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Hydrogeochemical Study of the Selected Thermal and Mineral Waters in Dikili Town, İzmir, Turkey

Tuğbanur ÖZEN, Gültekin TARCAN and Ünsal GEMİCİ

Dokuz Eylül Üniversitesi Jeoloji Mühendisliği, 35100, Bornova-İzmir-Turkey

E-mail: tugbanur.ozen@ogr.deu.edu.tr

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ABSTRACT

Selected thermal and mineral waters of Dikili town have been physically divided into three groups; Dikili Spa, Kaynarca and Kocaoba geothermal areas. Thermal and mineral waters, issuing from natural springs and drilling wells, were evaluated from hydrogeological and hydrogeochemical points of view. Origins, mineral saturations, aquifer temperatures, aquifer fluid compositions and aqueous species distributions have been studied by using analytical data of waters. Miocene Yuntdağ volcanic-I, which consists of andesitic volcanics, is the oldest unit and occurs as aquifer for aforementioned all the geothermal systems. Overlying Pliocene Demirtaş pyroclastics, which are ignimbrite and felsic pyroclastics, cap the systems because of their low permeability values. Quaternary alluvium is the aquifer for cold ground waters.

$\delta^{18}O$ and δD data of geothermal waters indicate that they are of meteoric origin and show relatively $\delta^{18}O$ enrichment. The measured outlet temperatures of the thermal waters range from 30ºC to 99ºC. Different geothermometers indicate that reservoir temperatures vary between 120-200ºC in the study area. The types of thermal waters are Na-HCO_3-SO_4, Na-SO_4-HCO_3 and Na-Ca-SO_4 in Dikili Spa, Kaynarca and Kocaoba respectively. Hardness values (^oFr) of them are between 3 and 123. Their conductivity values vary between 1900-3200 μS/cm. Thermal and mineral waters are generally undersaturated with respect to gypsum, quartz, amorphous silica, siderite and fluorite, and oversaturated with respect to calcite, aragonite and dolomite. Mineral equilibrium modelling shows that calcite, aragonite and dolomite scaling problems are expected in product wells during the extraction of thermal and mineral waters in the study area. These waters may cause environmental problems because of their high amount of boron and ion concentrations. Contribution of these waters to surface and ground waters should be prevented after the use of district and greenhouse heating, balneological and thermal tourism purposes. Thus, wastewaters should be re-injected to minimize the negative effects of it to the environment and to feed the geothermal aquifers.

1. INTRODUCTION

Thermal and mineral waters of Dikili town are located in 100 km far from İzmir City Center (Figure 1). They have been used for bathing and washing purposes since ancient times. The thermal springs have total discharge rate of ~210 l/s and their temperatures vary from 30 to 99ºC. Six geothermal gradient wells having depths of 58-202 m and one deep geothermal well having depths of 1500m have been drilled by MTA (General Directorate of Mineral Research and Exploration of Turkey). While aquifer temperature was expected 200ºC from the deep well, but maximum bottomhole temperature was found to be 130ºC. According to hydrogeological investigations, made by different researchers (Filiz, 1982; Yılmazer 1984; Yılmazer and Özgüler, 1986; MTA and JICA, 1987; Eşder, 1989; Jeckelman, 1996), isotopic data show that mineral and thermal waters in research area are of meteoric origins, which filter within subsurface from Kozak Region.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

In the western Anatolia, the Pliocene grabens were formed after the compressional stress fields of the Miocene to Pliocene time. In Dikili and surrounding geothermal areas following the compressional fields during late Miocene to early Pliocene time, the area became a site of N-S oriented tensional stress fields in late Pliocene age. As a result, a basin was formed and there are many thermal springs whose distribution is controlled by fracture patterns (Akyürek and Soysal, 1978). The geology of Dikili area and its neighborhood comprises late Miocene-Pliocene. The Yuntdağ volcanics were divided into three groups: Yuntdağ volcanic-I (Tyu_1), Yuntdağ volcanic-II (Tyu_2) and Yuntdağ volcanic-III (Tyu_3) (MTA-JICA, 1987). The oldest Yuntdağ volcanic-I consists of widely altered andesite. Tertiary Demirtaş pyroclastics mainly made up of felsic pyroclastics cover the Yuntdağ volcanic-I. Overlying Yuntdağ volcanic-II is restricted to the western of the study area. The rock consists of dark compact basalt and pyroxene andesite lava. In the rocks, a few small hydrothermal veins are found. This unit is covered with the youngest Yuntdağ volcanic-III. The rock that consists of biotite, hornblende and andesite is dome shaped volcano type.

In the study area, there are three kinds of faults; NW-SE, NE-SW and WNW-ESE trending but NE-SW and WNW-ESE trending faults could be followed with geophysical methods and monitoring. The geological texture of the study area I on the basis of directions is characterized by the NW-SE trending graben controlled by NW-SE step faults (MTA-JICA, 1986; Figure 1). Geothermal activity is observed as thermal springs around the youngest Yuntdağ volcanic-III and reservoirs are expected to Yuntdağ volcanic-I. Miocene Yuntdağ volcanic-I consisting of andesitic volcanics is the oldest unit and occurs as aquifer for aforementioned all the geothermal systems. Overlying Pliocene Demirtaş pyroclastics ignimbrite and felsic pyroclastics cap the systems because of their low permeabilities. Quaternary alluvium is the aquifer for cold ground waters. Dikili, Kaynarca and Kocaoba geothermal areas are closely related to major fault and fracture zones. The meteoric water recharged in Kozak Region and heated at depth and moved up to the surface along the faults.

Geothermal systems of the study area can be divided into three groups: (1) Dikili, (2) Kaynarca and (3) Kocaoba geothermal systems on the basis of locality. In summary, there is a bath in Dikili-Çamur (meaning mud-bath) Spas. Thermal waters issue from Quaternary alluvium. However, it is very likely that the water originally comes from joints in the andesite near the bath. The name Çamur Spas refers to the turbid and muddy water in the pools. The thermal field of Kaynarca is situated 4.8 km east of the Dikili intersection in the alluvial plain. In an area over 250.000m^2 there are approximately 80 thermal springs and steam outlets. They consist of small holes in the ground and funnel-shaped incrustations in the alluvium and occur of a size of a few centimeters or meters in diameter to 70m large lakes. This thermal water occurrence is a direct result of the 1939 earthquake western of Dikili Town. Kocaoba consists of thermal water overflows out of the gravel of the riverbed. The local people use this site for bathing. Between 1986 and 1987, the areas were investigated by a joint Japanese-Turkish pilot project (MTA-JICA, 1987). In the study area, three geothermal gradient wells having depths of 58-680 m were drilled by MTA. Finally, high geothermal potential was included in Kaynarca geothermal field. Therefore, a deep geothermal well (K_1) having depth of 1500m was drilled by MTA to meet geothermal fluids, which is suitable for electricity generation. Although aquifer temperature was expected 200ºC from the deep well, maximum bottomhole temperature was found to be 130ºC.

