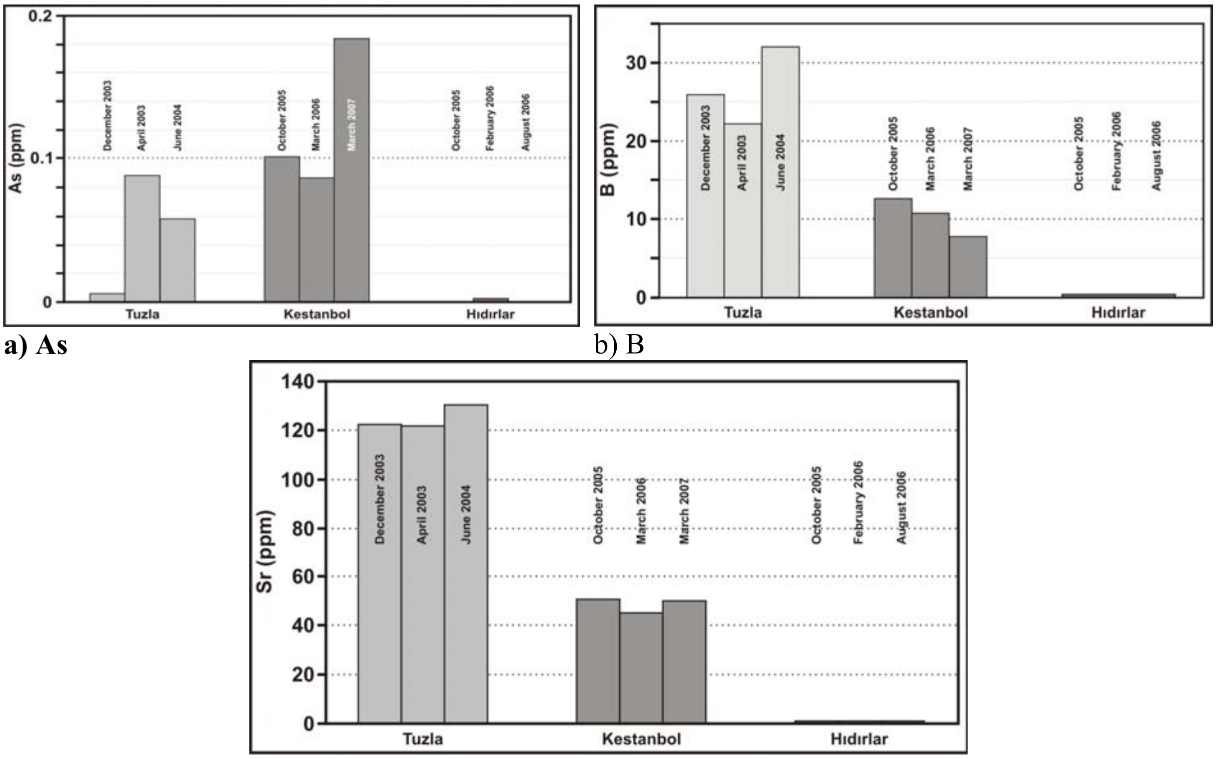


FIGURE 6: Piper and Schoeller diagrams of water samples in Tuzla, Kestanbol and Hıdırlar geothermal fields

Due to high electrical conductivity and acidic character, production of geothermal fluid can affect the quality and quantity of cold water and soil around geothermal field. The results of the hydrogeochemical analyses of As, B and Sr in the collected samples are listed in Table 1. These toxic trace elements in each geothermal fluid are quite different. The increment of As in Kestanbol is higher than that of Tuzla and Hıdırlar (Figure 7a). The concentration of arsenic is due to altered volcanic rocks. Yet the concentration of Ba and Sr in Tuzla geothermal field is higher than Kestanbol and Hıdırlar (Figure 7b and c). The concentrations of As range from 0 to 0.18 ppm and follow the order: Kestanbol>Tuzla> Hıdırlar; whereas those of B range from 0.1 to 32 ppm and follow the order: Tuzla>Kestanbol> Hıdırlar.

Isotopic composition shows that these three geothermal fluids have different origins (Figure 8). Isotope results indicate that the hot saline waters (brine) in the Tuzla geothermal field originate from connate water along faults (Baba et al., 2008). Kestanbol water samples easily depict by Oxygen (δ^{18}O ($^0/_{00}$)) and Deuterium (δ^2H ($^0/_{00}$)) diagram (Figure 8) and show a mixing type of meteoric or cold water and sea water. Hıdırlar geothermal fluid has the same recharge area, shallow circulation and meteoric in origin as depicted by their δ^{18}O (‰) and δ^2H (‰) contents. Age of these three geothermal fluids is more than 50 years as determined by Tritium (^3H) data (Table 1).



