Hydrogeochemical Investigation of Yerköy (Yozgat-Turkey) Geothermal Waters

Elif Yilmaz Turali[1], Sakir Simsek[1], Kemal Koc[1]

[1]Hacettepe University, Engineering Faculty Department of Geological (Hydrogeological) Eng., Beytepe, Ankara

elifylmz@hacettepe.edu.tr

Keywords: Yerköy-Yozgat, Geothermal, Hydrogeochemistry, Geothermometers, Conceptual Model.

ABSTRACT

Yerköy geothermal area is located in the Central Anatolia of Turkey. Thermal water springs which have been used for spas for many years have temperatures of 41- 45 °C and flow rates of 0.5-2.5 l/s in the area. Geothermal reservoir units are rhyolites, altered granodiorites fractured and faulted zones in the field. Eocene and Oligocene sediments are caprock and overlie unconformably on rhyolites and granodiorites. Quaternary alluvium units overlie unconformably these sediments. Normal slip faults, which are generally NW-SE and NE-SW trending, developed in the region depending on stress tectonics in Neogene and Quaternary. Thermal water springs discharge from the intersection of these faults.

Between the years 1992 and 1997, seven shallow wells were drilled ranging from 59 to 262 m with a maximum temperature of 47 °C, in order to the development of spa tourism. For the purpose of investigation of the geothermal potential of the area and development of district heating, two exploration/production wells, YK-2 and YK-3, were drilled ranging from 550 to 750 m, respectively in 2006. The maximum bottom-hole temperatures were measured between 67 and 72°C, respectively in these wells. The thermal waters are alkali sodium chloride type and have high specific electrical conductivities. Hydrothermal alteration minerals, such as chalcedony, quartz, albite, microcline, shows the mineral equilibrium temperature between 60 and 100 °C. According to the isotopic data, thermal waters are meteoric and have a positive $\delta^{18}O$ shifts because of water-rock interaction. The low tritium values indicate that thermal waters recharged by precipitation before 1952. As a result of these studies, hydrogeochemical model has been evaluated for hydrothermal system of the area.

1. INTRODUCTION

The study area is located 34 km SW of the province of Yozgat and 5 km to Ankara-Yozgat highway (Fig.1). In the past, there was two thermal springs (Güven and Camur springs) for spa uses in the area. Güven spring had a temperature of 41°C with a flowrate of 0.5 l/s. Camur spring temperature were 45 °C (Simsek, 1993; Gündüz, 1993). Between the years 1992 and 1997, seven shallow wells were drilled ranging from 59 to 262 m. After the drilling study, Güven thermal spring was dry (Gündüz, and Özten, 1994).

In 1992, two shallow wells were drilled by State Hydraulic Works (DSI-1 and DSI-2) with an average temperature of 41 °C and flowrate of 2 l/s, for increasing the water flowrate for thermal spas. In 1993, YK-1 well was drilled by General Directorate of Mineral Research and Exploration (MTA) at the depth of 250 m with a 47°C temperature and 10 l/s artesian flowrate (Gündüz, 1993; Gündüz, and Özten, 1994). Also, there are four production wells in the area for a privately operated Koyunbasoglu spa, which have an average temperature of 40.3 °C and flowrate of 2.5 l/s (Canik, 2004). This spa is located 600 m west of Güven spring. Two deep wells YK-2 and YK-3 were drilled by Yozgat Governorship to supply hot water for bathing and determine potential of district heating, in 2006. Depths of the YK-2 and YK-3 wells are between 550 and 750 m, flowrates are 45 and 55 l/s and temperatures are 54.5 and 56.5 °C, respectively. The maximum bottom-hole temperatures were measured between 67 and 72°C in YK-2 and YK-3 wells, respectively (Simsek et al., 2006).

There is a hot water spring and spa in Cicekdag-Bulamacli, located about 3 km SW of Yerköy geothermal area. This spring has a temperature of 43.8 °C and flowrate of 2.5 l/s. Its water chemistry was compared with Yerköy geothermal waters.

In this study, water samples of cold and thermal waters were collected and analysed for major ion constituents, isotopic composition and tritium activity. Chemical analyses and ^{3}H isotopes were analyzed in Hacettepe University (HU) Water Chemistry Laboratory in Hydrogeology Engineering Department and environmental isotopes of deuterium ($\delta^{2}H$) and oxygen-18 ($\delta^{18}O$) were analyzed in the Scientific and Technological Research Council of Turkey (TUBITAK) Marmara Research Center (MAM). Based on these data, it was carried out to present a conceptual hydrothermal model of Yerköy geothermal area.