The thermal springs at Dikili Spa, Kaynarca and Kocaoba contain very low tritium concentration (Table 1). The smallest δD values (-35.5 to -47.1 ‰) of the thermal waters indicate that thermal waters up flow from deepest level. Isotopic data (^{18}O and ^{2}H) suggest that thermal waters in the geothermal fields are of meteoric origin and show relatively $\delta^{18}O$ enrichment (Figure 2). The low tritium activities of them indicate a minimum age of 50 years in subsurface.

3. HYDROGEOCHEMICAL FEATURES OF THE WATERS

The results of chemical analyses of the thermal and mineral waters from the study area are listed in Table 2 and locations of the water samples are shown in Figure 1. Classifications of the water samples in Table 2 were made according to principles of IAH (1979). Total equivalents of cations and anions separately were accepted as 100% and ions with more than 20% (meq/l) were taken into consideration in this classification. The chemistry of the thermal and mineral waters in the study area is a little similar and the water types are Na-HCO_3-SO_4 in Dikili Spa, Na-SO_4-HCO_3 in Kaynarca and Na-Ca-SO_4, in Kocaoba. The variations in ground water geochemistry of waters in the study area along the anticipated flow direction can also be observed in a Piper diagram (Figure 3). The high concentrations of Na^+ and HCO_3^- in the thermomineral water are probably dominated by a combination of mixing cold ground water and/or water-rock interaction and ion exchange reactions in thermal aquifers. Cold waters in the study area are different. Dominant ion species are generally Ca^{2+} and/or Mg^{2+}. Some waters have no dominant cation species; HCO_3^- and/or SO_4^{2-} are generally dominant anions. Hardness values of waters are between 12-36, 8-123 and 25-30 Dikili Spa, Kaynarca and Kocaoba Spa respectively. Conductivity values of waters in study field vary between 1900-5500 µS/cm (Table 2). One of the environmental problems for cold waters in the study area is boron contamination of aquifers and soils.

Boron contents of the thermomineral waters are quite high. These suggest that the cause of the high boron contents in cold ground waters and surface waters is thermomineral fluids issuing from the geothermal systems. To prevent boron contamination of cold waters used for irrigational purposes, re-injection of produced thermomineral waters to the geothermal reservoir may be necessary.

3.1 Geothermometer Applications

A number of solute geothermometers were used to estimate the reservoir temperature of the thermomineral waters in Dikili, Kaynarca and Kocaoba geothermal fields (Table 3). Some of them are lower than the measured surface temperatures or much higher than possible (Table 2). Comparing the measured reservoir temperature (130ºC in the K_1 well in the Kaynarca field) most of the Na/K geothermometry results are generally too high to be reservoir temperatures, probably due to the mixing of thermal waters with cold waters. The temperatures obtained from silica geothermometers are more reasonable than those of the other cation geothermometers (Table 3). The temperatures obtained by silica geothermometers in Dikili, Kaynarca and Kocaoba geothermal fields vary between 100-150˚C, 130-200˚C and 70-120˚C respectively.

A ternary plot of Na/1000-K/100-$Mg^{0.5}$ was proposed by Giggenbach (1988) as a method to describe reservoir temperature and to recognize immature waters, which have attained equilibrium with relevant hydrothermal minerals from immature waters. Fournier (1990) proposed a slight revision of the diagram. Some of the thermal waters, indicating by mixing (with cold groundwater and/or sea water), or come from low temperature environments, cation geothermometers give unreasonable results. The graphical resolutions of this combined geothermometer for the study area illustrated in Figure 4. Most of the thermal waters fall into the immature fields. It can be suggested that these water are not in equilibrium with reservoir rocks, and are probably dominated by mixing with cold ground water. Thus, the application of cation geothermometers should be considered doubtful and should be correlated with the results obtained from silica geothermometry results (Özen and Tarcan, 2000). Reservoir temperature values estimated by this geothermometer are about 200ºC and all water points are located over line of 200ºC.

A different approach to geothermometer is shown in Figure 5, where the changes in saturation indices (SIs) of relevant minerals with temperature were investigated for the Dikili Spa, Kaynarca and Kocaoba Spa mineral and thermal waters. Reed and Spycher (1984) have proposed that considering the changes in the SIs of minerals with temperature for a given aqueous solution can give the best estimate of reservoir temperature. Equilibrium constants for mineral dissolution often vary strongly with temperature. Therefore, if the SIs with respect to several minerals converges to zero at a particular temperature, this temperature corresponds to the most mineral solution equilibrium temperature or at least the equilibrium temperature of that particular water. Figure 5 shows the SIs with respect to selected hydrothermal minerals versus temperature for the thermal waters for the Dikili, Kaynarca and Kocaoba geothermal areas. SIs was initially calculated by using the WATCH (Arnórsson et al., 1982; Bjarnason, 1994) computer code. The thermodynamic database for the speciation calculations is given by Arnórsson et al. (1982). The pH in version 2.1A of WATCH is calculated by taking into account all species of that can combine with H^+. For this purpose chalcedony geothermometer (Fournier, 1977) by using the WATCH code were used as the reservoir temperatures and the boiling temperature was accepted as 100ºC. Mineral equilibrium diagrams versus temperature depict the equilibrium state of the fluid for each mineral as a function of temperature. The zero line in the SI diagram shows the equilibrium state with an aqueous solution for each mineral. Positive SI corresponds to supersaturation whereas negative values correspond to undersaturation. The point at which several minerals cross the zero lines gives the most reliable estimate of reservoir temperature. According to these diagrams in Figure 5 reservoir temperatures are estimated to vary between 100 and 125ºC, 125-150ºC and 75-125ºC in Dikili Spa, Kaynarca and Kocaoba Spa respectively. All these findings confirm that the thermal waters of the study area are non-equilibrated or partially equilibrated waters derived from mixed fluids of different temperatures. They support the existence of reservoir temperature varies between 100 and 120ºC, 130-150ºC and 70-125ºC for Dikili Spa, Kaynarca and Kocaoba, respectively.

3.2 Mineral Saturation

It is known that thermal waters have different temperatures and chemistry at subsurface conditions. However, their analyzed components reflect the surface conditions. Therefore, aquifer chemistry studies were carried out by using the PhreeqC computer code (Parkhust and Appelo, 1999). Saturation indices for the selected minerals were initially calculated at both outlet temperature and measured pH. Temperature was then changed iteratively and SIs recomputed. Figure 6, shows the SIs with respect to selected hydrothermal minerals versus temperature and trend curves depicted for the thermal waters of the Dikili, Kocaoba and Kaynarca geothermal areas.

