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Geological and Hydrogeochemical Properties of Heybeli (Afyonkarahisar) Geothermal Field, Western Turkey

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ABSTRACT

The Heybeli (Kizilkirse) geothermal field located at 25 km south-east of Afyonkarahisar province (western Turkey) is one of the most important geothermal sites in the region. The basement rocks in the study area are the Paleozoic metamorphics and recrystallized limestones. This Paleozoic basement is overlain by Senozoic marl-conglomerate-sandstone-mudstone, tuffite, trachyandesite and alluvium units. The Paleozoic recrystallized limestone is the reservoir rock for the thermal waters whereas the Senozoic impermeable units are used as the caprock. The Heybeli geothermal area is mainly controlled by NW-SE trending normal faults that are related to the Afyon-Simav fault system. In this region, there are one thermal spring and eight thermal wells. They were drilled by governmental agencies and private companies, with a depth vary from 240 to 650 meters. Thermal water has been utilised for greenhouse heating and thermal tourism. Temperature, electrical conductivity (EC) and pH of thermal water are within the range of 29.3°C to 54.7°C, 587 to 3580 µmho/cm, and 6.32 to 7.37, respectively. Thermal water is of the Na-Ca-HCO_3 and Na-Ca-HCO_3-SO_4 type. The thermal water in the Heybeli geothermal field is classified as immature. The maximum temperature of the thermal water reservoir measured by the silica geothermometer is 115°C. The δ^{18}O-δ^{2}H isotopic data shows that thermal water from the study area has a meteoric origin. When water percolates through the permeable rocks in the recharge area, it is heated by geothermal gradient and ascends to the surface along the major faults.

1. INTRODUCTION

With a theoretical geothermal potential of 31500 MWt, Turkey has been ranked first in Europe and seventh in the world. Its installed electric generation capacity is 62000 MW while 0.4 % of this capacity (248 MW) is obtained from geothermal energy. The installed geothermal capacity of Turkey is 310 MW, it has not only been used for electric production but also been involved for district heating at about 90.000 houses, greenhouse heating to 2.97 million m^2 area and balneologic applications (Anonymous, 2013). Turkey is located in the Alpine-Himalayan belt which can be viewed as one of world's most important zones. Since young tectonic activities and volcanism take place intensively in Turkey, many geothermal fields are formed as a result. Although there are more than 1000 geothermal localities in Turkey, only 170 of them have a temperature that is above 40 degree celcius. 79% of these places are located in Western Anatolia (Denizli, Aydın, İzmir, Çanakkale, Afyonkarahisar, Kütahya, etc.), 8.5% located in Central Anatolia, 7.5% located in the Marmara Region, 4.5% located in Eastern Anatolia and 0.5% are located in other regions. (Figure 1).