2. GEOLOGY AND HYDROGEOLOGY

2.1 Geological settings

The basement rocks in the field are granites and rhyolites (Figure 1). Granites known as Yozgat granitoid (Ky), refer to intrusives of Central Anatolia, have calc-alkaline compound and is outcrop as batholith, pluton, vein in the field. Rhyolites are a member of Kotudag Volcanics (Kyk) that consist of rhyolites, rhyodacites, granite porphyry etc. Kotudag Volcanics outcrop south and east of study area (Sarikaya Hill) and contact with Yozgat granitoid in the southeast of the area. The formation of intrusive rocks is between early Cretaceous-Late Eocene (Ketin, 1955, Büyükönal, 1977).

Eocene sediments (Te) consisting of alternation of conglomerate, sandstone, marl with sand and marl overlie unconformity with Kotudag Volcanics.

Oligocene unit (Deliceirmak Formation, Td) that covers conformably Eocene sediments consists of evaporitic (gypsum and halite) and terrestrial sediments (alternation of conglomerate, sandstone) and is outcrop north of the area which covers wide portions.

Quaternary terrace, alluvium and travertine are the youngest rocks in the study area. Terrace covers in the south-eastern part of Yerkoy. Travertines are located around hot and mineral water springs in the area that is a little portions.

Yerköy geothermal area is controlled by mainly NW-SE and NE-SW trending faults which normal and step. Thermal waters emerge from location that these faults closer each other.

2.2 Hydrogeological settings

Basement rock rhyolites and altered granodiorites which have secondary porosity with tectonic movements are permeable. These rocks are the hot water reservoir in the field. Eocene, Oligocene, Pliocene sediments which are alternation of evaporates, limestone, marl, limestone with clay and sandstone, are cap rock with low permeability. Also, limestone, sedimentary rocks (mainly limestone) in fault zone and alluviums in the Delice Stream bed consisting of conglomerate, sand and clay are important aquifer for cold water.

Yerköy geothermal area is located in Delice basin covers an area of approximately 9160 km^2. The average annual air temperature within the basin is 9.6 ºC and average rainfall within the basin is 408.16 mm/year. Evapotransporation within the basin were determined to be 337 mm/year (Yilmaz, 2007).