As is shown in Figure 6, calcite is oversaturated at each temperature in Kocaoba Spa, Kaynarca, Kaynarca-3 well and DG-1. The remaining samples are oversaturated with respect to calcite at temperatures between 50 and 160ºC. Aragonite shows similar trends with the calcite trend in most water points. The equilibrium state of anhydrite (SI=0) varies between the 110 and 165ºC in Kocaoba Spa, Kaynarca, DG-1 well and Kaynarca-3 well, but it is undersaturated at each temperature in DG-3 well. Dolomite is mostly undersaturation in these geothermal fields. Quartz suggest to reflection of the saturation between temperatures of 120-190ºC in all thermal and mineral waters except for DG-3 well. It is oversaturated at each temperature in DG-3 well. Chalcedony shows similar trends with quartz but saturation temperatures of chalcedony are lower than those of quartz. Gypsum is undersaturated at each mineral and thermal waters of the area. Amorphous silica is undersaturated in Dikili Spa, Kocaoba Spa and Kaynarca-1 well. The remaining samples oversaturated with respect to amorphous silica at temperatures between 60 and 170ºC temperature intervals.

As combinational comments of the saturation states of selected mineral, scaling problems of carbonated minerals (calcite, aragonite and dolomite) are most likely to be precipitated from the thermal waters of these geothermal fields and using stages. Additionally, both some silica minerals (quartz and chalcedony) and anhydrite are likely to be precipitated at various temperatures for thermal waters. Silica scales only form if the thermal water becomes amorphous silica (Arnórsson, 2000). Therefore the silica scaling has not appeared to be an important problem in this area, whereas carbonated minerals and anhydrite are observed scaling minerals for thermal waters in most of the Turkish geothermal areas.

4. SUMMARY AND CONCLUSIONS

Miocene Yuntdağ volcanic-I consisting of andesitic volcanics is the oldest unit and occurs as aquifer for aforementioned all the geothermal systems. Overlying Pliocene Demirtaş pyroclastics ignimbrite and felsic pyroclastics cap the systems because of their low permeabilities. Quaternary alluvium is the aquifer for cold ground waters. Dikili, Kaynarca and Kocaoba geothermal areas are closely related to major fault and fracture zones. The meteoric water recharged in Kozak Region and heated at depth and move up to the surface along the faults. Isotopic data (^{18}O and ^{2}H) suggests that thermal waters in these geothermal fields are of meteoric origin and show relatively $\delta^{18}O$ enrichment. Their low tritium activities indicate a minimum age of 50 years in subsurface.

The chemistry of the mineral and thermal waters in the study area is similar. Based on their chemical composition, the waters can be divided into three groups: The types of thermal waters are Na-HCO_3-SO_4, Na-SO_4-HCO_3 and Na-Ca-SO_4 in Dikili Spa, Kaynarca and Kocaoba respectively. The high concentrations of Na^+ and HCO_3^- in the thermo-mineral water are probably dominated by a combination of mixing cold ground water and/or water-rock interaction and ion exchange reactions in thermal aquifers. One of the environmental problems for cold waters in the study area is boron contamination of aquifers and soils. Boron contents of the thermo-mineral waters are quite high. These suggest that the cause of the high boron contents in cold ground waters and surface waters is thermomineral fluids issuing from the geothermal systems. To prevent boron contamination of cold waters used for irrigational purposes, re-injection of produced thermomineral waters to the geothermal reservoir may be necessary. The temperatures obtained by silica geothermometers in geothermal fields vary between 70 and 150˚C. All the thermal waters fall into the immature waters or mixed waters in a Na-K-Mg ternary diagram. Hydrogeochemical assessment shows that thermal waters were mixed with cold water before and/or after heating at depth. SIs can be used as geothermometers by plotting of temperature versus SI diagrams and indicated a reservoir temperature estimation varying between 100 and 150ºC. The SIs of the water samples at each given temperature interval indicate that all thermal waters are undersaturated with respect to gypsum, mostly oversaturated with respect to calcite and aragonite. They reflect the oversaturation or undersaturation with respect to anhydrite, dolomite, quartz, chalcedony and amorphous silica. According to combinational comments of geochemical studies and field observations, scaling problems of carbonated minerals (calcite, aragonite and dolomite) are most likely to be precipitated from the thermal waters of these geothermal fields and using stages. Additionally, both some silica minerals (quartz and chalcedony) and anhydrite are likely to be precipitated at various temperatures for thermal waters.

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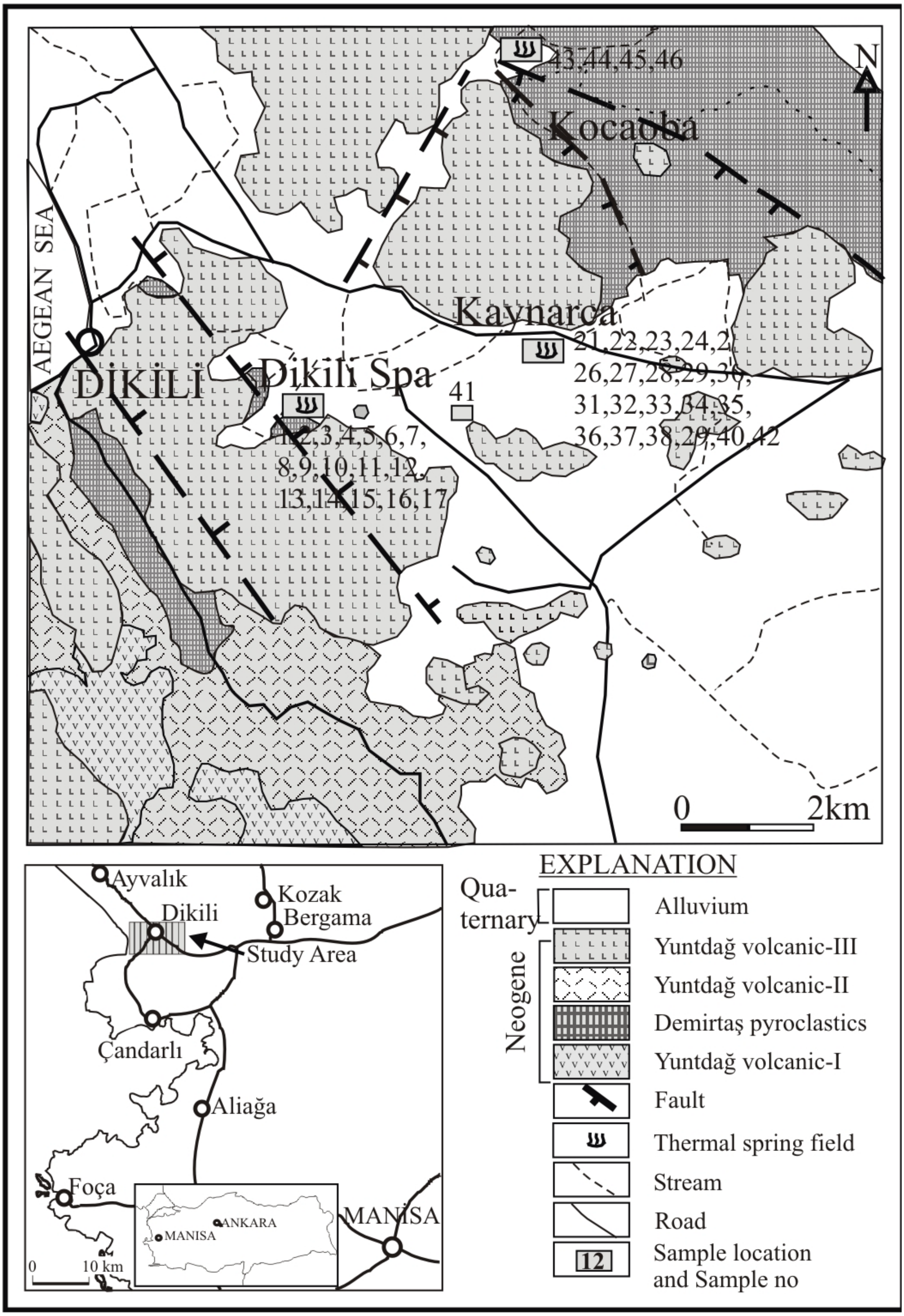