a) As b) B

c) Sr

FIGURE 7: Concentration of a) As; b) B; and c) Sr in geothermal fluid

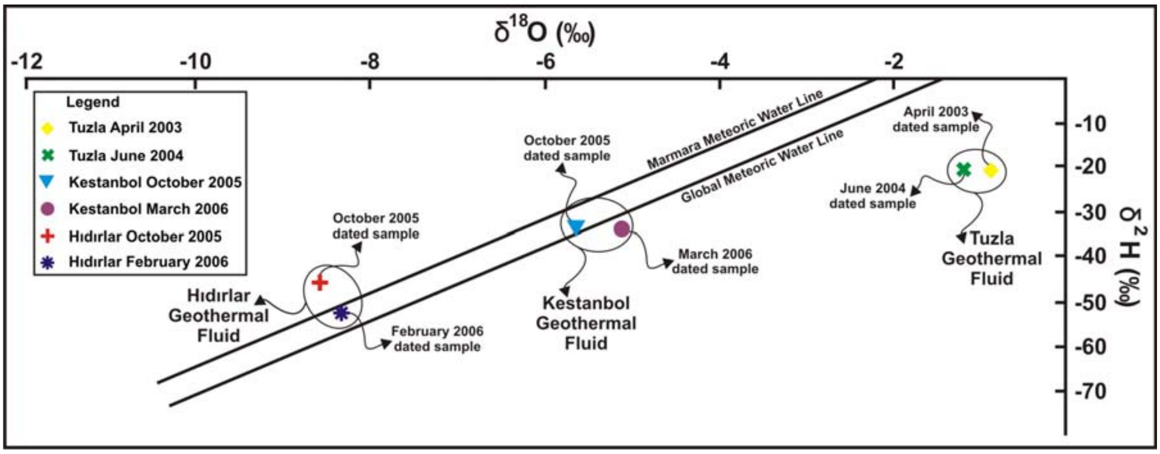


FIGURE 8: $\delta^{18}O$-$\delta^{2}H$ diagram of water samples in Tuzla, Kestanbol and Hıdırlar geothermal fields

5. ESTIMATION OF RESERVOIR TEMPERATURES

Tuzla geothermal field is one of the highest temperature geothermal sources in Turkey. The reservoir temperature of Tuzla geothermal fluid is 173°C, which was measured during drilling in 1982. Some companies have been working on this geothermal site for production of energy. Also, the other geothermal source has been used for bath. One borehole, 290.7 m deep, was drilled in 1975 in Kestanbol field and one borehole, 385 m depth, was drilled in 1989 in the Hıdırlar geothermal field by the General Directorate of Mineral Research and Exploration (MTA). The surface fluid temperature of these two drillholes was more than 85°C.

Chemical analyses of geothermal fluids can be used to estimate subsurface reservoir temperature. Chemical geothermometers depend on the water-mineral equilibrium and give the last equilibration temperature for the reservoir (Nicholson, 1993). Several geothermometer techniques have been developed to predict reservoir temperatures in geothermal systems (Fournier & Truesdell, 1973; Truesdell, 1976; 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. Solute geothermometer techniques were applied to geothermal fluid in Kestanbol and Hıdırlar. Surface temperatures of Kestanbol geothermal fluid vary between 66 and 74°C. According to silica geothermometers the temperature of the reservoir varies between 95 and 159°C (Baba and Ertekin, 2007). According to cation geothermometers, the temperature of the reservoir varies between 81 and 163°C in Hıdırlar geothermal fluid (Baba and Deniz, 2008).

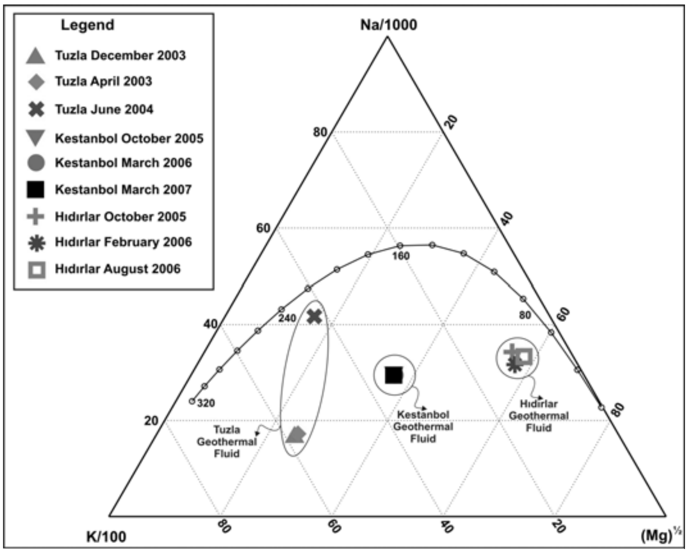


FIGURE 9: Giggenbach (1988) diagram of water samples in Tuzla, Kestanbol and Hıdırlar geothermal fields

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. Geothermal fluid samples plotted into the partially equilibrated or mixed water zone in Figure 9. Reservoir temperature value estimated by this method is in the range of approximately 80-225°C; whereas, Na-K geothermometers show unacceptable results for water samples plotted in the partially equilibrated or mixed water zone.

6. CONCLUSIONS

Hot saline waters (brine) in the Tuzla geothermal field originate from connate water along faults. Thermal water in the Kestanbol area originates from the deep reservoir filled seawater in the pores, but mixes with meteoric or cold water in various ratios. Hıdırlar geothermal fluid has the same recharge area, shallow circulation and meteoric in origin. Age of these three geothermal fluids is more than 50 years. The nature of high salt content of thermal water in Tuzla and Kestanbol is related to the age of it. More than 50 years age indicates that it has interacted with the host rock for a long time. These three geothermal fields are currently used for primitive thermal spas. Therefore, it is possible to increase the flow from these sources and obtain hotter than 100°C hot water by drilling with the help of field observations and the data obtained. This geothermal district could make a considerable contribution to thermal tourism, agriculture, heating and fish industry. High contents of the As, B and Sr are monitored in the utilization of cold water and soil aquifer.

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