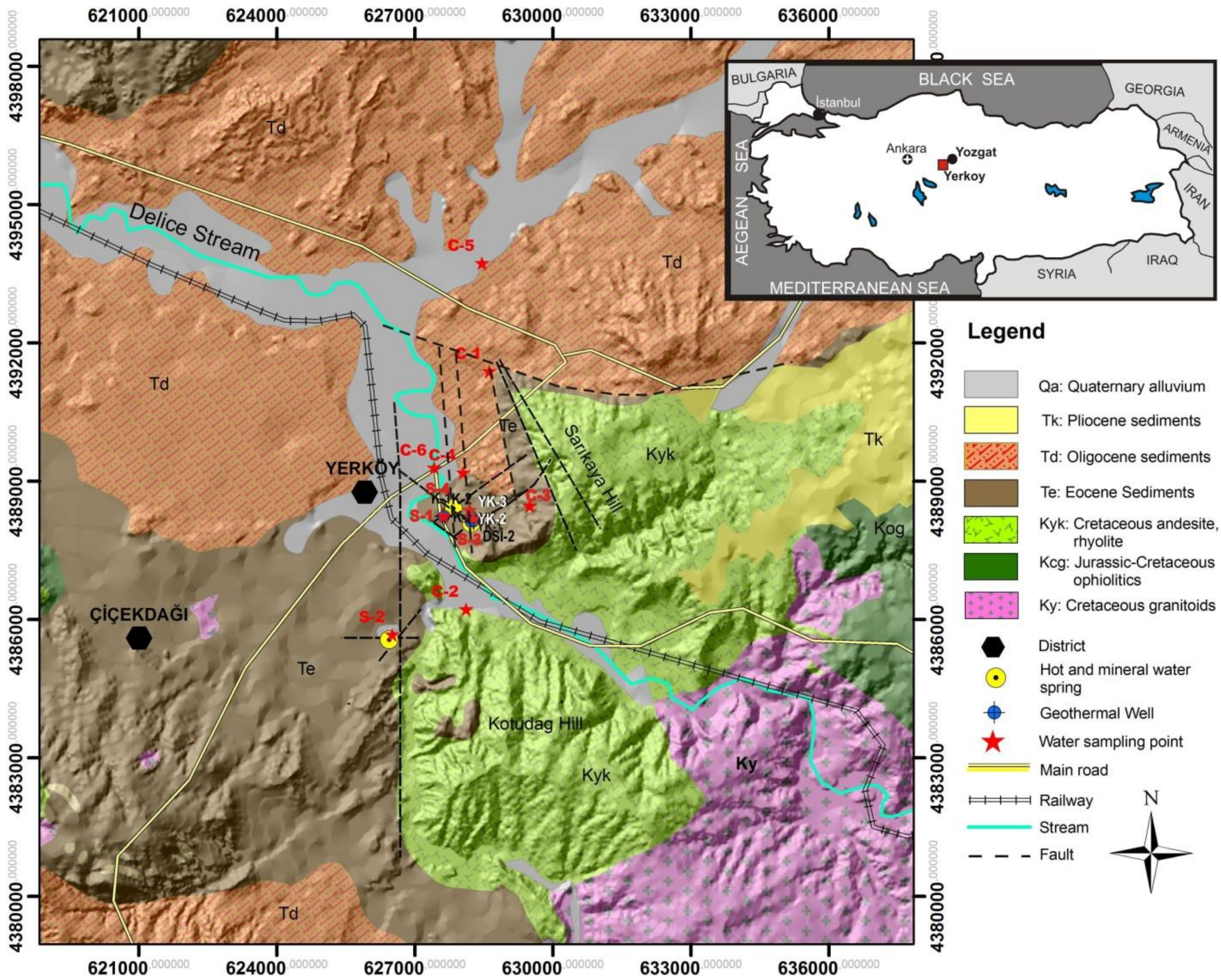

Figure 1: Geological map of Yerköy and its vicinity and locations of wells, springs and water sampling

3. HYDROGEOCHEMISTRY

Geothermal and cold water samples were collected in the geothermal area to determine the physical, chemical, and isotopic compositions of waters. The sample locations are shown in Figure 1. Temperature, pH and EC were carried out on site. The physical and chemical parameters are provided in Table 1.

3.1 Sampling points

Geothermal water samples were collected from wells. These wells are Koyunbasoglu spa well (S-1), Bulamacli spa well (S-2) and the last drilled geothermal wells of YK-2 and YK-3. Present, hot and mineral water springs do not observed in the field due to drilling works. However, these two old springs (Güven (S-3) and Camur (S-4) springs) have been examined with thermal well samples (Gündüz, 1993).

Cold waters were collected from three springs (C-1, C-3 and C-4), two shallow wells (C-2 and C-5) and Delice Stream (C-6).

3.2 Chemical and physical characteristics of waters

In situ measured temperatures of geothermal waters are between 40.3 and 56.2 °C and electrical conductivities (EC) are between 6470 and 17320 µS/cm, pH are between 6.93 and 8.51 (Table 1). Measured temperatures of cold waters are between 13 and 19.9 °C, electrical conductivities are between 678 and 6970 µS/cm and pH are between 7.28 and 7.94.

According to the ionic compound, sodium the most abundant cation and chloride is the most important anion in thermal waters. Geothermal waters are type of Na-Cl.

Cold waters have three subgroups, including types of Na-Cl (C-1), Na-HCO_3 (C-3, C-4 and C-6), and Na-SO_4 (C-2 and C-5). The relations of waters were examined by semi-logarithmic and triangular diagrams (Fig.2). According to the diagrams, the waters are three different types, including Yerköy thermal waters (S-1, S-3, S-4, YK-2, YK-3), Bulamacli water (S-2), and cold waters (C-2, C-3, C-4, C-5 and C-6). Cold water spring of C-1, which has highly salinity, differs from other cold waters. This sample and Bulamacli spring shows a mixing between cold and thermal water (Figure 2a).

Chloride and boron relationship of thermal and cold waters were examined with a log-log diagram (Figure 3). According to the Figure 3, the chlorides and boron are well correlated on a linear trend and S-2 and C-1 samples indicate a mixing between cold and thermal waters.

The diagrams indicate that Yerköy geothermal waters are highly salinity sodium-chloride type and have different composition from Bulamacli thermal water.