Figure 1: Geological map of the study area (modified from MTA-JICA, 1987) and locations of the sampled water points.

Table 1: Stable isotopes of mineral and thermal water in the study area (Sample numbers as in Figure 1).

No	Location	$\delta^{18}O$ (SM0W)	δD (SM0W)	^{3}H (TU)	Reference
1	Dikili Spa	-6.3	-41.5	<0.3	MTA-JICA, 1987
2	Dikili Spa	-5.8	-44.4	<0.3	MTA-JICA, 1987
8	Dikili Spa	-6.4	-43.5	0.7	Jeckelman, 1996
9	Dikili Spa	-5.9	-41.5	1.1	Jeckelman, 1996
10	Dikili Spa	-6.4	-45.0	8.7	Jeckelman, 1996
11	Dikili Spa	-6.3	-45.9	0.9	Jeckelman, 1996
12	Dikili Spa	-6.5	-47.1	-	Jeckelman, 1996
13	Dikili Spa	-4.7	-39.0	1.1	Jeckelman, 1996
14	Dikili Spa	-5.2	-31.7	-	Jeckelman, 1996
15	Plain near Dikili	-5.9	-33.8	-	Jeckelman, 1996
16	Sülüklü fountain	-5.4	-32.6	-	Jeckelman, 1996
17	Plain near Dikili	-6.2	-46.8	-	Jeckelman, 1996
22	Kaynarca	-6.3	-39.3	1.5	MTA-JICA, 1987
23	Kaynarca	-4.9	-37.4	-	MTA-JICA, 1987
24	Kaynarca	-6.1	-39.3	-	MTA-JICA, 1987
26	Kaynarca	-6.1	-39.3	0.8	MTA-JICA, 1987
27	Kaynarca	-6.4	-43.0	<0.3	MTA-JICA, 1987
28	Kaynarca	-4.8	-37.5	-	MTA-JICA, 1987
31	Kaynarca	-5.9	-41.8	<1.1	Jeckelman, 1996
32	Kaynarca	-4.8	-38.2	0.8	Jeckelman, 1996
33	Kaynarca	-5.6	-35.5	7.6	Jeckelman, 1996
34	Kaynarca east	-5.0	-30.7	9.9	Jeckelman, 1996
35	Kaynarca west	-5.7	-34.7	-	Jeckelman, 1996
41	DG-1 well	-5.9	-39.2	<0.8	MTA-JICA, 1987
42	DG-3 well	-5.4	-35.5	<0.8	MTA-JICA, 1987
45	Kocaoba Spa	-7.5	-46.3	-	Jeckelman, 1996
46	Near Kocaoba	-6.4	-37.0	3.3	Jeckelman, 1996

Table 2: Chemical characteristics of waters from Dikili geothermal field. All concentrations are in mg/kg unless otherwise specified.