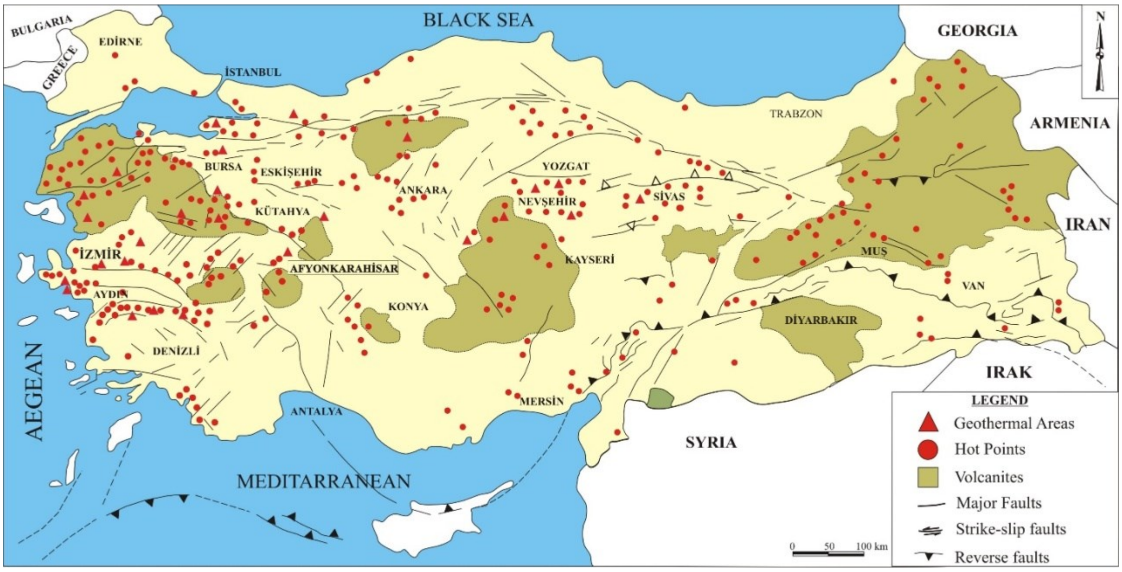

Figure 1: Main neotectonic lines and hot spring distribution of Turkey (Şimşek, 2009).

Apart from Denizli, Aydın, Kütahya, İzmir and Manisa, one of the most crucial geothermal fields would be Afyonkarahisar which is located in West-Anatolia. There are four major geothermal fields associated with Afyon-Akşehir graben (AAG) faults and the

Heybeli (Kizilkirse) geothermal field located at 25 km south-east of Afyonkarahisar province (western Turkey) is one of the most important geothermal sites in the region. . In this region there are one thermal spring and eight thermal wells with depths in the range of 240 to 650 meters, they were either drilled by governmental agencies or by private companies. The temperature of thermal water vary between 29.3°C and 54.7°C. Thermal water is generally utilised for greenhouse heating (100.000 m^2) and thermal tourism (300 beds).

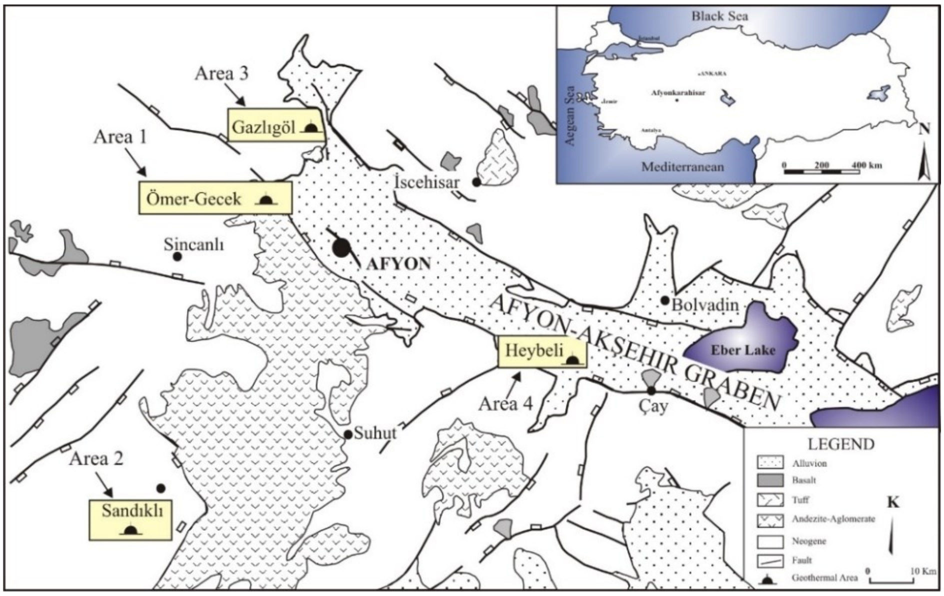

Figure 2: Geothermal areas in the Afyon-Akşehir graben system (modified from Gürsoy at al. 2003).

2. GEOLOGICAL SETTINGS

The area under investigation is located in Anatolide belt as stated by Ketin (1966). Anatolides, the metamorphosed northern extension of the Taurides, consist of several zones and the Afyon zone is one of them (Figure 3). Afyon zone is composed of low-grade greenschist facies metamorphic rocks (Tolluoğlu et al. 1997). The metamorphic rocks at and around Afyonkarahisar are defined as Afyon Metamorphics. These metamorphic rocks are overlain by Anatolian carbonate platform. The succession which consists of Afyon metamorphics and Anatolian Carbonate platform is called Afyon metasedimentary group. This group is overlain by the Triassic-Jurassic carbonates and Neogene aged volcanic and volcano-sedimentary units covers all these units (Tolluoğlu et al. 1997).