Table 1: Chemical and physical properties of Yerköy waters

Samp No	Sample	Date	T (°C)	pH	EC (µS/cm)	Na	K	Ca	Mg	HCO_3	Cl	SO_4	SiO_2	B
C-1	Mineral spring	July 2006	19.9	7.94	6970	1095.6	17.5	460.2	10.9	101.9	2048.6	792.6	16.4	3.5
C-2	Cold spring	July 2006	15.7	7.28	2360	282.3	6.5	174.9	56.3	279.8	293.3	684.8	20.0	1.0
C-3	Cold spring	July 2006	18.9	7.52	678	70.9	1.0	60.8	14.4	254.8	21.3	46.8	15.3	0.2
C-4	Cold spring	July 2006	19.0	7.53	860	101.3	1.3	68.1	19.7	410.7	18.7	66.4	13.8	0.3
C-5	Cold well	July 2006	13.0	7.48	1470	187.8	2.9	76.3	56.8	353.5	69.6	402.6	19.3	0.4
C-6	Delice Stream	July 2006	22.0	7.87	1130	116.8	7.01	81.3	33.0	222.9	136.7	163.7	12.2	0.4
S-1	Koyunbasoglu Spa well	July 2006	41.2*	7.79	19440	3745.4	102.5	1673.8	2.5	38.2	9380.1	270.6	22.8	9.2
S-2	Bulamacli Spa well	July 2006	43.8	6.93	7160	1357.5	91.7	220.9	10.3	817.4	2062.3	365.9	80.4	3.9
S-3**	Güven Spa spring	June 1993	47	7.4	11760	2100	60	821	61	55	4418	428	30	6.6
S-4**	Camur Spa spring	June 1993	45	7.12	17100	2900	70	1222	12.2	43	6700	359	22	7.4
YK-2	Geothermal well	March 2006	54.5*	8.51	16660	2905.9	77.9	1334.2	3.3	11.5	6812.3	316.4	19.9	7.0
YK-3	Geothermal well	July 2006	56.2*	8.24	13610	2243.0	63.9	929.9	3.9	60.5	5332.1	407.7	26.8	5.6

* Wellhead temperatures; ** Gündüz, 1993

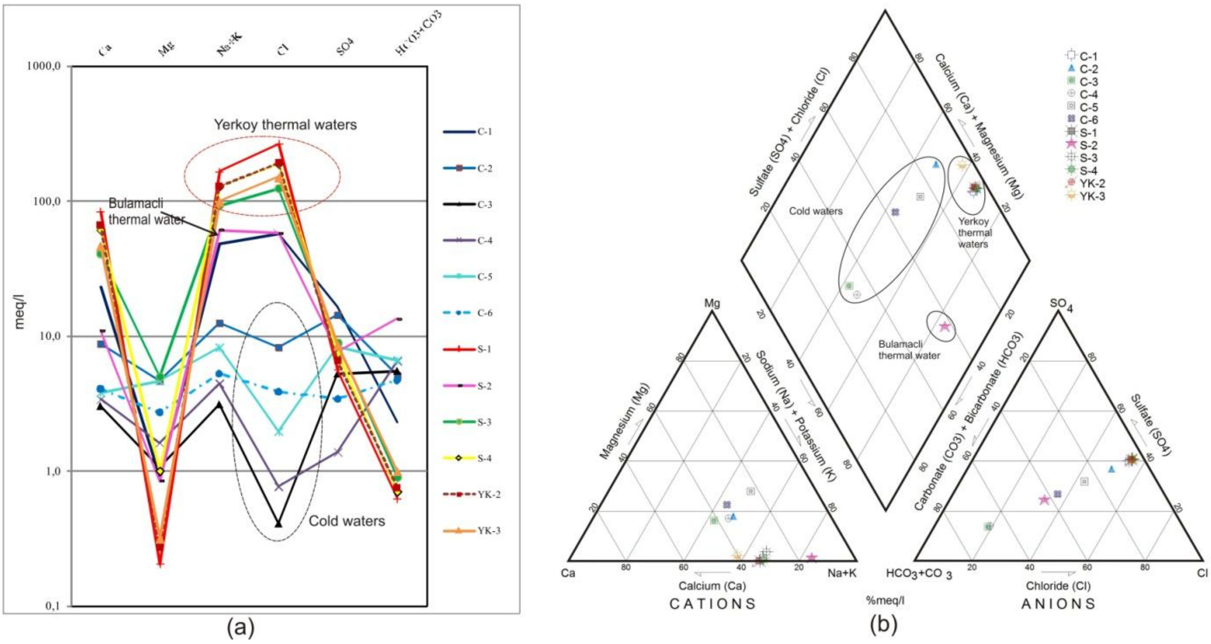

Figure 2: Semi-logarithmic Schoeller (a) and Triangular diagram (b) for cold and thermal water samples in Yerköy geothermal area