No	Location	T°C	pH	EC	Na	K	Mg	Ca	Cl	SO_4	HCO_3	SiO_2	B	Fe	F	Har.	Water Type
1-a	Dikili Spa	65	7.3	2900	660	42	7.4	37	97.7	564	1090	99	12.5	1	5.8	12.3	Na-HCO_3-SO_4
2-a	Dikili Spa	40	7.3	2900	570	41	8.6	43	102.5	481	1140	109	11.0	5	5.5	14.3	Na-HCO_3-SO_4
3-a	Dikili Spa	40	7.3	2900	585	43	6.9	47	103.4	481	1140	101	10.6	2.7	5.4	14.6	Na-HCO_3-SO_4
4-a	Dikili Spa	66	7.1	2800	555	38	6.9	42	87.1	465	1040	99	10.4	1.1	4.9	13.3	Na-HCO_3-SO_4
5-a	Dikili Spa	65	7.0	2800	545	38	6.4	50	88.1	473	1060	109	10.9	1.4	5.3	15.1	Na-HCO_3-SO_4
6-a	Dikili Spa	73	7.2	2600	540	40	6.2	46	89	477	1040	99	10.4	1.5	3.7	14.0	Na-HCO_3-SO_4
7-a	Dikili Spa	34	7.4	3600	820	35	8.3	41	96.7	565	1620	109	11.9	0.5	-	13.6	Na-HCO_3-SO_4
8-b	Dikili Spa	72	6.2	2560	570	34.6	0.1	48.9	88.7	480	1035	77	-	0.9	-	12.2	Na-HCO_3-SO_4
9-b	Dikili Spa	41	6.7	2670	493.7	35.7	0.4	49.4	100.1	537	1159	78	-	0.8	-	12.4	Na-HCO_3-SO_4
10-b	Dikili Spa	36	6.4	2540	505.1	38.4	0.2	46.9	103.7	445	1007	-	-	1.7	-	11.8	Na-HCO_3-SO_4
11-b	Dikili Spa	65	6.8	2600	552.4	38.9	0.2	48.6	84.3	431	1074	-	-	1.5	-	12.2	Na-HCO_3-SO_4
12-b	Dikili Spa	30	6.6	3030	567.8	41.4	0.8	141.7	89.3	437	1489	141	7.6	6.8	-	35.7	Na-Ca-HCO_3-SO_4
13-b	Near Dikili	32	7.9	3200	525.9	31.2	0.1	53.0	111.6	580	1403	94	12.3	1.2	-	13.3	Na-HCO_3-SO_4
14-b	Dikili Spa	18	7.2	1150	132.2	1.6	32.2	70.6	91.4	106	482	39	0.4	1.4	-	30.9	Na-Ca-Mg-HCO_3-Cl
15-b	Plain near Dikili	24	6.7	495	52.4	7.9	7.6	34.6	48.4	12.4	159	123	0.1	0.0	-	11.8	Na-Ca-HCO_3-Cl
16-b	Sülüklü spr.	24	7.2	631	445.1	7.0	18.2	76.6	37.2	17.5	299	49	0.1	0.0	-	26.6	Na-Ca-Mg-HCO_3
17-b	Plain near Dikili	18	7.4	1987	445.1	10.0	26.1	45.9	263.7	27.4	1037	69	6.5	4.1	-	22.2	Na-HCO3-Cl
18-c	Agrobay-1, well	93	6.9	2140	415	32	4.7	62	74	661	356	102	-	*	-	17.4	Na –SO_4-HCO_3
19-c	Agrobay-2, well	89	6.8	2150	424	32	13	63	76	665	322	102	-	0.4	-	20.9	Na –SO_4-HCO_3
20-c	Dikili sea water	18	8.1	56200	12050	205	1390	542	22952	3000	102	4.3	-	0.2	-	707.0	Na-Cl
21-a	Kaynarca	42	8.1	2700	570	36	1.4	33	72.8	786	598	168	4.7	0.1	7.6	8.8	Na-HCO_3-SO_4
22-a	Kaynarca	82	7.7	2500	530	36	<0.5	32	68.9	735	586	226	5.1	0.1	7.2	8.2	Na-HCO_3-SO_4
23-a	Kaynarca	48	8.0	2700	570	37	3.8	37	72.8	774	598	193	5.0	0.1	7.4	10.8	Na-HCO_3-SO_4
24-a	Kaynarca	53	7.7	2500	540	34	0.5	39	71.8	753	586	226	5.0	0.1	7.6	9.9	Na-HCO_3-SO_4
25-a	Kaynarca	80	7.8	2600	530	33	3.3	44	70.9	735	598	241	5.1	0.2	7.2	12.3	Na-HCO_3-SO_4
26-a	Kaynarca	74	7.4	2600	540	34	0.5	37	70.9	781	604	215	5.1	1.1	7.4	9.4	Na-HCO_3-SO_4
27-a	Kaynarca	99	8.6	2500	540	33	0.5	33	69.9	744	610	203	5.3	0.1	6.8	8.4	Na-HCO_3-SO_4
28-a	Kaynarca	46	8.4	2600	570	34	1.0	33	72.8	743	610	165	5.3	0.1	7.6	8.6	Na-HCO_3-SO_4
29-a	Kaynarca	83	7.4	2600	520	33	<0.5	21	69.9	615	543	266	4.9	0.1	6.7	5.5	Na-HCO_3-SO_4
30-a	Kaynarca	76	7.4	2700	530	39	<0.5	36	70.9	482	586	178	-	0.1	6.8	9.2	Na-HCO_3-SO_4
31-b	Kaynarca	88	7.4	2530	522.8	36.6	2.4	34.2	61.2	615	561	-	-	0.6	-	9.5	Na-SO_4-HCO_3
32-b	Kaynarca	41	7.8	2623	515.1	29.8	3.0	42.2	67.9	796	555	194	6.0	0.1	-	11.8	Na-SO_4-HCO_3
33-b	Kaynarca east	70	7.1	2560	464.5	29.1	2.5	40.5	65.0	747	574	99	5.7	0.0	-	11.1	Na-SO_4-HCO_3
34-b	Kaynarca west	32	7.4	1901	240.8	15.6	63.4	238.8	245.5	656	465	241	0.6	0.0	-	85.6	Ca-Na-SO_4-HCO_3
35-b	Kaynarca west	19	7.3	3921	33.8	30.3	127	281.9	910.3	677	635	72	0.6	0.2	-	123.3	Na-Ca-Cl -SO_4
36-b	Kaynarca	18	7.0	1640	148.8	3.3	60.4	107.9	69.2	436	397	149	0.8	0.2	-	51.7	Na-Ca-SO_4-HCO_3
37-b	Kaynarca, spring	79	7.6	410	491	41	1	39.6	80	706	283	287	-	-	-	10.3	Na-SO_4-HCO_3
38-c	Kaynarca well-1	67	6.9	2040	375	24	7.8	67.2	225	641	181	115	-	1.4	-	19.9	Na-SO_4-Cl
39-c	Kaynarca well-3	87	8.2	2360	495	38.2	4.6	22	79	743	322	178	-	*	-	7.4	Na-SO_4-HCO_3
40-c	Kaynarca petrol	68	7	2320	432.8	32.1	7.8	68.4	82	701	334	146	-	0.8	-	13.3	Na-SO_4-HCO_3
41-a	DG-1, well	98	9	1800	363	32.1	2.3	10.8	51.2	553	282	363	1.7	6.9	4.2	20.3	Na-SO_4-HCO_3
42-a	DG-3, well	45	7.7	5500	737	87.0	63.0	3.3	1530	131	251	737	1.0	1.0	0.3	3.6	Na-Ca-Cl
43-c	Kocaoba brook	16	8.6	2360	18.8	2.7	18.5	73.6	30	124	134	26.7	-	*	-	104	Ca-Mg-SO_4-HCO_3
44-c	Kocaoba Spa	52	7.4	1763	259	13.9	2.2	119	54	765	122	75.5	-	0.2	-	25.9	Na-Ca-SO_4
45-b	Kocaoba Spa	54	7.2	1430	232.6	15.5	6.1	117.7	34.7	696	159	63.1	0.5	0.4	-	30.5	Na-Ca-SO_4
46-b	Near Kocaoba	17	7.3	1901	183.4	11.0	34.5	148.7	131.8	524	354	62.6	0.4	0.9	-	31.8	Ca-SO_4-HC0$_3$-Cl

a: taken from MTA-JICA (1987), b:taken from Jeckelman (1996) and c: sampled for this study. T (°C): measured outlet temperatures at surface;. pH: standard unit; EC: electrical conductivity (µS/cm) * under detection limit, Har.: hardness of waters in French scale.

Table 3: The results of the chemical geothermometers (Sample numbers as in Table 1 corresponding to locality numbers in Figure 1).