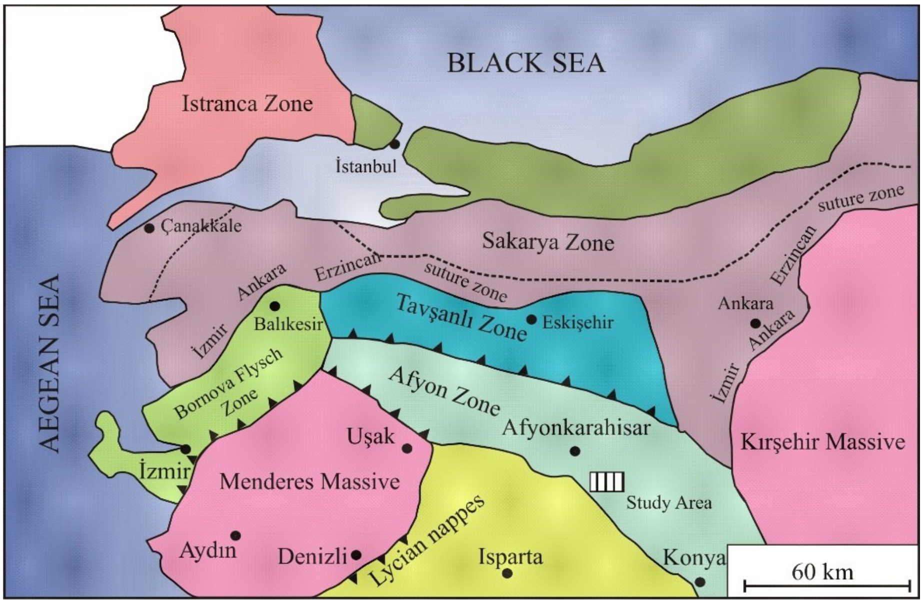

Figure 3: Paleotectonic map of west anatolia (simplified from Göncüoğlu et al. 1996).

The Afyon Metamorphics, consist of Sultandede Green Schist formation and Karahasan Limestones, are the basement rocks in the region. The basement is overlain by Senozoic sediments consists of Gebeceler and Kaymakcı Formations. Konarı trachyandezites characterised the volcanism in this region (Figure 4). These units are described in details next page.