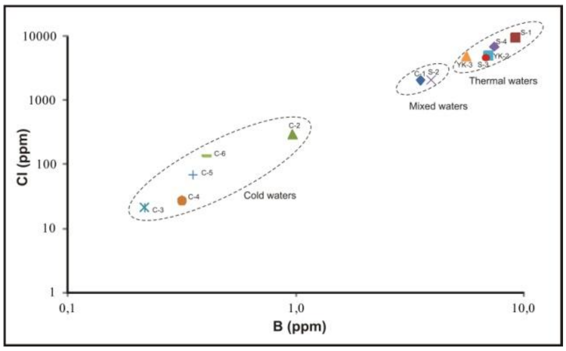

Figure 3: The chloride–boron relationship in thermal and cold water in Yerköy geothermal area

3.2 Geothermometers

The Na-K-Mg triangular diagram of Giggenbach (1988) indicates the equilibrium temperatures of minerals containing these elements (Fig. 4). According to the diagram, sample S-1 is as fully equilibrated waters, the other samples (S-2, S-3, S-4, YK-2 and YK-3) are as partially equilibrated waters and indicating reservoir temperature between 77 and 214 ºC. But, it was considered that reservoir temperature, which estimates with cation geothermometers, give relatively higher value because of high salinity solution.

According to the quartz and chalcedony equations of Fournier (1977), Fournier and Potter (1982), Arnorsson et al. (1983), D'Amore and Arnorsson (2000), reservoir temperatures were calculated up to 92 ºC by chalcedony and 85 ºC by quartz geothermometers.

3.3 Solution-mineral equilibrium

Mineral equilibrium diagrams were formed by calculating saturation indexes of minerals at various temperatures. The mineral equilibrium calculations were performed using Watch computer program of Bjarnason (1994). The mineral equilibrium diagrams represent saturation indexes (log (Q/K)) versus temperature of thermal waters of S-1, S-2, YK-2, and YK-3 for main secondary minerals (Fig.5). According to the diagram, equilibrium temperatures are between 80 and 100 °C for S-1 water, 60 and 80 °C for YK-2, 60 and 100 °C for YK-3, and 100 and 140 °C for Bulamacli spring (S-2). As it can be seen in Figure 5, the saturations of albite ($NaAlSi_3O_8$), K-feldspar, and quartz minerals, which are main rock forming minerals in igneous rocks, indicate that the aquifer rock is possibly granite or rhyolites. Thermal waters are close to the equilibrium with chalcedony, quartz minerals and feldspar such as albite and microcline.