No	Location	T (^{o}C)	SiO_2 a1	SiO_2 a2	SiO_2 b1	SiO_2 b2	SiO_2 c	SiO_2 d1	SiO_2 a3	SiO_2 d2	SiO_2 d3	Na/K d4	Na/K e	K/Mg f
1	Dikili Spa	65	137	132	137	105	125	108	86	108	131	153	198	108
2	Dikili Spa	40	142	137	142	110	130	114	91	113	136	164	208	105
3	Dikili Spa	40	138	133	138	106	126	110	87	109	132	166	210	110
4	Dikili Spa	66	137	132	137	105	125	108	86	108	131	159	204	106
5	Dikili Spa	65	142	137	142	110	130	114	91	113	136	161	205	107
6	Dikili Spa	73	137	132	137	105	125	108	86	108	131	166	210	109
7	Dikili Spa	34	142	137	142	110	130	114	91	113	136	122	167	101
8	Dikili Spa	72	123	121	123	95	110	94	72	96	120	149	194	174
9	Dikili Spa	41	124	121	124	96	111	95	73	97	120	164	208	149
12	Dikili Spa	30	157	149	158	121	147	130	107	127	149	165	209	142
13	Dikili Spa	32	134	130	134	103	122	106	83	106	129	147	192	170
18	Agrobay-1, well	93	138	133	138	107	126	110	87	110	132	170	214	107
19	Agrobay-2, well	89	138	133	138	107	126	110	87	110	132	168	212	93
21	Kaynarca	42	168	159	169	129	159	141	118	137	158	152	197	128
22	Kaynarca	82	188	175	189	144	181	162	139	154	175	159	203	145
23	Kaynarca	48	178	166	178	136	169	151	128	145	166	155	199	114
24	Kaynarca	53	188	175	189	144	181	162	139	154	175	152	197	143
25	Kaynarca	80	193	179	194	148	186	167	144	159	178	151	196	113
26	Kaynarca	74	185	172	186	142	177	158	135	151	172	154	198	143
27	Kaynarca	99	181	169	182	139	173	154	131	148	168	150	194	142
28	Kaynarca	46	167	158	168	128	158	140	117	136	157	148	192	132
29	Kaynarca	83	200	185	201	153	195	174	151	165	184	153	197	142
30	Kaynarca	76	172	162	173	132	163	145	122	140	161	166	210	148
32	Kaynarca	41	178	166	178	136	169	151	128	145	166	145	190	111
33	Kaynarca	70	136	132	136	105	124	108	86	108	131	152	196	113
34	Kaynarca west	32	136	132	136	105	124	108	86	108	131	155	199	57
37	Kaynarca spring	79	206	189	207	157	201	180	157	170	189	178	222	138
38	Kaynarca-1, well	67	145	140	145	112	134	117	95	116	139	153	198	92
39	Kaynarca-3,well	87	172	162	173	132	163	145	122	140	161	170	214	112
40	Kaynarca petrol	68	117	115	117	90	104	88	66	90	114	166	210	100
41	DG-1, well	98	65	71	66	47	50	37	16	44	69	183	226	117
42	DG-3, well	45	135	131	135	104	123	107	84	107	130	213	254	98
44	Kocaoba Spa	52	122	120	122	94	109	94	71	95	119	139	184	94
45	Kocaoba Spa	54	113	112	113	87	100	84	62	87	111	157	202	84

T (^{o}C): measured outlet temperatures at surface; a1: SiO_2 (Quartz-no steam loss), Fournier 1977; a2: SiO_2 (Quartz-max. steam loss), Fournier 1977; a3: SiO_2 (alpha cristobalite), Fournier 1977; b1: SiO_2 (Chalcedony), Fournier and Potter, 1982; b2: SiO_2 (Quartz), Fournier and Potter, 1982; c: SiO2 (Quartz), Arnórsson et al. 1998; d1: SiO_2 (chalcedony, conductive cooling), Arnórsson et al., 1983; d2: SiO_2 (chacedony after adiabatic steam loss to 100^{o}C), d3: SiO_2 (Quartz after adiabatic steam loss to 100^{o}C), Arnórsson et al., 1983; d4: Na/K, Arnórsson et al., 1983; e: Na/K, Fournier and Potter 1979; f: K-Mg, Giggenbach et al., (1983).

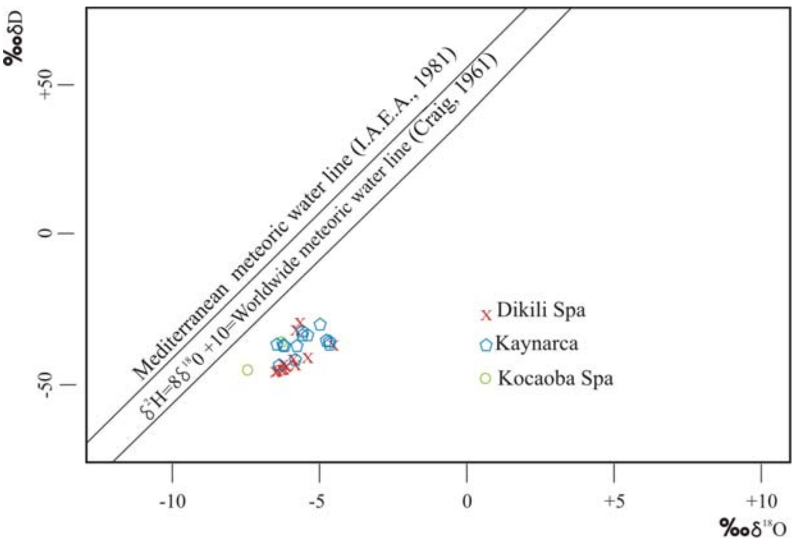

Figure 2: Plot of $\delta^{18}O$- $\delta^{2}H$ for some waters in the study area. Global meteoric water line (Craig, 1961); Mediterranean meteoric water line (I.A.E.A., 1981).