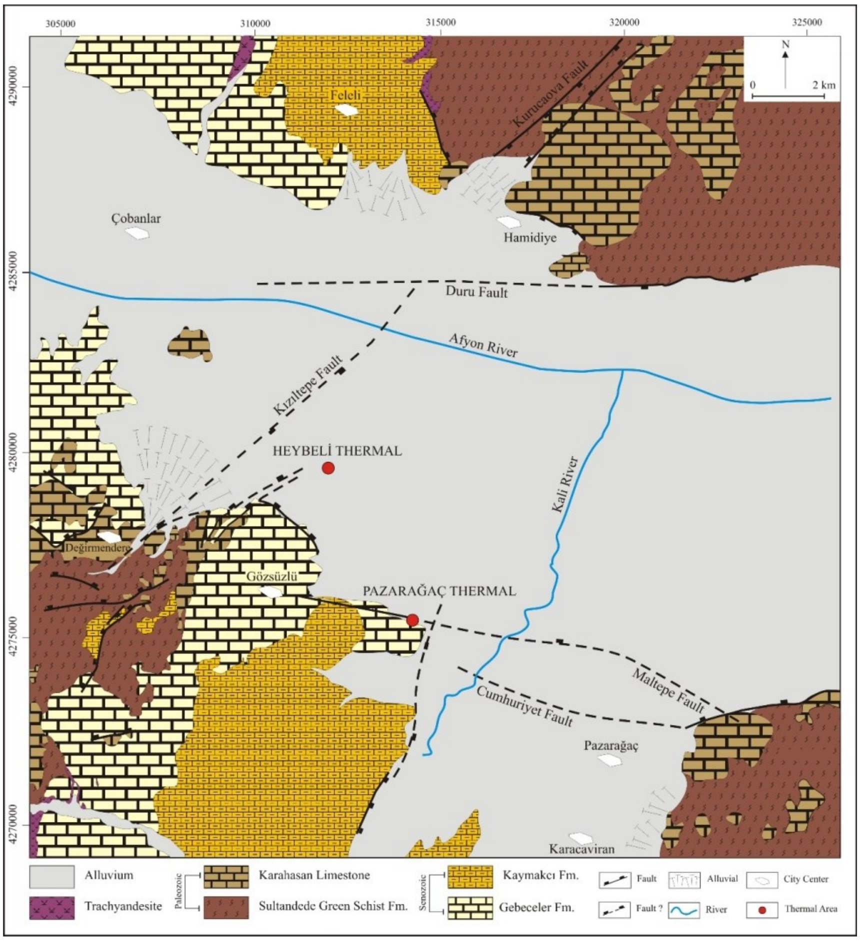

Figure 4: Geological map of Heybeli Geothermal Area (simplified from Erişen. 1972).

2.1. Sultandede Greenschist Formation

Sultandede formation consists of low grade metamorphosed chlorite-sericite schist/phyllit, calcschist, micaschist and quartzite. The schistosity planes of these brown-green coloured basement rocks are quite significant and common in the south-east and north-east of study area. (Figure 5a). The unit includes chlorite-sericite-quartz-feldispar and some opaque minerals such as tourmaline and titanite. Their ages are Devonien and older (Erişen, 1972).

2.2. Karahasan Limestone

This unit is dark gray coloured, properly medium and thick bedded; and it is usually composed of crystallized limestones which appear like marble lithologies (Figure 5b). Karahasan Limestones are interbedded with Sultandede formation. The main constituent of rock is determined to be calcite. In previous studies, the age of these limestones have been identified as Upper Carboniferous-Upper Permian (Erişen, 1972).

2.3. Gebeceler Formation

This Pliocene aged gray-beige coloured sedimentary unit is generally composed of lacustrine limestones and includes tuff lenses. These sediments overlie unconformably Paleozoic units (Figure 5c).

2.4. Kaymakcı Formation

Kaymakcı Formation takes place unconformity on the Gebeceler Formation. This unit shows graded bedding in the form of marl-conglomerate-sand stone-clay stone (Figure 5d). In the petrographic studies conducted on Upper Pliocene and younger aged marls micro fossil were determined and they were described as planorbis sp. (Figure 5e).

2.5. Konarı Trachyandezite

This unit outcrops in small areas in the northern and southern edges of the study area. Intensive cooling cracks are observed on dark gray and burgundy colored trachyandezites (Kuşcu et al. 2006) (Figure 5f).

In Afyonkarahisar region, NW-SE-trending normal fault system surface is about 3-30 km wide and 500 km long. This large seismogenic zone is called as Akşehir Simav Fault System (ASFS) (Koçyiğit and Deveci, 2007). With a length of 130 km and a width of 4-20 km, Afyon-Akşehir Graben is one of the most important grabens and geothermal systems in ASFS. The graben has a WNW–ESE trending structure bounded by normal fault systems and the subsidence plant of the graben is called as Akarcay basin. In the study area there are Kurucaova, Duru Cumhuriyet-Maltepe faults which are boundary faults of these graben system and secondary faults across them. (Figure 4).

Figure 5: Geological units appearance in the study area. a: Sultandede formation, b: Karahasan limestone, c: Gebeceler formation, d: Kaymakcı formation, e: macro fossil in marl, f: Konarı trachyandezite.

3. HYDROGEOLOGY AND HYDROGEOCHEMISTRY

The Paleozoic recrystallized limestone is the reservoir rock for the thermal waters whereas the Senozoic impermeable units are the caprock. On the other hand, these Senozoic marl-conglomerate and alluvium are the reservoir rocks for cold water. The Heybeli geothermal area is mainly controlled by NW-SE trending normal faults which are related to the Afyon-Simav fault system. Water which percolates deeply into the crust gains heat from magmatic intrusions and magmatic emanations. The recharge is mainly meteoric and it involves surface and underground waters infiltrating the basin. The geothermal fluid ascends to the productive aquifers through the major faults will bound the Afyon-Akşehir Graben faults after being heated at greater depth.