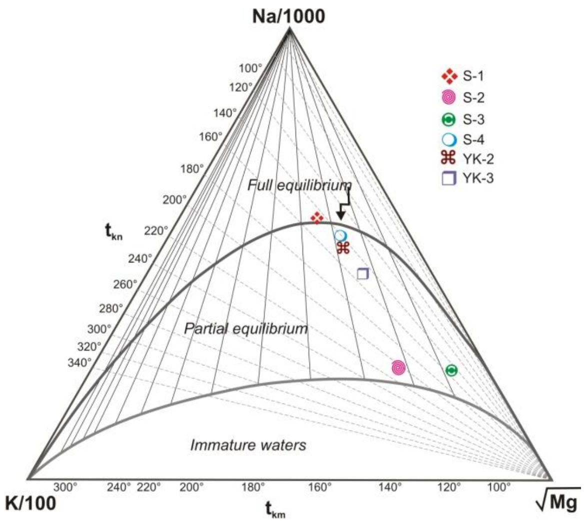

Figure 4: Na-K-Mg ternary diagram of Yerköy thermal waters

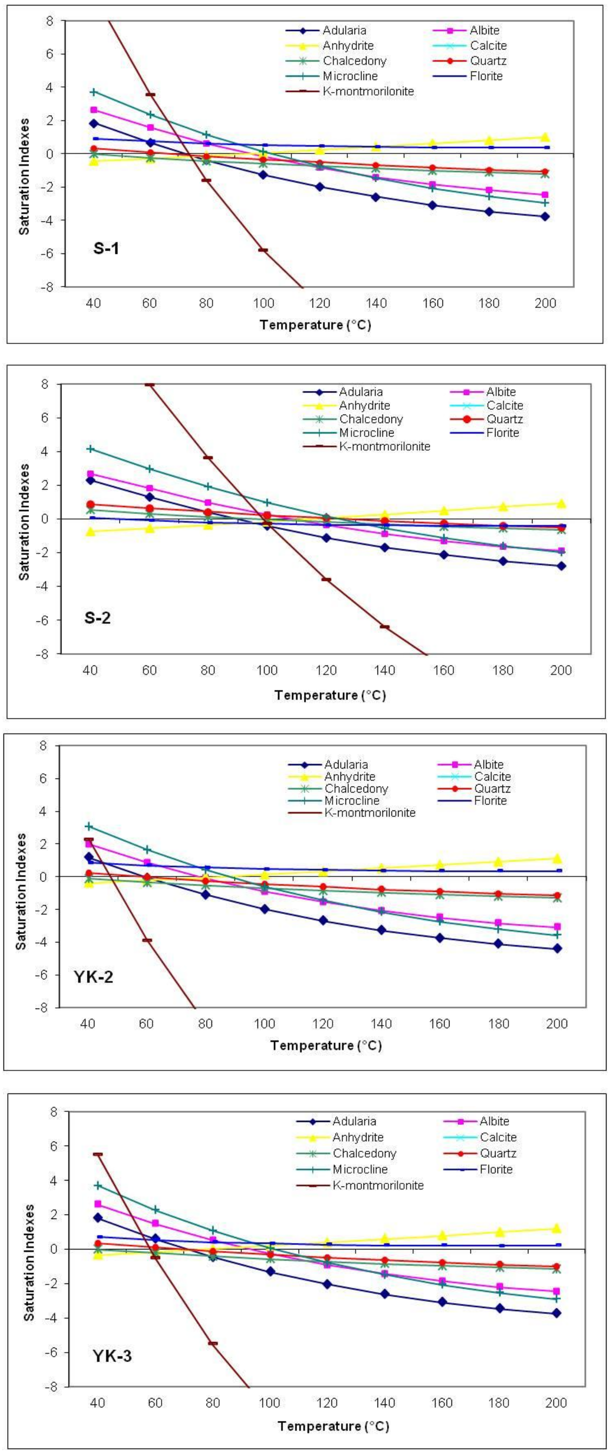

Figure 5: Diagrams showing the change in calculated saturation indexes (log Q/K) of various minerals as a function of temperature.

3.4 Isotopic characteristics of waters

Environmental isotopes of deuterium (δ^2H) and oxygen-18 (δ^{18}O) ratios are good indicators of water origins. The isotope analyses were performed by TUBITAK, MAM. The oxygen-18 values of waters are between -11.63 and -9.34 ‰. The deuterium values of these waters are between -83.95 and -67.56 ‰ (Table 2).

According to this environmental isotopic analysis, hot waters are of meteoric origin and recharged by precipitation from higher elevations in accordance with cold water samples (Figure 6). An oxygen-18 shift is observed as 2.4‰ δ^{18}O in YK-3 geothermal well water. This shift indicates a deep circulation and water-rock interactions. Also, Figure 5 shows that Bulamacli thermal water (S-2) is recharged by precipitation from higher elevations in accordance with Yerköy thermal waters.

Table 2: Tritium and stable isotope content of samples in the study area

Sample No	Sampling Date	δ^{18}O (‰SMOW)	δ^2H (‰SMOW)	Tritium (TU)
C-1	July 2006	-9.49	-76.84	3.81
C-2	July 2006	-8.73	-64.22	6.48
C-3	July 2006	-9.61	-67.56	5.54
S-1	July 2006	-10.43	-78.09	0.39
S-2	July 2006	-11.63	-90.02	0.81
YK-3	July 2006	-9.34	-83.95	1.1

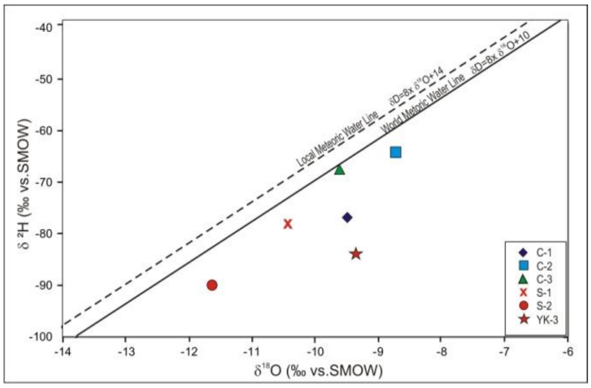

Figure 6: δ^{18}O - δ^2H diagram of Yerköy waters

Tritium values of cold waters (C-1, C-2, C-3, C-4, and C-5, and C-6) are an average 5.53 tritium units. These waters are modern water. The tritium values of thermal waters are about zero and indicate that thermal waters recharged by precipitation before 1952 (Clark and Fritz, 1997).