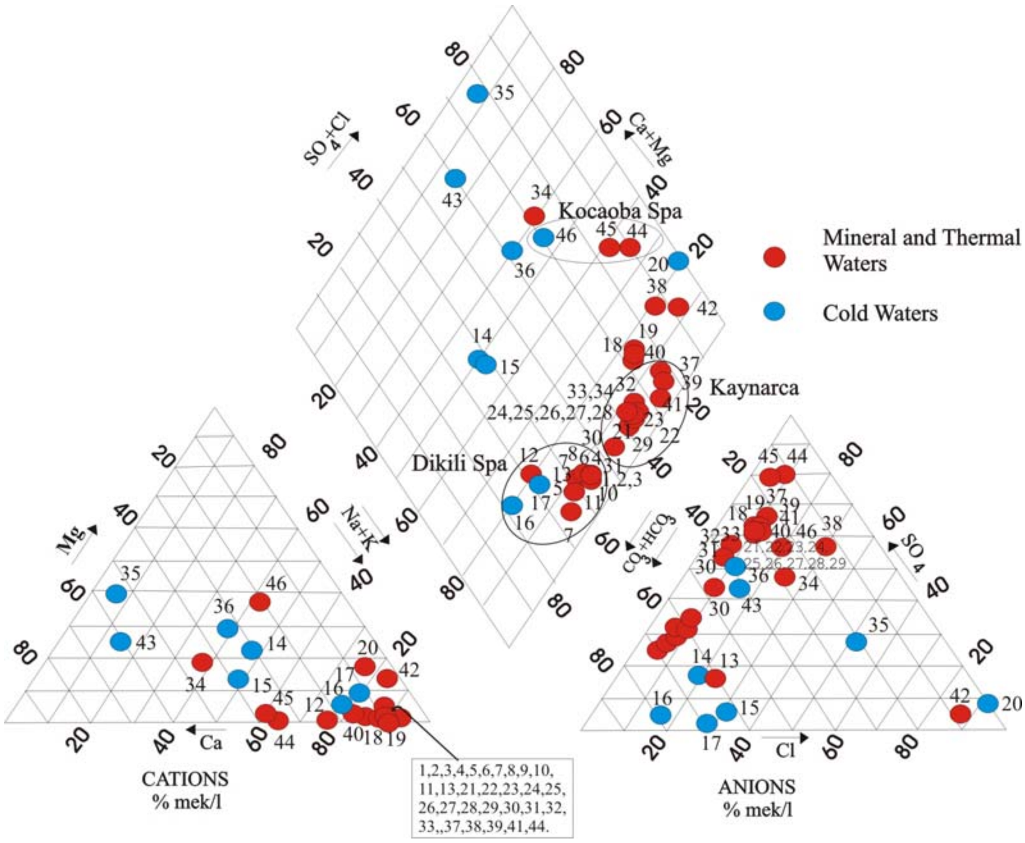

Figure 3: Piper trilinear diagrams of the waters from the study area (Sample numbers as in Figure 1).

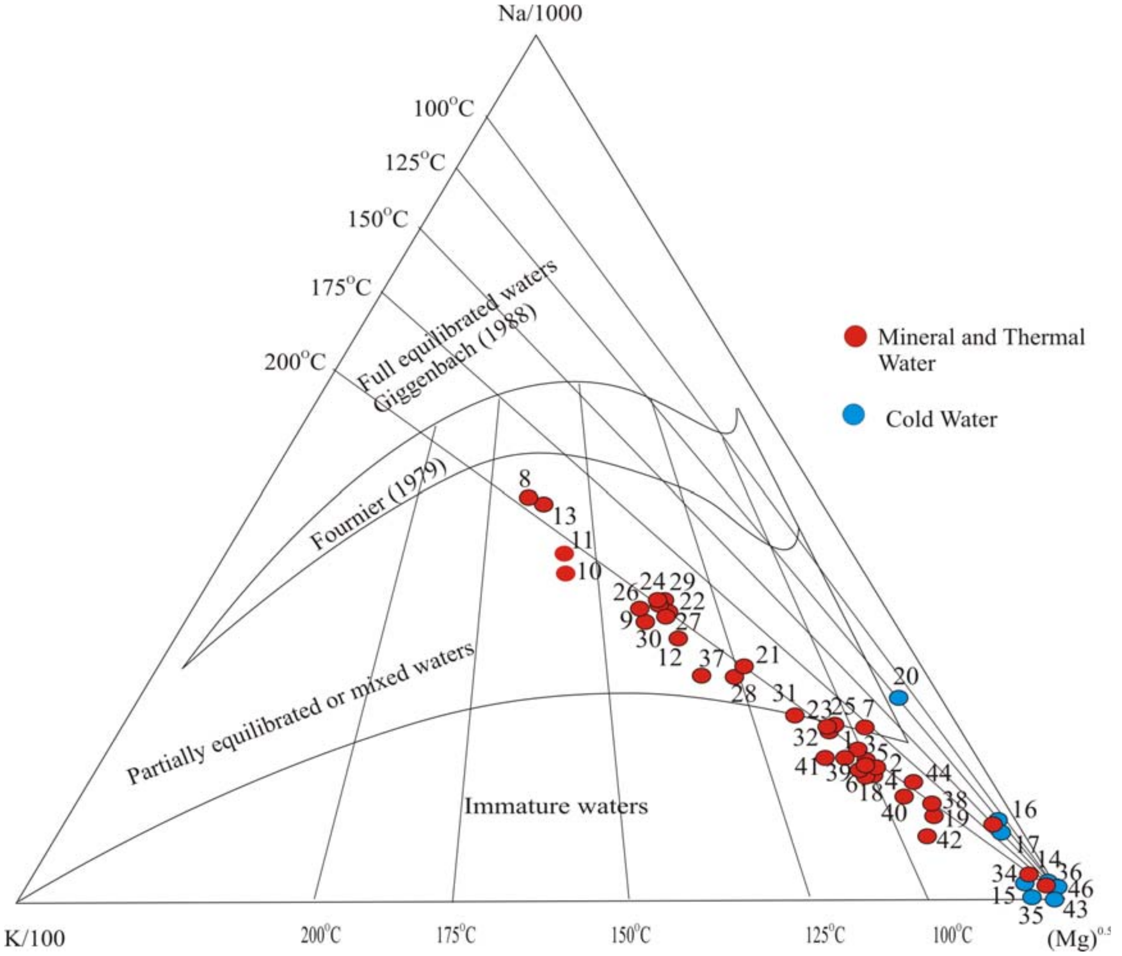

Figure 4: Distribution of the thermal waters from the study area in a Na-K-Mg trilinear diagram (modified from Giggenbach, 1988; Fournier, 1990; Janik et al., 1992; sample numbers as in Figure 1).