All wells in the Heybeli area were drilled to a depth in between 250 to 600 meters. The temperature, electrical conductivity (EC) and pH of the thermal waters in the field range from 29.3 to 54.7°C , 587 to 3580 µs/cm, and 6.32 to 7.37, respectively. The in-situ measurement results of all samples are given below (Table 1).The temperatures and EC values of water produced from shallower places are lower because of the mixing with cold groundwater of thermal waters. Electrical conductivity (EC) and pH of cold water vary between 78.9-1368 µs/cm and 6.41-7.83 respectively.

In total 36 water samples were collected and analyzed during the period of June-July 2013 in order to compare the physico-chemical characteristics of the thermaland cold waters in Heybeli geothermal field. Analyses were conducted at the geochemistry laboratory of the Geological Engineering Department in Pamukkale University, Denizli, Turkey.

The thermal water is of the Na-Ca-HCO_3 and Na-Ca-HCO_3-SO_4 type, whereas cold water samples are of the Na-HCO_3 type. If there is an increase in depth and mixing between thermal and cold groundwater during ascending to the surface of thermal water along extensional cracks, then electrical conductivity and temperature will increase as well. In Piper diagram, it can be seen that at some orientations calcium may lead to sodium and bicarbonate may lead to sulfate. It is observed that the sodium content of water enriched as a result of the high temperature condition and pyrite contained in reservoir rocks is the source of sulfate enrichment (Figure 6a). Schoeller diagram indicates that geothermal fluids are originated from the same reservoir within each other. In general, as the drilling depth and sample temperature increase, mineral concentration will also increase. Therefore the hottest water samples have the highest mineral concentration and the coldest spring waters have the lowest mineral content (Figure 6b).

Table 1: İn-situ parameters of collected samples.

Sample	Type	Depth	T (^{0}C)	EC (µs/cm)	pH
1	Thermal Well	258	54,7	3580	6,93
2	Thermal Well	260	54	3310	6,56
3	Thermal Well	256	52,9	2770	6,75
4	Thermal Well	410	51,4	3450	6,93
5	Thermal Well	600	37,6	2350	6,91
6	Thermal Well	25	29,3	1380	6,56
7	Thermal Well	?	37,9	2119	6,32
8	Thermal Well	?	28,9	1447	6,52
9	Thermal Spring	-	29,7	587	7,37
10	Cold Water Well	60	20,3	955	6,79
11	Cold Water Well	150	20,1	563	7,35
12	Cold Water Well	?	20,5	1387	7,01
13	Cold Water Well	?	17,9	908	6,98
14	Cold Water Well	?	16	718	7,57
15	Cold Water Well	?	16,5	689	7,47
16	Cold Water Well	60	15,2	563	7,41
17	Cold Water Well	-	15,3	812	7,02
18	Cold Water Well	-	16,1	555	7,37
19	Cold Water Well	140	17,5	1338	6,41
20	Cold Water Well	200	18,9	331	7,79
21	Cold Water Well	110	13,4	282	7,83
22	Cold Water Well	35	13,9	567	7,21
23	Cold Water Well	-	18,5	515	7,16
24	Cold Water Well	-	16,7	512	7,27
25	Cold Water Well	25	14,7	1368	6,91
26	Cold Water Well	?	16,5	551	7,4
27	Cold Water Well	?	18,3	784	7,11
28	Cold Water Well	-	14,6	282	7,64
29	Cold Water Spring	-	17,9	373	7,39
30	Cold Water Spring	-	18,6	396	7,69
31	Cold Water Spring	-	13,5	548	7,1
32	Cold Water Spring	-	16,2	415	7,37
33	Cold Water Spring	-	16,7	78,9	7,25
34	Cold Water Spring	-	13,4	286	7,29
35	River	-	23,6	1369	7,81
36	River	-	28,3	1206	9,52