4. CONCLUSIONS

In this study, a hydrothermal conceptual model of the geothermal field has been developed by hydrogeochemical study (Figure 7).

According to the hydrogeochemistry study, three main water types were determined based on their chemical composition in Yerköy geothermal area. Thermal waters are Na-Cl type. However, Yerköy geothermal water chemistry is different from Bulamacli geothermal water. Bulamacli water is more diluted with cold water. Cold water types are Na-Cl, Na-HCO_3, and Na-SO_4 type.

According to the silica geothermometers and mineral equilibrium calculations, temperatures have been estimated up to 100 ºC, which are closer to the measured as 72 ºC at the bottom hole (750 m) in YK-3 well, drilled in 2006 m. $\delta^{18}O$-$\delta^{2}H$ values show that positive $\delta^{18}O$ shifts because of water-rock interaction and it is indicates a deep circulating system. The low tritium values indicate that thermal waters recharged by precipitation before 1952.

Yerköy hydrothermal system mainly recharged from the Kotudag volcanic (Sarikaya Hill) and Eocene, Oligocene, Pliocene formations. Meteoric waters are infiltrated from these units into underground and heated by heat flux and thermal gradient, and rises by convection. These waters rise along the main faults and fractures and stored in the Cretaceous Kotudag Volcanic member and Yozgat granitoid rocks and also, Eocene limestone that are assumed as the shallow geothermal reservoir (Fig. 7).

When thermal water outcrops, it is mixed by cold water in Eocene conglomerate and limestone. Volcanic units like rhyolites, tuff, and agglomerate that no fault and fractures zones and Eocene, Oligocene, Pliocene sediments, which are alternation of limestone, marl, limestone with clay and sandstone, are cap rocks with low permeability. Thermal waters in the study area have highly salinity due to these waters are acquired Na-Cl by water-rock interactions during infiltrating and rising into Eocene, Oligocene, Pliocene formations consisting of gypsum and halite.

A large-scale utilization is carried out for the greenhouse, tourism and balneological uses in the field. In case of using the thermal water for greenhouse heating, it is certainly should be reinjected because of high salinity.