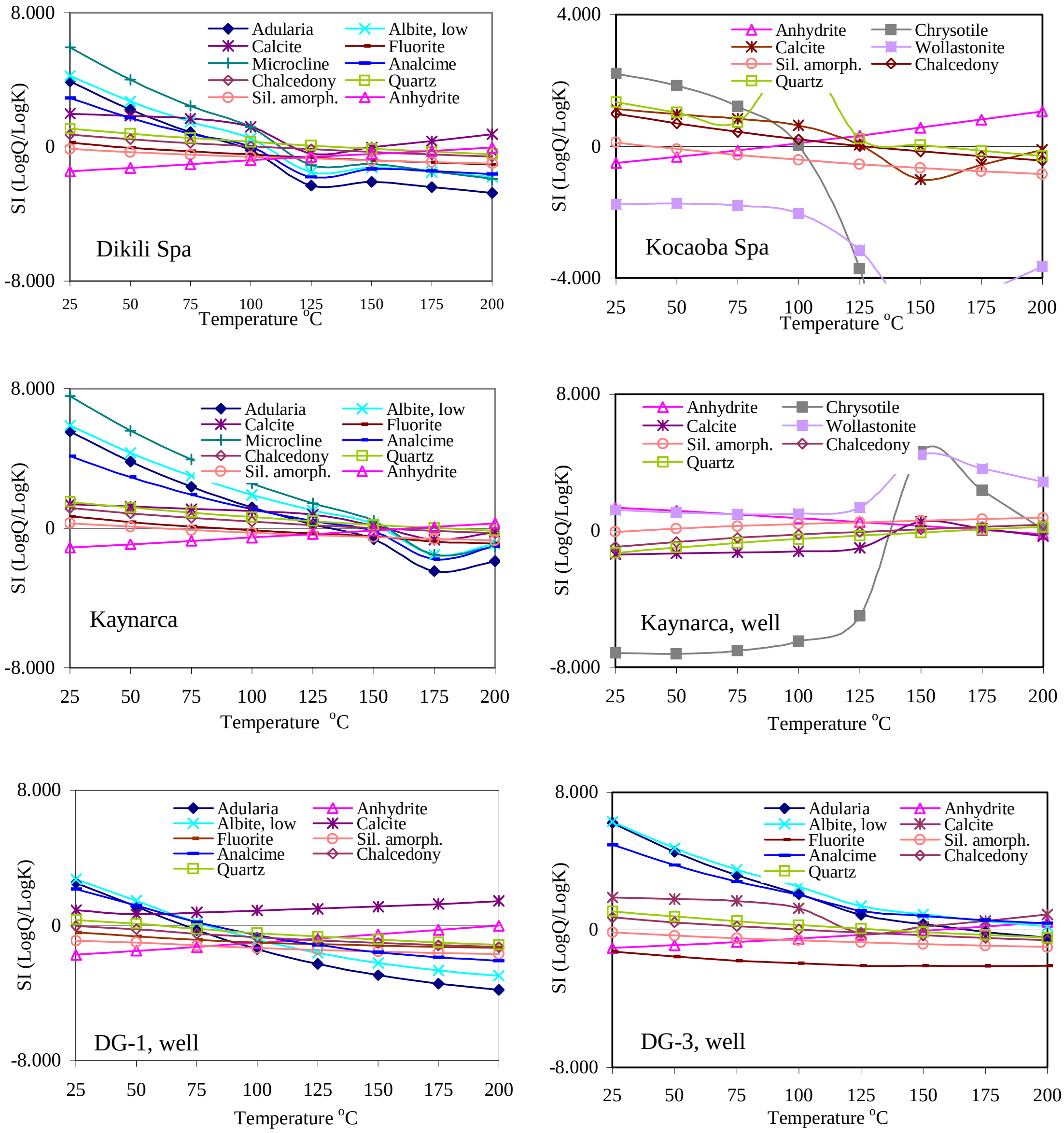

Figure 5: Mineral equilibrium diagrams for thermal waters from the selected geothermal area, Turkey (Sample numbers are as in Figure 1).

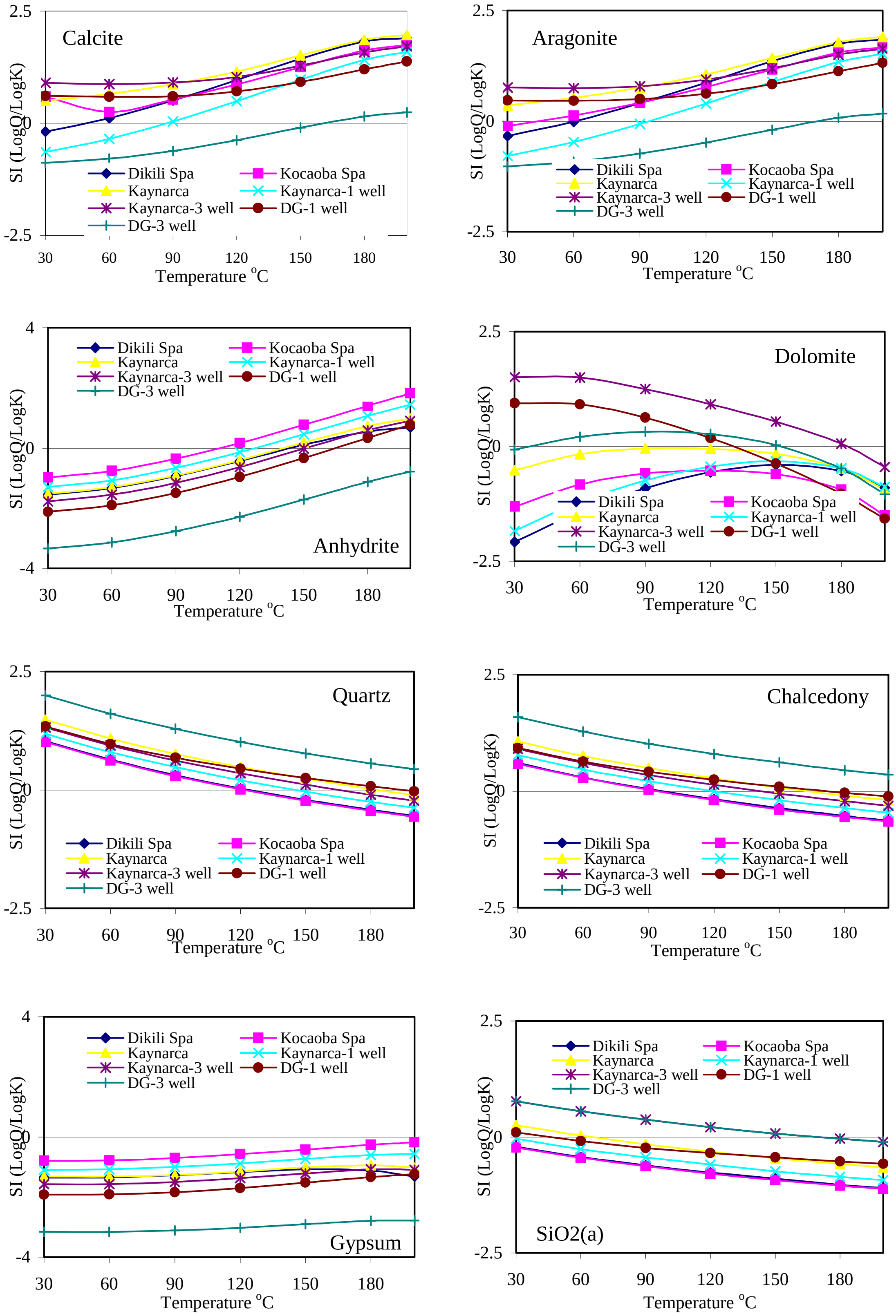

Figure 6: Changes in the saturation states of the selected minerals in thermal waters from the study area, Turkey.