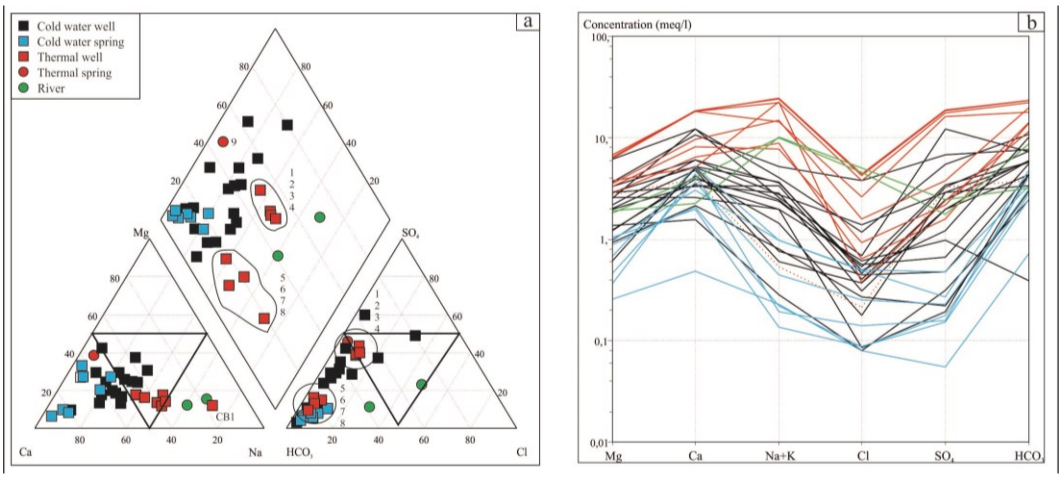

Figure 6: a: Piper diagram, b: Schoeller diagram of Heybeli geothermal area water.

Cl-SO_4-HCO_3 triangular diagram is used to classify water of the genetic basis (Nicholson 1993). As shown in the diagram, cold spring water is around the HCO_3 corner, the cold well water and thermal water oriented towards the sulfate area due to pyrite contents of reservoir rocks (Figure 7a). Na-K-Mg triangular diagram is used to determine the origin of geothermal waters, to control the balance situation and provide information for the selection of appropriate geothermometer (Giggenbach 1988). This diagram shows that Heybeli water is immature (Figure 7b), therefore, silica geothermometers were applied to the samples instead of cation geothermometers. The silica geothermometer models suggest the maximum temperature of Heybeli thermal water reservoir is 115°C (Table 2).

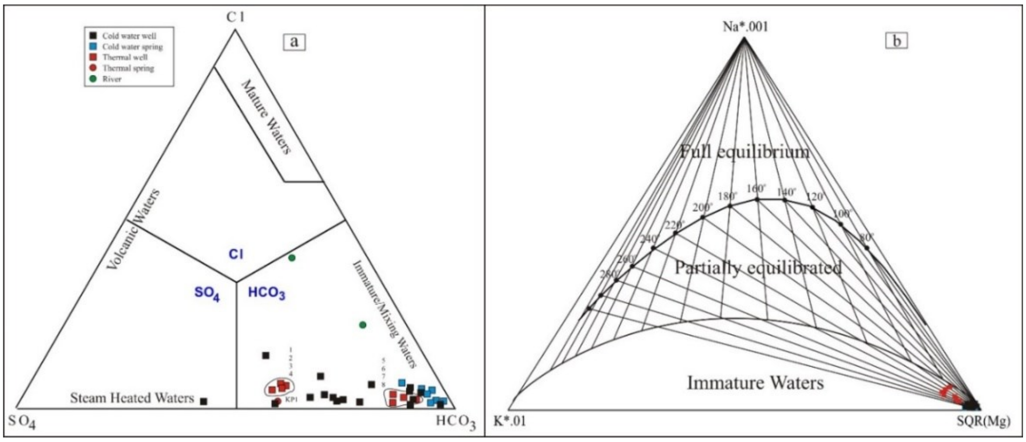

Figure 7: A: Cl-SO4-HCO3 diagram, B: Giggenbach (1988) diagram of Heybeli geothermal area waters.

Table 2. The gothermometer resuts of water samples.