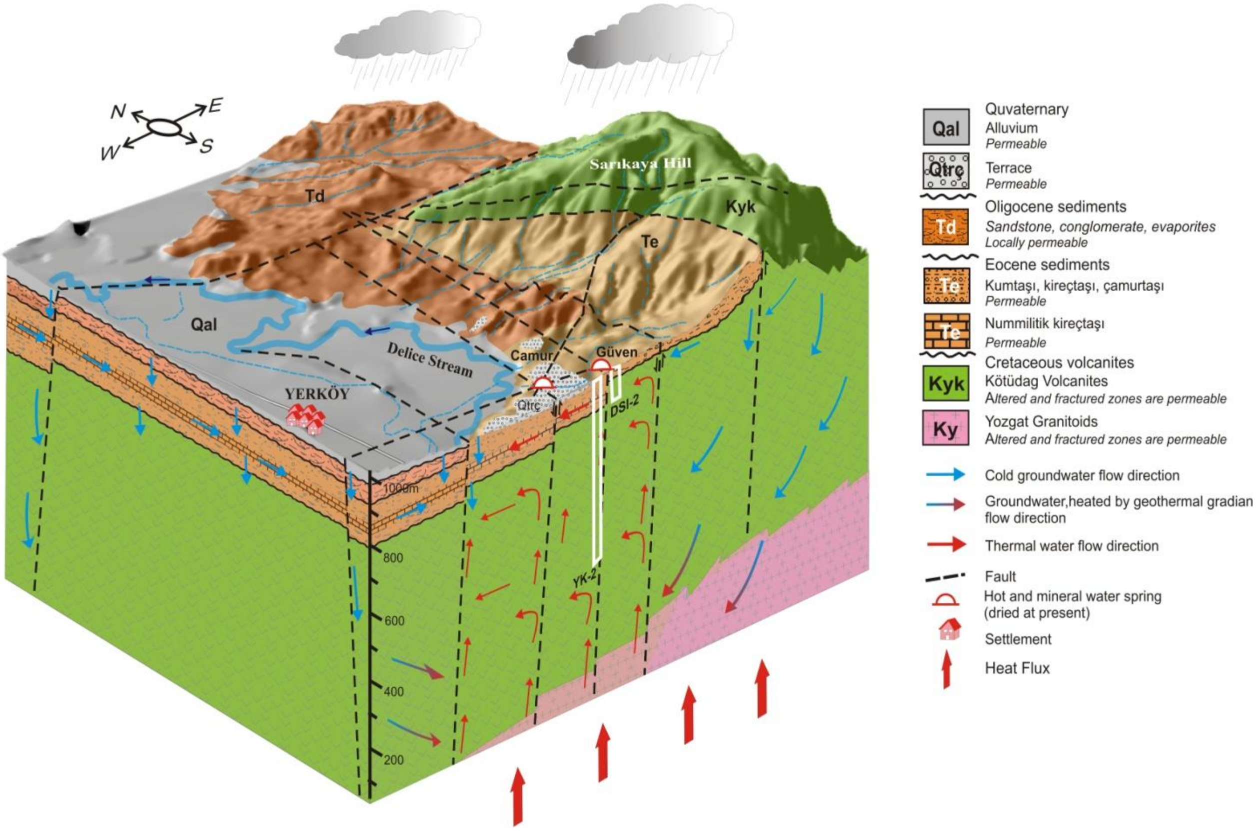

Figure 7: Schematic conceptual model of Yerköy hydrothermal system

REFERENCES

Arnnórsson, S., Gunnlaugsson, E., Svavarsson, H.: The Chemistry of Geothermal Waters in Iceland, III. Chemical Geothermometry in Geothermal Investigations, *Geochimica et Cosmochimica Acta*, 47, (1983), 567-577**.**

Bjarnason, J.O.: The speciation program WATCH, version 2.1. The National Energy Authority, Reykjavik, 7 p, (1994)

Büyükönal, G.: Petrography and Petrochemistry of Igneous Rocks in Yozgat and its Vicinity, Ankara University, Faculty of Science, Chair of Mineralogy, Ankara (1977) (in Turkish).

Canik, B.: Report of Geology-Hydrogeology and Geophysics Study of Yerköy Güven Spa (Uyuz Bath), District Governorship of Yerkoy, (2004) (in Turkish).

Clark, I. D. and Fritz, P.: Environmental isotopes in hydrogeology, *Lewis Publishers*, New York, (1997), p.328.

D'Amore F. and Arnorsson, S.: Geothermometry, in. Isotopic and Chemical Techniques in Geothermal

Exploration, Development and Use. Arnorsson, S. (ed.), *IAEA*, Vienna (2000), 152-199.

Fournier, R.O.: Chemical Geothermometers and Mixing Models for Geothermal Systems, *Geothermics,* 5. (1977), 41-50.

Fournier, R.O., Potter, R.W.II.: A Revised And Expanded Silica (Quartz) Geothermometer, *Geothermal Research Council Bull*., 11, (1982), 3-9.

Giggenbach, W.F.: Geothermal Solute Equilibria. Derivation of Na-K-Mg-Ca Geoindicators, *Geochimica et Cosmochimica Acta*, 55, (1988), 2749-2765.

Gündüz, M.: Hydrogeological Study of Güven (Yerkoy) Spa, *Mineral Research and Exploration General Directorate of Turkey. MTA Report No:* 9595, Ankara, (1993) (in Turkish).

Gündüz, M., Özten, A.: YK-1 Well Completion and Protected Area Report of Yozgat Yerköy Güven Spa Drilling, *Mineral Research and Exploration General Directorate of Turkey MTA Report No:* 9796, Ankara, (1994) (in Turkish).

Ketin, I.: Geology of Yozgat area and tectonics of the Central Anatolian Massif. *Bulletin of Turkey Geological Survey*, IV, 1, (1955), 1-40. (in Turkish).

Simsek, S.: Isotope Survey of Geothermal Systems of Central Anatolia, Hacettepe University International Research and Application Center for Karst Water Resources, HU-IAEA Research Contract 6716/RB Final Report, Ankara, (1993).

Simsek, S., Koc, K., Yilmaz E.: Geology, Hydrogeology, Drilling and Testing Consultancy Report of YK-2 and YK-3 Wells in Yerköy, Hacettepe University, Yozgat Governorship Office and District Governorship of Yerkoy, (2006), (in Turkish).

Yilmaz, E., Hydrogeoch emical Investigation of Thermal and Mineral Waters of Yerköy (Yozgat), Master’s thesis, Hacettepe University, Ankara, (2007).

Acknowledgements

The authors wish to thank the Governorship of Yozgat and District Governorship of Yerköy Staffs for their support and thank for analyses of water samples to Hacettepe University Laboratory and TUBITAK MAM Laboratory Staffs and chemists.