	1	2	3	4	5	6	7	8	9	References
1-SiO_2 (amorphous silica)	-10	-12	-18	-16	-34	-11	-31	-2	-46	Fournier 1977
2-SiO_2 (alpha cristobalite)	56	54	47	49	28	55	31	65	14	Fournier 1977
3-SiO_2 (beta-cristobalite)	9	7	0	3	-17	8	-14	17	-30	Fournier 1977
4-SiO_2 (chalcedony)	77	74	67	70	46	76	50	86	31	Fournier 1977
5-SiO_2 (quartz)	107	104	97	100	78	105	81	**115**	63	Fournier 1977
6-SiO_2 (steam loss)	107	105	99	101	82	106	85	114	69	Fournier 1977
7-SiO_2 (chalcedony, con. cooling)	78	75	68	71	49	77	53	87	35	Arnorsson vd. , 1983
8-SiO_2 (quartz, steam loss)	81	79	73	75	55	80	58	89	42	Arnorsson vd. , 1983
9-SiO_2 (quartz, steam loss)	73	71	63	66	43	72	46	83	28	Arnorsson vd. , 1983
10-SiO_2 (quartz, steam loss)	96	93	86	88	65	94	69	105	50	Arnorsson vd. , 1983
11-SiO_2 (quartz, steam loss)	105	103	97	99	80	104	83	113	67	Arnorsson vd. , 1983
12-SiO_2 (chalcedony mmol)	77	74	67	70	48	76	51	86	33	Arnorsson vd. , 1983
13-K/Mg	85	81	72	84	70	83	69	72	31	Giggenbach vd., 1983

According to $\delta^{18}O$-$\delta^{2}H$ diagram, Heybeli thermal water is located at a line between GMWL (Global Meteoric Water Line) and Ankara Meteoric Water Line (Figure 8). This suggests a meteoric origin and some water samples are enriched in oxygen-18 due to the evaporation.

4. CONCLUSIONS

Heybeli thermal area is one of the most important geothermal areas in Afyonkarahisar. There are approximately 10 thermal wells with depth of 240-600 meters. Paleozoic aged Karahasan limestones are the reservoir rock and the Miocene units are cap rock for thermal water. The geothermal area is mainly controlled by NW-SE trending normal faults that are related to the Afyon-Simav fault system. The geothermal water percolates along these faults, getting heated and rises to the surface. This thermal water will not only be used for thermal spa (300 beds), but also for greenhouse heating (100.000 m^2).

Temperature of the thermal water is in the range of 29.3 to 54.7°C. It is of Na-Ca-HCO_3 and Na-Ca-HCO_3-SO_4 type in general. The electrical conductivity and pH vary between 587-3580 µs/cm and 6.32-7.37 respectively. Cold water is of the Ca-HCO_3 type and its electrical conductivity (EC) and pH vary between 78.9-1368 µs/cm and 6.41-7.83 respectively. The ^{18}O-D graphic shows that all water samples have meteoric origin and some cold spring/well samples are directed to the evaporation area. The thermal water is immature and applied silica geothermometers suggest the maximum reservoir temperature is 115ºC.

5. ACKNOWLEDGMENTS

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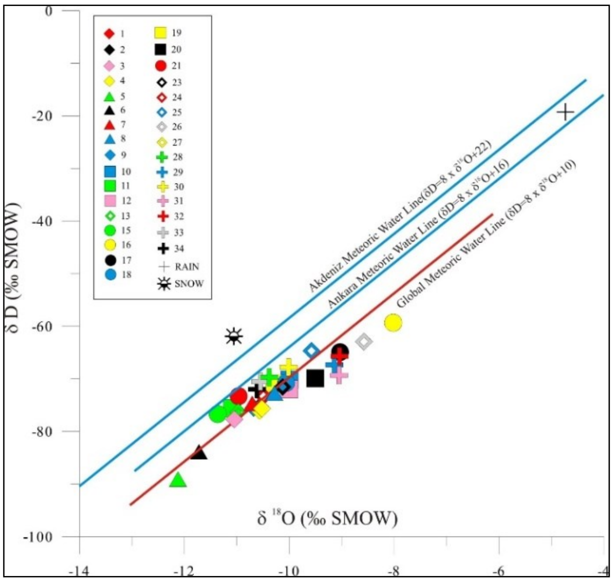

Figure 8: 18O-D diagram of water samples.

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